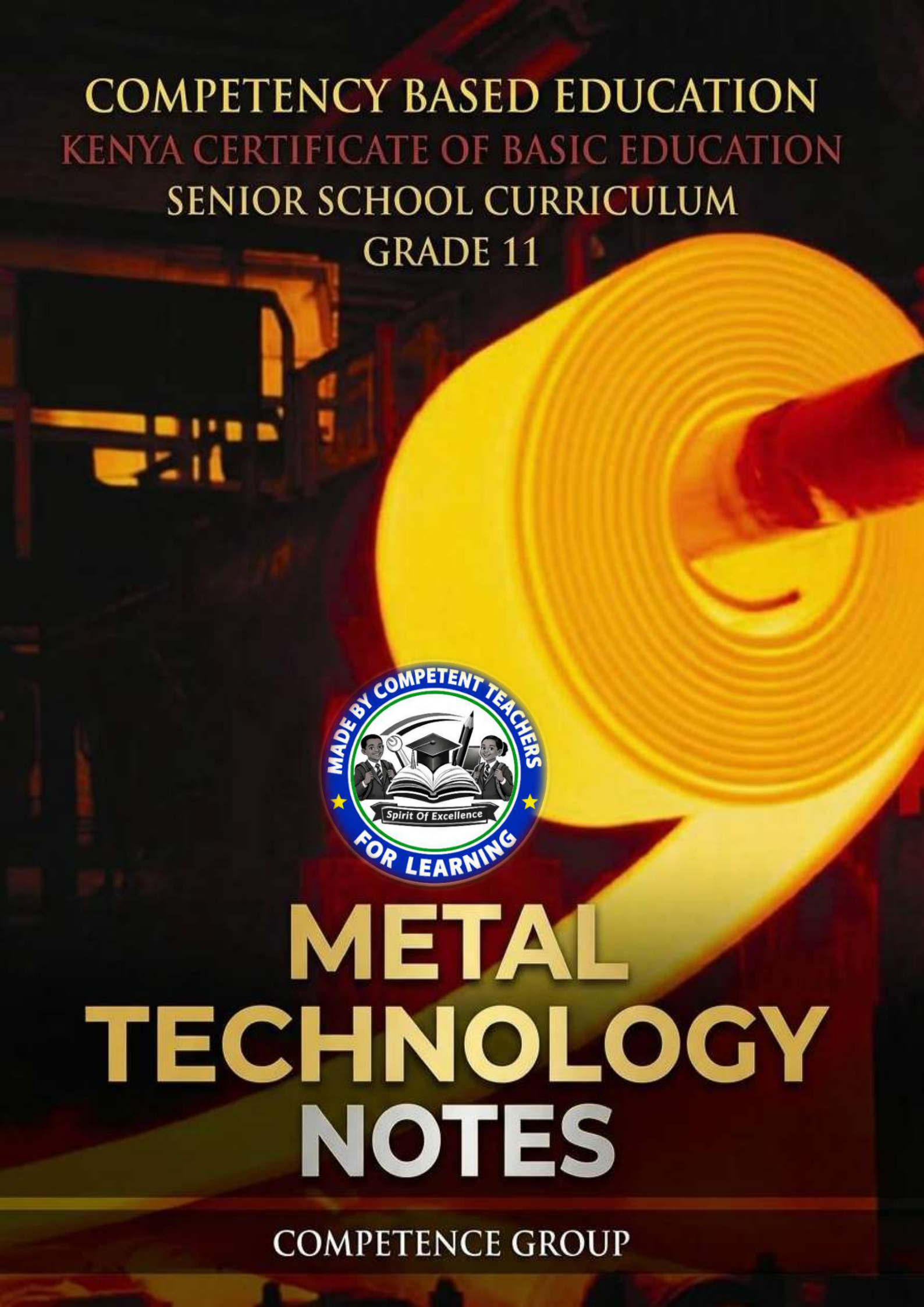
COMPETENCY BASED EDUCATION

KENYA CERTIFICATE OF BASIC EDUCATION

SENIOR SCHOOL CURRICULUM

GRADE 11




# METAL TECHNOLOGY NOTES

COMPETENCE GROUP

**STRAND 1.0: FUNDAMENTALS OF METALWORK**

**SUB-STRAND 1.1: WORKSHOP PLANNING AND ORGANIZATION**

## 1.0 INTRODUCTION TO WORKSHOP PLANNING AND ORGANIZATION

Metalwork is an important technical subject that equips learners with practical skills and knowledge for working with metals. It involves activities such as measuring, marking out, cutting, shaping, joining, finishing and assembling metallic materials to produce useful products.

Metalwork activities are carried out in specially designed places known as metalwork workshops.

A metalwork workshop must be properly planned and organized to ensure that activities are performed efficiently, safely and economically.

Workshop planning involves deciding how the available space, machines, tools, materials, workers and other resources will be arranged and used to achieve the intended objectives.

Workshop organization involves putting the workshop plan into practice by arranging equipment, assigning responsibilities, establishing procedures and maintaining order.

Examples of metalwork products made in Kenyan workshops include:

- Metal doors and window frames.
- School desks and chairs.
- Metal gates and security grills.
- Water tanks and metal containers.
- Wheelbarrows.
- Agricultural tools such as jembes and hoes.
- Metallic shelves and cupboards.
- Structural steel components used in building construction.

## 2.0 MEANING OF KEY TERMS

**1. Metalwork workshop**

A metalwork workshop is a specially prepared working area equipped with tools, machines, materials and facilities used for carrying out metalworking operations.

**2. Workshop planning**

Workshop planning is the process of deciding in advance how a metalwork workshop will be established, arranged and operated to achieve maximum efficiency and safety.

**3. Workshop organization**

Workshop organization is the systematic arrangement of people, tools, machines, materials and activities to ensure smooth operations in a workshop.

**4. Material handling**

Material handling refers to the movement, storage, protection and control of raw materials, work-in-progress and finished products within a workshop.

**5. Waste management**

Waste management refers to the collection, separation, storage, treatment, recycling and safe disposal of waste produced during metalworking activities.

**6. Workshop layout**

Workshop layout is the physical arrangement of machines, workbenches, storage facilities, equipment and working areas within a workshop.

**7. Ergonomics**

Ergonomics is the practice of designing workplaces and arranging equipment to suit the abilities and comfort of workers, reducing fatigue and injuries.

## 3.0 MATERIAL HANDLING IN A METALWORK WORKSHOP

### 3.1 Meaning of Material Handling

Material handling is the process of moving, storing, protecting and controlling materials throughout the different stages of metal production.

It begins when raw materials are received in the workshop and ends when finished products are transferred to the storage area or customers.

Materials commonly handled in a metalwork workshop include:

1. Mild steel sheets.
2. Steel plates.
3. Round steel bars.
4. Flat steel bars.
5. Angle iron.
6. Square hollow sections.
7. Rectangular hollow sections.
8. Steel pipes.
9. Aluminium sheets and sections.
10. Copper rods and sheets.
11. Welding electrodes.
12. Fasteners such as nuts, bolts and rivets.

### 3.2 Importance of Material Handling

Proper material handling is important because it:

1. **Prevents accidents:** Proper movement of heavy materials reduces injuries caused by falling objects, sharp edges and improper lifting.

2. **Reduces material damage:** Correct handling prevents bending, scratching, corrosion and breakage of metallic materials.

3. **Saves time:** Materials can be moved quickly from one working station to another.

4. **Improves productivity:** Workers spend less time searching for and transporting materials.

5. **Reduces production costs:** Proper handling minimizes material wastage and unnecessary labour.

6. **Promotes good workshop organization:** Materials are kept in designated storage areas.

7. **Improves quality of products:** Materials are protected from damage and contamination.

8. **Makes better use of workshop space:** Proper storage prevents congestion.

9. **Facilitates stock control:** Materials can easily be counted, recorded and monitored.

10. **Promotes worker comfort:** Suitable handling equipment reduces physical strain.

**3.3 Methods of Material Handling**

Different methods are used to handle materials depending on their weight, size, shape and nature.

**A. Manual handling**

Manual handling involves moving materials using human physical effort.

Examples include:

- Carrying small steel bars.
- Lifting small metal components.
- Moving light tools.
- Carrying small sheets of metal.

**Precautions during manual handling**

1. Assess the weight of the material before lifting.
2. Bend the knees rather than the back.
3. Keep the back as straight as possible.
4. Hold the material firmly.
5. Keep the load close to the body.
6. Avoid twisting the body while carrying loads.
7. Ask for assistance when handling heavy materials.
8. Wear protective gloves when handling sharp metallic materials.
9. Use appropriate safety footwear.
10. Avoid carrying materials that block visibility.

**B. Mechanical handling**

Mechanical handling involves using machines or equipment to move materials from one location to another.

Examples include:

- Overhead cranes.
- Forklift trucks.
- Hoists.
- Hand-operated trolleys.
- Pallet trucks.
- Chain blocks.

**Advantages of mechanical handling**

1. Enables movement of heavy materials.
2. Reduces physical strain on workers.
3. Saves time and labour.
4. Improves workshop efficiency.

5. Reduces the risk of injuries caused by manual lifting.
6. Makes it possible to handle large metallic components.

**Safety precautions**

- Only trained personnel should operate lifting equipment.
- Inspect lifting equipment before use.
- Never exceed the recommended load capacity.
- Ensure loads are securely attached.
- Keep people away from suspended loads.
- Use suitable lifting accessories.
- Avoid operating equipment on unstable surfaces.

**C. Automated material handling**

Automated material handling uses programmed machines and systems to move materials with minimal human involvement.

Examples include:

- Conveyor systems.
- Automated guided vehicles.
- Robotic material-handling systems.
- Computer-controlled storage systems.

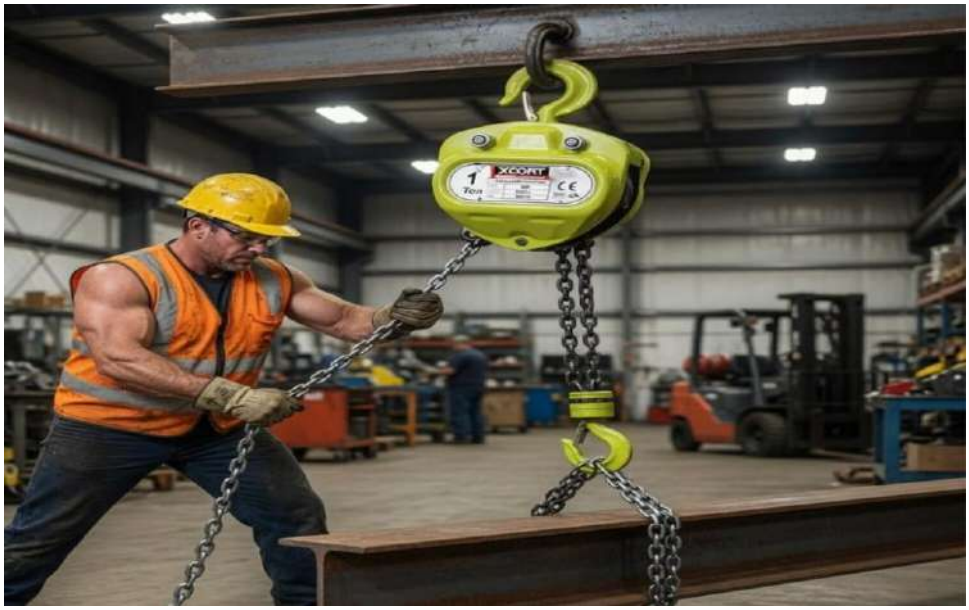
This method is mainly used in large manufacturing industries.

**3.4 Material Handling Equipment**

The following equipment is commonly used in metalwork workshops.







**1. Hand trolley**

- A hand trolley is a wheeled device used to move materials from one location to another.
- It is suitable for transporting small machines, metal components and tools.
- It reduces the need for workers to carry heavy materials manually.

**2. Overhead crane**

- An overhead crane is a lifting machine mounted on beams above the workshop floor.
- It is used to lift and move heavy materials horizontally and vertically.
- It is suitable for large metal fabrication workshops.

**3. Chain block**

- A chain block is a manually operated lifting device.
- It uses chains and gears to raise or lower heavy objects.
- It is commonly used when positioning heavy machine components.

**4. Forklift truck**

- A forklift is a powered industrial vehicle fitted with two lifting forks.
- It is used to lift, transport and stack heavy materials.
- It is useful in large workshops and warehouses.

**5. Pallet truck**

- A pallet truck is used to lift and move materials placed on pallets.
- It is commonly used for transporting packaged materials.

**6. Conveyor system**

- A conveyor is a mechanical system used to move materials continuously between different working stations.
- It is commonly found in large manufacturing industries.

**3.5 Procedures for Proper Material Handling**

The following procedures should be followed:

1. Identify the material to be handled.
2. Determine its weight, dimensions and physical characteristics.
3. Select appropriate handling equipment.
4. Inspect the handling equipment for defects.
5. Wear suitable personal protective equipment.
6. Clear the movement route of obstructions.
7. Secure the material before lifting.
8. Move the material carefully to the intended location.
9. Avoid dropping or dragging materials unnecessarily.
10. Store materials in designated areas.
11. Record materials received and issued.
12. Return unused materials to the appropriate storage area.

**3.6 Storage of Materials in a Metalwork Workshop**

Storage involves keeping materials in designated places to protect them from damage, loss and unauthorized use.

**Methods of storing metalwork materials**

**A. Rack storage**



- Long metallic materials such as pipes, angle bars and steel rods are stored on racks.
- Racks should be strong enough to support the weight of materials.
- Materials should be arranged according to their sizes and types.
- Heavy materials should be stored at lower levels.

**B. Sheet storage**



- Metal sheets are stored in suitable horizontal or purpose-designed vertical racks.
- Sheets should be supported to prevent bending.
- Sharp edges should be protected where necessary.
- Heavy sheets should be handled using suitable lifting equipment.

**C. Cabinet storage**

- Small tools, fasteners and accessories are stored in cabinets.
- Cabinets protect materials against dust, damage and loss.
- Different items should be placed in labelled compartments.

**D. Floor storage**

- Large and heavy materials may be stored in designated floor areas.
- The materials must be properly supported and secured against rolling or falling.
- Emergency routes and walkways must remain clear.

**3.7 Factors to Consider When Storing Materials**

1. **Weight:** Heavy materials require strong supports and suitable lifting equipment.
2. **Size:** Long materials require racks that can accommodate their dimensions.
3. **Shape:** Round bars and pipes need supports to prevent rolling.
4. **Nature of material:** Some metals require protection against moisture and corrosion.
5. **Frequency of use:** Frequently used materials should be stored where they are easily accessible.

6. **Safety:** Materials should not obstruct walkways or emergency exits.

7. **Available space:** Storage facilities should fit the available workshop area.

8. **Security:** Expensive materials should be stored in secure areas.

9. **Accessibility:** Materials should be easy to identify and retrieve.

10. **Weight distribution:** Storage structures must safely support the loads placed on them.

## 4.0 WORKSHOP PLANNING

### 4.1 Meaning of Workshop Planning

Workshop planning is the process of determining the physical arrangement, resources, facilities, equipment and operational procedures required to establish and operate a metalwork workshop.

It involves making decisions before setting up the workshop.

A properly planned workshop enables learners and workers to carry out metalworking activities efficiently while minimizing accidents and unnecessary expenditure.

### 4.2 Objectives of Workshop Planning

The main objectives include:

1. To ensure efficient use of available space.
2. To promote safety among learners and workers.
3. To improve the movement of materials.
4. To reduce unnecessary movement of workers.
5. To ensure proper arrangement of machines.
6. To improve production efficiency.
7. To minimize production costs.
8. To facilitate supervision of workshop activities.
9. To provide suitable working conditions.
10. To allow future expansion.
11. To ensure compliance with government regulations.
12. To promote proper waste management.

### 4.3 Factors Considered When Planning a Metalwork Workshop

Several factors must be considered when selecting and planning a metalwork workshop.

**1. Location of the workshop**

The location refers to the geographical position or site where the workshop is established.

Factors to consider include:

- Accessibility to roads and transport facilities.
- Availability of electricity and water.
- Proximity to suppliers of metal materials.
- Proximity to customers.
- Security of the area.

- Availability of suitable land.
- Drainage conditions.
- Distance from residential areas where noise may cause disturbance.
- Availability of emergency services.
- Compliance with land-use requirements.

**Example:** A school metalwork workshop should be located where learners can access it safely without interfering with other school activities.

**2. Available space**

Space refers to the total area available for workshop activities.

The space should accommodate:

- Machines and equipment.
- Workbenches.
- Storage facilities.
- Material-handling routes.
- Welding areas.
- Finishing sections.
- Inspection areas.
- Emergency exits.
- Waste collection points.

**Importance of adequate space**

1. Prevents overcrowding.
2. Allows free movement of workers.
3. Reduces accidents.
4. Provides sufficient working space around machines.
5. Makes supervision easier.
6. Allows future expansion.

**3. Workshop amenities**

Amenities are facilities provided to support the comfort, safety and efficient operation of the workshop.

Examples include:

- Electricity supply.
- Clean water.
- Toilets and washrooms.
- Changing rooms.
- First-aid facilities.
- Adequate lighting.
- Ventilation systems.

- Firefighting equipment.
- Drinking water.
- Waste disposal facilities.
- Communication facilities.

**4. Safety requirements**

Safety is one of the most important considerations when planning a metalwork workshop.

The workshop should provide:

- Clearly marked emergency exits.
- Fire extinguishers.
- First-aid kits.
- Machine guards.
- Welding screens.
- Adequate ventilation.
- Non-slip floors.
- Proper electrical installations.
- Suitable personal protective equipment.
- Clearly displayed safety signs.
- Safe storage of flammable materials.

**5. Government regulations**

A metalwork workshop must comply with applicable laws, standards and regulations in Kenya.

Important considerations include:

- Occupational safety and health requirements under the Occupational Safety and Health Act, 2007.
- Environmental management requirements under applicable environmental laws.
- Relevant National Environment Management Authority (NEMA) requirements.
- County government planning and business licensing requirements, where applicable.
- Public health and sanitation requirements.
- Fire safety requirements.
- Electrical installation safety standards.
- Building and construction requirements.

Compliance protects workers, learners, the public and the environment.

**6. Types of machines required**

The machines required depend on the nature of metalwork operations to be performed.

Examples include:




- Drilling machines.
- Lathe machines.
- Milling machines.
- Grinding machines.
- Power hacksaws.
- Shearing machines.
- Bending machines.
- Welding machines.
- Power presses.

When selecting machines, consider:

1. Cost of purchase.
2. Available workshop space.
3. Power requirements.
4. Maintenance costs.
5. Safety features.
6. Machine capacity.
7. Availability of spare parts.
8. Availability of trained operators.

**7. Operations involved**

The workshop layout should be determined by the metalworking operations to be carried out.

Examples include:

| **Operation** | **Equipment required** |
|---|---|
| Measuring | Steel rule, tape measure |
| Marking out | Scriber, dividers, surface plate |
| Cutting | Hacksaw, shearing machine |
| Drilling | Drilling machine, drill bits |
| Turning | Lathe machine |
| Grinding | Bench grinder |
| Welding | Welding machine |

| | |
|---|---|
| Bending | Bending machine |
| Filing | Files and vice |
| Finishing | Files, abrasive paper and painting equipment |

The arrangement should follow a logical production sequence to reduce unnecessary movement.

**8. Availability of skilled labour**

- The workshop should have trained personnel who understand metalworking operations.
- Machine operators should have relevant skills.
- Workers should understand workshop safety procedures.
- Adequate supervision should be provided.
- Training should be organized when new equipment is introduced.

**9. Cost and available finances**

Planning should consider the financial resources available.

Costs include:

- Construction or rental of workshop premises.
- Purchase of machines.
- Purchase of tools.
- Installation of electrical systems.
- Water supply.
- Safety equipment.
- Maintenance.
- Wages and salaries.
- Waste disposal.
- Insurance and licensing, where applicable.

**10. Ventilation and lighting**

**Ventilation**

Ventilation refers to the provision of fresh air and removal of contaminated air from the workshop.

It is important because it:

- Removes welding fumes.
- Reduces accumulation of dust.
- Controls excessive heat.
- Improves air quality.
- Promotes worker comfort.

**Lighting**

Adequate lighting enables workers to see clearly during operations.

Good lighting:

- Improves accuracy during marking out.

- Reduces eye strain.
- Prevents accidents.
- Improves the quality of finished products.

**11. Future expansion**

The workshop should be planned to accommodate future changes.

Consider:

- Additional machines.
- Increased production.
- More workers.
- New metalworking operations.
- Additional storage facilities.
- Improved technology.

**12. Environmental considerations**

The workshop should be planned to minimize environmental pollution.

Consider:

- Proper disposal of metal scraps.
- Collection of used oil.
- Control of welding fumes.
- Noise reduction.
- Prevention of oil spills.
- Recycling of reusable materials.
- Proper drainage.

## 5.0 WORKSHOP LAYOUT

### 5.1 Meaning of Workshop Layout

Workshop layout refers to the physical arrangement of machines, workbenches, storage facilities, equipment and working areas within a workshop.

The layout determines how workers, materials and products move during metalworking operations.

### 5.2 Importance of Proper Workshop Layout

1. Improves workflow.
2. Reduces material movement.
3. Prevents congestion.
4. Promotes safety.
5. Improves supervision.
6. Reduces production time.
7. Makes better use of available space.
8. Reduces unnecessary handling costs.

9. Improves communication.
10. Facilitates cleaning and maintenance.

**5.3 Types of Workshop Layout**

**A. Process layout**

In a process layout, similar machines and equipment are grouped together according to the operations they perform.

For example:

- All drilling machines are placed in one section.
- All grinding machines are placed in another section.
- Welding equipment is placed in a designated welding area.

**Advantages**

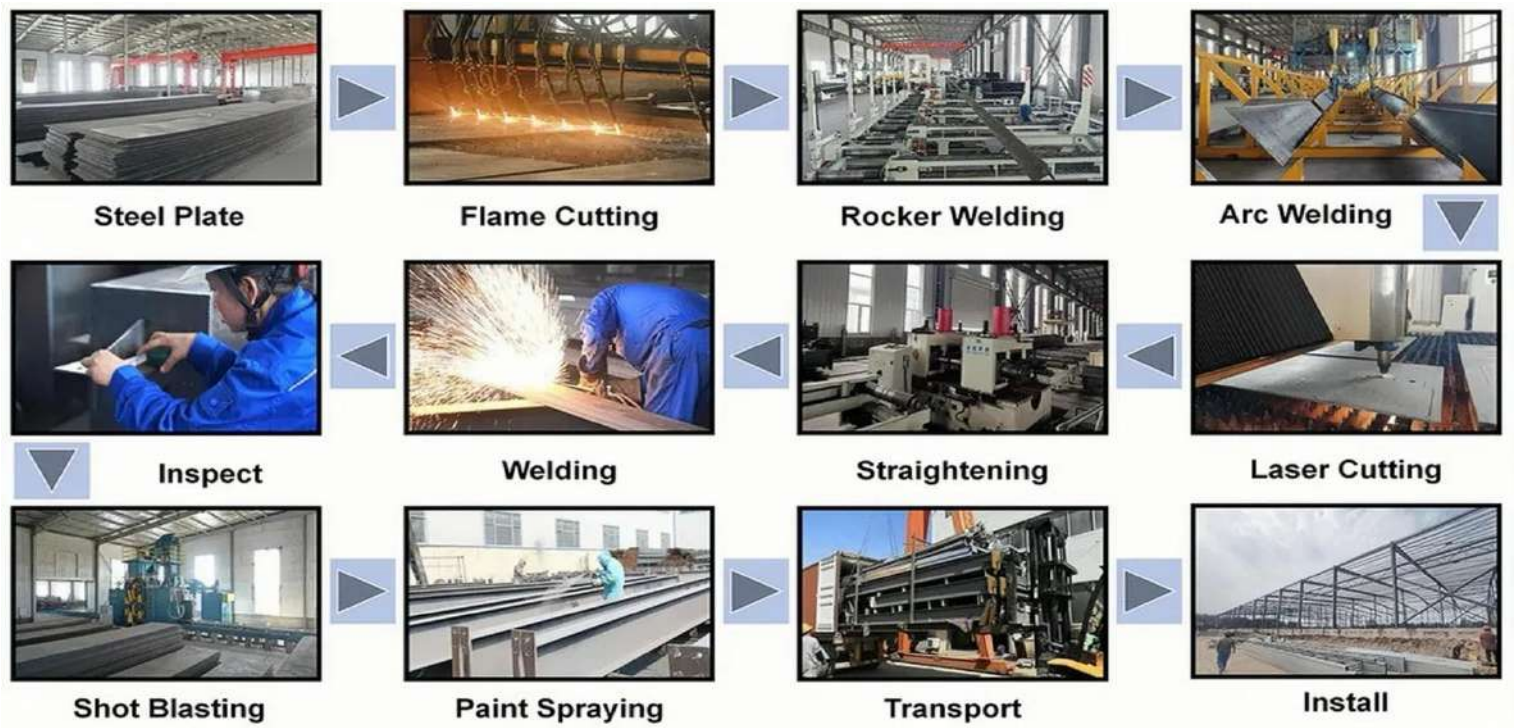
1. Suitable for workshops producing different types of products.
2. Allows flexibility.
3. Makes supervision of similar operations easier.
4. Allows specialized workers to operate particular machines.

**Disadvantages**

1. Materials may travel long distances.
2. Production may take more time.
3. Movement of materials may become complicated.
4. Requires proper coordination.

**B. Product layout**

In a product layout, machines and equipment are arranged according to the sequence of operations involved in producing a particular product.



**Advantages**

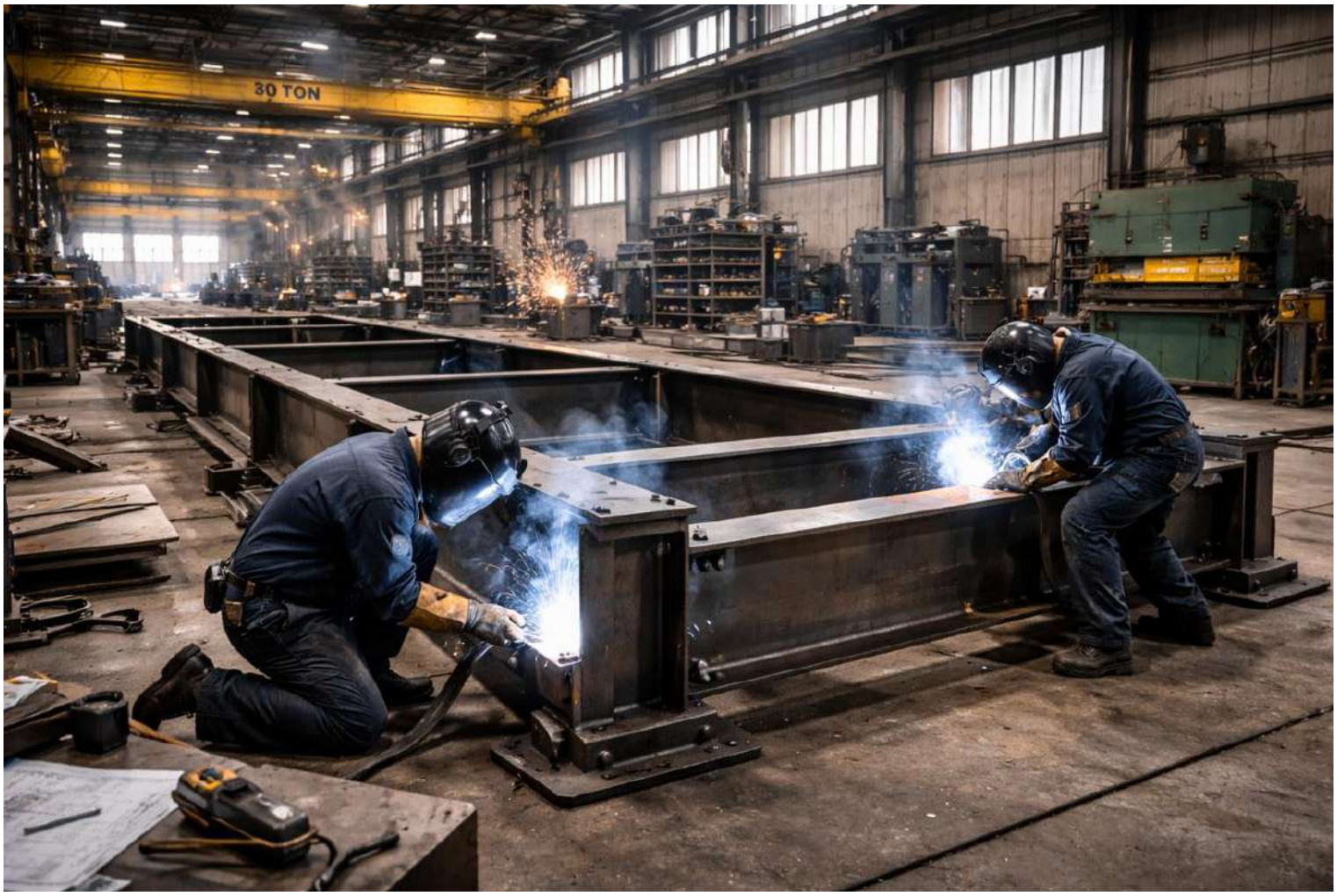
1. Reduces movement of materials.
2. Improves production speed.
3. Simplifies supervision.
4. Reduces handling costs.
5. Suitable for mass production.

**Disadvantages**

1. Limited flexibility.
2. Breakdown of one machine may interrupt production.
3. Requires careful initial planning.
4. May involve high installation costs.

**C. Fixed-position layout**

In this layout, the product remains in one location while workers, tools, machines and materials are brought to it.




**Examples**

- Fabrication of large steel tanks.
- Construction of large metallic structures.
- Manufacture of large industrial equipment.

**Advantages**

1. Suitable for large and heavy products.
2. Reduces movement of large products.
3. Allows different operations to be performed at the same location.

**Disadvantages**

1. Requires careful coordination.
2. Materials and equipment must be moved to the product.
3. May require considerable working space.

**5.4 Main Sections of a Metalwork Workshop**

A well-organized workshop should have different sections depending on its activities.

**1. Material receiving area**

- Used for receiving raw materials.
- Materials are inspected and recorded.
- Damaged materials are identified.

**2. Material storage area**

- Used for storing raw materials.
- Materials are arranged according to type, size and shape.
- Storage racks should be strong and stable.

**3. Measuring and marking-out area**

- Used for measuring and marking materials before processing.
- Should have suitable workbenches and measuring equipment.
- Surface plates may be provided.

**4. Machine section**

- Contains machines such as drilling machines, grinders and lathes.
- Machines should have adequate working clearance.
- Machine guards should be provided.

**5. Welding section**

- Used for joining metal components by welding.
- Should have welding screens.
- Adequate ventilation is necessary.
- Suitable fire extinguishers should be available.

**6. Fitting and assembly section**

- Used for assembling components.
- Contains benches, vices, clamps and hand tools.

**7. Finishing section**

- Used for filing, grinding, polishing and painting.
- Appropriate dust and fume control measures should be provided.

**8. Inspection section**

- Used for checking finished products.
- Measuring instruments are used to establish whether products meet required dimensions.

**9. Finished products storage area**

- Used for keeping completed products before delivery.
- Products should be protected against damage and corrosion.

**10. Waste collection area**

- Used for temporary storage of different waste materials.
- Waste should be separated according to its nature.

## 6.0 ORGANIZATION OF A METALWORK WORKSHOP

### 6.1 Meaning of Workshop Organization

Workshop organization refers to the systematic arrangement and management of workshop resources, activities and personnel to ensure efficient operation.

It involves ensuring that every tool, machine, material and worker has an appropriate place and responsibility.

### 6.2 Principles of Good Workshop Organization

**1. Proper arrangement of tools**

- Every tool should have a designated storage location.
- Tools should be arranged according to their types and uses.
- Toolboards and cabinets should be clearly labelled.
- Tools should be returned after use.

**2. Proper arrangement of machines**

- Machines should be positioned according to workshop operations.
- Adequate space should be provided around machines.
- Machines should be securely installed.
- Machine operating instructions should be displayed.

**3. Cleanliness and orderliness**

- Floors should be kept clean.
- Oil spills should be cleaned immediately using suitable procedures.
- Scrap metal should be collected.
- Tools should not be left scattered on workbenches.
- Walkways should remain free of obstructions.

**4. Proper allocation of duties**

Workers should be assigned duties according to their skills and responsibilities.

Examples include:

- Workshop supervisor.
- Machine operator.
- Storekeeper.
- Safety officer.
- Maintenance technician.
- Learner or trainee.

**5. Proper record keeping**

Records help in controlling workshop resources.

Examples include:

- Tool issue and return register.
- Materials stock register.
- Machine maintenance records.
- Accident and incident register.
- Waste disposal records.
- Equipment inspection records.

**6. Maintenance of equipment**

Machines and tools should be regularly inspected and maintained.

Maintenance activities include:

- Cleaning.
- Lubrication.
- Tightening loose components.
- Replacing worn-out parts.
- Checking electrical connections.
- Repairing defective equipment.

**7. Proper supervision**

- Workshop activities should be supervised by competent personnel.
- Learners should receive instructions before operating machines.
- Unsafe practices should be corrected immediately.
- Safety rules should be enforced.

### 6.3 The 5S System of Workshop Organization

The 5S system is a workplace organization method that promotes cleanliness, efficiency and safety.




The five principles are:

**1. Sort (Seiri)**

- Remove unnecessary items from the workshop.
- Separate useful tools from damaged or unused equipment.
- Dispose of unwanted materials appropriately.

**2. Set in Order (Seiton)**

- Arrange tools and materials in their proper places.
- Label storage areas.
- Make frequently used tools easy to access.
- Use toolboards and storage racks.

**3. Shine (Seiso)**

- Clean the workshop regularly.
- Remove dust, metal chips and oil spills.
- Inspect machines during cleaning.
- Maintain clean workbenches and floors.

**4. Standardize (Seiketsu)**

- Establish standard cleaning procedures.
- Use labels and signs.

- Develop regular inspection schedules.
- Maintain consistent storage arrangements.

**5. Sustain (Shitsuke)**

- Develop discipline among workers.
- Follow established workshop procedures.
- Conduct regular inspections.
- Encourage continuous improvement.

**Importance of the 5S system**

1. Improves workplace cleanliness.
2. Reduces accidents.
3. Saves time.
4. Improves productivity.
5. Prevents loss of tools.
6. Improves equipment maintenance.
7. Promotes responsibility and discipline.

## 7.0 PERSONAL PROTECTIVE EQUIPMENT IN A METALWORK WORKSHOP

### 7.1 Meaning of Personal Protective Equipment

Personal Protective Equipment (PPE) refers to clothing and equipment worn by workers to protect themselves against workplace hazards.



### 7.2 Types of PPE and Their Uses

| PPE | Function |
|---|---|
| Safety goggles | Protect the eyes from flying particles and sparks. |
| Face shield | Protects the face from sparks and flying debris. |
| Safety boots | Protect the feet from falling objects and sharp materials. |
| Overalls | Protect the body and ordinary clothing from dirt and minor hazards. |
| Welding helmet | Protects the eyes and face against welding radiation and sparks. |
| Leather gloves | Protect hands during suitable material-handling and welding tasks. |
| Earplugs | Reduce exposure to excessive noise. |
| Earmuffs | Protect hearing in noisy working environments. |
| Respirators | Protect against specified airborne contaminants when properly selected. |
| Welding apron | Protects the body against welding sparks and heat. |

**Important safety note:** PPE must be appropriate for the operation. Gloves should not be worn near rotating machinery where they could become entangled. Respiratory protection does not replace proper ventilation and fume extraction.

## 8.0 WASTE MANAGEMENT IN A METALWORK WORKSHOP

### 8.1 Meaning of Waste Management

Waste management refers to the systematic collection, separation, storage, treatment, recycling and safe disposal of waste materials generated during metalworking operations.

Metalwork activities generate different types of waste, some of which can be reused or recycled.

Examples include:

- Metal offcuts.
- Steel filings.
- Metal chips.
- Welding electrode stubs.
- Used grinding discs.
- Used lubricating oil.
- Oily rags.
- Empty paint containers.
- Packaging materials.
- Dust and contaminated filters.

### 8.2 Sources of Waste in a Metalwork Workshop

| Metalwork operation | Waste generated |
|---|---|
| Cutting | Metal offcuts and scrap pieces |
| Drilling | Metal chips and filings |
| Grinding | Grinding dust and worn-out discs |
| Welding | Electrode stubs and slag |
| Turning | Metal swarf and chips |
| Painting | Empty paint containers and contaminated materials |
| Lubrication | Used oil and oily materials |
| Cleaning | Dust and contaminated cleaning materials |

**8.3 Types of Workshop Waste**

**A. Reusable waste**

Reusable waste consists of materials that can be used again without undergoing major processing.

Examples:

- Usable metal offcuts.
- Reusable bolts and nuts.
- Suitable leftover steel sections.
- Unused materials returned to stores.

**B. Recyclable waste**

Recyclable waste consists of materials that can be processed into new products.

Examples:

- Scrap steel.
- Aluminium offcuts.
- Copper scraps.
- Brass scraps.
- Suitable metal packaging.

**C. Hazardous waste**

Hazardous waste consists of materials that can cause harm to people or the environment if improperly handled.

Examples:

- Used lubricating oil.
- Oil-contaminated rags.
- Paint residues.
- Solvent-contaminated materials.
- Certain chemical containers.
- Contaminated grinding dust.

Such materials require appropriate identification, secure storage and disposal through authorized procedures.

**D. General waste**

General waste consists of ordinary waste that is not classified as hazardous or recyclable.

Examples:

- Clean packaging.
- Paper.
- Certain food waste.
- Non-contaminated general refuse.

## 8.4 Waste Management Techniques

### 1. Waste reduction

Waste reduction involves minimizing the amount of waste produced during metalworking activities.

Methods include:

- Accurate measurement before cutting.
- Proper marking out.
- Careful selection of materials.
- Using suitable cutting methods.
- Maintaining machines to reduce defects.
- Planning production processes carefully.

**Example:** A learner making a metal stool should prepare an accurate cutting list to reduce unnecessary steel offcuts.

### 2. Reuse

Reuse involves using materials again for the same or another suitable purpose without major processing.

Examples:

- Using suitable metal offcuts for small projects.
- Reusing undamaged fasteners.
- Reusing suitable storage containers.
- Returning unused materials to the store.

### 3. Recycling

Recycling involves processing waste materials to produce new materials or products.

Examples:

- Selling scrap steel to authorized metal recyclers.
- Recycling aluminium offcuts.
- Recovering copper from suitable scrap.
- Sending recyclable materials to approved recycling facilities.

### 4. Waste segregation

Waste segregation involves separating waste according to its type and characteristics.

For example:

- Scrap steel in a designated metal scrap container.
- Aluminium offcuts in a separate container.
- Used oil in suitable sealed containers.
- General waste in designated bins.

Segregation prevents contamination and makes recycling easier.

### 5. Safe storage

Waste should be stored safely before collection or disposal.

Important practices include:

- Using clearly labelled containers.
- Keeping hazardous waste in suitable closed containers.
- Protecting waste from rainwater.
- Preventing oil leakage.
- Keeping waste away from ignition sources.
- Restricting unauthorized access.
- Avoiding overfilling waste containers.

**6. Safe disposal**

Safe disposal involves transferring waste to appropriate authorized collection, treatment or disposal facilities.

Examples:

- Delivering scrap metal to licensed recyclers.
- Sending used oil to authorized waste handlers.
- Disposing of contaminated materials through appropriate approved channels.
- Using authorized municipal waste collection services for suitable general waste.

**7. Composting**

Composting involves allowing biodegradable organic waste to decompose into organic manure.

It is suitable for certain organic wastes such as food remains and leaves from workshop surroundings. It is not suitable for metal scraps, used oil or chemical-contaminated waste.

**8.5 Importance of Proper Waste Management**

1. Prevents environmental pollution.
2. Reduces the risk of accidents.
3. Promotes cleanliness.
4. Conserves natural resources.
5. Reduces production costs.
6. Creates opportunities for recycling businesses.
7. Prevents blocked drainage systems.
8. Reduces fire hazards associated with poorly stored combustible waste.
9. Improves workshop appearance.
10. Promotes sustainable industrial development.
11. Protects workers and the surrounding community.
12. Encourages responsible use of materials.

**8.6 Environmental Effects of Poor Waste Management**

Poor waste management can result in:

1. **Soil pollution:** Oil and chemical spills may contaminate the soil.

2. **Water pollution:** Improper disposal of oils and chemicals may contaminate rivers, lakes and groundwater.

3. **Air pollution:** Metal dust, fumes and burning waste may pollute the air.

4. **Injuries:** Sharp metal offcuts can cause cuts and puncture wounds.

5. **Fire outbreaks:** Improperly stored flammable substances may increase fire risks.

6. **Blocked drainage:** Accumulated waste may block drainage channels.

7. **Spread of diseases:** Poor sanitation and accumulated waste may attract pests.

8. **Loss of resources:** Recyclable materials may be wasted when disposed of carelessly.

**8.7 Safe Disposal Procedures for Different Workshop Waste**

| Waste material | Recommended management |
|---|---|
| Steel offcuts | Separate and send for recycling. |
| Aluminium scraps | Collect separately for recycling. |
| Copper scraps | Store securely and send to authorized recyclers. |
| Metal filings | Collect carefully in designated containers. |
| Used oil | Store in sealed, labelled containers for authorized collection. |
| Oily rags | Store in suitable closed, fire-safe containers and manage as hazardous waste. |
| Used electrodes | Collect and manage as metal waste where appropriate. |
| Paint residues | Store securely and send to authorized hazardous-waste handlers. |
| Empty chemical containers | Manage according to their contamination and product safety instructions. |
| General refuse | Place in designated bins for authorized collection. |

**Important:** Never burn workshop waste in the open, pour used oil into drains, or bury hazardous waste in the ground.

**9.0 SAFETY AND HEALTH IN WORKSHOP PLANNING AND ORGANIZATION**

**9.1 Common Hazards in a Metalwork Workshop**

A hazard is anything with the potential to cause injury, illness, damage or loss.

Common workshop hazards include:

1. Sharp metal edges.
2. Flying metal particles.
3. Excessive noise.
4. Welding radiation.
5. Hot metallic surfaces.
6. Electrical faults.
7. Rotating machine parts.
8. Slippery floors.
9. Heavy materials.
10. Welding fumes.
11. Fire and explosions.
12. Poor ventilation.

**9.2 Safety Measures**

1. Wear appropriate PPE.
2. Keep machines properly guarded.
3. Use equipment only after receiving proper training.

4. Keep floors dry and clean.
5. Store materials safely.
6. Provide adequate ventilation.
7. Install appropriate firefighting equipment.
8. Display safety signs.
9. Provide first-aid facilities.
10. Inspect tools and machines regularly.
11. Keep emergency exits clear.
12. Report accidents and unsafe conditions immediately.

**9.3 Common Safety Signs**



- **Mandatory signs:** Indicate actions that must be followed, such as wearing eye protection.
- **Warning signs:** Alert workers to possible dangers, such as electrical hazards.
- **Prohibition signs:** Indicate activities that are not allowed, such as smoking in restricted areas.
- **Emergency signs:** Show the location of emergency exits and safety facilities.

## 10.0 PRACTICAL ACTIVITY: PLANNING AND ORGANIZING A SCHOOL METALWORK WORKSHOP

### 10.1 Purpose of the Activity

To enable learners to apply workshop planning and organization skills using locally available resources.

### 10.2 Materials and Equipment

- Drawing paper.
- Pencils.
- Rulers.
- Measuring tape.
- Erasers.
- Available workshop tools.
- Safety signs.
- Storage labels.
- Waste collection containers.

### 10.3 Procedure

1. Visit the school metalwork workshop or another accessible metalwork workshop.
2. Observe the available working space.
3. Identify the machines and tools available.
4. Identify the different metalworking operations performed.
5. Identify the material storage facilities.
6. Examine the arrangement of machines and workbenches.
7. Identify the safety facilities available.
8. Observe how waste materials are collected and disposed of.
9. Identify areas that require improvement.
10. Draw a proposed workshop layout.
11. Label the different working sections.
12. Present the proposed layout to the class.
13. Discuss how the proposed arrangement can improve safety and efficiency.

### 10.4 Example of a Proposed Workshop Arrangement

A proposed school workshop may include:

- Material receiving and storage section.
- Measuring and marking-out section.

- Machine operating section.
- Welding section.
- Fitting and assembly section.
- Finishing section.
- Finished products section.
- Tool storage section.
- Waste collection section.
- First-aid and emergency facilities.

**10.5 Expected Outcomes**

At the end of the activity, the learner should be able to:

1. Identify the main sections of a metalwork workshop.
2. Explain the importance of proper workshop arrangement.
3. Identify suitable material-handling equipment.
4. Draw a simple workshop layout.
5. Identify safety facilities.
6. Demonstrate appropriate waste segregation.
7. Suggest improvements to an existing workshop.

**11.0 IMPORTANCE OF WORKSHOP PLANNING AND ORGANIZATION IN METALWORK**

Workshop planning and organization are important because they:

1. Promote efficient use of resources.
2. Improve productivity.
3. Reduce accidents and injuries.
4. Improve the quality of finished products.
5. Reduce material wastage.
6. Promote cleanliness and orderliness.
7. Improve worker morale.
8. Reduce production costs.
9. Facilitate effective supervision.
10. Improve movement of materials.
11. Promote proper maintenance of machines.
12. Ensure compliance with safety and environmental regulations.
13. Provide a suitable learning environment.
14. Promote teamwork and cooperation.
15. Encourage responsible use of natural resources.

## 12.0 CAREER OPPORTUNITIES RELATED TO WORKSHOP PLANNING AND ORGANIZATION

The knowledge and skills acquired in this sub-strand can prepare learners for various careers and entrepreneurial opportunities.

Examples include:

1. Metal fabrication technician.
2. Welding technician.
3. Mechanical engineering technician.
4. Workshop supervisor.
5. Production technician.
6. Machine operator.
7. Metalwork instructor.
8. Quality control inspector.
9. Storekeeper.
10. Occupational safety assistant.
11. Metal recycling entrepreneur.
12. Workshop owner.

**Entrepreneurial opportunities in Kenya**

Learners can use the knowledge gained to establish small enterprises dealing with:

- Fabrication of metal doors and gates.
- Production of school furniture.
- Repair of agricultural implements.
- Fabrication of window frames.
- Production of metallic shelves.
- Welding and repair services.
- Metal recycling and recovery.

## 13.0 STRAND SUMMARY

In this sub-strand, we have learnt that:

1. Workshop planning involves deciding how workshop resources and facilities will be arranged.
2. Workshop organization involves systematic management of workshop activities and resources.
3. Material handling involves moving, storing and controlling materials.
4. Material-handling equipment includes cranes, forklifts, trolleys and chain blocks.
5. Workshop planning considers location, space, amenities, safety, government regulations, machines and operations.
6. Workshop layouts include process, product and fixed-position layouts.
7. The 5S system promotes effective workshop organization.
8. PPE protects workers against workplace hazards.

9. Waste management involves reducing, reusing, recycling and safely disposing of waste.
10. Proper workshop planning improves productivity, safety and resource utilization.

**REVISION QUESTIONS**

Section A: 30 Marks

**SECTION A: MULTIPLE-CHOICE QUESTIONS**

Choose the correct answer from the alternatives A, B, C and D.

**1.** What is workshop planning?

A. The process of selling finished products.

B. The process of deciding how workshop resources and facilities will be arranged.

C. The process of repairing damaged tools.

D. The process of disposing of all workshop materials.

**2.** Which of the following best describes material handling?

A. Manufacturing metallic products.

B. Painting metallic surfaces.

C. Moving, storing and controlling materials.

D. Measuring metallic components.

**3.** Which equipment is most suitable for transporting heavy metallic materials over short distances within a workshop?

A. Hand trolley.

B. Steel rule.

C. Centre punch.

D. Try square.

**4.** Which of the following is a mechanical material-handling device?

A. Scriber.

B. Hacksaw.

C. Steel rule.

D. Overhead crane.

**5.** Which factor should be considered when selecting a workshop location?

A. Colour of workers' uniforms.

B. Availability of transport facilities.

C. Shape of finished products only.

D. Number of office chairs.

**6.** What is the main purpose of providing adequate workshop space?

A. To increase congestion.

B. To reduce the number of workers.

C. To allow safe movement and efficient working.

D. To eliminate the need for storage.

**7.** Which of the following is an example of a workshop amenity?

A. Drinking water supply.

B. Steel offcuts.

C. Welding slag.

D. Metal filings.

**8.** Which law in Kenya primarily addresses occupational safety and health in workplaces?

A. Basic Education Act, 2013.

B. Traffic Act.

C. Employment Act, 2007.

D. Occupational Safety and Health Act, 2007.

**9.** Which machine is mainly used for producing cylindrical components?

A. Bench grinder.

B. Lathe machine.

C. Power hacksaw.

D. Shearing machine.

**10.** Which workshop layout groups similar machines according to the operations they perform?

A. Fixed-position layout.

B. Product layout.

C. Process layout.

D. Random layout.

**11.** In which type of layout does the product remain in one position while workers and equipment move to it?

A. Fixed-position layout.

B. Product layout.

C. Process layout.

D. Circular layout.

**12.** Which of the following is an advantage of a product layout?

A. Increased movement of materials.

B. Reduced production speed.

C. Increased congestion.

D. Faster production flow.

**13.** Which section is mainly used for checking the dimensions of finished products?

A. Waste collection section.

B. Inspection section.

C. Material receiving section.

D. Changing room.

**14.** Which of the following is the first principle of the 5S system?

A. Shine.

B. Sustain.

C. Sort.

D. Standardize.

**15.** What does the 5S principle of Set in Order involve?

A. Arranging tools and materials in designated places.

B. Removing all useful equipment.

C. Disposing of all materials.

D. Painting all machines.

**16.** Which PPE is mainly used to protect the eyes from flying metal particles?

A. Safety boots.

B. Overalls.

C. Earplugs.

D. Safety goggles.

**17.** Which equipment protects a welder's eyes and face from harmful welding radiation and sparks?

A. Dust mask.

B. Welding helmet.

C. Safety boots.

D. Cotton gloves.

**18.** Which of the following should NOT be done when lifting a heavy object manually?

A. Keeping the load close to the body.

B. Bending the knees.

C. Twisting the body while carrying the load.

D. Asking for assistance.

**19.** Which of the following is an example of recyclable workshop waste?

A. Steel offcuts.

B. Contaminated paint residue.

C. Used oil.

D. Oily rags.

**20.** What is waste segregation?

A. Burning all workshop waste.

B. Mixing all waste materials together.

C. Burying all waste materials.

D. Separating waste according to its type.

**21.** Which of the following is an example of hazardous workshop waste?

A. Clean cardboard.

B. Used lubricating oil.

C. Clean steel offcuts.

D. Uncontaminated paper.

**22.** What is the most appropriate way to manage used lubricating oil?

A. Pouring it into a drainage channel.

B. Burning it in the open.

C. Storing it in sealed, labelled containers for authorized collection.

D. Pouring it onto workshop floors.

**23.** Which of the following practices helps to reduce metal wastage?

A. Accurate measurement before cutting.

B. Cutting materials without marking out.

C. Using blunt cutting tools.

D. Discarding all metal offcuts.

**24.** What is the main function of a material storage rack?

A. To sharpen cutting tools.

B. To weld metallic components.

C. To measure materials.

D. To store materials safely and systematically.

**25.** Which of the following helps remove welding fumes from a workshop?

A. Poor ventilation.

B. Suitable local exhaust ventilation.

C. Closed windows without extraction.

D. Increased storage congestion.

**26.** Which record is used to monitor tools issued to and returned by workers?

A. Accident register.

B. Visitors' book.

C. Tool issue and return register.

D. Attendance register.

**27.** Which of the following is a major advantage of proper workshop organization?

A. Improved productivity and safety.

B. Increased tool loss.

C. Increased material wastage.

D. Reduced supervision.

**28.** What is ergonomics?

A. The process of recycling metal.

B. The process of welding steel.

C. The arrangement of waste bins.

D. Designing the workplace to suit workers' abilities and comfort.

**29.** Which waste-management method involves processing waste materials into new products?

A. Storage.

B. Recycling.

C. Burning.

D. Dumping.

**30.** Why should a metalwork workshop have clearly marked emergency exits?

A. To provide additional storage.

B. To increase machine capacity.

C. To enable safe evacuation during emergencies.

D. To prevent workers from entering the workshop.

**SECTION B: STRUCTURED QUESTIONS**

50 Marks

**Answer ALL questions.**

**QUESTION 1: MATERIAL HANDLING (8 MARKS)**

a) Define material handling as applied in a metalwork workshop. (2 marks)

b) State four examples of mechanical material-handling equipment used in a metalwork workshop. (4 marks)

c) State two precautions that should be observed when manually handling metallic materials. (2 marks)

**QUESTION 2: WORKSHOP PLANNING (8 MARKS)**

A school intends to establish a new metalwork workshop to support practical learning among Grade 11 learners.

a) Explain four factors that should be considered when selecting a suitable location for the workshop. (4 marks)

b) State four workshop amenities that should be provided to support efficient operations. (4 marks)

**QUESTION 3: WORKSHOP LAYOUT (8 MARKS)**

a) Define workshop layout. (2 marks)

b) Describe three types of workshop layouts used in metalworking industries. (6 marks)

**QUESTION 4: WORKSHOP ORGANIZATION AND SAFETY (8 MARKS)**

a) Explain the five principles of the 5S system of workshop organization. (5 marks)

b) State three reasons why personal protective equipment is important in a metalwork workshop. (3 marks)

**QUESTION 5: WASTE MANAGEMENT (9 MARKS)**

A metalwork workshop produces steel offcuts, used lubricating oil, metal filings, empty paint containers and general refuse.

a) Define waste management. (2 marks)

b) Explain four appropriate waste-management techniques that can be applied in the workshop. (4 marks)

c) State three environmental effects of poor waste management in a metalwork workshop. (3 marks)

**QUESTION 6: PRACTICAL WORKSHOP PLANNING (9 MARKS)**

A school has been provided with an empty room to establish a metalwork workshop. The school intends to provide facilities for measuring, cutting, drilling, welding, fitting and finishing.

a) Identify four important sections that should be included in the workshop layout. (4 marks)

b) State three safety facilities that should be provided in the workshop. (3 marks)

c) Explain two ways in which proper workshop organization can improve learning and productivity. (2 marks)

**MARKING SCHEME**

**SECTION A: MULTIPLE-CHOICE ANSWERS**

| Question | Answer | Question | Answer |
|---|---|---|---|
| 1 | B | 16 | D |
| 2 | C | 17 | B |
| 3 | A | 18 | C |
| 4 | D | 19 | A |
| 5 | B | 20 | D |
| 6 | C | 21 | B |
| 7 | A | 22 | C |
| 8 | D | 23 | A |
| 9 | B | 24 | D |
| 10 | C | 25 | B |
| 11 | A | 26 | C |
| 12 | D | 27 | A |
| 13 | B | 28 | D |
| 14 | C | 29 | B |
| 15 | A | 30 | C |

**SECTION B: SUGGESTED MARKING SCHEME**

**QUESTION 1: MATERIAL HANDLING (8 MARKS)**

a) Material handling is the movement, storage, protection and control of raw materials, work-in-progress and finished products within a workshop. (2 marks)

b) Any four:

1. Overhead crane.
2. Forklift truck.
3. Chain block.
4. Hand trolley.
5. Pallet truck.
6. Conveyor system.
7. Hoist.

(1 mark each)

c) Any two:

1. Bend the knees when lifting.
2. Keep the load close to the body.
3. Avoid twisting the body.
4. Wear protective gloves when appropriate.
5. Seek assistance when handling heavy loads.
6. Assess the load before lifting.

(1 mark each)

**QUESTION 2: WORKSHOP PLANNING (8 MARKS)**

a) Any four explained factors:

1. Accessibility – The location should be accessible through suitable roads and transport facilities.
2. Security – The area should provide protection against theft and vandalism.
3. Availability of utilities – Water and electricity should be available.
4. Space – The location should have sufficient space for machines, storage and movement.
5. Proximity to suppliers – The workshop should be accessible to suppliers of metal materials.
6. Drainage – The location should have suitable drainage to prevent water accumulation.
7. Safety – The location should allow safe operation without exposing nearby people to unnecessary hazards.
8. Government regulations – The site should comply with applicable planning and environmental requirements.

(1 mark each)

b) Any four:

1. Electricity supply.
2. Water supply.
3. Toilets and washrooms.
4. First-aid facilities.
5. Firefighting equipment.
6. Adequate lighting.
7. Ventilation systems.
8. Changing rooms.
9. Waste disposal facilities.

(1 mark each)

**QUESTION 3: WORKSHOP LAYOUT (8 MARKS)**

a) Workshop layout is the physical arrangement of machines, equipment, workbenches, storage facilities and working areas within a workshop. (2 marks)

b) Any three:

**1. Process layout**

- Similar machines are grouped according to the operations they perform. (1 mark)
- Example: All drilling machines are placed in one section. (1 mark)

**2. Product layout**

- Machines are arranged according to the sequence of operations involved in producing a product. (1 mark)
- Example: Cutting, drilling, welding and finishing stations arranged sequentially. (1 mark)

**3. Fixed-position layout**

- The product remains in one location while workers, tools and equipment move to it. (1 mark)
- Example: Fabrication of a large steel tank. (1 mark)

**QUESTION 4: WORKSHOP ORGANIZATION AND SAFETY (8 MARKS)**

a) Five principles:

1. Sort – Removing unnecessary items from the workshop. (1 mark)
2. Set in Order – Arranging tools and materials in designated places. (1 mark)
3. Shine – Cleaning and inspecting the workshop regularly. (1 mark)
4. Standardize – Establishing consistent procedures for cleanliness and organization. (1 mark)
5. Sustain – Maintaining discipline and continuously following the established procedures. (1 mark)

b) Any three:

1. Protects workers against injuries.
2. Protects the eyes from flying particles.
3. Protects the feet from falling materials.
4. Reduces exposure to excessive noise.
5. Protects against welding radiation.
6. Reduces exposure to specified airborne contaminants when suitable respiratory protection is used.

(1 mark each)

**QUESTION 5: WASTE MANAGEMENT (9 MARKS)**

a) Waste management is the systematic collection, segregation, storage, treatment, recycling and safe disposal of waste materials generated in a workshop. (2 marks)

b) Any four explained techniques:

1. Waste reduction – Minimizing waste through accurate measurement and cutting.
2. Reuse – Using suitable metal offcuts again for other projects.
3. Recycling – Sending scrap metals to authorized recycling facilities.
4. Waste segregation – Separating metal scraps, used oils and general waste.
5. Safe storage – Keeping waste in appropriate labelled containers.
6. Safe disposal – Sending hazardous waste to authorized waste handlers.

(1 mark each)

c) Any three:

1. Soil pollution.
2. Water pollution.
3. Air pollution.
4. Injuries caused by sharp metal scraps.
5. Blockage of drainage systems.
6. Increased risk of fire.
7. Loss of recyclable resources.

(1 mark each)

**QUESTION 6: PRACTICAL WORKSHOP PLANNING (9 MARKS)**

a) Any four:

1. Measuring and marking-out section.

2. Cutting section.
3. Drilling and machining section.
4. Welding section.
5. Fitting and assembly section.
6. Finishing section.
7. Material storage section.
8. Inspection section.
9. Waste collection section.

(1 mark each)

b) Any three:

1. Fire extinguishers.
2. First-aid kit.
3. Emergency exits.
4. Safety signs.
5. Machine guards.
6. Welding screens.
7. Suitable ventilation.
8. Emergency eye-wash facilities where required.

(1 mark each)

c) Any two explained:

1. **Improves safety:** Proper arrangement reduces accidents and injuries.
2. **Saves time:** Learners can easily locate tools and materials.
3. **Improves productivity:** Activities can be completed efficiently.
4. **Promotes effective learning:** Learners can access suitable equipment and working areas.
5. **Reduces wastage:** Materials are stored and used appropriately.

(1 mark each)

**STRAND 1.0: FUNDAMENTALS OF METALWORK**

**SUB-STRAND 1.2: FIRE AND FIRE FIGHTING**









**1.0 Introduction to Fire and Fire Fighting**

A metalwork workshop contains various materials, machines, tools and equipment that may cause or contribute to fires. Activities such as welding, gas cutting, grinding, heating metals and electrical operations can produce sparks, flames and excessive heat.

Fire is one of the major hazards in a metalwork workshop because it can cause:

- Severe burns and other injuries to learners and w[illegible]

- Destruction of machines, tools and workshop equipment.
- Damage to buildings and other property.
- Loss of learning materials and valuable metalwork products.
- Interruption of workshop activities.
- Death of people and animals.
- Environmental pollution through smoke and harmful gases.

Fire safety involves preventing fires, identifying fire hazards, providing firefighting equipment and training workshop users on appropriate emergency procedures.

**Fire fighting** refers to the process of controlling and extinguishing an unwanted fire using appropriate equipment and techniques.

**Fire prevention** refers to the measures taken to stop fires from starting or spreading.

**Importance of fire safety in a metalwork workshop**

1. Protects human life by reducing the risk of injuries and deaths.
2. Protects workshop property, including machines, tools and materials.
3. Prevents destruction of buildings and other facilities.
4. Reduces financial losses associated with fire damage.
5. Promotes a safe working and learning environment.
6. Ensures continuity of teaching, learning and production activities.
7. Promotes responsible handling and storage of flammable materials.
8. Develops emergency preparedness among learners and workshop personnel.

**2.0 Specific Learning Outcomes**

By the end of this sub-strand, the learner should be able to:

a) Describe the classes of fire as outlined in occupational safety and health requirements.

b) Examine the various firefighting techniques used in extinguishing fires in a metalwork workshop.

c) Perform fire drills and firefighting in a metalwork workshop.

d) Appreciate the importance of fire safety in a metalwork workshop.

**3.0 Meaning of Fire**

**Fire** is a chemical process known as combustion in which a combustible substance reacts with oxygen in the presence of sufficient heat, releasing energy in the form of heat and light.

Fire can be useful when controlled, for example, during:

- Heating metals before forging.
- Gas welding and cutting.
- Heat treatment of metals.
- Brazing and soldering.
- Melting metals in foundry operations.

However, uncontrolled fire becomes a serious safety hazard.

### 3.1 The fire triangle

The fire triangle illustrates the three essential elements required for a fire to start and continue burning.




The three elements are:

**1. Heat**

- Heat provides the energy required to raise a combustible material to its ignition temperature.
- Sources of heat in a metalwork workshop include welding flames, grinding sparks, electrical faults and hot metal surfaces.
- Removing heat can help extinguish a fire.

**2. Fuel**

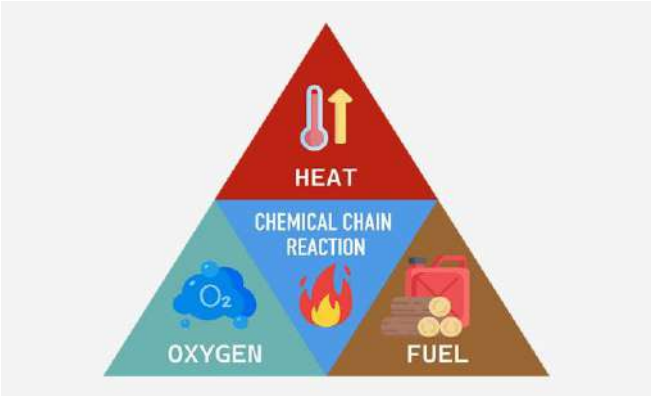
- Fuel is any combustible material that can burn.
- Examples include petrol, diesel, kerosene, paint, timber, paper, charcoal, plastics and some gases.
- Removing or isolating the fuel can prevent a fire from continuing to burn.

**3. Oxygen**

- Oxygen supports combustion.
- It is normally obtained from the surrounding air.
- Smothering a fire with a suitable fire blanket or foam can reduce the supply of oxygen.

### 3.2 The fire tetrahedron

The fire tetrahedron is an expanded model of the fire triangle. It explains that four elements are necessary to sustain combustion.




The four elements are:

1. **Heat:** Provides the energy needed to initiate and sustain combustion.
2. **Fuel:** Provides the material that burns.
3. **Oxygen:** Supports the combustion process.

4. **Chemical chain reaction:** Maintains the chemical reactions that allow the fire to continue burning.

**Application in fire fighting:** Fire can be extinguished by removing or interrupting at least one of the four elements.

**4.0 Causes of Fire in a Metalwork Workshop**

Fire outbreaks in metalwork workshops may result from unsafe practices, faulty equipment or poor storage of materials.

**4.1 Electrical faults**

These occur when electrical installations or equipment develop defects that generate excessive heat or sparks.

Examples include:

- Short circuits in electrical wiring.
- Overloaded electrical sockets.
- Damaged insulation on electric cables.
- Faulty welding machines.
- Loose electrical connections.
- Poorly maintained electrical motors.
- Exposed electrical conductors.

**Prevention measures:**

1. Inspect electrical installations regularly.
2. Replace damaged cables immediately.
3. Avoid overloading electrical sockets.
4. Switch off machines when they are not in use.
5. Ensure electrical repairs are performed by qualified electricians.
6. Keep electrical equipment away from water and flammable materials.

**4.2 Welding and gas-cutting activities**

Welding and gas cutting involve high temperatures and sparks that can ignite combustible materials.

Causes include:

- Sparks landing on paper, timber or oily rags.
- Leakage of acetylene or LPG gas.
- Poor handling of gas cylinders.
- Defective welding equipment.
- Welding near petrol, paint or other flammable substances.
- Failure to clear combustible materials before hot work.

**Prevention measures:**

- Remove combustible materials from the hot-work area.
- Inspect gas hoses, regulators and connections for leaks.
- Store gas cylinders upright and secure them appropriately.
- Use suitable protective equipment.

- Keep appropriate firefighting equipment nearby.
- Provide adequate ventilation.
- Supervise welding and gas-cutting operations.

**4.3 Improper storage of flammable materials**

Flammable materials can easily catch fire when exposed to heat or sparks.

Examples include:

- Petrol.
- Diesel.
- Kerosene.
- Paints and thinners.
- Lubricating oils.
- Grease.
- Solvents.
- LPG and acetylene.

**Prevention measures:**

1. Store flammable liquids in approved, properly labelled containers.
2. Keep flammable substances away from welding and grinding areas.
3. Store gas cylinders in designated, secure and ventilated areas.
4. Avoid storing unnecessary quantities of flammable substances.
5. Close containers immediately after use.
6. Display appropriate warning signs.

**4.4 Poor housekeeping**

Poor housekeeping increases the possibility of fire outbreaks and allows fires to spread rapidly.

Examples include:

- Accumulation of oily rags.
- Leaving sawdust and paper near hot surfaces.
- Allowing waste materials to accumulate.
- Leaving combustible packaging near machines.
- Poor disposal of used cleaning materials.

**Prevention measures:**

- Clean the workshop regularly.
- Dispose of combustible waste safely.
- Store oily rags in suitable closed metal containers.
- Keep floors and passageways free from unnecessary materials.
- Maintain adequate space around machines.

**4.5 Smoking and naked flames**

Careless smoking and use of naked flames may ignite combustible substances.

Examples:

- Smoking near petrol or diesel storage.
- Throwing burning cigarette ends into waste bins.
- Using matches near gas cylinders.
- Lighting fires near paint and solvent storage areas.

**Prevention measures:**

- Prohibit smoking in hazardous workshop areas.
- Display NO SMOKING signs.
- Provide designated smoking areas away from hazardous materials where permitted.
- Keep matches and lighters away from flammable substances.

**4.6 Friction and overheating**

Friction between moving machine components may generate excessive heat.

Examples:

- Overheated bearings.
- Poorly lubricated machine parts.
- Grinding sparks.
- Overheating electric motors.
- Metal particles accumulating around hot machinery.

**Prevention measures:**

- Lubricate machines appropriately.
- Conduct regular machine maintenance.
- Avoid operating machines beyond their recommended capacity.
- Replace worn-out machine components.
- Remove accumulated metal dust and waste.

**4.7 Chemical reactions**

Some substances may react with one another and produce heat or ignition.

Examples include:

- Incompatible chemicals stored together.
- Reactive metals exposed to water.
- Improper storage of chemical substances.
- Contact between certain metal powders and oxidising substances.

**Prevention measures:**

- Identify hazardous chemicals before storage.

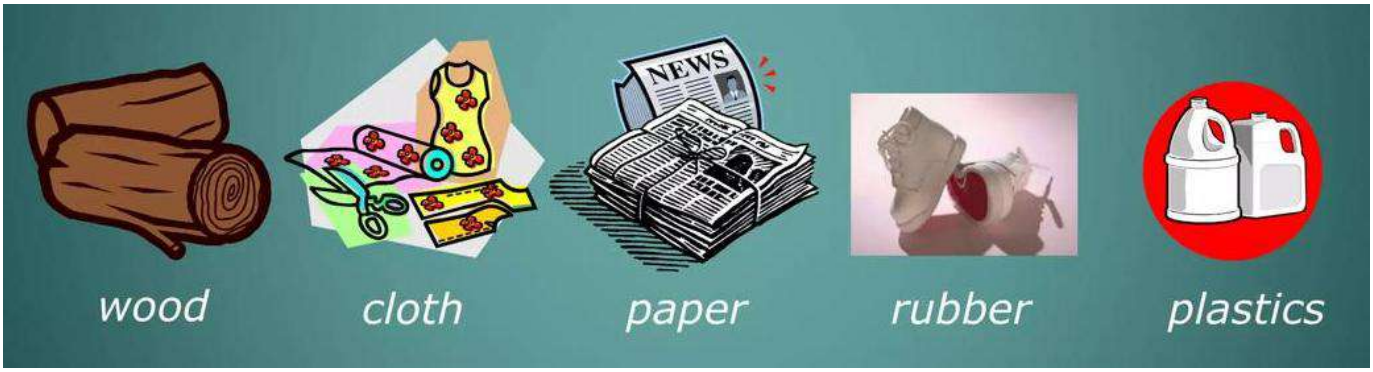
- Follow manufacturers' safety instructions.
- Store incompatible chemicals separately.
- Use appropriate protective equipment.
- Consult Safety Data Sheets (SDS).

**5.0 Classes of Fire**

Fire classification is based on the type of combustible material involved in the fire.

Under Kenya's Factories and Other Places of Work (Fire Risk Reduction) Rules, 2007, four principal classes are identified: Class A, Class B, Class C and Class D.

**5.1 Class A fires – Ordinary combustible materials**




**Definition:** Class A fires are fires involving ordinary combustible solid materials such as paper, wood, cloth, rubber and plastic materials.

Examples in a metalwork workshop:

- Wooden workbenches.
- Timber storage shelves.
- Paper drawings and records.
- Cardboard packaging.
- Cotton cleaning cloths.
- Some plastic workshop containers.

**Characteristics:**

1. They involve ordinary solid combustible materials.
2. They may produce glowing embers.
3. They can spread through direct contact with other combustible materials.
4. They can often be extinguished by cooling the burning material.
5. They may continue smouldering after visible flames disappear.

**Suitable firefighting methods:**

- **Water:** Cools the burning material and reduces its temperature below the ignition point.
- **Foam:** Covers the burning material and helps suppress the flames.
- **ABC dry chemical powder:** Interrupts the combustion process and is suitable for Class A fires.

**Important precaution:** Water must not be used if the fire involves energised electrical equipment or substances that react dangerously with water.

**5.2 Class B fires – Flammable liquids and gases**









**Definition:** Class B fires are fires involving flammable or combustible liquids, flammable gases, greases or similar materials as defined in the Kenyan fire-risk-reduction rules.

Examples:

- Petrol.
- Diesel.
- Kerosene.
- Paint thinners.
- Lubricating oils.
- Grease.
- LPG.
- Acetylene.
- Other flammable gases.

**Characteristics:**

1. They may spread rapidly over the surface of liquids.
2. They can produce intense heat.
3. Some flammable liquids produce vapours that ignite easily.
4. Gas fires may continue burning as long as gas escapes from the source.
5. Water may spread burning liquids and increase the danger.

**Suitable firefighting methods:**

- **Foam extinguishers:** Form a blanket over suitable flammable liquid surfaces, suppressing vapours and separating the fuel from oxygen.
- **Carbon dioxide ($CO_2$) extinguishers:** Displace oxygen around the fire and help interrupt combustion.
- **Dry chemical powder extinguishers:** Interrupt the chemical chain reaction.
- **Gas isolation:** Where safe, shut off the supply of leaking gas.

**Important precautions:**

- Never pour water directly onto burning petrol or oil.

- Do not approach a leaking gas cylinder that is burning.
- Evacuate the area if the gas supply cannot be safely isolated.
- Call the emergency response team.

**5.3 Class C fires – Energised electrical equipment**



**Definition:** Under the Kenyan Fire Risk Reduction Rules, Class C fires involve energised electrical equipment where the safety of the person fighting the fire requires the use of electrically non-conductive extinguishing media.

Examples:

- Electric welding machines.
- Distribution boards.
- Electric motors.
- Electrical cables.
- Power sockets.
- Battery-charging equipment.
- Electrical control panels.

**Characteristics:**

1. They involve equipment connected to an electrical power source.
2. They may cause electric shock to people using unsuitable extinguishing agents.
3. They may result from short circuits and overloaded electrical systems.
4. They can reignite if the electrical fault is not corrected.
5. They may involve burning insulation, plastics and other surrounding materials.

**Suitable firefighting methods:**

- **Carbon dioxide ($CO_2$):** Non-conductive and suitable for many electrical equipment fires.
- **Dry chemical powder:** Suitable when the extinguisher is appropriately rated for electrical fires.
- **Power isolation:** Switch off the electrical supply if this can be done safely.

**Important precautions:**

- Never use ordinary water on energised electrical equipment.
- Do not touch exposed electrical wires.

- Avoid standing in water when dealing with an electrical fire.
- Isolate the electrical supply if safe to do so.
- After isolation, identify the actual burning material and use the appropriate extinguisher.

**5.4 Class D fires – Combustible metals**



**Definition:** Class D fires involve combustible metals such as magnesium, zirconium, sodium, lithium and potassium.

Examples of metals that may burn under suitable conditions:

- Magnesium.
- Sodium.
- Potassium.
- Lithium.
- Zirconium.
- Certain forms of titanium.
- Certain forms of aluminium, especially fine powders and dust.

**Characteristics:**

1. They may burn at extremely high temperatures.
2. Some react violently with water.
3. Some produce intense light during combustion.
4. Ordinary fire extinguishers may be ineffective.
5. They require specialised extinguishing agents.

**Suitable firefighting methods:**

- **Special Class D dry powder:** Designed for particular combustible metal fires.
- **Approved dry extinguishing agents:** Selected according to the metal involved.
- **Isolation:** Prevents other combustible materials from becoming involved.

**Important precautions:**

- Never use water on a combustible metal fire unless a competent specialist has confirmed that a particular application is safe.
- Never use ordinary foam or general-purpose extinguishers as a substitute for a Class D agent.
- Do not disturb burning metal powder or shavings unnecessarily.
- Evacuate the workshop and call trained emergency responders.
- Only trained personnel should tackle such fires using the correct specialist equipment.

**5.5 Summary of the four classes of fire**

| Class | Material involved | Workshop examples |
|---|---|---|
| A | Ordinary combustible solids | Wood, paper, cloth |
| B | Flammable liquids and gases | Petrol, paint, LPG |
| C | Energised electrical equipment | Welding machines, wiring |
| D | Combustible metals | Magnesium, sodium, lithium |

**Important curriculum note:** The classification above follows the Kenyan 2007 Fire Risk Reduction Rules specified in the learning outcome. Other international standards may classify gas fires, electrical fires and cooking-oil fires differently. Learners should therefore follow the applicable Kenyan classification and the extinguisher manufacturer's instructions.

**6.0 Firefighting Techniques Used in a Metalwork Workshop**

Firefighting techniques are methods used to control or extinguish fires by removing one or more elements of the fire tetrahedron.

**6.1 Cooling**

**Definition:** Cooling is a firefighting technique that involves reducing the temperature of burning materials below their ignition temperature.

How it works:

1. The extinguishing agent absorbs heat from the burning material.
2. The temperature of the material decreases.
3. The material can no longer sustain combustion.
4. The fire gradually goes out.

Examples:

- Applying water to a Class A fire.
- Using an appropriate water-based extinguisher on burning timber.
- Cooling surrounding combustible materials where it is safe.

**Advantages:**

- Effective on many ordinary combustible materials.
- Reduces the temperature of burning objects.
- Helps prevent reignition when applied correctly.

**Limitations:**

- Water must not be used on energised electrical equipment.
- Water may spread burning liquids.

- Water can react dangerously with some combustible metals.

**6.2 Smothering**

**Definition:** Smothering is the process of extinguishing fire by reducing or preventing the supply of oxygen to the burning material.

How it works:

1. A suitable material is placed over or around the fire.
2. The supply of oxygen is reduced.
3. Combustion is interrupted.
4. The fire is extinguished.

Examples:

- Using a suitable fire blanket on a small contained fire.
- Applying suitable foam to a flammable liquid fire.
- Using a suitable lid to cover a small contained fire where this can be done safely.
- Using carbon dioxide to displace oxygen around a fire.

**Advantages:**

- Effective for suitable fires involving flammable liquids.
- Can prevent flames from spreading.
- Some methods do not leave significant residue.

**Limitations:**

- Not all fires can safely be smothered.
- The covering material must be appropriate for the fire.
- Smouldering materials may reignite if oxygen is reintroduced.

**6.3 Starvation**

**Definition:** Starvation is a firefighting technique that involves removing or isolating the fuel supplying the fire.

How it works:

1. Identify the source of fuel.
2. Stop the supply if it is safe to do so.
3. Remove nearby combustible materials where possible.
4. The fire gradually dies out when sufficient fuel is no longer available.

Examples:

- Closing the fuel supply valve to a gas burner if safely accessible.
- Moving unused timber away from a fire.
- Shutting down a fuel pump.
- Isolating leaking fuel supplies through safe emergency procedures.

**Advantages:**

- Prevents additional fuel from feeding the fire.



- Helps limit the spread of fire.
- Can reduce the intensity of some fires.

**Limitations:**

- Fuel may not be safely accessible.
- Removing burning materials may spread the fire.
- A fire involving gas should never be approached to isolate a valve if doing so exposes a person to danger.

**6.4 Chemical inhibition**

**Definition:** Chemical inhibition involves interrupting the chemical chain reaction responsible for sustaining combustion.

How it works:

1. A suitable chemical extinguishing agent is released.
2. The agent interferes with the chemical reactions taking place in the flame.
3. The chain reaction is interrupted.
4. Combustion stops.

Examples:

- Applying suitable dry chemical powder to a Class B fire.
- Using an appropriate ABC dry powder extinguisher.

**Advantages:**

- Rapidly suppresses many small fires.
- Useful for several types of workshop fires.
- Some dry chemical extinguishers are suitable for multiple fire classes.

**Limitations:**

- Powder may contaminate sensitive machinery.
- Visibility may be reduced during discharge.
- The wrong powder may be dangerous or ineffective on certain metal fires.

**7.0 Firefighting Equipment Used in a Metalwork Workshop**

Firefighting equipment refers to tools and appliances used to detect, control or extinguish fires.

**7.1 Portable fire extinguishers**



A **fire extinguisher** is a portable device containing an extinguishing agent that can be discharged to control or extinguish a fire.

Types include:

**A. Water extinguisher**

- Contains water under pressure.
- Extinguishes suitable Class A fires through cooling.
- Commonly used on burning paper, wood and cloth.
- Must not be used on energised electrical equipment.
- Must not be used on burning flammable liquids or reactive metals.

**B. Foam extinguisher**

- Contains a suitable foam-forming extinguishing agent.
- Forms a blanket over suitable flammable liquid fires.
- Helps suppress flammable vapours.
- Some foam extinguishers are also suitable for Class A fires.
- Must not be used on energised electrical equipment unless specifically approved for that application.

**C. Carbon dioxide extinguisher ($CO_2$)**

- Contains carbon dioxide under pressure.
- Releases gas that helps suppress combustion.
- Suitable for many Class B and Class C fires.
- Does not normally leave powder residue.
- Can be useful around electrical machinery.
- Its discharge horn can become extremely cold.
- Must be used with care in confined spaces because $CO_2$ can displace breathable oxygen.

**D. Dry chemical powder extinguisher**

- Contains specially formulated extinguishing powder.
- Interrupts the chemical chain reaction.
- ABC powder is suitable for Class A, B and C fires under the applicable classification.
- BC powder is suitable for Class B and C fires.
- Can be used in many workshop emergencies.
- May leave powder residue that damages sensitive electrical equipment.

**E. Special Class D extinguisher**

- Contains a specialised extinguishing agent for combustible metal fires.
- The agent must be suitable for the specific metal involved.
- Used for fires involving magnesium, sodium, lithium and other combustible metals.
- Requires trained personnel.

### 7.2 Fire blankets




**Definition:** A fire blanket is a sheet made from fire-resistant material used to smother a small fire.

Uses:

- Smothering a small fire involving clothing.
- Covering a small contained fire where appropriate.
- Providing protection when used according to its instructions.

Advantages:

1. Simple to use after training.
2. Does not require pressurised gas or chemicals.
3. Does not normally leave chemical residue.
4. Can be stored in an accessible location.

Precautions:

- Never wrap a person in a blanket and allow them to run.
- If clothing catches fire, stop, drop and roll or use a suitable fire blanket with trained assistance.
- Do not use a fire blanket to approach a large or spreading fire.

### 7.3 Fire hose reels



**Definition:** A fire hose reel is a permanently mounted firefighting device consisting of a hose connected to a water supply.

Uses:

- Supplying water to suitable Class A fires.
- Extinguishing burning timber and paper where safe.
- Cooling suitable surrounding combustible materials.

Precautions:

- Never use on energised electrical fires.
- Never use on burning flammable liquids.
- Never use on reactive metal fires.
- Only trained personnel should operate the equipment during emergencies.

**7.4 Fire buckets**



Fire buckets are containers used to hold suitable materials such as dry sand for emergency fire control.

Uses:

- Dry sand may be used for certain small contained fires where appropriate.
- Approved dry sand may help contain small spills involving burning liquids.
- Special dry materials may be used in specific metalwork emergencies when approved for the substance involved.

**Precaution:** Ordinary sand must not be assumed to be suitable for every combustible metal fire. Use only a suitable, dry, approved extinguishing agent for the metal involved.

**7.5 Fire alarm systems**



**Definition:** A fire alarm system is a device or arrangement to alert people when a fire is detected.

Types:

- Manual fire alarm call points.
- Automatic smoke detectors.
- Heat detectors.
- Audible fire alarm bells.
- Visual flashing alarm devices.

Importance:

1. Warns people of an outbreak of fire.
2. Initiates emergency evacuation.
3. Reduces delays in responding to fires.
4. Helps protect lives and property.
5. Alerts the designated emergency response team.

**7.6 Smoke detectors**




A smoke detector is a device that detects smoke particles in the air and activates an alarm or sends a signal to a fire alarm system.

Importance:

- Provides early warning.
- Helps people evacuate before smoke becomes dangerous.
- Reduces the possibility of unnoticed fires.
- Supports rapid emergency response.

**7.7 Other firefighting and emergency equipment**

Other important equipment includes:

- Fire-resistant gloves.
- Protective clothing.
- Emergency lighting.
- First-aid kits.
- Emergency exit signs.
- Fire-resistant doors.

- Breathing apparatus for trained emergency responders.
- Emergency communication equipment.

**8.0 Selecting the Appropriate Fire Extinguisher**

Selecting an appropriate extinguisher is important because different fires require different extinguishing agents.

The wrong extinguisher may increase the intensity of a fire, damage equipment or expose the user to serious danger.

**8.1 Factors to consider when selecting a fire extinguisher**

1. **Class of fire:** Identify the burning material before selecting an extinguisher.
2. **Nature of the material:** Determine whether the fire involves solids, liquids, electrical equipment or combustible metals.
3. **Size of the fire:** The extinguisher must have adequate capacity for the anticipated hazard.
4. **Location of the fire:** Consider whether the fire is near electrical equipment, gas cylinders or flammable substances.
5. **Safety of the user:** Select an extinguisher that can be operated safely by trained personnel.
6. **Manufacturer's instructions:** Read the extinguisher label and follow the operating instructions.
7. **Environmental conditions:** Consider whether the extinguisher can be safely used in an enclosed or ventilated space.
8. **Maintenance condition:** Ensure the extinguisher is inspected, serviced and ready for use.
9. **Accessibility:** Position extinguishers where they can be accessed quickly without obstructing escape routes.
10. **Compatibility:** Ensure the extinguishing agent is compatible with the material involved.

**8.2 Matching fire classes with extinguishers**

| Fire class | Suitable extinguishing agents |
|---|---|
| Class A | Water, suitable foam, ABC dry powder |
| Class B | Suitable foam, $CO_2$, BC or ABC dry powder |
| Class C | $CO_2$ or appropriately rated dry powder |
| Class D | Special Class D extinguishing powder |

*Always confirm the extinguisher's approved rating and manufacturer's instructions. The table is a general guide, not a substitute for a workshop fire-risk assessment.*

**8.3 Examples of extinguisher selection in a metalwork workshop**

**Situation 1: A wooden workbench catches fire.**

- Fire class: Class A.
- Suitable extinguisher: Water or ABC dry powder.
- Reason: Water cools the burning wood while ABC powder interrupts combustion.

**Situation 2: Petrol catches fire near a machine.**

- Fire class: Class B.
- Suitable extinguisher: Foam, $CO_2$ or appropriate dry powder.
- Reason: These agents help suppress combustion without spreading the burning liquid as water could.

**Situation 3: An electrical distribution board catches fire while connected to power.**

- Fire class: Class C.
- Suitable extinguisher: $CO_2$ or appropriately rated dry powder.

- Reason: These agents are suitable for use on energised electrical equipment when used according to instructions.

**Situation 4: Magnesium shavings catch fire.**

- Fire class: Class D.
- Suitable extinguisher: Special Class D agent approved for magnesium.
- Reason: Ordinary extinguishing agents may react dangerously or fail to extinguish the burning metal.

**9.0 Fire Extinguisher Operation**

A portable extinguisher should only be operated by a person who has received appropriate training.

**9.1 The PASS method**

PASS is a commonly used method for operating many portable fire extinguishers.




**P – Pull the pin**

- Remove the safety pin.
- This unlocks the operating mechanism.
- Hold the extinguisher upright.

**A – Aim at the base of the fire**

- Direct the nozzle towards the base of the flames.
- Avoid aiming at the upper flames.
- Maintain a safe distance as specified by the manufacturer.

**S – Squeeze the handle**

- Press the operating handle.
- This releases the extinguishing agent.
- Use controlled discharge.

**S – Sweep from side to side**

- Move the nozzle across the base of the fire.
- Cover the burning area systematically.
- Continue only while maintaining a safe escape route.

**Important safety precautions:**

- Raise the alarm before attempting to fight a fire.
- Ensure other people are evacuating.
- Keep an unobstructed escape route behind you.
- Fight only a small, contained fire.
- Stop and evacuate if the fire grows, smoke increases or the extinguisher becomes ineffective.
- Never turn your back on a fire.
- Do not re-enter a building to retrieve property.

**10.0 Fire Prevention Measures in a Metalwork Workshop**

Fire prevention involves identifying and controlling conditions that may lead to fire outbreaks.

**10.1 Proper storage of materials**

- Keep flammable liquids in approved containers.
- Store gas cylinders securely in suitable locations.
- Separate combustible materials from welding areas.
- Label all chemical containers clearly.
- Avoid unnecessary accumulation of combustible substances.

**10.2 Electrical safety**

- Inspect electrical installations regularly.
- Avoid overloading sockets.
- Switch off unused machines.
- Replace defective electrical cables.
- Ensure proper earthing and electrical protection.
- Allow only authorised persons to repair electrical equipment.

**10.3 Safe welding practices**

- Inspect welding equipment before use.
- Remove flammable materials from the welding area.
- Use welding screens and suitable protective equipment.
- Check gas connections for leaks.
- Keep appropriate extinguishers nearby.
- Carry out hot work under proper supervision.

**10.4 Good housekeeping**

- Keep the workshop clean.
- Dispose of waste materials appropriately.
- Remove oil spills immediately using suitable procedures.
- Keep emergency exits clear.

- Store tools and materials properly.

**10.5 Fire safety signs**




Fire safety signs provide information and warnings that help prevent fire outbreaks and guide people during emergencies.

Examples:

1. **Fire extinguisher sign:** Shows the location of an extinguisher.
2. **Fire hose reel sign:** Identifies the location of a hose reel.
3. **Fire alarm sign:** Indicates where the alarm can be activated.
4. **Emergency exit sign:** Shows the escape route.
5. **No smoking sign:** Prohibits smoking in hazardous areas.
6. **Flammable materials sign:** Warns people about substances that can easily catch fire.
7. **Assembly point sign:** Shows where people should gather after evacuation.

**11.0 Fire Drills in a Metalwork Workshop**

**Definition:** A fire drill is a planned exercise carried out to prepare people for the actions they should take in the event of an actual fire.

Fire drills help learners and workshop personnel understand evacuation procedures and develop appropriate emergency responses.

**11.1 Importance of fire drills**

1. Familiarise learners with emergency exits.
2. Teach learners how to respond to fire alarms.
3. Reduce panic during actual fire outbreaks.
4. Improve evacuation speed and organisation.

5. Test the effectiveness of emergency procedures.
6. Identify weaknesses in workshop safety arrangements.
7. Train learners to assemble at designated points.
8. Help assess the preparedness of the emergency response team.
9. Promote teamwork and responsibility.
10. Improve awareness of fire prevention measures.

**11.2 Procedures for conducting a fire drill**



**Step 1: Planning the drill**

- Identify the objectives of the drill.
- Select a suitable time.
- Appoint responsible persons.
- Identify safe evacuation routes.
- Establish an assembly point.

**Step 2: Informing participants**

- Explain the purpose of the exercise.
- Give participants basic safety instructions.
- Identify the emergency response team.
- Explain the alarm signals.

**Step 3: Activating the alarm**

- Activate the fire alarm.
- Stop workshop activities.
- Switch off machines only if this can be done safely and without delaying evacuation.
- Stop welding and other hot-work activities if safe to do so.

**Step 4: Evacuating the workshop**

- Leave the workshop immediately.
- Follow designated emergency exit routes.
- Walk calmly without pushing or running.

- Assist persons who require help.
- Do not stop to collect personal belongings.
- Avoid lifts where provided.

**Step 5: Assembling at the designated point**

- Move to the assembly point.
- Remain there until further instructions are given.
- Allow the responsible person to conduct a headcount.

**Step 6: Conducting firefighting demonstrations**

- Under controlled conditions, trained personnel demonstrate the operation of appropriate extinguishers.
- Participants observe safe extinguisher handling.
- Only authorised and trained persons handle live-fire demonstrations.
- Suitable training equipment and controlled conditions must be provided.

**Step 7: Evaluation**

- Assess the evacuation process.
- Identify any problems encountered.
- Record the time taken to evacuate.
- Identify blocked routes or missing safety equipment.
- Recommend improvements.

**Step 8: Reporting**

- Prepare a fire drill report.
- Record participants and observations.
- Document identified weaknesses.
- Recommend corrective actions.

### 11.3 Responsibilities during a fire drill

| Person | Responsibility |
|---|---|
| Workshop instructor | Supervises the evacuation and ensures learner safety |
| Fire safety officer | Coordinates the drill |
| Firefighting team | Demonstrates firefighting procedures |
| Class representatives | Assist with orderly movement |
| First-aid personnel | Provide first aid when required |
| Learners | Follow instructions and evacuate calmly |

### 11.4 Sample fire drill report

| Item | Details |
|---|---|
| Institution | Name of school |
| Date | Date of drill |
| Location | Metalwork workshop |
| Type of exercise | Fire evacuation drill |
| Alarm activated by | Responsible officer |
| Number of participants | Actual number |
| Assembly point | Designated safe area |
| Observations | Challenges identified |

| | |
|---|---|
| Recommendations | Corrective measures |
| Prepared by | Name and signature |

**12.0 Procedure for Responding to an Actual Fire Outbreak**

A fire emergency requires immediate and organised action.

1. Raise the alarm immediately.
2. Stop workshop operations if safe to do so.
3. Evacuate everyone through the designated emergency exits.
4. Contact the fire and emergency response services.
5. Isolate electricity or fuel supplies only if safe.
6. Keep people away from the affected area.
7. Do not attempt to fight a large or rapidly spreading fire.
8. Only trained persons should attempt to extinguish a small fire using the correct equipment.
9. Assist injured persons after reaching a safe location.
10. Conduct a headcount at the assembly point.
11. Do not re-enter the building until authorised by emergency responders.

**Kenyan emergency preparedness:** Schools and workshops should display locally verified emergency contact numbers, including the relevant county fire and rescue service contacts.

**13.0 Fire Safety Requirements in Kenyan Workplaces**

Fire safety in Kenyan workplaces is guided by the Occupational Safety and Health Act, 2007 and the Factories and Other Places of Work (Fire Risk Reduction) Rules, 2007.

Important requirements include:

1. Provision of adequate and suitable firefighting equipment.
2. Proper maintenance of firefighting appliances.
3. Display of fire safety information and signs.
4. Provision of adequate means of escape.
5. Keeping emergency exits and escape routes unobstructed.
6. Training workers in the safe use of firefighting appliances.
7. Establishment of appropriate emergency response arrangements.
8. Conducting fire drills.
9. Inspection and maintenance of fire detection systems.
10. Carrying out fire safety audits as required.

Under Section 81 of the Occupational Safety and Health Act, workplaces must have suitable firefighting means, trained persons and adequate escape arrangements.

The Fire Risk Reduction Rules also provide for the selection and distribution of extinguishers according to anticipated fire classes and the level of hazard. They provide for inspection and maintenance arrangements, including inspection of firefighting appliances by a competent person at least once every twelve months.

**14.0 Practical Learning Activities**

**Activity 1: Identifying causes of fire**

**Materials required:**

- Pictures of workshop fire hazards.
- Charts.
- Samples of warning signs.
- Writing materials.

**Procedure:**

1. Visit the school metalwork workshop.
2. Observe the electrical installations.
3. Identify flammable materials.
4. Examine the welding and grinding areas.
5. Identify possible sources of ignition.
6. Record the hazards observed.
7. Suggest suitable preventive measures.

**Expected learning outcome:** The learner identifies common causes of fire and suggests appropriate preventive measures.

**Activity 2: Identifying classes of fire**

**Procedure:**

1. Collect pictures showing different types of fires.
2. Observe the materials involved.
3. Group the fires into Classes A, B, C and D.
4. Explain the characteristics of each class.
5. Identify suitable extinguishing agents.
6. Present findings to the class.

**Expected learning outcome:** The learner correctly identifies the four classes of fire as specified in the Kenyan fire-risk-reduction rules.

**Activity 3: Identifying firefighting equipment**

**Procedure:**

1. Observe different fire extinguishers.
2. Read the labels on the extinguishers.
3. Identify their contents and fire ratings.
4. Examine their operating mechanisms.
5. Explain the correct use of each extinguisher.
6. Record the findings.

**Expected learning outcome:** The learner selects appropriate firefighting equipment for different workshop fire hazards.

**Activity 4: Conducting a fire drill**

**Procedure:**

1. Organise a supervised fire drill.
2. Activate the fire alarm.
3. Stop workshop activities.
4. Evacuate through the designated emergency routes.
5. Assemble at the designated point.
6. Conduct a headcount.
7. Evaluate the exercise.
8. Record recommendations.

**Expected learning outcome:** The learner demonstrates appropriate emergency evacuation procedures.

**Activity 5: Fire extinguisher demonstration**

**Procedure:**

1. Observe a trained instructor demonstrating the use of a fire extinguisher.
2. Identify the type of extinguisher.
3. Explain the PASS method.
4. Observe the correct stance and handling.
5. Participate in a supervised simulation using a training extinguisher where available.
6. Discuss the safety precautions.

**Expected learning outcome:** The learner demonstrates awareness of correct extinguisher operation and personal safety.

**15.0 Challenges Associated with Firefighting in Metalwork Workshops**

1. **Inadequate firefighting equipment:** Some workshops lack sufficient extinguishers and other emergency appliances.
2. **Lack of training:** Learners and workers may not know how to select and operate extinguishers.
3. **Poor maintenance:** Faulty or expired extinguishers may fail during emergencies.
4. **Blocked emergency exits:** Poor storage arrangements may obstruct escape routes.
5. **Inadequate water supply:** Some workshops may lack reliable water supplies for suitable Class A firefighting.
6. **Electrical hazards:** Damaged wiring may expose people to electric shock.
7. **Improper storage of flammable substances:** Poor storage increases the likelihood of fire outbreaks.
8. **Panic and confusion:** People may fail to follow evacuation procedures.
9. **Inadequate fire detection:** Delayed detection can allow fires to spread.
10. **Limited access to emergency services:** Some workshops may be located far from fire and rescue services.

**16.0 Importance of Appreciating Fire Safety**

Learners should develop positive attitudes towards fire prevention and emergency preparedness.

This can be demonstrated through:

- Observing workshop safety regulations.
- Reporting fire hazards promptly.
- Using equipment responsibly.
- Keeping the workshop clean.
- Participating actively in fire drills.
- Respecting fire safety signs.
- Avoiding unnecessary risks.
- Helping others during evacuation without exposing themselves to danger.
- Maintaining firefighting equipment.
- Promoting a culture of safety in the school and community.

**Summary of the Sub-Strand**

| Concept | Main points |
|---|---|
| Fire | Uncontrolled combustion that can cause damage and injury |
| Fire triangle | Heat, fuel and oxygen |
| Fire tetrahedron | Heat, fuel, oxygen and chemical chain reaction |
| Class A | Ordinary combustible materials |
| Class B | Flammable liquids and gases |
| Class C | Energised electrical equipment |
| Class D | Combustible metals |
| Cooling | Removing heat |
| Smothering | Reducing oxygen supply |
| Starvation | Removing fuel |
| Chemical inhibition | Interrupting the chemical chain reaction |
| Fire drill | Planned emergency evacuation exercise |
| PASS | Pull, Aim, Squeeze and Sweep |

TOPIC: FIRE SAFETY IN A METALWORK WORKSHOP

**PART I: REVISION QUESTIONS**

**SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)**

Instructions: Answer all the questions by selecting the correct answer from the alternatives A, B, C and D. Each question carries 1 mark.

1. What is fire?

A. A process of cooling metals
B. A chemical process involving combustion
C. A process of shaping metals
D. A method of joining metals

2. Which of the following represents the three elements of the fire triangle?

A. Heat, water and smoke
B. Fuel, water and carbon dioxide
C. Heat, fuel and oxygen
D. Oxygen, smoke and water

3. Which additional element is included in the fire tetrahedron?

A. Water
B. Chemical chain reaction
C. Smoke
D. Carbon dioxide

4. Which of the following materials is associated with Class A fires?

A. Petrol
B. Magnesium
C. Paper
D. LPG

5. A fire involving petrol is classified as:

A. Class A
B. Class B
C. Class C
D. Class D

6. Which class of fire involves energised electrical equipment under the Kenyan fire-risk-reduction classification?

A. Class A
B. Class B
C. Class C
D. Class D

7. A fire involving burning magnesium shavings belongs to:

A. Class A
B. Class B
C. Class C
D. Class D

8. Which of the following is a common cause of fire in a metalwork workshop?

A. Proper storage of materials
B. Regular equipment maintenance
C. Electrical short circuits
D. Proper workshop ventilation

9. Which firefighting technique involves reducing the temperature of burning materials?

A. Starvation
B. Cooling
C. Smothering
D. Chemical inhibition

10. Removing the fuel supply from a fire is known as:

A. Cooling
B. Smothering
C. Starvation
D. Ventilation

11. Which firefighting technique involves reducing the oxygen supply?

A. Smothering
B. Cooling
C. Starvation
D. Heating

12. Chemical inhibition works by:

A. Increasing the temperature of the fire
B. Interrupting the chemical chain reaction
C. Increasing the fuel supply
D. Increasing oxygen supply

13. Which extinguisher is suitable for many fires involving electrical equipment?

A. Water extinguisher
B. Carbon dioxide extinguisher
C. Ordinary water hose
D. Water bucket

14. Which extinguisher is commonly used for suitable Class A fires?

A. Water extinguisher
B. Special Class D extinguisher
C. Ordinary water extinguisher on live electrical equipment
D. None of the above

15. Which extinguishing agent is specifically designed for combustible metal fires?

A. Ordinary foam
B. Water
C. Special Class D powder
D. Ordinary water mist

16. What is the main function of a fire blanket?

A. To increase oxygen supply
B. To smother a suitable small fire
C. To cool electrical machines
D. To increase the temperature of burning materials

17. What does the letter P represent in the PASS method?

A. Push
B. Pull
C. Press
D. Protect

18. In the PASS method, the nozzle should be aimed at:

A. The top of the flames
B. The ceiling
C. The base of the fire
D. The smoke

19. Which of the following should be done first when a fire is discovered?

A. Collect personal belongings
B. Raise the alarm
C. Continue working
D. Open all windows

20. What is a fire drill?

A. A metal drilling operation
B. A planned emergency preparedness exercise
C. A method of welding
D. A machine maintenance procedure

21. Which equipment is used to detect smoke?

A. Fire blanket
B. Smoke detector
C. Fire bucket
D. Welding screen

22. What is the main purpose of a fire alarm?

A. To cool burning materials
B. To alert people of a fire emergency
C. To supply oxygen
D. To extinguish electrical fires

23. Which of the following is a suitable fire prevention measure?

A. Overloading electrical sockets
B. Storing petrol near welding equipment
C. Regular inspection of electrical installations
D. Accumulating oily rags near machines

24. Why should emergency exits be kept clear?

A. To provide storage space
B. To allow safe evacuation
C. To improve machine performance
D. To increase workshop production

25. Which of the following materials should be stored away from welding areas?

A. Metal rulers
B. Flammable liquids
C. Steel squares
D. Metal clamps

26. Which organisation is responsible for enforcing occupational safety and health legislation in Kenyan workplaces?

A. KNEC
B. KICD
C. Directorate of Occupational Safety and Health Services
D. TSC

27. Why should a fire extinguisher be inspected regularly?

A. To increase its weight
B. To ensure it is in good working condition
C. To change its colour
D. To make it produce more smoke

28. Which of the following is an appropriate action during workshop evacuation?

A. Running and pushing others
B. Returning for personal belongings
C. Following designated emergency exits
D. Hiding inside the workshop

29. What should be done when a fire becomes too large to control safely?

A. Continue fighting it alone
B. Approach it closely
C. Evacuate and contact emergency responders
D. Pour water on every type of fire

30. Why is fire safety important in a metalwork workshop?

A. To increase workshop hazards
B. To protect lives and property
C. To encourage unsafe practices
D. To reduce workshop cleanliness

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

Instructions: Answer all questions. Show clear understanding and give relevant examples from a metalwork workshop.

**QUESTION 1: FIRE AND ITS CAUSES (8 MARKS)**

a) Define the term fire. (2 marks)

b) State three elements of the fire triangle. (3 marks)

c) Explain three causes of fire in a metalwork workshop. (3 marks)

**QUESTION 2: CLASSES OF FIRE (8 MARKS)**

a) Explain the four classes of fire as outlined in the Kenyan Fire Risk Reduction Rules, 2007. (4 marks)

b) Give one example of a material or substance associated with each class of fire. (4 marks)

**QUESTION 3: FIREFIGHTING TECHNIQUES (8 MARKS)**

a) Explain the following firefighting techniques:

i. Cooling. (2 marks)

ii. Smothering. (2 marks)

iii. Starvation. (2 marks)

b) Explain how chemical inhibition helps extinguish fire. (2 marks)

**QUESTION 4: FIREFIGHTING EQUIPMENT (8 MARKS)**

a) Identify four types of fire extinguishers used in a metalwork workshop. (4 marks)

b) State one appropriate application of each of the following:

i. Carbon dioxide extinguisher. (1 mark)

ii. Water extinguisher. (1 mark)

iii. Special Class D extinguisher. (1 mark)

iv. Foam extinguisher. (1 mark)

**QUESTION 5: FIRE EXTINGUISHER OPERATION AND SAFETY (9 MARKS)**

a) Explain the meaning of the PASS method used when operating a fire extinguisher. (4 marks)

b) State three precautions to observe when fighting a fire in a metalwork workshop. (3 marks)

c) Explain two reasons why the correct selection of a fire extinguisher is important. (2 marks)

**QUESTION 6: FIRE DRILLS AND FIRE PREVENTION (9 MARKS)**

a) Define a fire drill. (2 marks)

b) Outline four steps followed when conducting a fire drill in a metalwork workshop. (4 marks)

c) State three measures that can be used to prevent fire outbreaks in a metalwork workshop. (3 marks)

**PART II: MARKING SCHEME**

**SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)**

Each correct answer carries 1 mark.

| Question | Answer |
|---|---|
| 1 | B |
| 2 | C |
| 3 | B |
| 4 | C |
| 5 | B |
| 6 | C |
| 7 | D |
| 8 | C |
| 9 | B |
| 10 | C |
| 11 | A |
| 12 | B |
| 13 | B |
| 14 | A |
| 15 | C |
| 16 | B |
| 17 | B |
| 18 | C |
| 19 | B |
| 20 | B |
| 21 | B |
| 22 | B |
| 23 | C |
| 24 | B |
| 25 | B |
| 26 | C |
| 27 | B |
| 28 | C |
| 29 | C |
| 30 | B |

Total: 30 marks

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

**QUESTION 1: FIRE AND ITS CAUSES (8 MARKS)**

a) Define the term fire. (2 marks)

Fire is a chemical process involving rapid combustion or burning of a material in the presence of oxygen, releasing heat and light energy. (2 marks)

Mark allocation:

- Chemical process involving combustion – 1 mark.
- Release of heat and light energy – 1 mark.

b) State three elements of the fire triangle. (3 marks)

1. Heat.
2. Fuel.
3. Oxygen.

(1 mark each)

c) Explain three causes of fire in a metalwork workshop. (3 marks)

Award 1 mark for each well-explained point.

1. Electrical short circuits: Damaged electrical cables, faulty connections or overloaded sockets can produce sparks and excessive heat that ignite nearby combustible materials.
2. Welding and cutting sparks: Hot metal particles produced during welding, grinding and gas cutting can ignite flammable materials.
3. Improper storage of flammable materials: Petrol, oils, solvents and other combustible substances can easily catch fire when exposed to heat or sparks.
4. Poor housekeeping: Accumulation of oily rags, sawdust, paper and other combustible waste can contribute to fire outbreaks.
5. Careless smoking: Cigarettes and matches can ignite flammable substances.
6. Faulty machinery: Overheating machines and friction between moving parts can generate enough heat to start a fire.

Accept any three correct explanations.

Total: 8 marks

**QUESTION 2: CLASSES OF FIRE (8 MARKS)**

a) Explain the four classes of fire as outlined in the Kenyan Fire Risk Reduction Rules, 2007. (4 marks)

1. Class A fires: Fires involving ordinary combustible solid materials that form glowing embers when burning, such as wood, paper, cloth and rubber. (1 mark)
2. Class B fires: Fires involving flammable liquids such as petrol, diesel, kerosene, paints and oils. (1 mark)
3. Class C fires: Fires involving energised electrical equipment, such as electrical motors, wiring, switches and transformers. (1 mark)
4. Class D fires: Fires involving combustible metals such as magnesium, sodium, potassium and aluminium powder. (1 mark)

b) Give one example of a material or substance associated with each class of fire. (4 marks)

1. Class A – Wood. (1 mark)

2. Class B – Petrol. (1 mark)
3. Class C – Electrical wiring or electrical motors. (1 mark)
4. Class D – Magnesium. (1 mark)

Total: 8 marks

**QUESTION 3: FIREFIGHTING TECHNIQUES (8 MARKS)**

a) Explain the following firefighting techniques:

i. Cooling. (2 marks)

- Cooling involves reducing the temperature of burning materials. (1 mark)
- Water is commonly used on suitable Class A fires to reduce the temperature below the ignition point. (1 mark)

ii. Smothering. (2 marks)

- Smothering involves cutting off or reducing the supply of oxygen to the burning material. (1 mark)
- It can be achieved using foam, a suitable fire blanket or carbon dioxide, depending on the type of fire. (1 mark)

iii. Starvation. (2 marks)

- Starvation involves removing or cutting off the supply of fuel feeding the fire. (1 mark)
- It can be achieved by closing fuel valves, removing combustible materials or isolating a leaking fuel supply where safe. (1 mark)

b) Explain how chemical inhibition helps extinguish fire. (2 marks)

- Chemical inhibition involves interrupting the chemical chain reaction that sustains combustion. (1 mark)
- Special extinguishing agents, such as suitable dry chemical powders, interfere with the combustion reactions and stop the fire from continuing to burn. (1 mark)

Total: 8 marks

**QUESTION 4: FIREFIGHTING EQUIPMENT (8 MARKS)**

a) Identify four types of fire extinguishers used in a metalwork workshop. (4 marks)

1. Water fire extinguisher.
2. Foam fire extinguisher.
3. Carbon dioxide ($CO_2$) fire extinguisher.
4. Dry powder fire extinguisher, including special Class D powder for combustible metal fires.

(1 mark each)

Other acceptable answers:

- Wet chemical extinguisher.
- Water mist extinguisher, where appropriate.

b) State one appropriate application of each of the following:

i. Carbon dioxide extinguisher. (1 mark)

- Used on suitable fires involving energised electrical equipment.
- Also suitable for certain flammable liquid fires.



ii. Water extinguisher. (1 mark)

- Used on Class A fires involving ordinary combustible solid materials such as wood, paper and cloth.

iii. Special Class D extinguisher. (1 mark)

- Used on fires involving combustible metals such as magnesium, sodium and potassium.

iv. Foam extinguisher. (1 mark)

- Used on suitable Class A and Class B fires, particularly those involving flammable liquids such as petrol and oils.

Total: 8 marks

**QUESTION 5: FIRE EXTINGUISHER OPERATION AND SAFETY (9 MARKS)**

a) Explain the meaning of the PASS method used when operating a fire extinguisher. (4 marks)

PASS is a procedure used when operating a fire extinguisher.

1. P – Pull: Pull out the safety pin to unlock the extinguisher. (1 mark)
2. A – Aim: Aim the nozzle or hose at the base of the fire. (1 mark)
3. S – Squeeze: Squeeze the operating handle to release the extinguishing agent. (1 mark)
4. S – Sweep: Sweep the nozzle from side to side across the base of the fire until it is extinguished or the extinguisher is empty. (1 mark)

b) State three precautions to observe when fighting a fire in a metalwork workshop. (3 marks)

Award 1 mark each for any three:

1. Raise the alarm immediately before attempting to fight the fire.
2. Ensure that the correct type of fire extinguisher is selected.
3. Maintain a safe distance from the fire.
4. Keep an escape route behind you.
5. Never use water on energised electrical equipment.
6. Never use ordinary water or foam on combustible metal fires.
7. Avoid inhaling smoke and toxic fumes.
8. Do not attempt to fight a fire that is too large or spreading rapidly.
9. Wear appropriate protective equipment where available.
10. Evacuate immediately if conditions become unsafe.

c) Explain two reasons why the correct selection of a fire extinguisher is important. (2 marks)

1. Prevents the spread of fire: Using the correct extinguisher helps control and extinguish the fire effectively. (1 mark)
2. Prevents injuries and further damage: Using an unsuitable extinguishing agent can cause dangerous reactions, electric shock or spread burning materials. (1 mark)

Total: 9 marks

**QUESTION 6: FIRE DRILLS AND FIRE PREVENTION (9 MARKS)**

a) Define a fire drill. (2 marks)

A fire drill is a planned emergency preparedness exercise carried out to train people on how to respond safely and quickly in case of a fire outbreak.

Mark allocation:

- Planned emergency preparedness exercise – 1 mark.
- Training people on safe evacuation and response during a fire emergency – 1 mark.

b) Outline four steps followed when conducting a fire drill in a metalwork workshop. (4 marks)

1. Raise the alarm: Activate the fire alarm to alert everyone that a fire emergency has occurred. (1 mark)
2. Stop workshop activities: Switch off machines and equipment where safe to do so and leave tools in safe positions. (1 mark)
3. Evacuate the workshop: Use designated emergency exits and follow the evacuation routes without running or pushing others. (1 mark)
4. Assemble and conduct a headcount: Gather at the designated assembly point and confirm that everyone is accounted for. (1 mark)

Other acceptable steps:

- Notify emergency response personnel.
- Demonstrate the use of firefighting equipment in a controlled exercise.
- Evaluate the evacuation process and identify areas for improvement.

c) State three measures that can be used to prevent fire outbreaks in a metalwork workshop. (3 marks)

Award 1 mark each for any three correct measures.

1. Regular inspection and maintenance of electrical installations.
2. Proper storage of flammable liquids away from heat and sparks.
3. Keeping welding and grinding areas free from combustible materials.
4. Avoiding overloading electrical sockets.
5. Providing suitable fire extinguishers at accessible locations.
6. Training workers and learners on fire safety procedures.
7. Conducting regular fire drills.
8. Ensuring proper workshop ventilation.
9. Maintaining good housekeeping practices.
10. Prohibiting smoking in unauthorised areas.
11. Keeping emergency exits and escape routes clear.
12. Regular inspection and maintenance of workshop machinery.

**Suggested Practical Assessment**

**Practical task: Fire safety inspection and emergency preparedness in a metalwork workshop.**

The learner should:

1. Identify at least four potential fire hazards.
2. Identify the available firefighting equipment.
3. Match extinguishers to the appropriate fire classes.
4. Demonstrate the PASS method using a training extinguisher.
5. Participate in a supervised fire drill.
6. Identify emergency exits and assembly points.
7. Prepare a brief fire safety inspection report.

**Assessment criteria**

| **Assessment area** | **Marks** |
|---|---|
| Identification of fire hazards | 4 |
| Identification of firefighting equipment | 4 |
| Correct selection of extinguishers | 4 |
| Demonstration of extinguisher operation | 4 |
| Participation in fire drill | 4 |
| Observation of safety precautions | 4 |
| Total | 24 |

**STRAND 2.0: TOOLS AND MATERIALS IN METALWORK**

**SUB-STRAND 2.1: PRECISION MEASURING TOOLS**

## 1.0 INTRODUCTION TO PRECISION MEASUREMENT

Precision measurement is an essential activity in metalwork. Metalworkers use measuring instruments to determine the exact dimensions of metal components during marking out, cutting, drilling, machining, fitting and fabrication.

In a metal workshop, ordinary measuring tools such as steel rules and tape measures may not provide sufficient accuracy for certain operations. Precision measuring instruments are therefore used where very small differences in dimensions can affect the quality, fit and performance of a component.

For example, when manufacturing a shaft that must fit into a bearing, the diameter of the shaft must be measured accurately. A shaft that is too large may fail to enter the bearing, while one that is too small may cause excessive movement.

### 1.1 Definition of precision measurement

**Precision measurement** is the process of determining the dimensions of a component or object using specialised measuring instruments that provide accurate and consistent readings to a specified degree of resolution.

It involves measuring dimensions such as:

- Length.
- Thickness.
- Internal diameter.
- External diameter.
- Depth.
- Height.
- Step dimensions.
- Small gaps and clearances.

### 1.2 Meaning of accuracy and precision

These two terms are closely related but have different meanings.

**Accuracy**

- Accuracy refers to how close a measured value is to the actual or accepted value of a dimension.
- An accurate instrument gives readings that are close to the true measurement.

**Precision**

- Precision refers to how closely repeated measurements agree with one another.
- A precise instrument produces consistent readings when the same dimension is measured repeatedly under similar conditions.

**Example:**

If the actual diameter of a metal rod is 20.00 mm:

- A reading of 20.01 mm is highly accurate.
- Repeated readings of 20.10 mm, 20.10 mm and 20.11 mm are consistent but may not be accurate.

### 1.3 Importance of precision measurement in metalwork

Precision measurement is important because it:

1. **Ensures dimensional accuracy:** Helps produce components with dimensions that meet the required specifications.
2. **Promotes proper fitting:** Ensures that manufactured parts fit together correctly, such as shafts and bearings.
3. **Improves product quality:** Reduces dimensional errors and defects in finished metal products.
4. **Reduces material wastage:** Prevents unnecessary cutting, drilling and machining caused by incorrect measurements.
5. **Saves production time:** Reduces repeated operations and corrections.
6. **Promotes interchangeability:** Enables similar components to fit into the same assembly without unnecessary modification.
7. **Improves safety:** Prevents the manufacture of defective components that may fail during use.
8. **Supports quality control:** Enables metalworkers to check whether finished products meet specified dimensions.
9. **Reduces production costs:** Minimises rejected products, repairs and material losses.
10. **Promotes professional workmanship:** Ensures that products meet acceptable workshop and industrial standards.

### 1.4 Applications of precision measurement in metalwork

Precision measuring tools are used in:

- Measuring the diameter of shafts.
- Measuring the thickness of metal sheets.
- Checking the depth of drilled holes.
- Measuring the height of machined components.
- Checking the dimensions of machine parts.
- Measuring the internal diameter of pipes and bushes.
- Inspecting manufactured components.
- Checking the accuracy of turned metal components.
- Measuring the dimensions of tools and machine parts.

## 2.0 CLASSIFICATION OF PRECISION MEASURING TOOLS

Precision measuring tools are specialised instruments designed to measure dimensions more accurately than ordinary measuring tools.

The main precision measuring instruments covered in this sub-strand are:

1. Vernier caliper.
2. Micrometer screw gauge.
3. Vernier height gauge.

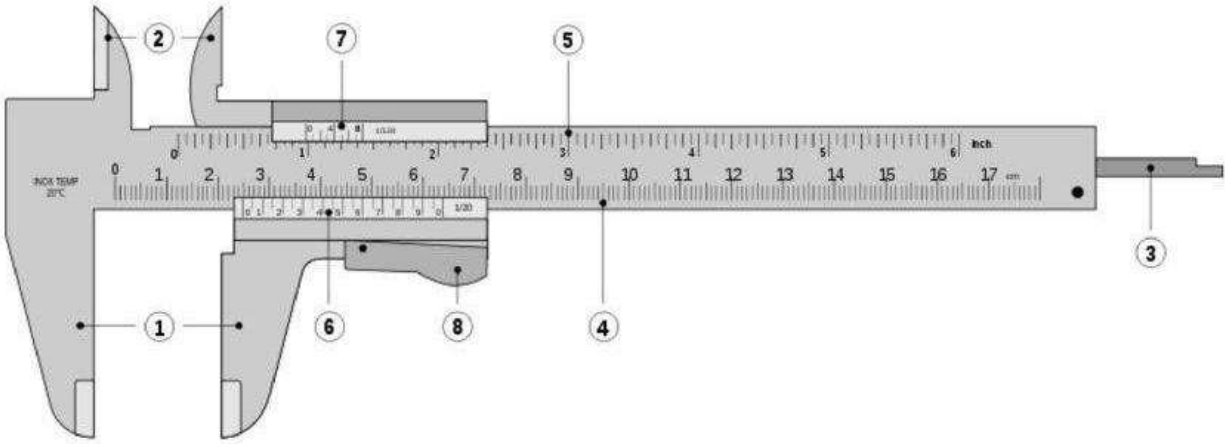
Other precision measuring instruments used in metalwork include:

- Vernier depth gauge.
- Dial indicator.
- Bore gauge.

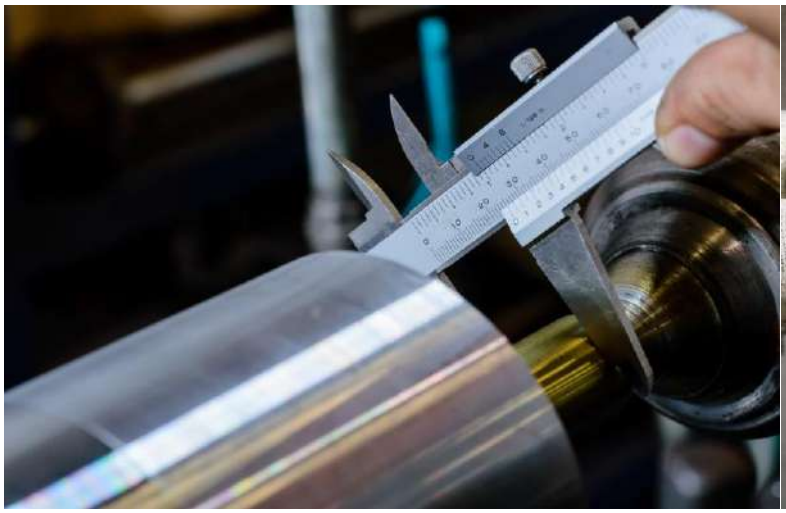
- Digital caliper.
- Digital micrometer.

The three main instruments are discussed in detail below.

**3.0 VERNIER CALIPER**




**1.Outside jaws**: used to measure external diameter or width of an object
**2.Inside jaws**: used to measure internal diameter of an object
**3.Depth gauge**: used to measure depths of an object or a hole
**4.Main scale**: scale marked every mm
**5.Main scale**: scale marked in inches and fractions
**6.Vernier** gives interpolated measurements to 0.02 mm or better
**7.Vernier** gives interpolated measurements in thousands of an inch 0.001".
**8.Retainer**: used to block movable part to allow the easy transferring of a measurement





**3.1 Definition of a vernier caliper**

A **vernier caliper** is a precision measuring instrument used for measuring external dimensions, internal dimensions, depths and step dimensions of objects.

It consists of a fixed main scale and a sliding vernier scale that enable measurements to be taken more accurately than with an ordinary steel rule.

Vernier calipers are commonly used in metal workshops, engineering workshops, machine shops and manufacturing industries.

**3.2 Uses of a vernier caliper**

A vernier caliper is used for measuring:

1. **External dimensions**

- Used to measure the outside diameter of cylindrical objects.
- Measures the thickness of metal plates.
- Measures the external width of rectangular components.

2. **Internal dimensions**

- Measures the inside diameter of holes.
- Measures the internal width of pipes and hollow metal components.

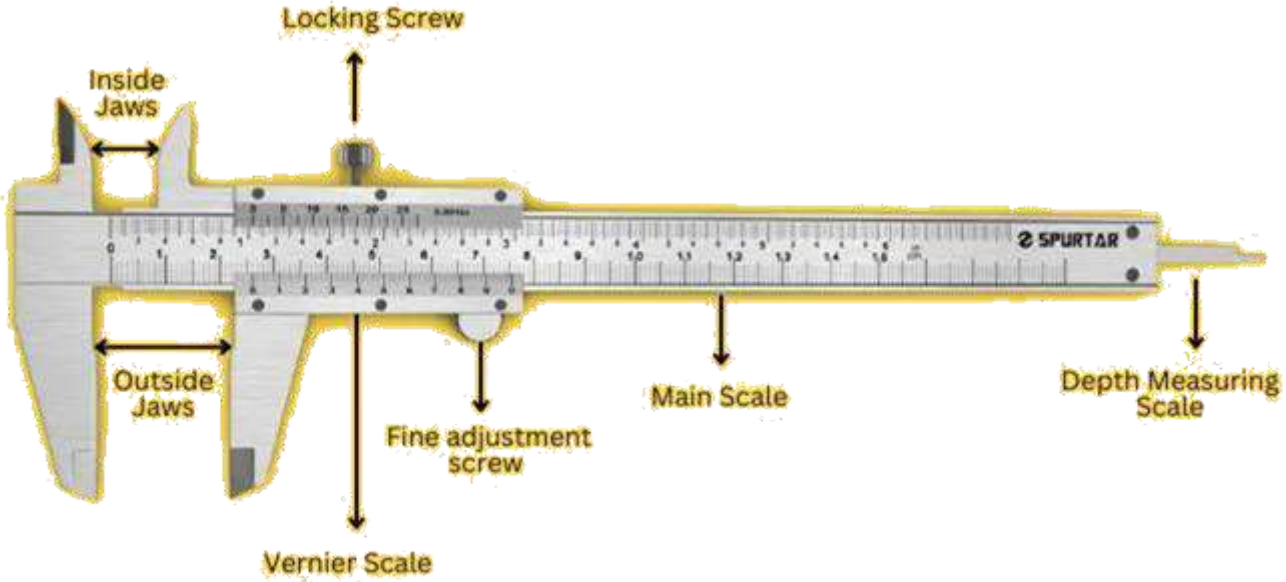
3. **Depth**

- Measures the depth of drilled holes, slots and recesses.

4. **Step dimensions**

- Measures the difference in height between two surfaces or steps of a component.

**3.3 Parts of a vernier caliper**




The main parts of a vernier caliper include:

**1. Main scale**

- It is the fixed graduated scale on the body of the instrument.
- It carries the main measurement markings.
- It may be graduated in millimetres or inches.
- It provides the whole-number portion of the measurement.

**2. Vernier scale**

- It is the smaller graduated scale attached to the sliding jaw.
- It moves along the main scale.
- It helps determine the fractional part of the measurement.

- It increases the precision of the instrument.

**3. Outside measuring jaws**

- These are the larger jaws located at the lower part of the caliper.
- They are used to measure external dimensions.
- They are placed around an object when measuring its outside diameter or thickness.

**4. Inside measuring jaws**

- These are the smaller jaws located at the upper part of the caliper.
- They are used to measure internal dimensions.
- They are inserted into holes, pipes and hollow components.

**5. Depth rod or depth blade**

- It is a narrow rod that extends from the end of the caliper as the sliding jaw moves.
- It is used to measure the depth of holes and recesses.

**6. Locking screw**

- It is used to lock the sliding jaw in position.
- It prevents accidental movement after taking a measurement.
- It helps the user record a reading without changing the jaw position.

**7. Thumb roller or fine adjustment wheel**

- It enables smooth and controlled movement of the sliding jaw.
- It helps the user position the jaws gently against the workpiece.

**8. Beam or body**

- It supports the main scale.
- It provides a straight guide along which the sliding jaw moves.

**3.4 Types of vernier calipers**







**1. Standard or mechanical vernier caliper**

- Uses a main scale and a vernier scale.
- The reading is obtained by combining the main-scale reading and vernier-scale reading.
- It does not require batteries.
- It is commonly used in training and general metalwork operations.

**2. Dial vernier caliper**

- Uses a graduated circular dial to display the fractional measurement.
- The dial pointer moves as the sliding jaw moves.
- It is easier to read than some traditional vernier calipers.
- It requires careful handling to prevent damage to the dial mechanism.

**3. Digital vernier caliper**

- Uses an electronic display to show measurements.
- It provides direct digital readings.
- Some models allow switching between millimetres and inches.
- It requires a battery.
- It is convenient for repetitive measuring tasks.

**3.5 Principle of operation of a vernier caliper**

The vernier caliper operates on the principle of the difference between the graduations on the main scale and those on the vernier scale.

The vernier scale is designed so that its graduations are slightly different in length or spacing from those of the main scale.

When the jaws are placed against an object:

- The main scale provides the main measurement.
- The vernier scale provides the additional fractional measurement.
- The two readings are combined to obtain the final measurement.

**3.6 Least count of a vernier caliper**

**Least count** is the smallest measurement that an instrument can accurately read.

For a vernier caliper:

LC=1 main scale division−1 vernier scale division

For example, consider a vernier caliper in which:

- 1 main scale division = 1 mm.
- 10 vernier scale divisions = 9 mm.

Therefore:

1 VSD=9/10=0.9 mm

LC=1−0.9

LC=0.1 mm

This means that the instrument can measure to the nearest 0.1 mm.

Some vernier calipers have a least count of 0.05 mm or 0.02 mm, depending on their graduation design.

**3.7 How to read a vernier caliper**

The reading is obtained using the following formula:

Total reading=MSR+(VSR×LC)

Where:

- MSR = Main Scale Reading.
- VSR = Vernier Scale Reading (the number of the coinciding vernier division).
- LC = Least Count.

**Procedure for reading a vernier caliper**

1. Clean the measuring jaws and the surface of the workpiece.
2. Check that the instrument reads zero when the jaws are completely closed.
3. Place the workpiece between the appropriate measuring jaws.
4. Close the jaws gently until they make proper contact with the workpiece.
5. Lock the sliding jaw if necessary.
6. Read the main scale immediately to the left of the vernier zero.
7. Identify the vernier division that exactly coincides with a main-scale marking.
8. Multiply the vernier division number by the least count.
9. Add the vernier reading to the main-scale reading.
10. Record the final measurement together with its unit.

**3.8 Worked example on reading a vernier caliper**

A vernier caliper has a least count of 0.1 mm. When measuring a metal rod:

- Main scale reading = 25 mm.
- Coinciding vernier division = 6.

Find the total reading.

**Solution**

Total reading=MSR+(VSR×LC)

=25+(6×0.1)

=25+0.6

25.6 mm

Therefore, the diameter of the metal rod is 25.6 mm.

**3.9 Procedure for using a vernier caliper**

**A. Measuring external dimensions**

1. Select the appropriate vernier caliper.
2. Clean the outside jaws.
3. Open the jaws sufficiently to accommodate the workpiece.
4. Place the object between the outside jaws.
5. Ensure that the jaws are perpendicular to the dimension being measured.
6. Close the jaws gently until they touch the workpiece.
7. Avoid applying excessive pressure.

8. Lock the sliding jaw where necessary.
9. Take and record the reading.

**B. Measuring internal dimensions**

1. Clean the inside jaws.
2. Insert the smaller jaws into the hole or pipe.
3. Open the jaws until they touch the opposite internal surfaces.
4. Keep the caliper properly aligned with the dimension being measured.
5. Avoid tilting the instrument.
6. Take the reading.
7. Remove the instrument carefully.

**C. Measuring depth**

1. Clean the depth rod and the reference surface.
2. Place the end of the caliper body firmly on the top surface of the component.
3. Extend the depth rod into the hole or recess.
4. Ensure that the rod reaches the bottom.
5. Keep the instrument perpendicular to the surface.
6. Read and record the measurement.

**D. Measuring step dimensions**

1. Place the rear step-measuring surfaces against the two levels of the component.
2. Ensure that the instrument is properly seated.
3. Check that the surfaces make firm contact.
4. Read and record the difference in height.

**3.10 Advantages of a vernier caliper**

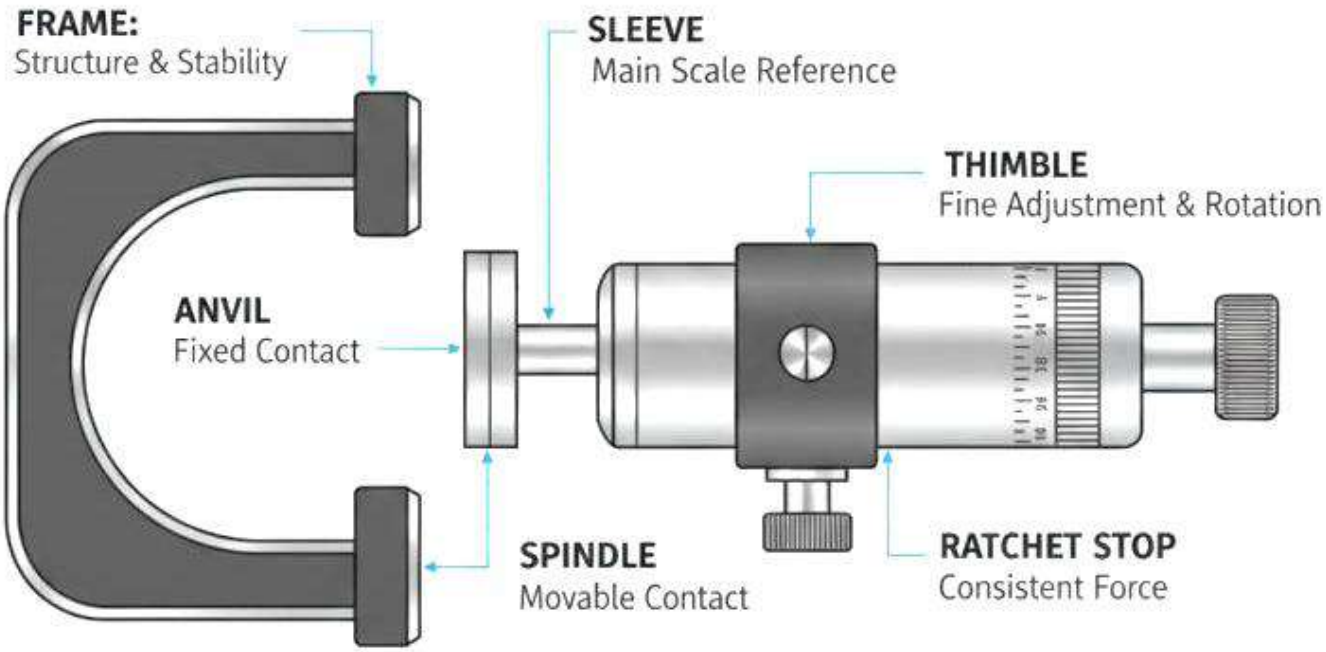
- It measures external dimensions.
- It measures internal dimensions.
- It measures depths.
- It measures step dimensions.
- It provides greater precision than an ordinary steel rule.
- It is portable and easy to carry.
- It is suitable for a variety of metalwork applications.
- It is available in analogue and digital forms.
- It is relatively easy to use after proper training.

**3.11 Limitations of a vernier caliper**

- It may be less precise than a micrometer screw gauge.
- Incorrect alignment may produce inaccurate readings.

- Dirt on the measuring surfaces can affect the results.
- Parallax errors may occur when reading analogue scales.
- Excessive force may affect the measurement.
- The instrument may be damaged if dropped.
- Digital models require batteries.

**4.0 MICROMETER SCREW GAUGE**









**4.1 Definition of a micrometer screw gauge**

A **micrometer screw gauge** is a precision measuring instrument that uses the movement of a calibrated screw to measure small dimensions accurately.

It is commonly used to measure:

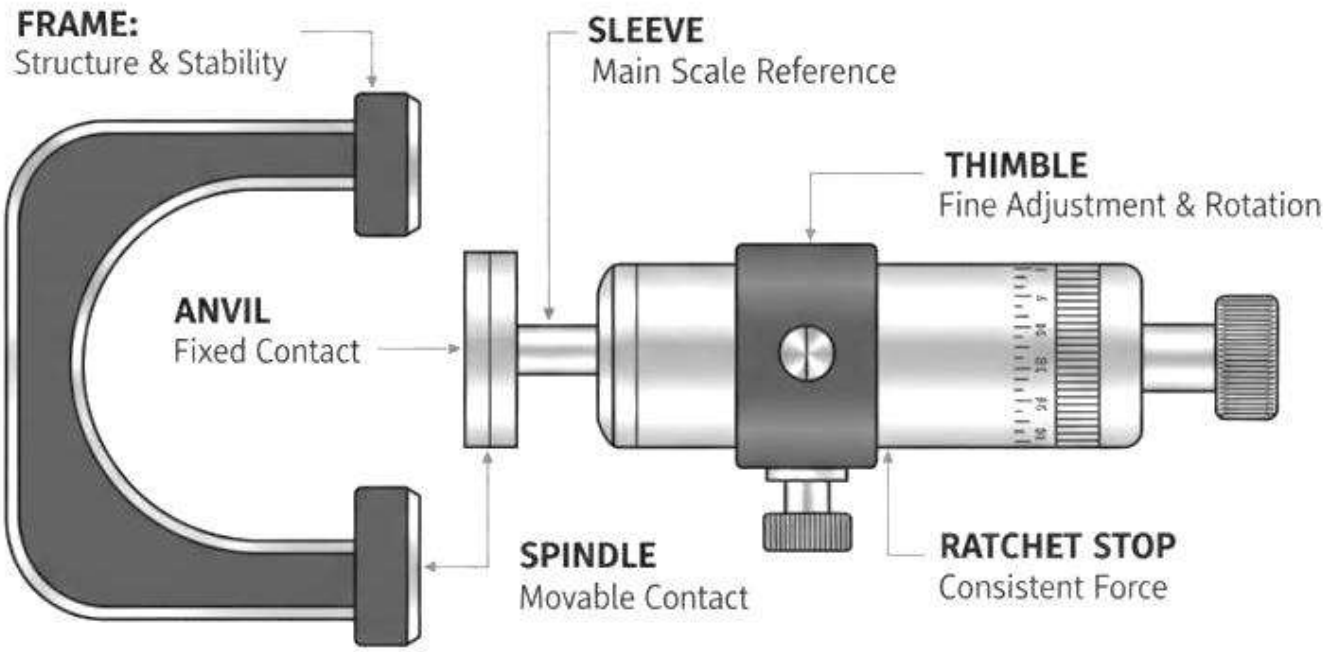
- External diameters of shafts and wires.
- Thickness of metal sheets.
- Thickness of small metal components.
- Diameters of small cylindrical objects.
- Dimensions of machined components.

A micrometer screw gauge is generally more precise than a standard vernier caliper and is particularly useful when very small dimensional differences need to be detected.

**4.2 Applications of a micrometer screw gauge in metalwork**

1. Measuring the diameter of a metal wire.
2. Checking the thickness of a metal sheet.
3. Measuring the diameter of a turned shaft.
4. Measuring the thickness of small machine components.
5. Checking the dimensions of precision-engineered parts.
6. Inspecting the thickness of washers and thin metal plates.
7. Measuring the diameter of small pins and rods.
8. Checking whether a manufactured component meets the specified tolerance.

**4.3 Parts of a micrometer screw gauge**




The main parts include:

**1. Frame**

- It is the C-shaped body of the micrometer.
- It supports the other components.
- It provides rigidity during measurement.

- It is designed to withstand normal measuring forces without excessive deformation.

**2. Anvil**

- It is the fixed measuring surface.
- The workpiece is placed against it.
- It provides one of the two contact points during measurement.
- It must be clean and free from damage.

**3. Spindle**

- It is the movable measuring rod.
- It moves towards or away from the anvil when the thimble is rotated.
- It makes contact with the opposite side of the workpiece.

**4. Sleeve or barrel**

- It is the stationary cylindrical part of the instrument.
- It carries the main graduated scale.
- It provides the main scale reading.
- It is sometimes called the barrel.

**5. Thimble**

- It is the rotating cylindrical component.
- It carries the circular or thimble scale.
- Its rotation causes the spindle to move.
- It helps the user obtain the fractional measurement.

**6. Ratchet stop**

- It is found at the end of the micrometer.
- It applies a consistent measuring force.
- It prevents excessive tightening of the spindle.
- It helps reduce errors caused by applying too much pressure.

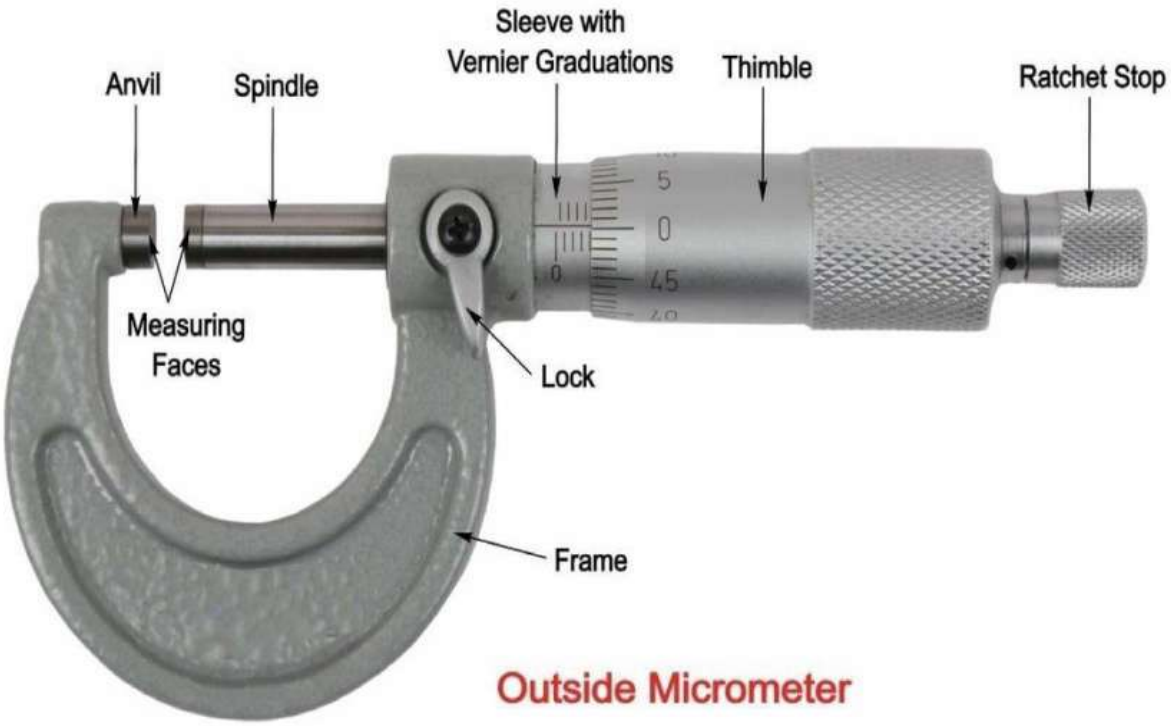
**7. Spindle lock**

- It is used to hold the spindle in a fixed position.
- It prevents movement after taking a measurement.
- It allows the user to record a reading without disturbing the instrument.

**8. Screw mechanism**

- It converts the rotary movement of the thimble into linear movement of the spindle.
- It enables very small and controlled movements.
- It is the main operating mechanism of the instrument.

**4.4 Types of micrometer screw gauges**









**1. Outside micrometer**

- Used to measure external dimensions.
- Measures the thickness of sheets and plates.
- Measures the external diameter of rods, shafts and wires.
- It is one of the most common micrometers in metalwork.

**2. Inside micrometer**

- Used to measure internal dimensions.
- Measures the internal diameter of holes and cylinders.
- Measures the internal width of hollow components.
- It is useful when checking the dimensions of machined bores.

**3. Depth micrometer**

- Used to measure the depth of holes, slots and recesses.
- It has a flat base that rests on the reference surface.
- Its measuring rod moves downwards to establish the depth.

**4. Digital micrometer**

- Uses an electronic display to show measurements.
- Provides direct readings without requiring manual interpretation of the thimble scale.
- Some models can switch between metric and imperial units.
- It requires a battery.

### 4.5 Working principle of a micrometer screw gauge

The micrometer screw gauge operates on the principle of a screw thread.

When the thimble is rotated:

- The screw rotates within a threaded nut.
- The rotational movement is converted into linear movement.
- The spindle moves towards or away from the anvil.
- The movement of the spindle is proportional to the amount of rotation.
- The calibrated scales indicate the distance travelled by the spindle.

A small rotation of the thimble produces a very small linear movement. This enables the instrument to measure small dimensions accurately.

### 4.6 Important terms used when operating a micrometer

**Pitch of the screw**

The pitch is the distance travelled by the spindle during one complete revolution of the screw.

For example, if the spindle moves 0.5 mm after one complete revolution, the pitch is 0.5 mm.

**Least count**

The least count is the smallest measurement that the instrument can read.

$$\boxed{LC = \frac{\text{Pitch of screw}}{\text{Number of thimble divisions}}}$$

**Example:**

A micrometer has:

- Screw pitch = 0.5 mm.
- Number of thimble divisions = 50.

Calculate its least count.

**Solution:**

Using the formula:

$$LC = \frac{\text{Pitch of screw}}{\text{Number of thimble divisions}}$$

Substituting the values:

$$LC = \frac{0.5}{50}$$

$$LC = 0.01 \text{ mm}$$

Therefore, the micrometer can measure to the nearest 0.01 mm.

**4.7 How to read a micrometer screw gauge**

The general formula for reading a metric micrometer is:

Total reading=MSR+Thimble reading

Where:

Thimble reading=Thimble division×LCThimble reading=Thimble division×*LC*

Therefore:

TR=MSR+(TSD×LC)

Where:

- TR = Total reading.
- MSR = Main scale reading.
- TSD = Thimble scale division coinciding with the reference line.
- LC = Least count.

**4.8 Worked example on reading a micrometer**

A micrometer screw gauge has a least count of 0.01 mm. When measuring a metal rod:

- Main scale reading = 12.5 mm.
- Thimble division coinciding with the reference line = 28.

Calculate the diameter of the metal rod.

**Solution:**

Using the formula:

$$TR = MSR + (TSD \times LC)$$

Substituting the values:

$$TR = 12.5 + (28 \times 0.01)$$

$$TR = 12.5 + 0.28$$

$$\boxed{TR = 12.78 \text{ mm}}$$

Therefore, the diameter of the metal rod is 12.78 mm.

**4.9 Procedure for using a micrometer screw gauge**

1. Select a micrometer with a suitable measuring range.
2. Inspect the instrument for physical damage.
3. Clean the anvil and spindle measuring faces.

4. Check the zero reading before taking measurements.
5. Open the micrometer by rotating the thimble.
6. Place the workpiece between the anvil and spindle.
7. Rotate the thimble until the spindle approaches the workpiece.
8. Use the ratchet stop to apply gentle and consistent pressure.
9. Stop rotating when the ratchet clicks or slips as designed.
10. Lock the spindle if necessary.
11. Read the main scale on the sleeve.
12. Read the thimble scale at the reference line.
13. Calculate the total measurement.
14. Record the reading in millimetres.
15. Release the spindle and remove the workpiece carefully.

**4.10 Zero error in a micrometer screw gauge**

A zero error occurs when the micrometer does not indicate zero when the anvil and spindle are brought into proper contact using the correct measuring force.

There are two main types:

**A. Positive zero error**

- Occurs when the instrument displays a positive reading when it should read zero.
- The indicated measurement is greater than the actual measurement.
- The zero error must be subtracted from the observed reading.

Correct reading=Observed reading−Positive zero errorCorrect reading=Observed reading−Positive zero error

**B. Negative zero error**

- Occurs when the instrument indicates a reading below zero.
- The indicated measurement is less than the actual measurement.
- The magnitude of the negative zero error is added to the observed reading.

Correct reading=Observed reading+|Negative zero error|Correct reading=Observed reading+|Negative zero error|

**Example:**

A micrometer gives an observed reading of 15.36 mm and has a positive zero error of 0.02 mm.

Correct reading=15.36−0.02

15.34 mm

**4.11 Advantages of a micrometer screw gauge**

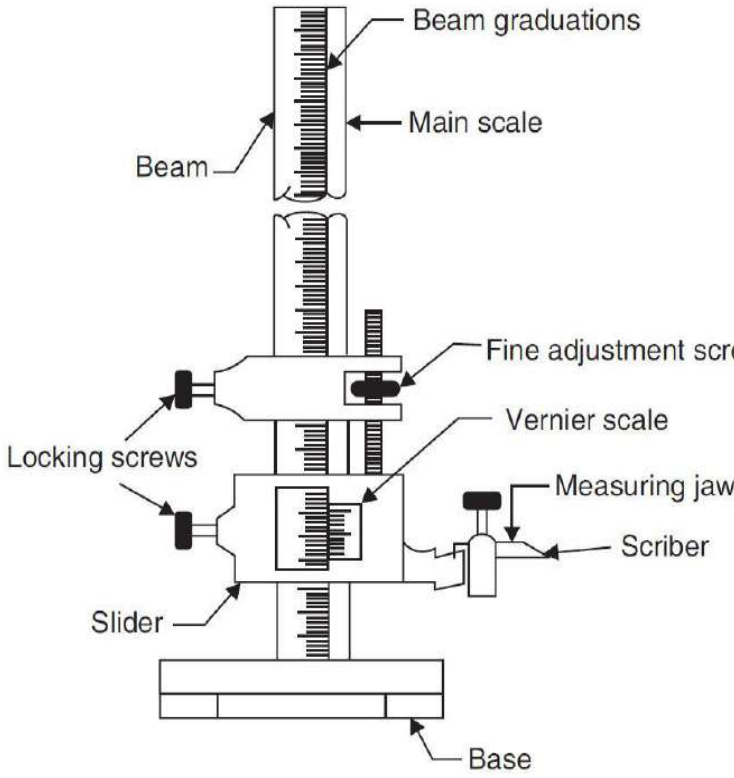
1. It provides very accurate measurements.
2. It has a small least count.
3. It is suitable for measuring small dimensions.
4. It is useful in quality-control operations.
5. The ratchet mechanism helps maintain consistent measuring pressure.

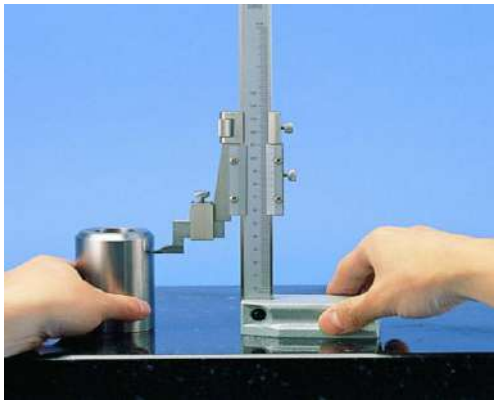
6. It is suitable for precision engineering.
7. It is available in different measuring ranges.
8. It is relatively simple to operate after training.

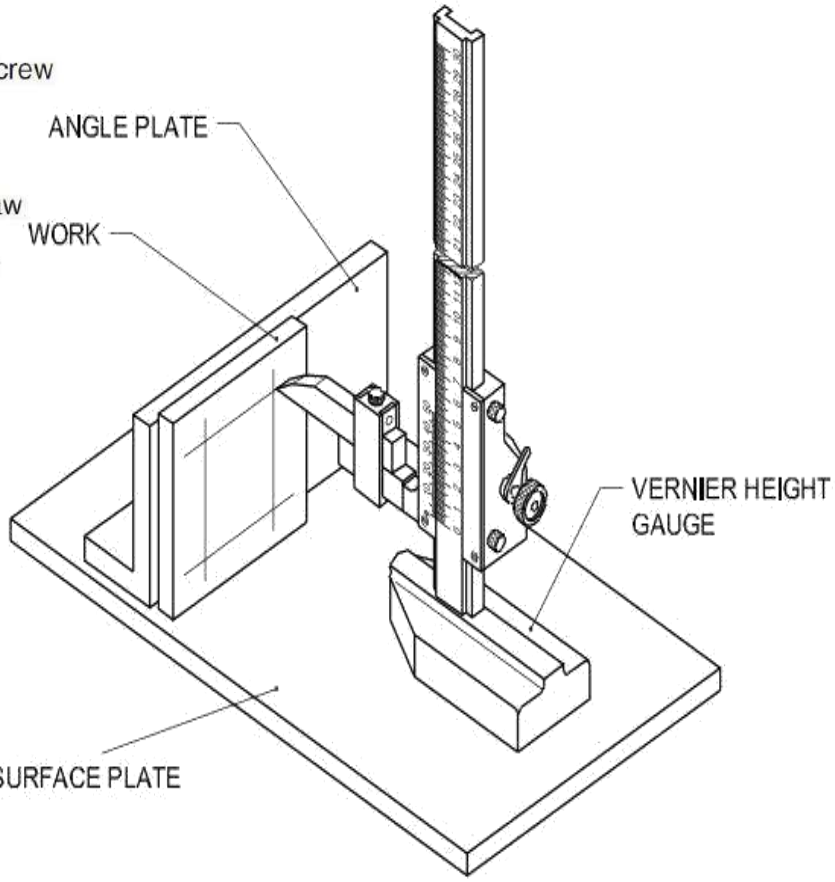
**4.12 Limitations of a micrometer screw gauge**

1. Most ordinary outside micrometers measure only external dimensions.
2. It has a limited measuring range.
3. It may be more expensive than a vernier caliper.
4. It requires careful handling.
5. Incorrect use of the ratchet may affect measurements.
6. Dirt or metal particles on the measuring faces may cause errors.
7. It may require zero-error correction.
8. It is not suitable for measuring large components beyond its range.

**5.0 VERNIER HEIGHT GAUGE**





**5.1 Definition of a vernier height gauge**

A **vernier height gauge** is a precision measuring and marking-out instrument used to measure vertical distances and mark accurate lines at specified heights from a reference surface.

It is commonly used with a surface plate in metal workshops and engineering inspection rooms.

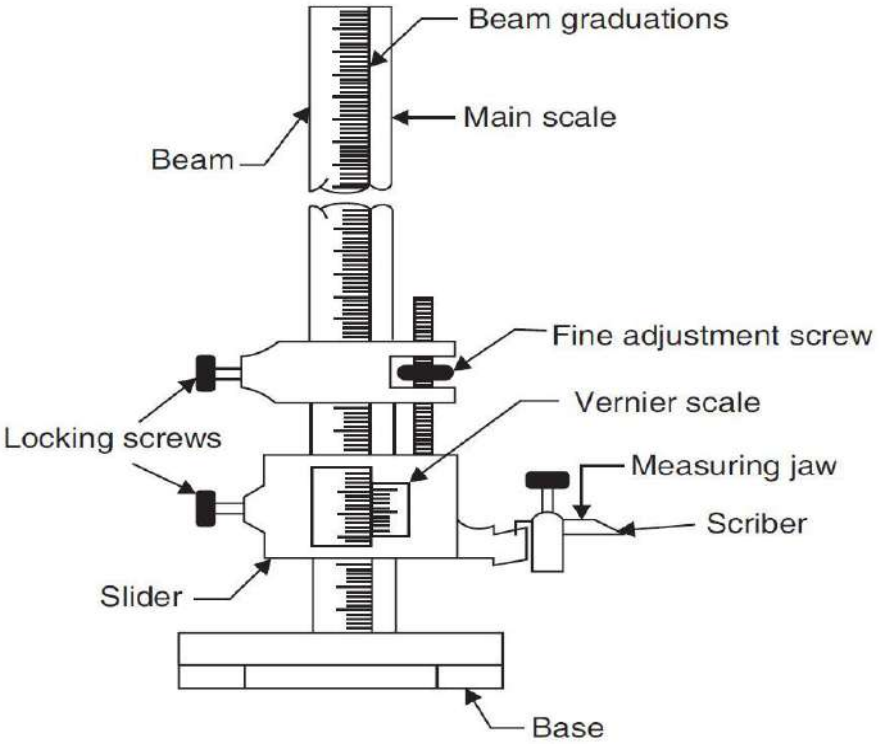
The instrument has a graduated vertical beam and a sliding measuring head carrying a scriber or measuring attachment.

**5.2 Uses of a vernier height gauge**

A vernier height gauge is used for:

1. Measuring the height of metal components.
2. Marking horizontal lines at specified heights on metal surfaces.
3. Checking the vertical dimensions of machine components.
4. Comparing the heights of different surfaces.
5. Marking out components before machining.
6. Checking the height of shoulders and steps.
7. Inspecting the dimensions of manufactured parts.
8. Transferring dimensions from engineering drawings to workpieces.
9. Checking the parallelism of surfaces when used with suitable inspection accessories.
10. Measuring the position of features relative to a reference surface.

**5.3 Parts of a vernier height gauge**




**1. Base**

- It is the heavy bottom part of the instrument.
- It rests on the surface plate.
- It provides stability during measuring and marking operations.

- Its bottom surface is accurately finished to ensure proper contact with the reference surface.

**2. Vertical beam or main scale**

- It is the upright graduated column.
- It carries the main measurement scale.
- It guides the movement of the sliding head.
- It provides the reference for measuring vertical dimensions.

**3. Vernier scale**

- It is attached to the sliding head.
- It provides the fractional measurement.
- It improves the reading precision of the instrument.

**4. Sliding head**

- It moves vertically along the main scale.
- It carries the measuring or marking attachment.
- It is positioned at the required height.

**5. Scriber**

- It is a sharp marking tool attached to the sliding head.
- It is used to scratch fine lines on a metal surface.
- It assists in marking out components before cutting, drilling or machining.

**6. Clamp**

- It locks the sliding head at the selected height.
- It prevents unwanted movement during measurement or marking.

**7. Fine adjustment mechanism**

- It enables small and controlled movements of the sliding head.
- It helps position the scriber or measuring attachment accurately.

**8. Measuring attachment**

- It may be fitted to the sliding head depending on the intended application.
- It can be used to measure heights or compare dimensions.

**5.4 Types of height gauges**







**1. Mechanical vernier height gauge**

- Uses a main scale and vernier scale.
- Requires the operator to read and calculate the measurement.
- Does not require electrical power.
- Commonly used for workshop measurement and marking out.

**2. Digital height gauge**

- Uses an electronic display.
- Shows measurements directly.
- May allow conversion between measurement units.
- Requires a battery or electrical power.

**3. Dial height gauge**

- Uses a dial indicator to display small changes in vertical position.
- It is useful for comparing heights and checking variations.
- Requires careful setting and handling.

**5.5 Working principle of a vernier height gauge**

The instrument works using the vernier principle.

- The main scale is fixed on the vertical beam.
- The sliding head moves vertically along the beam.
- The vernier scale moves with the sliding head.
- The difference between the main scale and vernier scale divisions allows fractional measurements to be determined.
- The position of the scriber or measuring attachment indicates the height being measured.

The instrument normally uses a flat and stable surface plate as its reference datum.

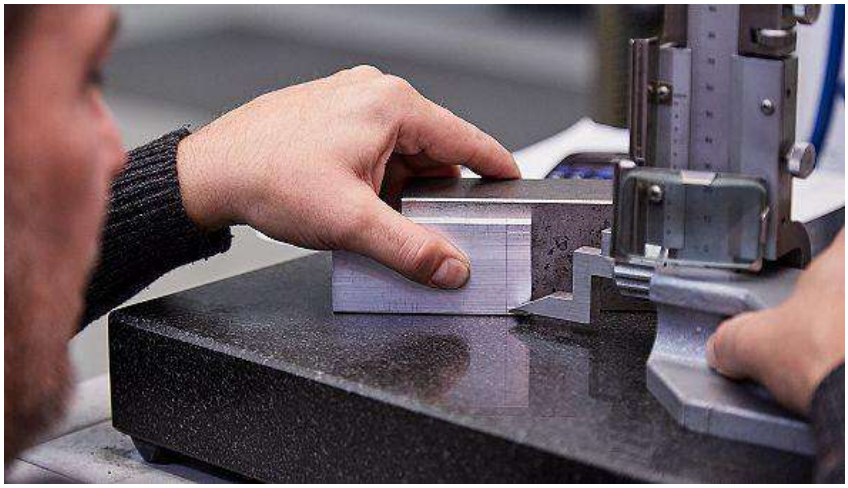
**5.6 Accessories used with a vernier height gauge**

The following accessories may be used:

1. **Scriber:** Used for marking lines on metal surfaces.
2. **Dial test indicator:** Used for comparing heights and checking small variations.
3. **Measuring probe:** Used for specific measuring operations.
4. **Clamps and holders:** Used for securing attachments.
5. **Surface plate:** Provides an accurate reference surface.
6. **Gauge blocks:** Used to establish or verify accurate dimensions.

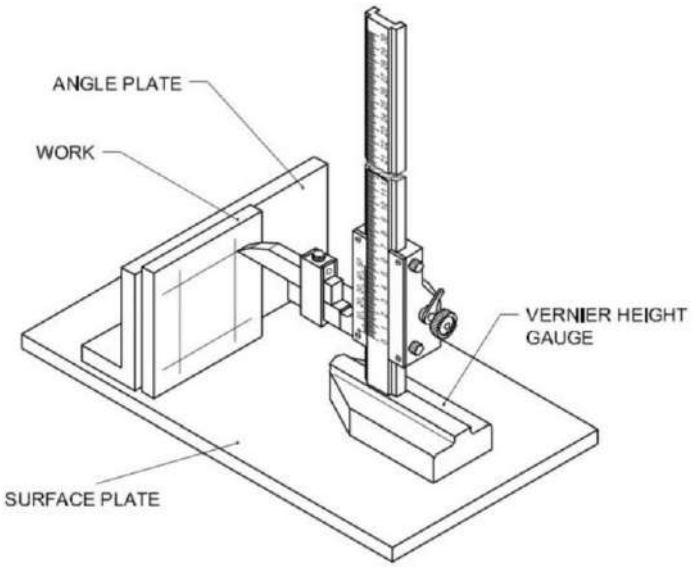
**5.7 Procedure for using a vernier height gauge**

**A. Measuring the height of a metal component**



1. Clean the surface plate and the base of the height gauge.
2. Inspect the instrument for damage.
3. Place the height gauge on the surface plate.
4. Ensure that the base rests evenly on the plate.
5. Place the metal component on the surface plate.
6. Loosen the clamp on the sliding head.
7. Move the measuring attachment towards the top surface of the component.
8. Use the fine adjustment mechanism to achieve the correct contact.
9. Lock the sliding head.
10. Read the main scale and vernier scale.
11. Calculate the total height.
12. Record the measurement in the correct unit.

**B. Marking out a metal component using a vernier height gauge**






1. Clean the surface plate and workpiece.

2. Apply marking blue or another suitable marking medium where appropriate.
3. Place the workpiece on the surface plate.
4. Set the height gauge to the required marking height.
5. Adjust the sliding head using the fine adjustment mechanism.
6. Lock the sliding head.
7. Position the scriber against the workpiece.
8. Move the workpiece or height gauge carefully as appropriate to produce the marking line.
9. Check that the line is clear and at the correct height.
10. Repeat the operation for other required marking positions.

**5.8 Advantages of a vernier height gauge**

1. It provides accurate vertical measurements.
2. It can be used for measuring and marking out.
3. It is suitable for precision engineering work.
4. It assists in transferring dimensions from drawings to workpieces.
5. It can be used with different measuring attachments.
6. It supports quality inspection.
7. It provides consistent measurements when correctly used.
8. It is useful for comparing the heights of different surfaces.

**5.9 Limitations of a vernier height gauge**

1. It requires a flat and accurate surface plate.
2. It is generally unsuitable for measuring very large objects beyond its capacity.
3. It can be damaged if knocked over.
4. Its accuracy depends on correct alignment.
5. It requires careful handling and calibration.
6. Dirt beneath the base may cause incorrect readings.
7. The scriber may become blunt or damaged.
8. It is less convenient to transport than a small vernier caliper.

**6.0 COMPARISON OF THE THREE MAIN PRECISION MEASURING TOOLS**

| Feature | Vernier caliper | Micrometer screw gauge | Vernier height gauge |
|---|---|---|---|
| Main purpose | Measures external, internal and depth dimensions | Measures small dimensions | Measures and marks vertical heights |
| Main mechanism | Vernier scale | Screw mechanism | Vertical beam and vernier scale |
| Common least count | 0.1 mm or 0.02 mm | 0.01 mm | Depends on instrument design |
| Main measuring surfaces | Jaws and depth rod | Anvil and spindle | Measuring attachment or scriber |

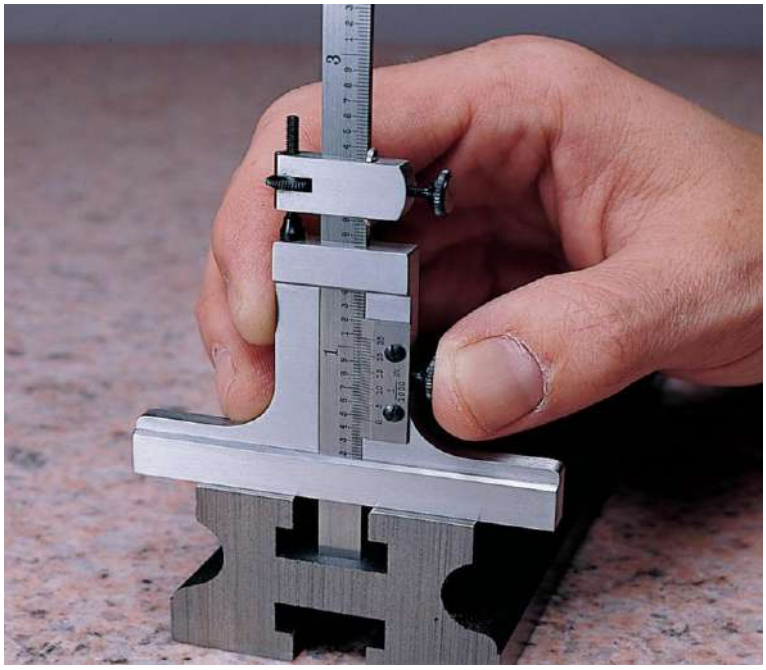
| | | | |
|---|---|---|---|
| Typical application | Measuring a shaft diameter | Measuring sheet thickness | Marking a line at a set height |
| Supporting surface | Not always required | Not always required | Surface plate normally required |

**Important:** Least count varies between models. Always check the graduation and manufacturer's specifications before using an instrument.

## 7.0 OTHER PRECISION MEASURING INSTRUMENTS USED IN METALWORK

Although the three instruments above form the main focus of this sub-strand, other precision instruments are also used in metal workshops.

### 7.1 Vernier depth gauge



**Definition:** A vernier depth gauge is a precision instrument used to measure the depth of holes, slots, recesses and other depressed surfaces.

**Parts**

- Base.
- Main scale.
- Vernier scale.
- Sliding head.
- Depth blade or measuring rod.
- Locking screw.

**Uses**

- Measuring the depth of drilled holes.
- Measuring the depth of grooves.
- Checking the depth of recesses.
- Measuring the depth of machined slots.

**7.2 Dial indicator**



**Definition:** A dial indicator is a precision instrument used to detect and measure small linear movements or variations in the position of a surface.

**Uses**

- Checking the run-out of rotating shafts.
- Checking the flatness of surfaces.
- Checking alignment of machine components.
- Measuring small variations in dimensions.
- Checking concentricity of cylindrical components.

**7.3 Bore gauge**



**Definition:** A bore gauge is a precision measuring instrument used to determine the internal diameter of holes, cylinders and bores.

**Uses**

- Measuring the internal diameter of engine cylinders.
- Checking the dimensions of machined holes.

- Detecting wear in cylindrical components.
- Checking whether a bore is uniform throughout its length.

**7.4 Digital measuring instruments**







Digital measuring instruments use electronic sensors and displays to indicate measurements.

**Advantages**

- Easy-to-read displays.
- Reduced manual scale-reading errors.
- Quick measurement recording.
- Some models provide metric and imperial conversion.
- Some can store or transmit measurements.

**Limitations**

- They require electrical power or batteries.
- Electronic components may be damaged by moisture.

- They may be more expensive than mechanical instruments.
- They still require correct calibration and careful handling.

**8.0 ERRORS IN PRECISION MEASUREMENT**

Measurement errors are differences between the measured value and the actual or accepted value of a dimension.

They may arise from the instrument, operator, environment or workpiece.

**8.1 Common measurement errors**

**1. Zero error**

- Occurs when an instrument does not indicate zero when it should.
- It may be positive or negative.
- It can be detected by checking the instrument before measurement.

**2. Parallax error**

- Occurs when the scale is viewed from an incorrect angle.
- It may cause the user to record an incorrect reading.
- It is common when reading analogue scales.

**3. Instrumental error**

- Results from worn, damaged or incorrectly calibrated instruments.
- A damaged measuring jaw may produce incorrect readings.

**4. Reading error**

- Occurs when the user reads the wrong scale division.
- It may result from poor concentration or lack of experience.

**5. Alignment error**

- Occurs when the measuring instrument is not correctly positioned against the workpiece.
- For example, a vernier caliper held at an angle may give an incorrect diameter.

**6. Excessive measuring pressure**

- Occurs when the operator applies too much force.
- It may deform thin workpieces or affect the instrument reading.

**7. Environmental error**

- Temperature changes may cause expansion or contraction of measuring instruments and workpieces.
- Dust, moisture and vibration may also affect measurements.

**8. Dirt and foreign particles**

- Dust, oil, burrs or metal chips between measuring surfaces may affect the reading.

**8.2 Ways of reducing measurement errors**

1. Use the correct measuring instrument for the task.
2. Check the zero setting before taking measurements.
3. Clean the instrument and workpiece.

4. Read analogue scales at eye level.
5. Hold the instrument correctly.
6. Avoid excessive measuring pressure.
7. Use the ratchet mechanism on a micrometer.
8. Ensure proper alignment between the instrument and workpiece.
9. Allow instruments and workpieces to reach a stable temperature where high accuracy is required.
10. Calibrate instruments regularly.
11. Take repeated readings where necessary.
12. Record measurements immediately.
13. Use trained personnel for precision measurement.
14. Avoid using damaged or worn instruments.

## 9.0 TOLERANCE AND ALLOWANCE IN METALWORK

### 9.1 Definition of tolerance

**Tolerance** is the permissible variation in a specified dimension of a manufactured component.

It indicates the maximum and minimum acceptable dimensions within which a component can be considered suitable.

For example, a shaft may have a specified diameter of:

20.00 mm±0.05 mm20.00 mm±0.05 mm

This means:

- Maximum acceptable diameter = 20.05 mm.
- Minimum acceptable diameter = 19.95 mm.

A shaft measuring 20.02 mm is within the specified tolerance.

### 9.2 Importance of tolerance

- Ensures proper fitting of components.
- Allows interchangeability of manufactured parts.
- Reduces rejection of products.
- Supports quality control.
- Helps achieve reliable machine performance.
- Reduces unnecessary production costs.

### 9.3 Definition of allowance

**Allowance** is the intentional difference between the dimensions of two mating components at maximum material condition. It determines whether the fit is designed to have clearance or interference.

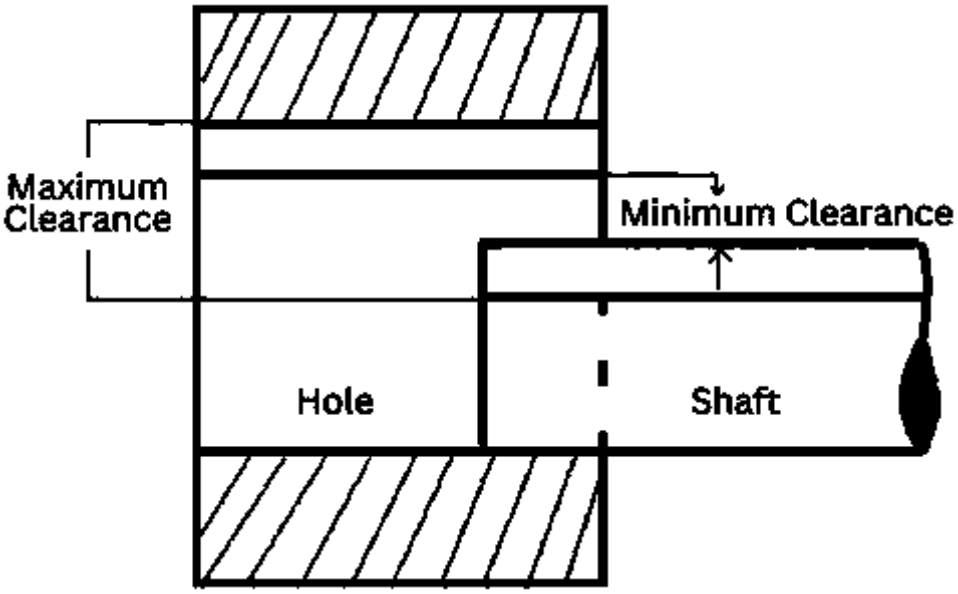
**Example:**

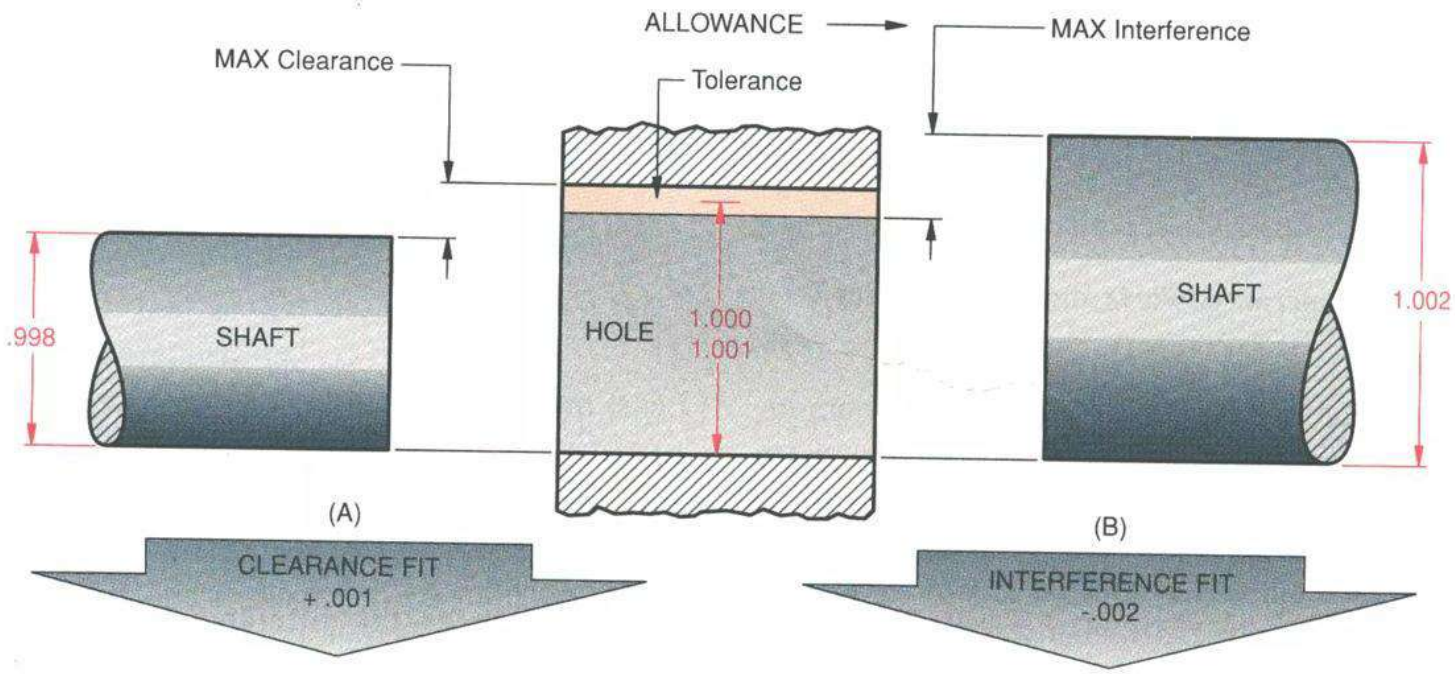
If a hole is 20.10 mm and a shaft is 20.00 mm, the clearance is:

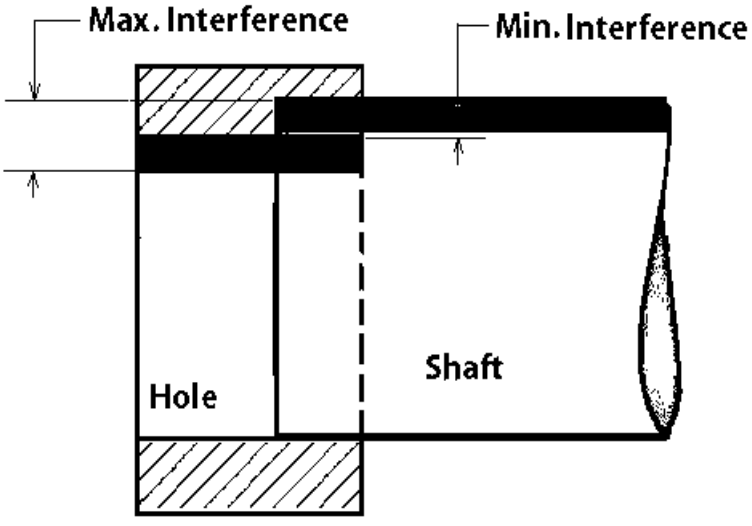
20.10−20.00=0.10 mm20.10−20.00=0.10 mm

The components have a clearance of 0.10 mm.

**9.4 Types of fits**



**1. Clearance fit**

- The hole is always larger than the shaft.
- There is space between the mating components.
- The components can move relative to each other.
- Example: A shaft that rotates freely in a bearing.

**2. Interference fit**

- The shaft is larger than the hole.
- The components require force or another suitable assembly method to fit together.
- It provides a tight connection.
- Example: A press-fitted metal bush.

**3. Transition fit**

- The fit may produce either a small clearance or a small interference depending on the actual manufactured dimensions.
- It provides a relatively accurate fit.
- It is used where accurate location is required.

## 10.0 SAFE USE OF PRECISION MEASURING TOOLS

Precision measuring instruments are delicate and expensive workshop equipment. They must be handled correctly to maintain their accuracy and prevent damage.

### 10.1 General safety precautions

1. Use the correct instrument for the intended measuring operation.
2. Inspect the instrument before use.
3. Do not use an instrument with damaged measuring surfaces.
4. Keep the workpiece securely positioned.
5. Avoid measuring a rotating workpiece.
6. Switch off a machine before measuring a component mounted on it, unless a specifically approved procedure allows otherwise.
7. Do not use measuring instruments as clamps, hammers or levers.
8. Avoid dropping measuring instruments.
9. Keep sharp scribers safely covered when not in use.
10. Handle instruments with clean, dry hands.
11. Do not apply excessive pressure.
12. Store instruments in their protective cases.
13. Keep measuring instruments away from welding sparks and excessive heat.
14. Follow the teacher's or workshop supervisor's instructions.
15. Wear appropriate personal protective equipment during workshop activities.

**10.2 Personal protective equipment during metalwork activities**







Appropriate protective equipment includes:

- Safety goggles to protect the eyes from metal particles.
- Safety boots to protect the feet from falling objects.
- Protective clothing or an apron to protect the body.
- Hearing protection where noisy machinery is operating.
- Suitable gloves for handling sharp metal stock when appropriate.

**Important:** Gloves should not be worn near rotating machinery where they may become entangled. Follow the machine-specific safety procedures.

## 11.0 CARE AND MAINTENANCE OF PRECISION MEASURING TOOLS

### 11.1 Meaning of maintenance

**Maintenance** refers to the activities carried out to keep tools and equipment in good working condition and prevent premature damage or failure.

Precision measuring instruments require regular care because even small amounts of wear, dirt or damage can affect their accuracy.

### 11.2 General maintenance practices

1. Clean the instrument after every use.
2. Wipe measuring surfaces with a clean, soft cloth.
3. Remove dust, oil and metal particles.
4. Store instruments in protective cases.
5. Keep instruments in a dry and clean environment.
6. Apply suitable protective oil to metal surfaces where recommended.
7. Avoid dropping or knocking instruments.
8. Do not mix precision instruments with ordinary workshop tools.
9. Check zero readings regularly.
10. Have instruments calibrated periodically.
11. Avoid exposing instruments to excessive temperatures.
12. Keep measuring surfaces free from rust.
13. Do not force moving parts.
14. Follow the manufacturer's maintenance instructions.
15. Report damaged instruments to the workshop supervisor.

### 11.3 Care of a vernier caliper




- Clean the jaws after use.
- Keep the main and vernier scales free from dirt.
- Check that the sliding jaw moves smoothly.
- Ensure that the zero reading is correct.

- Avoid using the jaws to grip or hold objects.
- Do not drop the caliper.
- Store it in its protective case.
- Avoid scratching the graduated scales.

**11.4 Care of a micrometer screw gauge**




- Clean the anvil and spindle faces after use.
- Use the ratchet stop instead of excessive hand pressure.
- Keep the screw mechanism free from dirt.
- Apply appropriate lubrication where recommended.
- Avoid fully tightening the spindle when storing.
- Store the instrument in its protective case.
- Check the zero reading regularly.
- Protect it against rust and corrosion.

**11.5 Care of a vernier height gauge**



- Clean the base before and after use.
- Keep the vertical beam free from dust.
- Protect the vernier scale from scratches.

- Keep the scriber sharp and properly secured.
- Avoid knocking or overturning the instrument.
- Store it in a safe and dry location.
- Clean the surface plate before use.
- Ensure the sliding head moves smoothly.
- Check the accuracy periodically.

**11.6 Importance of maintaining precision measuring tools**

- Maintains measurement accuracy.
- Extends the service life of instruments.
- Prevents rust and corrosion.
- Reduces repair and replacement costs.
- Promotes safe workshop practices.
- Prevents errors in manufactured components.
- Ensures reliable quality-control results.
- Improves the efficiency of workshop operations.

**12.0 PRACTICAL LEARNING ACTIVITIES IN A KENYAN METALWORK WORKSHOP**

The learner should participate in practical activities to develop competence in identifying, using and maintaining precision measuring tools.

**Activity 1: Identification of precision measuring tools**

**Resources required:**

- Vernier caliper.
- Micrometer screw gauge.
- Vernier height gauge.
- Vernier depth gauge.
- Digital measuring instruments.
- Charts or labelled pictures.

**Procedure:**

1. Observe the measuring instruments provided.
2. Identify each instrument by name.
3. Identify its main parts.
4. Discuss the function of each part.
5. State the dimensions each instrument measures.
6. Present findings to other learners.

**Expected learning outcome:** The learner identifies precision measuring instruments and explains their functions.

**Activity 2: Measuring the diameter of a metal rod**



**Resources required:**

- Vernier caliper.
- Metal rods of different diameters.
- Cleaning cloth.
- Recording sheet.

**Procedure:**

1. Collect different metal rods.
2. Inspect and clean the vernier caliper.
3. Check its zero reading.
4. Place the first rod between the outside jaws.
5. Take the measurement.
6. Repeat the measurement at different positions.
7. Record the readings.
8. Compare the readings and discuss possible variations.

**Sample observation table**

| Workpiece | Position | Measurement |
|---|---|---|
| Rod A | Position 1 | |
| Rod A | Position 2 | |
| Rod A | Position 3 | |
| Rod B | Position 1 | |
| Rod B | Position 2 | |

**Activity 3: Measuring sheet thickness using a micrometer**



**Resources required:**

- Micrometer screw gauge.
- Different metal sheets.
- Cleaning cloth.
- Recording sheet.

**Procedure:**

1. Inspect the micrometer.
2. Clean the anvil and spindle.
3. Check the zero reading.
4. Place a metal sheet between the measuring faces.
5. Turn the thimble carefully.
6. Use the ratchet stop to apply consistent pressure.
7. Record the reading.
8. Repeat for other metal sheets.
9. Compare the thicknesses obtained.

**Activity 4: Measuring component height using a vernier height gauge**



**Resources required:**

- Vernier height gauge.
- Surface plate.

- Metal blocks of different heights.
- Recording sheet.

**Procedure:**

1. Clean the surface plate.
2. Clean the base of the height gauge.
3. Position the instrument on the surface plate.
4. Place a metal block beside the gauge.
5. Adjust the sliding head to the top surface.
6. Lock the head.
7. Take the reading.
8. Repeat with other blocks.
9. Record and compare the results.

**Activity 5: Maintenance of precision measuring instruments**

**Resources required:**

- Soft cleaning cloth.
- Protective instrument cases.
- Suitable maintenance materials.
- Vernier caliper.
- Micrometer.
- Vernier height gauge.

**Procedure:**

1. Inspect each instrument.
2. Identify dirt, rust or visible damage.
3. Clean the instruments appropriately.
4. Check the moving parts.
5. Check zero readings.
6. Store each instrument correctly.
7. Explain the importance of proper maintenance.

**12.1 Suggested learner assessment checklist**

| Competence | Achieved | Not yet achieved |
|---|---|---|
| Identifies a vernier caliper | | |
| Identifies a micrometer screw gauge | | |
| Identifies a vernier height gauge | | |
| Explains the function of instrument parts | | |
| Selects the correct instrument for a task | | |
| Checks the zero setting | | |
| Takes measurements correctly | | |
| Records measurements with correct units | | |



| | | |
|---|---|---|
| Observes workshop safety | | |
| Cleans and stores instruments correctly | | |

## 13.0 ENTREPRENEURSHIP AND CAREER OPPORTUNITIES IN PRECISION MEASUREMENT

Precision measurement provides opportunities for employment, self-employment and enterprise development.

### 13.1 Career opportunities

Learners who develop competence in precision measurement may pursue careers as:

1. Mechanical engineering technicians.
2. Machinists.
3. Metal fabrication technicians.
4. Quality-control inspectors.
5. Tool and die makers.
6. Automotive engineering technicians.
7. Production technicians.
8. Workshop supervisors.
9. Engineering technologists.
10. Metrology technicians.

### 13.2 Entrepreneurial opportunities

Precision measurement skills can support businesses such as:

- Metal fabrication workshops.
- Engineering repair workshops.
- Machine-part production.
- Metal product inspection services.
- Small-scale manufacturing.
- Automotive component repair.
- Precision machining services.

### 13.3 Values and core competencies developed

**Values**

- Responsibility when handling expensive instruments.
- Integrity when recording measurements.
- Respect for workshop rules.
- Care for equipment and resources.
- Cooperation during group activities.
- Accountability for personal and shared tools.

**Core competencies**

- Communication and collaboration through group measuring activities.
- Critical thinking and problem-solving through the identification of measurement errors.

- Creativity and imagination through designing and marking out metal components.
- Digital literacy through the use of digital measuring instruments.
- Learning to learn through practical experimentation.
- Self-efficacy through independent measuring activities.

**13.4 Environmental considerations**

Learners should:

- Avoid unnecessary wastage of metal materials during measurement and marking out.
- Reuse suitable metal offcuts.
- Keep the workshop clean.
- Dispose of damaged batteries from digital instruments appropriately.
- Prevent oil and cleaning chemicals from contaminating the environment.
- Use resources responsibly.

**14.0 KEY TERMS AND THEIR MEANINGS**

| Term | Meaning |
|---|---|
| Precision measurement | Measurement using specialised instruments to obtain consistent and sufficiently detailed readings |
| Accuracy | Closeness of a measurement to the actual value |
| Precision | Closeness of repeated measurements to one another |
| Least count | Smallest measurement an instrument can read |
| Main scale | The primary graduated scale of a measuring instrument |
| Vernier scale | A secondary scale used to determine fractional measurements |
| Micrometer | An instrument that uses a screw mechanism for precise measurement |
| Scriber | A sharp instrument used for marking lines on metal |
| Surface plate | A flat, accurate reference surface used for inspection and marking |
| Zero error | An incorrect reading shown when an instrument should indicate zero |
| Calibration | Comparison and adjustment of an instrument against a recognised measurement standard |
| Tolerance | Permissible variation in a specified dimension |
| Allowance | Intentional dimensional difference between mating components |
| Clearance fit | A fit in which the hole is larger than the shaft |
| Interference fit | A fit in which the shaft is larger than the hole |
| Parallax error | Error caused by viewing a scale from an incorrect angle |
| Datum | A reference point, line or surface from which measurements are taken |
| Metrology | The science of measurement |

**STRAND 2.0: METALWORK PROCESSES AND TECHNOLOGY**

**SUB-STRAND 2.1: PRECISION MEASURING TOOLS**

**PART I: REVISION QUESTIONS**

**SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)**

Instructions: Choose the correct answer from the alternatives A, B, C and D. Each question carries 1 mark.

1. What is precision measurement?

A. Measuring objects using ordinary measuring tools
B. Determining dimensions using specialised instruments to obtain detailed and consistent readings
C. Estimating the weight of metal components
D. Comparing the colour of different metals

2. Which of the following is a precision measuring instrument?

A. Ball-peen hammer
B. Cold chisel
C. Vernier caliper
D. Hacksaw

3. The main purpose of a vernier caliper is to measure:

A. Temperature of metal
B. External, internal and depth dimensions
C. Weight of metal components
D. Hardness of metals

4. Which part of a vernier caliper is used to measure internal diameters?

A. Outside jaws
B. Depth rod
C. Inside jaws
D. Locking screw

5. The depth rod of a vernier caliper is used for measuring:

A. External diameter
B. Depth of holes and recesses
C. Internal circumference
D. Surface roughness

6. Which part of a vernier caliper carries the primary graduations?

A. Main scale
B. Vernier scale
C. Locking screw
D. Thumb roller

7. The smallest measurement that an instrument can read is known as:

A. Pitch
B. Tolerance
C. Allowance
D. Least count

8. A vernier caliper has 1 main scale division equal to 1 mm and 1 vernier scale division equal to 0.9 mm. What is its least count?

A. 1.9 mm
B. 0.1 mm
C. 0.9 mm
D. 0.01 mm

9. Which instrument is most suitable for measuring the thickness of a thin metal sheet accurately?

A. Steel rule
B. Try square
C. Micrometer screw gauge
D. Scriber

10. Which component of a micrometer screw gauge moves towards the anvil?

A. Frame
B. Sleeve
C. Spindle
D. Ratchet stop

11. The fixed measuring surface of a micrometer screw gauge is called the:

A. Thimble
B. Anvil
C. Sleeve
D. Frame

12. Which part of a micrometer screw gauge helps prevent excessive measuring pressure?

A. Ratchet stop
B. Main scale
C. Frame
D. Sleeve

13. A micrometer has a screw pitch of 0.5 mm and 50 thimble divisions. Its least count is:

A. 0.5 mm
B. 0.05 mm
C. 0.1 mm
D. 0.01 mm

14. A micrometer has a main scale reading of 8.5 mm and a thimble reading of 25 divisions. If its least count is 0.01 mm, what is the total reading?

A. 8.25 mm
B. 8.75 mm
C. 8.50 mm
D. 8.35 mm

15. The micrometer screw gauge operates based on the principle of:

A. Magnetic attraction
B. Hydraulic pressure
C. Screw movement
D. Electrical resistance

16. Which instrument is most suitable for measuring the internal diameter of a machined hole?

A. Outside micrometer
B. Inside micrometer
C. Vernier height gauge
D. Steel rule

17. A vernier height gauge is commonly used together with a:

A. Surface plate
B. Welding machine
C. Bench vice
D. Grinding wheel

18. The main purpose of a scriber attached to a vernier height gauge is to:

A. Cut metal sheets
B. Measure temperature
C. Mark lines at specified heights
D. Polish metal surfaces

19. Which part of a vernier height gauge provides stability?

A. Vernier scale
B. Scriber
C. Sliding head
D. Base

20. Which of the following instruments is most appropriate for marking a horizontal line at a specified height on a metal workpiece?

A. Micrometer screw gauge
B. Vernier height gauge
C. Outside caliper
D. Steel tape measure

21. What is a zero error?

A. An error caused by using the wrong unit
B. An error caused by measuring a large object
C. An incorrect reading when the instrument should indicate zero
D. An error caused by cutting metal incorrectly

22. Viewing an analogue measuring scale from an incorrect angle causes:

A. Parallax error
B. Zero error
C. Manufacturing error
D. Calibration error

23. Which practice helps reduce measurement errors?

A. Applying excessive pressure
B. Using dirty measuring instruments
C. Measuring rotating workpieces
D. Checking the zero setting before use

24. Which of the following may cause inaccurate measurements?

A. Clean measuring surfaces
B. Proper instrument alignment
C. Dirt between measuring surfaces
D. Correct calibration

25. What is calibration?

A. Cleaning an instrument using water
B. Comparing an instrument against a recognised measurement standard and adjusting it where necessary
C. Painting measuring instruments
D. Sharpening the jaws of a caliper

26. Which of the following is an example of a clearance fit?

A. A shaft that is larger than its hole
B. A shaft that is welded into a hole
C. A shaft that is always smaller than its hole
D. A shaft that cannot enter its hole

27. Which maintenance practice is appropriate for a micrometer screw gauge?

A. Dropping it after use
B. Tightening it excessively during storage
C. Using it as a clamp
D. Cleaning its measuring faces and storing it in a protective case

28. Why should precision measuring instruments be stored in protective cases?

A. To increase their weight
B. To protect them against damage, dirt and corrosion
C. To make them difficult to access
D. To change their measuring range

29. Which career involves checking whether manufactured components meet specified dimensions?

A. Welding operator only
B. Painting technician
C. Quality-control inspector
D. Storekeeper

30. Why is precision measurement important in manufacturing?

A. It increases material wastage
B. It reduces the need for workshop safety
C. It makes components unnecessarily expensive
D. It ensures components meet required dimensions and fit correctly

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

Instructions: Answer ALL questions. Show your working where calculations are required.

**QUESTION 1: INTRODUCTION TO PRECISION MEASUREMENT (8 MARKS)**

a) Define precision measurement. (2 marks)

b) Differentiate between accuracy and precision in metalwork measurement. (2 marks)

c) State four reasons why precision measurement is important in a metal workshop. (4 marks)

**QUESTION 2: VERNIER CALIPER (8 MARKS)**

a) Define a vernier caliper. (2 marks)

b) State four parts of a vernier caliper and give the function of each. (4 marks)

c) State two applications of a vernier caliper in a metal workshop. (2 marks)

**QUESTION 3: MICROMETER SCREW GAUGE (8 MARKS)**

a) Explain the working principle of a micrometer screw gauge. (2 marks)

b) State three parts of a micrometer screw gauge and explain their functions. (3 marks)

c) A micrometer screw gauge has a screw pitch of 0.5 mm and 50 divisions on its thimble.

Calculate its least count. (2 marks)

d) State one reason why a ratchet stop is important when taking measurements. (1 mark)

**QUESTION 4: VERNIER HEIGHT GAUGE (8 MARKS)**

a) Define a vernier height gauge. (2 marks)

b) State three uses of a vernier height gauge in metalwork. (3 marks)

c) Explain how a vernier height gauge is used to mark a horizontal line at a specified height on a metal component. (3 marks)

**QUESTION 5: MEASUREMENT ERRORS AND MAINTENANCE (9 MARKS)**

a) Explain three types of errors that may occur during precision measurement. (3 marks)

b) State three ways of reducing errors when using precision measuring instruments. (3 marks)

c) Explain three maintenance practices that should be observed when handling precision measuring instruments. (3 marks)

**QUESTION 6: PRACTICAL APPLICATIONS AND WORKSHOP SAFETY (9 MARKS)**

a) A metalworker is required to perform the following tasks:

i. Measure the external diameter of a metal shaft. (1 mark)

ii. Measure the thickness of a thin metal sheet. (1 mark)

iii. Mark a horizontal line at a specified height on a metal block. (1 mark)

Name the most suitable precision measuring instrument for each task.

b) Explain three safety precautions that should be observed when using precision measuring instruments. (3 marks)

c) A metal shaft has a specified diameter of 20.00 mm with a tolerance of ±0.05 mm.

i. Determine the maximum acceptable diameter. (1 mark)

ii. Determine the minimum acceptable diameter. (1 mark)

d) State one importance of tolerance in manufacturing. (1 mark)

**PART II: MARKING SCHEME**

**SECTION A: MULTIPLE-CHOICE ANSWERS (30 MARKS)**

Each correct answer carries 1 mark.

| Question | Answer | Question | Answer |
|---|---|---|---|
| 1 | B | 16 | B |
| 2 | C | 17 | A |
| 3 | B | 18 | C |
| 4 | C | 19 | D |
| 5 | B | 20 | B |
| 6 | A | 21 | C |
| 7 | D | 22 | A |
| 8 | B | 23 | D |
| 9 | C | 24 | C |
| 10 | C | 25 | B |
| 11 | B | 26 | C |
| 12 | A | 27 | D |
| 13 | D | 28 | B |
| 14 | B | 29 | C |
| 15 | C | 30 | D |

TOTAL: 30 MARKS

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

**QUESTION 1: INTRODUCTION TO PRECISION MEASUREMENT (8 MARKS)**

a) Define precision measurement. (2 marks)

Precision measurement is the process of determining the dimensions or sizes of objects using specialised measuring instruments capable of providing accurate, detailed and consistent readings.

Mark allocation:

- Determining dimensions or sizes of objects – 1 mark.
- Using specialised instruments to obtain accurate and consistent readings – 1 mark.

b) Differentiate between accuracy and precision in metalwork measurement. (2 marks)

- Accuracy: The degree to which a measured value is close to the actual or true value of a dimension. (1 mark)
- Precision: The degree to which repeated measurements of the same dimension give consistent or closely similar results. (1 mark)

c) State four reasons why precision measurement is important in a metal workshop. (4 marks)

Award 1 mark for each correct point.

1. Ensures manufactured components meet specified dimensions.
2. Promotes proper fitting of machine components

3. Reduces material wastage during manufacturing.
4. Improves the quality of finished products.
5. Ensures interchangeability of machine parts.
6. Reduces manufacturing errors and defects.
7. Promotes customer satisfaction.
8. Helps maintain required engineering standards.
9. Reduces the need for costly repairs and reworking.

Total: 8 marks

**QUESTION 2: VERNIER CALIPER (8 MARKS)**

a) Define a vernier caliper. (2 marks)

A vernier caliper is a precision measuring instrument used to measure external dimensions, internal dimensions and depths of objects with greater accuracy than an ordinary steel rule.

Mark allocation:

- Identification as a precision measuring instrument – 1 mark.
- Correct description of its measuring applications – 1 mark.

b) State four parts of a vernier caliper and give the function of each. (4 marks)

Award 1 mark for each correctly identified part and its function.

| **Part** | **Function** |
|---|---|
| 1. Main scale | Provides the main measurement graduations. |
| 2. Vernier scale | Provides additional graduations for accurate readings. |
| 3. Outside jaws | Measure external dimensions such as thickness and diameter. |
| 4. Inside jaws | Measure internal dimensions such as the diameter of holes. |
| 5. Depth rod | Measures the depth of holes and recesses. |
| 6. Locking screw | Holds the sliding jaw in position during reading. |

Accept any four correct parts with their functions.

c) State two applications of a vernier caliper in a metal workshop. (2 marks)

1. Measuring the external diameter of a metal shaft. (1 mark)
2. Measuring the internal diameter of a drilled hole. (1 mark)

Other acceptable answers:

- Measuring the depth of a recess.
- Measuring the thickness of a metal component.
- Measuring the width of a workpiece.

Total: 8 marks

**QUESTION 3: MICROMETER SCREW GAUGE (8 MARKS)**

a) Explain the working principle of a micrometer screw gauge. (2 marks)

- A micrometer screw gauge operates on the principle of screw movement, where rotational movement of the thimble is converted into linear movement of the spindle. (1 mark)
- The spindle moves towards or away from the anvil by a known distance depending on the rotation of the screw, allowing small dimensions to be measured accurately. (1 mark)

b) State three parts of a micrometer screw gauge and explain their functions. (3 marks)

Award 1 mark for each correct part and function.

| **Part** | **Function** |
|---|---|
| 1. Anvil | Provides a fixed measuring surface against which the workpiece rests. |
| 2. Spindle | Moves towards or away from the anvil to measure the workpiece. |
| 3. Sleeve/barrel | Carries the main scale graduations used for reading measurements. |
| 4. Thimble | Rotates the screw mechanism and carries the circular scale. |
| 5. Ratchet stop | Applies consistent measuring pressure and prevents excessive force. |
| 6. Frame | Supports and holds the measuring components together. |
| 7. Locking device | Locks the spindle in position when necessary. |

Accept any three correct parts with their functions.

c) Calculate the least count. (2 marks)

Given:

- Screw pitch = 0.5 mm
- Number of thimble divisions = 50

Formula:

$$\text{Least Count} = \frac{\text{Screw Pitch}}{\text{Number of Thimble Divisions}}$$

Substitution:

$$LC = \frac{0.5}{50}$$

$$LC = 0.01 \text{ mm}$$

Mark allocation:

- Correct formula and substitution – 1 mark.
- Correct answer with unit – 1 mark.

d) State one reason why a ratchet stop is important when taking measurements. (1 mark)

- It ensures consistent measuring pressure when taking readings.
- It prevents excessive pressure that could distort the workpiece or affect the measurement.

Accept either response.

Total: 8 marks

**QUESTION 4: VERNIER HEIGHT GAUGE (8 MARKS)**

a) Define a vernier height gauge. (2 marks)

A vernier height gauge is a precision measuring and marking-out instrument used to measure vertical heights and mark lines at specified heights on a workpiece, usually when placed on a surface plate.

Mark allocation:

- Identification as a precision measuring/marking instrument – 1 mark.
- Correct description of its use in measuring or marking heights – 1 mark.

b) State three uses of a vernier height gauge in metalwork. (3 marks)

Award 1 mark each for any three:

1. Measuring the height of metal components.
2. Marking horizontal lines at specified heights on workpieces.
3. Checking the difference in height between two surfaces.
4. Marking out components before machining.
5. Checking the parallelism of surfaces.
6. Locating the position of holes or other features at specified heights.
7. Inspecting manufactured components against specified dimensions.

c) Explain how a vernier height gauge is used to mark a horizontal line at a specified height on a metal component. (3 marks)

1. Clean the surface plate and the base of the vernier height gauge to remove dirt and metal particles. (1 mark)
2. Place the workpiece on the surface plate and adjust the sliding head until the scriber reaches the required height using the main and vernier scales. (1 mark)
3. Lock the sliding head and move the scriber across the workpiece surface to produce a horizontal marking line. (1 mark)

Total: 8 marks

**QUESTION 5: MEASUREMENT ERRORS AND MAINTENANCE (9 MARKS)**

a) Explain three types of errors that may occur during precision measurement. (3 marks)

Award 1 mark for each correct explanation.

1. Zero error: Occurs when a measuring instrument does not indicate zero when its measuring faces are in the correct zero position.
2. Parallax error: Occurs when a measuring scale is viewed from an incorrect angle, resulting in an inaccurate reading.
3. Instrumental error: Occurs due to defects, wear, damage or incorrect calibration of a measuring instrument.
4. Human error: Occurs due to mistakes made by the person taking the measurement, such as incorrect reading or improper handling.
5. Environmental error: Occurs due to changes in temperature or other environmental conditions that affect the instrument or workpiece.

Accept any three.

b) State three ways of reducing errors when using precision measuring instruments. (3 marks)

Award 1 mark each for any three:

1. Check the zero setting before taking measurements.
2. Ensure measuring surfaces are clean.
3. Read scales at eye level to avoid parallax error.
4. Use the correct measuring instrument for the task.
5. Avoid applying excessive measuring pressure.
6. Ensure instruments are properly calibrated.
7. Allow instruments and workpieces to reach a stable temperature.
8. Take repeated measurements and compare the readings.
9. Ensure the instrument is properly aligned with the workpiece.

c) Explain three maintenance practices that should be observed when handling precision measuring instruments. (3 marks)

Award 1 mark each for any three well-explained practices.

1. Cleaning: Wipe measuring faces and instrument surfaces after use to remove dirt, grease and metal particles.
2. Proper storage: Store instruments in protective cases to prevent physical damage and corrosion.
3. Lubrication: Apply suitable light lubricant to moving parts where recommended to prevent rust and ensure smooth operation.
4. Calibration: Check instruments regularly against recognised measurement standards to maintain accuracy.
5. Careful handling: Avoid dropping or knocking instruments because this may damage their measuring surfaces.
6. Rust prevention: Keep instruments dry and protect them from moisture.
7. Regular inspection: Check for worn measuring faces, loose parts and other defects before use.

Total: 9 marks

**QUESTION 6: PRACTICAL APPLICATIONS AND WORKSHOP SAFETY (9 MARKS)**

a) Name the most suitable precision measuring instrument for each task. (3 marks)

i. Measuring the external diameter of a metal shaft:

- Vernier caliper. (1 mark)

ii. Measuring the thickness of a thin metal sheet:

- Micrometer screw gauge (outside micrometer). (1 mark)

iii. Marking a horizontal line at a specified height on a metal block:

- Vernier height gauge. (1 mark)

b) Explain three safety precautions that should be observed when using precision measuring instruments. (3 marks)

Award 1 mark each for any three correct precautions with explanations.

1. Handle instruments carefully: Avoid dropping or knocking them to prevent damage to their measuring surfaces.
2. Keep hands and workpieces clean: Remove grease, dirt and metal particles to ensure reliable measurements.

3. Do not measure rotating workpieces: Stop machines before taking measurements to prevent injuries and damage to instruments.
4. Use instruments for their intended purpose: Do not use micrometers or vernier calipers as clamps or marking tools.
5. Wear appropriate protective equipment: Use suitable workshop protective equipment when handling metal components.
6. Store instruments safely: Return measuring instruments to their protective cases after use.
7. Avoid excessive force: Apply appropriate measuring pressure to prevent damage to the instrument and workpiece.

c) A metal shaft has a specified diameter of 20.00 mm with a tolerance of ±0.05 mm.

i. Determine the maximum acceptable diameter. (1 mark)

Formula:

Formula:

$$\text{Maximum diameter} = \text{Basic size} + \text{Tolerance}$$

$$= 20.00 + 0.05$$

$$\boxed{20.05 \text{ mm}}$$

**ii. Determine the minimum acceptable diameter. (1 mark)**

Formula:

$$\text{Minimum diameter} = \text{Basic size} - \text{Tolerance}$$

$$= 20.00 - 0.05$$

$$\boxed{19.95 \text{ mm}}$$

d) State one importance of tolerance in manufacturing. (1 mark)

- It specifies the allowable variation in component dimensions while ensuring proper fitting and functioning.

Other acceptable answers:

- Promotes interchangeability of components.
- Reduces manufacturing rejection.
- Allows controlled manufacturing variations.
- Ensures components function correctly when assembled.

Total: 9 marks

**STRAND 2.0: TOOLS AND MATERIALS IN METALWORK**

**SUB-STRAND 2.2: MACHINE TOOLS**




## 1.0 INTRODUCTION TO MACHINE TOOLS

Machine tools are important equipment used in metalwork workshops to shape, cut, drill, grind, bend and finish metallic materials into useful products.

In traditional metalworking, many operations are performed using hand tools. However, machine tools make metalworking operations faster, more accurate and more efficient.

Machine tools are widely used in:

- Engineering workshops.
- Motor vehicle repair workshops.
- Metal fabrication industries.
- Construction industries.
- Agricultural machinery manufacturing.
- Manufacturing industries.
- Plumbing and sheet-metal workshops.
- Railway and transport industries.

Examples of metal products manufactured using machine tools include:

- Metal gates and doors.
- Window frames.
- Water tanks.
- Metal furniture.
- Machine components.
- Vehicle body parts.
- Agricultural equipment.
- Roofing sheets.
- Metal brackets and supports.

**1.1 Definition of Machine Tools**

A **machine tool** is a powered mechanical device used to cut, shape, form, drill, grind or finish metallic materials into required dimensions and shapes.

Machine tools use mechanical power, electrical power or other forms of energy to perform metalworking operations.

Examples include:

1. Sawing machines.
2. Drilling machines.
3. Grinding machines.
4. Guillotine machines.
5. Bending machines.

**1.2 Characteristics of Machine Tools**

Machine tools have the following characteristics:

1. **Power-driven operation:** Most machine tools use electricity or another power source to operate.
2. **Accuracy:** They produce components with accurate measurements when correctly set and operated.
3. **Efficiency:** They reduce the time and effort required to perform metalworking operations.
4. **Versatility:** Some machines can perform different operations depending on the attachments and settings used.
5. **Repeatability:** They can produce several components of similar dimensions and quality.
6. **Durability:** Industrial machine tools are designed to withstand repeated use.
7. **Safety requirements:** They have moving parts that require proper handling and safety precautions.

**1.3 Importance of Machine Tools in Metalwork**

Machine tools are important because they:

1. **Increase production speed**

- They perform operations faster than most manual methods.
- For example, a powered sawing machine can cut several metal sections within a short period.

2. **Improve accuracy**

- They help produce components with accurate dimensions.
- This is important when manufacturing machine parts that must fit together.

3. **Reduce physical effort**

- Machines perform demanding tasks that would otherwise require considerable human effort.

4. **Improve the quality of products**

- Properly operated machines produce smooth, uniform and well-shaped components.

5. **Increase production capacity**

- Workshops can manufacture more products within a given period.

6. **Promote standardisation**

- Machines help produce components of similar sizes and shapes.

7. **Improve industrial development**

- They support manufacturing, construction, transport and agricultural industries in Kenya.

8. **Promote self-employment**

- Skilled individuals can establish metal fabrication businesses.

9. **Reduce material wastage**

- Accurate cutting and shaping can minimise errors and unnecessary material losses.

10. **Support innovation**

- Machine tools enable artisans and engineers to develop new products and designs.

**2.0 TYPES OF MACHINE TOOLS USED IN A METAL WORKSHOP**

The major machine tools covered in this sub-strand include:

1. Sawing machine.
2. Drilling machine.
3. Grinding machine.
4. Guillotine machine.
5. Bending machine.

Each machine is designed to perform particular operations. The choice of a machine depends on the nature of the material, the required operation, the dimensions of the workpiece and the desired finish.

**2.1 SAWING MACHINE**







### 2.1.1 Definition of a Sawing Machine

A **sawing machine** is a power-operated machine used to cut metallic materials into required lengths and shapes using a toothed cutting blade.

The blade moves against or through the workpiece, removing material along the cutting line.

Sawing machines are commonly used for cutting:

- Metal bars.
- Metal pipes.
- Angle irons.
- Flat metal sections.
- Steel rods.
- Square and rectangular hollow sections.
- Metal plates of suitable thickness.

### 2.1.2 Main Types of Sawing Machines

**A. Power Hacksaw Machine**



A power hacksaw is a machine that uses a reciprocating toothed blade to cut metal.

The blade moves backwards and forwards across the workpiece.

**Main features:**

1. Machine frame – supports the main components.
2. Hacksaw blade – contains teeth that remove metal.
3. Work vice – holds the workpiece firmly.
4. Motor – provides the power needed to operate the machine.
5. Drive mechanism – converts rotary motion into reciprocating motion.
6. Coolant system – helps cool the blade and workpiece where fitted.
7. Control switch – switches the machine on and off.

**Working principle:**

- The workpiece is placed in the machine vice.
- The vice is tightened to hold the material firmly.
- The blade is brought into contact with the workpiece.
- The motor drives the blade backwards and forwards.
- The teeth remove small amounts of metal during cutting.
- The cut piece is separated when the cutting operation is completed.

**Applications:**

- Cutting steel rods to length.
- Cutting metal pipes.
- Preparing metal sections for fabrication.
- Cutting metal stock before machining.

**B. Horizontal Bandsaw Machine**



A horizontal bandsaw machine uses a continuous toothed metal blade running around two or more wheels to cut metal.

**Main parts:**

1. Continuous saw blade.
2. Blade wheels.
3. Machine frame.

4. Workpiece vice.
5. Electric motor.
6. Blade guides.
7. Coolant delivery system.
8. Control panel.

**Working principle:**

- The workpiece is securely clamped.
- The motor rotates the blade wheels.
- The continuous blade moves through the cutting area.
- The teeth cut through the material.
- The machine head moves downwards or the workpiece is fed towards the blade, depending on the machine design.

**Uses:**

- Cutting solid metal bars.
- Cutting pipes and hollow sections.
- Cutting angle irons.
- Preparing materials for welding and fabrication.

**C. Vertical Bandsaw Machine**



A vertical bandsaw has a continuous blade that moves vertically through the cutting area.

**Uses:**

- Cutting irregular metal shapes.
- Cutting curves and profiles.
- Cutting metal sheets and plates within the machine's capacity.
- Trimming metal components.

**2.1.3 Advantages of Sawing Machines**

1. They cut metal faster than manual hacksaws in many production situations.
2. They produce relatively accurate cuts.
3. They reduce physical effort.
4. They can cut different metal sections.

5. They are suitable for repetitive cutting operations.
6. They help prepare materials for further processing.

**2.1.4 Disadvantages of Sawing Machines**

1. They require a power supply.
2. They need regular maintenance.
3. Cutting blades become blunt and require replacement.
4. Incorrect operation can cause accidents.
5. Some machines require considerable workshop space.
6. They may produce noise and metal chips.

**2.1.5 Safety Precautions When Using Sawing Machines**

1. Wear safety goggles to protect the eyes from flying metal particles.
2. Wear suitable protective footwear.
3. Secure the workpiece firmly in the vice.
4. Select the correct blade for the material.
5. Ensure the blade is correctly installed and tensioned.
6. Do not touch a moving blade.
7. Keep hands away from the cutting area.
8. Do not force the blade through the material.
9. Ensure all guards are correctly positioned.
10. Switch off the machine before making adjustments.
11. Remove metal chips using a brush, not bare hands.
12. Do not wear loose clothing or jewellery near moving machine parts.

**2.1.6 Maintenance of Sawing Machines**

- Clean the machine after use.
- Remove accumulated metal chips.
- Lubricate moving parts according to the manufacturer's instructions.
- Check the blade for wear, cracks and damaged teeth.
- Replace damaged blades.
- Inspect electrical cables and switches.
- Check the vice for proper operation.
- Ensure blade guides are correctly adjusted.
- Store the machine in a clean and dry workshop.
- Arrange professional servicing when necessary.

## 2.2 DRILLING MACHINE





### 2.2.1 Definition of a Drilling Machine

A **drilling machine** is a power-operated machine used to produce circular holes in metallic materials using a rotating cutting tool called a drill bit.

Drilling is an important operation in metalwork because many metal components require holes for fastening, joining, assembly and fitting.

Examples of metal components requiring drilled holes include:

- Metal gates.
- Steel brackets.
- Machine frames.
- Metal shelves.
- Vehicle components.
- Bolted structures.
- Agricultural equipment.

### 2.2.2 Types of Drilling Machines

**A. Bench Drilling Machine**



A bench drilling machine is a relatively small drilling machine mounted on a workbench.

**Characteristics:**

1. It is compact in size.
2. It is mounted on a bench.
3. It is suitable for small and medium-sized workpieces.
4. It is commonly used in school workshops.
5. It is operated using an electric motor.

**Uses:**

- Drilling holes in small metal plates.
- Drilling holes in brackets.
- Making holes in small metal components.
- Carrying out light workshop drilling tasks.

**B. Pillar Drilling Machine**



A pillar drilling machine is a floor-mounted machine supported by a strong vertical column.

**Main features:**

- Base.
- Vertical column.
- Worktable.
- Drill head.
- Electric motor.
- Spindle.
- Chuck.
- Feed handle.
- Belt and pulley system or variable-speed drive.

**Uses:**

- Drilling holes in larger workpieces.
- Drilling holes in thicker metal sections within its capacity.
- Carrying out repetitive drilling operations.
- Producing accurate holes in workshop components.

**C. Radial Arm Drilling Machine**



A radial arm drilling machine has a movable arm that supports the drilling head.

The drilling head can move along the arm, while the arm can be raised, lowered or rotated around the column.

**Uses:**

1. Drilling large metal workpieces.
2. Drilling holes at different positions without moving heavy workpieces.
3. Drilling large plates and machine components.
4. Performing drilling operations in engineering industries.

**2.2.3 Main Parts of a Drilling Machine**

1. **Base:** Supports the machine and provides stability.
2. **Column:** A vertical support connecting the base to the machine head.
3. **Worktable:** Supports the material being drilled.
4. **Drill head:** Houses the motor and driving mechanism.

5. **Electric motor:** Supplies power for rotating the drill.
6. **Spindle:** Transfers rotary motion to the drill chuck.
7. **Chuck:** Holds the drill bit firmly.
8. **Drill bit:** The cutting tool used to produce holes.
9. **Feed handle:** Controls the downward movement of the drill bit.
10. **Speed control:** Allows selection of the appropriate spindle speed.
11. **Guard:** Helps protect the operator from moving parts and flying particles.

### 2.2.4 Common Drilling Tools and Accessories





**1. Twist drill bit**

- The most commonly used drilling tool.
- Has two helical flutes.
- Used to produce circular holes in metal.

**2. Centre drill**

- Used to produce a small starting hole.
- Helps position a larger drill accurately.
- Reduces wandering of the drill bit.

**3. Machine vice**

- Holds the workpiece firmly during drilling.
- Prevents the workpiece from rotating.
- Improves drilling accuracy.

**4. Countersink tool**

- Used to produce a conical recess around the mouth of a drilled hole.
- Allows countersunk screw heads to sit flush with the surface.

**5. Reamer**

- Used to improve the accuracy and surface finish of an existing drilled hole.
- Removes a small amount of material from the hole.

### 2.2.5 Working Principle of a Drilling Machine

1. Select the correct drill bit according to the required hole size.
2. Fit the drill bit into the chuck.

3. Tighten the chuck securely.
4. Mark the drilling position on the workpiece.
5. Secure the workpiece in a machine vice.
6. Select the correct spindle speed.
7. Switch on the machine.
8. Lower the rotating drill bit gradually using the feed handle.
9. Apply appropriate cutting fluid where required.
10. Withdraw the drill bit after completing the hole.
11. Switch off the machine.
12. Allow the spindle to stop before removing the workpiece.
13. Remove sharp edges using an appropriate deburring tool.

**2.2.6 Factors to Consider When Selecting a Drilling Machine**

- Size of the workpiece.
- Thickness of the metal.
- Required hole diameter.
- Required drilling depth.
- Type and hardness of the metal.
- Accuracy required.
- Available machine capacity.
- Production quantity.

**2.2.7 Safety Precautions When Using Drilling Machines**

1. Wear appropriate eye protection.
2. Clamp the workpiece firmly.
3. Never hold a workpiece by hand while drilling.
4. Remove the chuck key before switching on the machine.
5. Avoid loose clothing and jewellery.
6. Tie back long hair.
7. Do not touch the rotating drill bit.
8. Use the correct spindle speed.
9. Apply cutting fluid where appropriate.
10. Switch off the machine before changing drill bits.
11. Remove metal swarf using a brush.
12. Do not attempt to stop the spindle by hand.
13. Ensure guards are in position.
14. Report unusual noise, vibration or overheating.

### 2.2.8 Maintenance of Drilling Machines

- Clean the machine after use.
- Lubricate moving parts as recommended.
- Check the drill chuck for wear.
- Sharpen or replace blunt drill bits.
- Inspect belts and pulleys.
- Check electrical connections.
- Ensure the worktable is secure.
- Inspect the machine vice.
- Keep the machine free from rust.
- Arrange regular servicing.

## 2.3 GRINDING MACHINE





### 2.3.1 Definition of a Grinding Machine

A **grinding machine** is a power-operated machine that uses a rotating abrasive wheel to remove small amounts of material from a workpiece to achieve the required shape, dimensions or surface finish.

Grinding is mainly used for finishing operations, sharpening cutting tools and removing unwanted material.

### 2.3.2 Uses of Grinding Machines

1. Sharpening cutting tools.
2. Removing burrs from metal components.
3. Smoothing rough metal surfaces.
4. Removing excess weld metal.
5. Finishing machined surfaces.
6. Producing accurate dimensions.
7. Cleaning metal surfaces.
8. Removing rust and scale using suitable abrasive attachments.

### 2.3.3 Types of Grinding Machines

### A. Bench Grinding Machine




A bench grinder is a small grinding machine mounted on a workbench.

It normally has two grinding wheels mounted on opposite ends of a motor shaft.

**Main parts:**

- Electric motor.
- Grinding wheels.
- Wheel guards.
- Tool rests.
- Eye shields.
- Power switch.
- Machine base.

**Uses:**

- Sharpening chisels.
- Sharpening punches.
- Sharpening selected workshop tools.
- Removing small burrs.
- Grinding small metal components.

**B. Pedestal Grinding Machine**



A pedestal grinding machine is mounted on a strong floor-standing pedestal.

It is generally larger than a bench grinder.

**Uses:**

- Grinding larger workpieces.
- Sharpening workshop tools.
- Removing unwanted metal.
- General metal surface preparation.

**C. Surface Grinding Machine**




A surface grinding machine is used to produce flat, smooth and accurately finished surfaces.

The workpiece is held on a magnetic chuck or another suitable holding device.

**Uses:**

- Producing flat metal surfaces.
- Achieving accurate thickness.
- Finishing machine components.
- Improving surface quality.

**D. Cylindrical Grinding Machine**



A cylindrical grinding machine is used to grind the external or internal cylindrical surfaces of components.

**Uses:**

- Finishing shafts.
- Grinding cylindrical machine parts.
- Producing accurate diameters.
- Improving the surface finish of round components.

### 2.3.4 Main Parts of a Bench Grinding Machine

1. **Electric motor:** Provides power to rotate the grinding wheels.
2. **Grinding wheel:** Contains abrasive particles that remove material.
3. **Wheel guard:** Covers part of the grinding wheel to reduce injury risks.
4. **Tool rest:** Supports the workpiece during grinding.
5. **Eye shield:** Helps protect the operator's eyes.
6. **Base:** Supports the entire machine.
7. **Power switch:** Controls the supply of electricity.
8. **Wheel flanges:** Help secure the grinding wheel.
9. **Shaft:** Transfers rotational motion from the motor to the wheels.

### 2.3.5 Abrasive Grinding Wheels

A grinding wheel is made from abrasive grains held together by a bonding material.

**Common abrasive materials include:**

1. **Aluminium oxide**

- Commonly used for grinding steel and other ferrous metals.

2. **Silicon carbide**

- Commonly used for grinding cast iron, non-ferrous metals and other suitable materials.

3. **Diamond abrasive**

- Used for specialised grinding of very hard materials and certain industrial applications.

**Functions of abrasive grains:**

- Cut away small particles of metal.
- Smooth rough surfaces.
- Shape workpieces.
- Remove unwanted material.

### 2.3.6 Working Principle of a Grinding Machine

1. Select a suitable grinding wheel.
2. Inspect the wheel for cracks or damage.
3. Ensure the wheel is correctly mounted.
4. Adjust the tool rest according to the manufacturer's requirements.
5. Position the workpiece securely.
6. Switch on the machine.
7. Allow the wheel to reach its operating speed.
8. Bring the workpiece gently into contact with the wheel.
9. Move the workpiece carefully to achieve the desired finish.
10. Avoid excessive pressure.

11. Remove the workpiece and switch off the machine.
12. Allow the wheel to stop naturally.

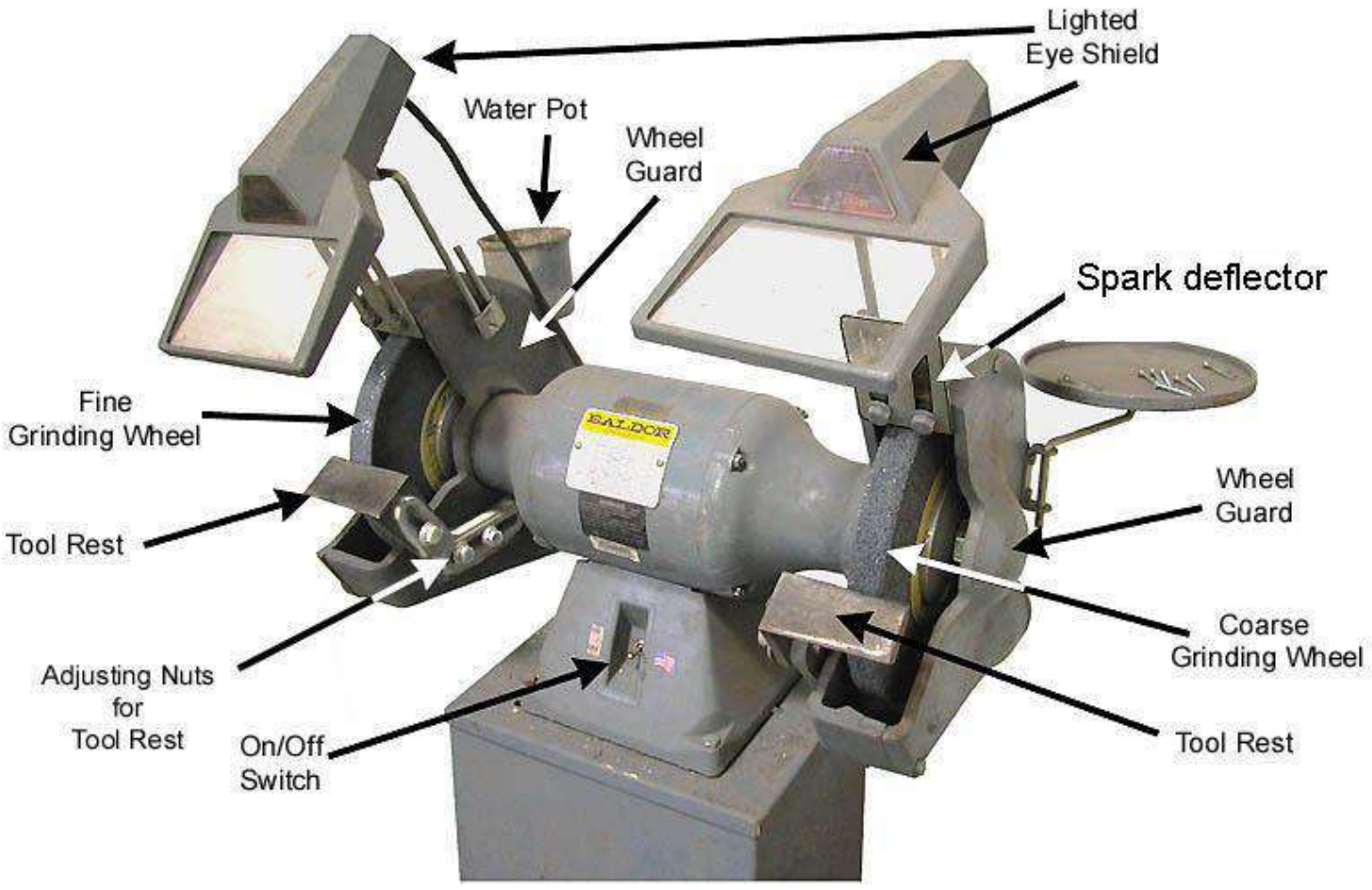
### 2.3.7 Advantages of Grinding Machines

- Produce smooth surface finishes.
- Achieve accurate dimensions.
- Sharpen metal cutting tools.
- Remove small amounts of unwanted material.
- Finish hardened metal components.
- Improve the appearance of metal products.

### 2.3.8 Limitations of Grinding Machines

- Grinding wheels wear out.
- They generate heat.
- They produce abrasive dust and sparks.
- Some grinding operations are relatively slow.
- Incorrect wheel selection can damage the workpiece.
- Damaged grinding wheels may shatter and cause serious injuries.

### 2.3.9 Safety Precautions When Using Grinding Machines




1. Wear safety goggles or a suitable face shield.

2. Inspect the grinding wheel before use.
3. Never use a cracked or damaged wheel.
4. Ensure the wheel guard is correctly fitted.
5. Adjust the tool rest to the manufacturer's specified clearance.
6. Stand to one side when starting the machine.
7. Allow the wheel to reach its operating speed before grinding.
8. Do not apply excessive pressure.
9. Use the correct grinding wheel for the material.
10. Do not grind on the side of a wheel unless it is designed for side grinding.
11. Avoid grinding materials that are unsuitable for the wheel.
12. Keep hands away from the rotating wheel.
13. Do not wear loose clothing.
14. Switch off the machine after use.

**Important:** Grinding wheels must be handled carefully. A cracked wheel can break apart at high speed and cause severe injuries.

### 2.3.10 Maintenance of Grinding Machines

- Clean the machine after use.
- Inspect wheels regularly.
- Replace worn or damaged wheels.
- Ensure wheel guards are secure.
- Keep tool rests correctly adjusted.
- Check the motor for unusual noise and overheating.
- Inspect electrical cables.
- Lubricate components where required.
- Keep the machine dry.
- Ensure the machine is firmly mounted.

## 2.4 GUILLOTINE MACHINE





### 2.4.1 Definition of a Guillotine Machine

A **guillotine machine** is a metalworking machine used to cut sheet metal into required sizes and shapes using two cutting blades that pass one another with a small clearance.

The upper blade moves downwards against the lower blade to shear the metal.

Unlike a sawing machine, which cuts using teeth, a guillotine machine cuts by applying shearing force.

### 2.4.2 Uses of a Guillotine Machine

A guillotine machine is used for:

1. Cutting sheet metal into rectangular pieces.
2. Cutting metal sheets into strips.
3. Preparing sheets for bending.
4. Cutting roofing sheet materials within machine capacity.
5. Producing components for metal cabinets.
6. Cutting sheet metal for fabrication.
7. Preparing materials for making metal boxes.
8. Cutting sheet materials used in ventilation ducting.

### 2.4.3 Types of Guillotine Machines

**A. Manual Guillotine Machine**



A manual guillotine machine is operated using human effort through a lever or handle.

**Characteristics:**

- Uses mechanical leverage.
- Suitable for relatively light cutting operations.
- Does not necessarily require electricity.

- Commonly used in small fabrication workshops.

**B. Mechanical Guillotine Machine**




A mechanical guillotine uses a motor and mechanical drive system to operate the cutting blade.

**Characteristics:**

- Uses mechanical power.
- Suitable for repetitive cutting.
- Can cut sheet metal efficiently.
- Requires proper machine guarding and maintenance.

**C. Hydraulic Guillotine Machine**



A hydraulic guillotine uses hydraulic pressure to move the cutting blade.

**Characteristics:**

- Uses hydraulic fluid under pressure.
- Can cut thicker sheets within its rated capacity.
- Offers controlled cutting force.
- Commonly used in industrial fabrication workshops.

**2.4.4 Main Parts of a Guillotine Machine**

1. **Frame:** Supports the machine components.
2. **Upper blade:** Moves to cut the sheet metal.

3. **Lower blade:** Provides the stationary cutting edge.
4. **Worktable:** Supports the sheet metal.
5. **Back gauge:** Helps position material to obtain the required cutting dimensions.
6. **Clamping system:** Holds the sheet metal during cutting.
7. **Operating lever or control system:** Initiates the cutting action.
8. **Motor:** Supplies power in powered machines.
9. **Hydraulic system:** Supplies cutting force in hydraulic machines.
10. **Safety guards:** Protect the operator from dangerous moving parts.

### 2.4.5 Working Principle of a Guillotine Machine

1. Measure and mark the required dimensions on the metal sheet.
2. Check the thickness and type of material.
3. Confirm that the machine can safely cut the material.
4. Adjust the back gauge to the required measurement.
5. Position the sheet metal on the worktable.
6. Ensure that the sheet is properly aligned.
7. Engage the clamping system.
8. Activate the cutting mechanism.
9. The upper blade moves against the lower blade.
10. The sheet metal is separated by shearing action.
11. Remove the cut material when the machine has stopped safely.
12. Inspect the cut edge for accuracy and defects.

### 2.4.6 Factors Affecting the Quality of Guillotine Cutting

- Thickness of the sheet metal.
- Type and hardness of the metal.
- Sharpness of the blades.
- Blade clearance.
- Alignment of the sheet.
- Accuracy of the back gauge.
- Condition of the machine.
- Cutting force.
- Operator skill.

### 2.4.7 Advantages of Guillotine Machines

1. They cut sheet metal quickly.
2. They produce relatively straight edges.
3. They are suitable for repetitive cutting.

4. They reduce manual effort.
5. They improve cutting accuracy.
6. They reduce material wastage when correctly set.
7. They can handle different sheet thicknesses depending on their capacity.

### 2.4.8 Safety Precautions When Using Guillotine Machines




1. Wear appropriate protective equipment.
2. Keep fingers and hands away from the cutting blades.
3. Never place hands beneath the clamping mechanism.
4. Ensure all guards are in position.
5. Do not exceed the machine's rated cutting capacity.
6. Ensure the sheet metal is correctly positioned.
7. Keep the working area free from obstructions.
8. Never attempt to remove offcuts while the blades are moving.
9. Do not operate the machine without proper training.
10. Use the emergency stop when necessary.
11. Switch off and isolate the machine before maintenance.
12. Handle cut sheet metal carefully because its edges may be sharp.

### 2.4.9 Maintenance of Guillotine Machines

- Clean the worktable after use.
- Inspect cutting blades for damage.
- Sharpen or replace blades when necessary.
- Lubricate moving components.
- Inspect the clamping mechanism.
- Check the back gauge for accuracy.
- Inspect hydraulic hoses for leaks.
- Check electrical connections.
- Ensure safety guards function correctly.
- Arrange regular professional servicing.

## 2.5 BENDING MACHINE





### 2.5.1 Definition of a Bending Machine

A **bending machine** is a metalworking machine used to change the shape of a metal workpiece by applying force without intentionally cutting or removing material.

The machine bends metal along a predetermined line to produce the required angle or shape.

Bending is widely used in sheet-metal fabrication and engineering.

### 2.5.2 Uses of Bending Machines

Bending machines are used to:

1. Bend sheet metal into different angles.
2. Make metal boxes and containers.
3. Manufacture metal cabinets.
4. Make roofing components.
5. Produce metal brackets.
6. Form metal channels and profiles.
7. Make ventilation ducts.
8. Produce metal frames.
9. Manufacture components for vehicle bodies.
10. Make metal furniture.

### 2.5.3 Types of Bending Machines

**A. Manual Sheet-Metal Bending Machine**



A manual bending machine uses human effort to apply bending force through a lever or handle.

**Characteristics:**

- Operated manually.
- Suitable for light sheet-metal work.
- Relatively simple to operate.
- Commonly used in small workshops.

**Uses:**

- Bending thin sheet metal.
- Making simple metal boxes.
- Producing small brackets.
- Folding sheet-metal edges.

**B. Mechanical Bending Machine**



A mechanical bending machine uses a motor and mechanical transmission system to apply bending force.

**Uses:**

- Repetitive metal bending.
- Producing standardised metal components.
- Bending materials within the machine's capacity.

**C. Hydraulic Press Brake**



A hydraulic press brake uses hydraulic pressure to move a punch against a die, bending the metal sheet to the required angle.

**Main features:**

1. Machine frame.
2. Hydraulic cylinders.
3. Upper beam or ram.
4. Punch.
5. Lower die.
6. Worktable.
7. Control system.
8. Back gauge.
9. Safety guards.

**Uses:**

- Bending thick sheet metal.
- Making accurate metal folds.
- Manufacturing metal cabinets.
- Producing machine enclosures.
- Making industrial metal components.

**D. Roll Bending Machine**



A roll bending machine uses rotating rollers to bend metal sheets or plates into curved and cylindrical shapes.

**Uses:**

- Making cylindrical tanks.
- Producing curved metal panels.
- Manufacturing pipes and cylindrical sections.
- Producing curved architectural components.

**2.5.4 Main Parts of a Manual Bending Machine**

1. **Frame:** Provides structural support.
2. **Clamping beam:** Holds the sheet metal firmly.
3. **Bending leaf:** Moves to bend the metal.
4. **Operating handle:** Provides the force needed to operate the machine.
5. **Worktable:** Supports the sheet metal.
6. **Angle adjustment:** Helps control the required bending angle.
7. **Stops:** Assist in positioning the workpiece accurately.

**2.5.5 Main Parts of a Press Brake**

1. **Frame:** Supports the entire machine.
2. **Ram:** Moves the upper punch towards the lower die.
3. **Punch:** Applies force to the sheet metal.
4. **Die:** Supports the sheet metal and determines the bending profile.
5. **Hydraulic cylinder:** Provides the force needed for bending.

6. **Back gauge:** Positions the material.
7. **Control panel:** Allows the operator to control the machine.
8. **Worktable:** Supports the workpiece.
9. **Safety system:** Helps protect the operator.

**2.5.6 Working Principle of a Bending Machine**

1. Measure the metal sheet.
2. Mark the required bending line.
3. Select a suitable bending machine.
4. Select the correct punch and die where applicable.
5. Position the workpiece correctly.
6. Adjust the bending angle.
7. Clamp or support the sheet securely.
8. Apply the bending force gradually.
9. Allow the metal to bend along the required line.
10. Release the workpiece.
11. Check the angle and dimensions.
12. Make any necessary corrections within safe machine limits.

**2.5.7 Factors to Consider When Bending Metal**

1. **Type of metal:** Different metals have different bending properties.
2. **Thickness:** Thicker metal generally requires greater bending force.
3. **Bending angle:** The required angle determines the machine settings.
4. **Bend radius:** This is the radius of the inside curve of the bend.
5. **Ductility:** Ductile metals can undergo plastic deformation without cracking easily.
6. **Grain direction:** In sheet metal, the direction of bending relative to the rolling direction may affect cracking.
7. **Tooling:** The punch and die must be suitable for the workpiece.
8. **Springback:** Metal may partially return towards its original shape after the bending force is removed.

**2.5.8 Understanding Springback**

**Springback** is the tendency of metal to recover partially towards its original shape after the bending force has been removed.

For example:

- A metal sheet is bent to an angle of 90 degrees.
- After the bending pressure is released, the sheet may open slightly.
- The final angle may therefore become greater than 90 degrees.

**Ways of controlling springback:**

- Use suitable bending settings.
- Apply appropriate overbending where permitted.

- Select suitable tooling.
- Consider the properties and thickness of the material.
- Carry out trial bending where necessary.

**2.5.9 Advantages of Bending Machines**

- Produce accurate bends.
- Reduce manual effort.
- Increase production speed.
- Produce uniform components.
- Allow production of different shapes.
- Reduce the need for welding in some fabrication tasks.
- Improve the appearance of fabricated products.

**2.5.10 Safety Precautions When Using Bending Machines**

1. Wear appropriate protective clothing and safety footwear.
2. Keep fingers away from the punch and die.
3. Never place hands between moving machine parts.
4. Ensure the workpiece is properly positioned.
5. Do not exceed the machine's capacity.
6. Check the machine before operation.
7. Use suitable tooling.
8. Keep the work area clear.
9. Do not distract the operator.
10. Operate the machine only after receiving proper training.
11. Use the machine's safety controls.
12. Switch off and isolate the machine before maintenance.

**2.5.11 Maintenance of Bending Machines**

- Clean the worktable.
- Inspect the punch and die for wear.
- Lubricate moving parts as recommended.
- Inspect hydraulic systems for leaks.
- Check electrical connections.
- Inspect safety devices.
- Ensure the back gauge is correctly adjusted.
- Check the machine frame for damage.
- Store accessories properly.
- Arrange regular servicing.

## 3.0 COMPARISON OF THE FIVE MACHINE TOOLS

| Machine tool | Main operation | Material or workpiece |
|---|---|---|
| Sawing machine | Cutting using toothed blades | Bars, pipes and metal sections |
| Drilling machine | Producing circular holes | Metal plates and components |
| Grinding machine | Abrading and finishing | Metal surfaces and tools |
| Guillotine machine | Shearing sheet metal | Metal sheets |
| Bending machine | Changing metal shape | Sheets, plates and sections |

### 3.1 Differences Between Sawing and Guillotine Machines

| Sawing machine | Guillotine machine |
|---|---|
| Uses a toothed blade. | Uses two shearing blades. |
| Can cut bars, pipes and sections. | Mainly cuts sheet metal. |
| Removes material along the cutting line. | Separates metal through shearing action. |
| Suitable for cutting solid sections. | Suitable for straight sheet-metal cuts. |
| Uses reciprocating or continuous blade movement. | Uses relative movement of upper and lower blades. |

### 3.2 Differences Between Grinding and Drilling Machines

| Grinding machine | Drilling machine |
|---|---|
| Uses an abrasive wheel. | Uses a rotating drill bit. |
| Removes small amounts of material. | Produces circular holes. |
| Mainly used for finishing and sharpening. | Mainly used for hole production. |
| Produces smooth surfaces. | Produces holes of required diameters. |
| May generate sparks and abrasive dust. | Produces metal swarf. |

## 4.0 SELECTION OF MACHINE TOOLS FOR DIFFERENT TASKS

The choice of a machine tool depends on the operation to be performed.

### 4.1 Factors Determining the Selection of a Machine Tool

**1. Nature of the operation**

- The machine must be suitable for the intended task.
- For example, a drilling machine is selected when circular holes are required.

**2. Type of material**

- Different metals have different properties.
- The machine must be suitable for the material being processed.

**3. Thickness of material**

- The machine must have sufficient capacity to handle the material thickness.
- A guillotine must not be used beyond its rated cutting capacity.

**4. Size of the workpiece**

- Large workpieces may require larger machines.
- Small components can be handled using bench-mounted machines.

**5. Accuracy required**

- Some operations require greater dimensional accuracy.
- Surface grinding may be selected where a high-quality flat surface is needed.

**6. Quantity of production**

- Powered machines are suitable for repetitive production.
- Manual machines may be sufficient for small quantities.

**7. Quality of surface finish**

- Grinding is suitable when a smooth and accurate surface is required.

**8. Availability of power**

- Some machines require electricity, while manual machines use human effort.

**9. Cost of operation**

- Consider purchase costs, electricity, maintenance and tooling.

**10. Safety**

- The selected machine should be suitable for the available workshop conditions and operator competence.

### 4.2 Selection of Machine Tools for Common Workshop Tasks

| Workshop task | Appropriate machine |
|---|---|
| Cutting a steel rod into pieces | Sawing machine |
| Producing a hole in a metal plate | Drilling machine |
| Sharpening a metal chisel | Grinding machine |
| Cutting a rectangular sheet-metal piece | Guillotine machine |
| Folding a sheet-metal edge | Bending machine |
| Producing a smooth flat surface | Surface grinding machine |
| Producing a cylindrical tank section | Roll bending machine |

| | |
|---|---|
| Cutting a metal pipe | Bandsaw machine |

## 5.0 SAFE USE OF MACHINE TOOLS IN A METAL WORKSHOP

Machine tools can cause serious injuries when used incorrectly. Every learner must understand and follow workshop safety procedures.








### 5.1 Meaning of Machine Tool Safety

Machine tool safety refers to the rules, precautions and procedures followed to prevent accidents, injuries and damage when operating machines in a workshop.

### 5.2 Personal Protective Equipment (PPE)

PPE refers to protective clothing and equipment worn to minimise exposure to workplace hazards.

Examples include:

**1. Safety goggles**

- Protect the eyes from metal particles and sparks.

**2. Face shield**

- Provides additional protection to the face during suitable grinding and cutting operations.

**3. Safety boots**

- Protect the feet from falling metal objects and sharp materials.

**4. Hearing protection**

- Reduces exposure to excessive machine noise.

**5. Protective apron**

- Protects the body and clothing from dirt and suitable workshop hazards.

**6. Suitable work clothing**

- Should fit properly and should not have loose parts that can become trapped in moving machinery.

**Important glove safety:** Gloves may be suitable for handling sharp metal when a machine is switched off, but they must not be worn near rotating spindles, drills or other machinery where they could become entangled.

**5.3 General Workshop Safety Rules**

1. Enter the workshop only with permission.
2. Follow instructions given by the teacher or workshop supervisor.
3. Operate machines only after receiving proper training.
4. Inspect machines before use.
5. Wear appropriate PPE.
6. Keep the workshop clean and organised.
7. Do not operate faulty machines.
8. Avoid playing or running in the workshop.
9. Keep hands away from moving parts.
10. Use machine guards correctly.
11. Do not distract people operating machines.
12. Know the location of emergency stops.
13. Switch off machines after use.
14. Report all accidents and near misses.
15. Never attempt unauthorised repairs.

**5.4 Common Hazards Associated with Machine Tools**

| Hazard | Possible consequence | Preventive measure |
|---|---|---|
| Rotating parts | Entanglement | Avoid loose clothing and jewellery |
| Flying metal particles | Eye injuries | Wear safety goggles |
| Sharp metal edges | Cuts | Handle materials carefully |
| Excessive noise | Hearing damage | Use hearing protection |
| Electrical faults | Electric shock | Inspect electrical systems |
| Grinding sparks | Burns or fire | Remove flammable materials |
| Moving blades | Cuts and amputations | Use guards and safe operating procedures |
| Heavy workpieces | Foot injuries | Use suitable lifting methods and safety boots |

### 5.5 Emergency Procedures in a Metal Workshop

In case of an emergency:

1. Stop the machine using the emergency stop if it is safe to do so.
2. Isolate the power supply where appropriate.
3. Inform the teacher or workshop supervisor immediately.
4. Do not attempt to rescue someone trapped in moving machinery without first making the situation safe.
5. Give first aid only within your training.
6. Call for emergency assistance when necessary.
7. Report the incident.
8. Do not restart the machine until it has been inspected and authorised for use.

## 6.0 CARE AND MAINTENANCE OF MACHINE TOOLS

### 6.1 Meaning of Machine Maintenance

**Machine maintenance** refers to the activities carried out to keep a machine in good working condition, prevent breakdowns and extend its useful life.

Maintenance is important because poorly maintained machines may produce inaccurate work, waste materials and cause accidents.

### 6.2 Types of Machine Maintenance

#### A. Routine Maintenance

This refers to regular care carried out before or after using a machine.

Examples:

- Cleaning the machine.
- Removing metal chips.
- Checking machine guards.
- Inspecting electrical cables.
- Checking the condition of cutting tools.

#### B. Preventive Maintenance

This is maintenance performed at planned intervals to prevent machine failure.

Examples:

- Scheduled lubrication.
- Replacing worn belts.
- Checking machine alignment.
- Inspecting bearings.
- Servicing hydraulic systems.

#### C. Corrective Maintenance

This involves repairing or replacing defective machine components after a fault has occurred.

Examples:

- Replacing a damaged motor.
- Repairing a faulty switch.
- Replacing worn bearings.
- Repairing a leaking hydraulic hose.

**D. Predictive Maintenance**

This involves monitoring the condition of a machine to identify signs of possible failure before a breakdown occurs.

Examples:

- Monitoring unusual vibrations.
- Checking operating temperatures.
- Listening for abnormal sounds.
- Monitoring machine performance.

**6.3 General Maintenance Procedures for Machine Tools**

1. Switch off the machine after use.
2. Isolate the power supply before maintenance.
3. Clean the machine using appropriate materials.
4. Remove metal chips and dust.
5. Lubricate moving parts according to instructions.
6. Inspect cutting tools and accessories.
7. Tighten loose fasteners where appropriate.
8. Check machine guards.
9. Inspect electrical connections.
10. Report damaged components.
11. Keep a maintenance record.
12. Arrange professional servicing.

**6.4 Importance of Maintaining Machine Tools**

1. **Improves safety:** Well-maintained machines are less likely to develop dangerous faults.
2. **Extends machine lifespan:** Regular maintenance reduces premature wear.
3. **Improves accuracy:** Properly maintained machines produce components with reliable dimensions.
4. **Reduces breakdowns:** Preventive maintenance helps identify faults early.
5. **Reduces operating costs:** It minimises expensive emergency repairs.
6. **Improves productivity:** Machines remain available for production.
7. **Improves product quality:** Well-maintained machines produce consistent results.
8. **Reduces material wastage:** Faulty machines may damage workpieces.
9. **Promotes responsible resource use:** Proper care reduces unnecessary replacement of equipment.

### 6.5 Machine Maintenance Checklist

| Activity | Sawing | Drilling | Grinding | Guillotine | Bending |
|---|---|---|---|---|---|
| Clean machine | ✓ | ✓ | ✓ | ✓ | ✓ |
| Inspect cutting tools | ✓ | ✓ | ✓ | ✓ | ✓ |
| Lubricate moving parts | ✓ | ✓ | ✓ | ✓ | ✓ |
| Inspect electrical system | ✓ | ✓ | ✓ | ✓ | ✓ |
| Check guards | ✓ | ✓ | ✓ | ✓ | ✓ |
| Inspect moving components | ✓ | ✓ | ✓ | ✓ | ✓ |
| Check hydraulic system where fitted | – | – | – | ✓ | ✓ |

## 7.0 APPLICATION OF MACHINE TOOLS IN EVERYDAY LIFE

Machine tools play an important role in producing items used in homes, schools, farms, industries and other workplaces.







### 7.1 Application in Construction

Machine tools are used to manufacture:

- Metal doors.
- Window frames.
- Roofing components.
- Steel brackets.
- Structural metal supports.
- Staircase railings.
- Metal gates.

### 7.2 Application in Agriculture

Machine tools support the production and repair of:

- Plough components.
- Wheelbarrows.
- Farm trailers.
- Irrigation equipment.
- Animal-feed equipment.
- Farm machinery parts.
- Storage tanks.

### 7.3 Application in Transport

They are used to manufacture and repair:

- Vehicle brackets.
- Metal frames.
- Exhaust components.
- Trailer parts.
- Motorcycle components.
- Bicycle frames.

### 7.4 Application in Education

Metal workshops use machine tools to manufacture:

- School desks.
- Laboratory stands.
- Metal shelves.
- Equipment supports.
- Workshop tools.
- School furniture.

### 7.5 Application in Domestic Activities

Machine tools help manufacture:

- Cooking stands.
- Metal beds.
- Metal cabinets.
- Tables.
- Chairs.
- Water tanks.
- Security grills.

### 7.6 Application in Kenyan Industries

In Kenya, machine tools support activities in:

- Jua Kali metal fabrication workshops.
- Vehicle repair workshops.
- Construction companies.
- Agricultural machinery workshops.
- Manufacturing industries.
- Engineering and technical training institutions.

**Example:** A Jua Kali artisan in Kilgoris can use a sawing machine to cut metal sections, a drilling machine to make bolt holes, a grinding machine to smooth sharp edges, and a bending machine to form brackets when fabricating a metal gate.

## 8.0 PRACTICAL APPLICATION: FABRICATING A SIMPLE METAL BRACKET



A metal bracket is a component used to support or connect different structures.

### 8.1 Materials Required

- Mild steel flat bar or suitable sheet metal.
- Appropriate fasteners.
- Marking materials.

**8.2 Tools and Machine Tools Required**

- Steel rule.
- Scriber.
- Try square.
- Centre punch.
- Hammer.
- Sawing machine.
- Drilling machine.
- Bending machine.
- Grinding machine.
- Machine vice.
- Appropriate PPE.

**8.3 Procedure**

1. Study the bracket drawing and identify the required dimensions.
2. Select suitable mild steel material.
3. Measure and mark the required length.
4. Cut the metal using an appropriate sawing machine.
5. Mark the drilling positions.
6. Centre-punch the drilling positions.
7. Secure the workpiece in a machine vice.
8. Drill the required holes.
9. Remove burrs and sharp edges using suitable finishing methods.
10. Position the metal on the bending machine.
11. Bend it to the required angle.
12. Check the dimensions and angle.
13. Inspect the finished bracket for defects.
14. Clean the work area and maintain the machines.

**8.4 Quality Checks**

The finished bracket should:

- Have the correct dimensions.
- Have properly positioned holes.
- Have the required bending angle.
- Be free from dangerous sharp edges.
- Have a satisfactory surface finish.
- Be free from cracks and major defects.

## 9.0 ENVIRONMENTAL CONSERVATION IN MACHINE TOOL OPERATIONS

Metalworking activities can affect the environment if waste materials, oils and other workshop substances are not properly managed.

### 9.1 Environmental Concerns

1. Accumulation of metal scrap.
2. Disposal of used lubricants.
3. Excessive noise.
4. Electricity consumption.
5. Air pollution from dust and fumes.
6. Waste of metal materials.
7. Contamination from hydraulic fluids.

### 9.2 Ways of Promoting Environmental Conservation

1. Collect and recycle metal offcuts.
2. Dispose of used oil through approved waste-management arrangements.
3. Switch off machines when not in use.
4. Use materials efficiently.
5. Maintain machines to reduce unnecessary energy consumption.
6. Use suitable dust extraction systems.
7. Control excessive noise where possible.
8. Avoid spilling lubricants and hydraulic fluids.
9. Keep the workshop clean.
10. Follow environmental regulations.

## 10.0 KEY TERMS AND DEFINITIONS

| Term | Meaning |
|---|---|
| Machine tool | Powered equipment used to cut, shape or finish materials. |
| Sawing | Cutting metal using a toothed blade. |
| Drilling | Producing circular holes using a rotating drill bit. |
| Grinding | Removing material using an abrasive wheel. |
| Shearing | Separating material using opposing cutting forces. |
| Guillotine | A machine used to shear sheet metal. |
| Bending | Changing the shape of metal by applying force. |
| Drill bit | A cutting tool used to produce holes. |
| Spindle | A rotating component that holds or drives a cutting tool. |
| Grinding wheel | A rotating abrasive tool used for grinding. |
| Workpiece | The material being processed. |
| Back gauge | A positioning device used to control the dimensions of cut or formed material. |
| Punch | A tool used to apply force to metal in a press brake. |
| Die | A tool that supports or shapes metal during forming. |
| Springback | Partial recovery of metal towards its original shape after bending. |
| Maintenance | Activities performed to keep machines in good working condition. |
| Lubrication | Application of a suitable substance to reduce friction between moving parts. |
| PPE | Personal protective equipment. |

| | |
|---|---|
| Swarf | Small pieces or particles of material produced during machining. |
| Deburring | Removing unwanted sharp edges or raised material from a workpiece. |

**REVISION QUESTIONS**

Section A – 30 Marks

**MULTIPLE-CHOICE QUESTIONS**

*Choose the correct answer from the alternatives A, B, C and D.*

**1.** Which of the following best describes a machine tool?

A. A manually operated measuring instrument.

B. A powered device used to cut, shape or finish materials.

C. A storage facility for workshop materials.

D. A protective device used by artisans.

**2.** Which machine tool is mainly used to produce circular holes in metal?

A. Grinding machine.

B. Guillotine machine.

C. Drilling machine.

D. Bending machine.

**3.** The main cutting component of a power hacksaw is the:

A. Grinding wheel.

B. Toothed blade.

C. Drill bit.

D. Punch.

**4.** Which machine uses a continuous toothed blade running around wheels?

A. Bandsaw machine.

B. Guillotine machine.

C. Surface grinder.

D. Press brake.

**5.** The main purpose of a machine vice on a drilling machine is to:

A. Increase spindle speed.

B. Cool the drill bit.

C. Hold the workpiece firmly.

D. Sharpen the drill bit.

**6.** Which component of a drilling machine holds the drill bit?

A. Column.

B. Chuck.

C. Base.

D. Worktable.

**7.** Which machine is most suitable for sharpening a metal chisel?

A. Guillotine machine.

B. Drilling machine.

C. Grinding machine.

D. Bending machine.

**8.** The abrasive material commonly used in grinding wheels for steel is:

A. Aluminium oxide.

B. Rubber.

C. Plastic.

D. Wood.

**9.** Which component of a bench grinder protects the operator by covering part of the grinding wheel?

A. Worktable.

B. Wheel guard.

C. Spindle handle.

D. Machine vice.

**10.** A guillotine machine separates sheet metal through:

A. Drilling action.

B. Grinding action.

C. Shearing action.

D. Rolling action.

**11.** The main function of a back gauge on a guillotine machine is to:

A. Sharpen the blades.

B. Position the sheet for accurate cutting.

C. Cool the machine.

D. Increase motor speed.

**12.** Which type of guillotine machine uses hydraulic pressure to operate its blade?

A. Manual guillotine.

B. Hydraulic guillotine.

C. Bench guillotine.

D. Hand hacksaw.

**13.** Which machine is suitable for folding sheet metal into a required angle?

A. Bending machine.

B. Drilling machine.

C. Grinding machine.

D. Sawing machine.

**14.** In a press brake, the component that applies force to the metal sheet is the:

A. Back gauge.

B. Punch.

C. Base.

D. Motor cover.

**15.** The tendency of metal to partially return to its original shape after bending is called:

A. Shearing.

B. Drilling.

C. Springback.

D. Grinding.

**16.** Which of the following factors should be considered when selecting a machine tool?

A. Colour of the machine.

B. Operator's favourite machine.

C. Nature of the operation.

D. Location of the machine's manufacturer only.

**17.** Which machine is most suitable for cutting a long steel rod into shorter lengths?

A. Drilling machine.

B. Sawing machine.

C. Grinding machine.

D. Bending machine.

**18.** What should be done before changing a drill bit?

A. Increase the spindle speed.

B. Hold the rotating chuck.

C. Switch off and isolate the machine.

D. Apply more pressure to the feed handle.

**19.** Which of the following is a suitable way of removing metal swarf?

A. Using bare hands.

B. Using a suitable brush.

C. Blowing it towards another learner.

D. Wiping it with bare fingers.

**20.** Why should a grinding wheel be inspected before use?

A. To increase its colour.

B. To check for cracks and damage.

C. To make it heavier.

D. To reduce its diameter.

**21.** Which of the following is a routine maintenance activity?

A. Replacing the entire machine.

B. Cleaning the machine after use.

C. Constructing a new workshop.

D. Purchasing additional equipment.

**22.** Preventive maintenance is mainly intended to:

A. Increase machine breakdowns.

B. Prevent unexpected machine failure.

C. Eliminate the need for operators.

D. Reduce the size of the workshop.

**23.** Which of the following is an example of corrective maintenance?

A. Cleaning the machine daily.

B. Inspecting the machine before use.

C. Replacing a damaged motor.

D. Recording machine operating hours.

**24.** Which machine tool is most appropriate for producing a flat and smooth metal surface?

A. Surface grinding machine.

B. Manual guillotine.

C. Power hacksaw.

D. Radial drilling machine.

**25.** Which of the following is a possible hazard when using a grinding machine?

A. Excessive illumination.

B. Flying abrasive particles.

C. Reduced material thickness only.

D. Lack of measuring instruments.

**26.** Why should loose clothing be avoided when operating rotating machinery?

A. It increases electricity consumption.

B. It may become entangled in moving parts.

C. It reduces machine accuracy.

D. It makes the machine heavier.

**27.** Which machine is most appropriate for producing curved cylindrical sheet-metal components?

A. Roll bending machine.

B. Bench drilling machine.

C. Power hacksaw.

D. Bench grinder.

**28.** Which of the following materials can be produced using machine tools in a metal workshop?

A. Metal gates.

B. Plastic paper bags.

C. Wooden books.

D. Cotton clothes.

**29.** One environmental benefit of recycling metal offcuts is that it:

A. Increases metal wastage.

B. Reduces the amount of metal waste.

C. Increases machine breakdowns.

D. Increases noise pollution.

**30.** What should an operator do when a machine develops unusual vibration?

A. Increase its operating speed.

B. Continue working without interruption.

C. Stop the machine safely and report the fault.

D. Remove the machine guard.

**SECTION B: STRUCTURED QUESTIONS**

50 Marks

*Answer all questions. Each question carries the indicated marks.*

**QUESTION 1: INTRODUCTION TO MACHINE TOOLS (8 MARKS)**

a) Define the term machine tool. (2 marks)

b) State four examples of machine tools used in a metalwork workshop. (4 marks)

c) Give two reasons why machine tools are important in modern metalworking. (2 marks)

**QUESTION 2: SAWING AND DRILLING MACHINES (8 MARKS)**

a) State two uses of a sawing machine in a metalwork workshop. (2 marks)

b) Identify three main parts of a drilling machine. (3 marks)

c) Explain three safety precautions that should be observed when operating a drilling machine. (3 marks)

**QUESTION 3: GRINDING MACHINES (8 MARKS)**

a) Define grinding. (2 marks)

b) State three uses of a grinding machine in a metalwork workshop. (3 marks)

c) Explain three maintenance practices for a bench grinding machine. (3 marks)

**QUESTION 4: GUILLOTINE MACHINES (8 MARKS)**

a) Explain how a guillotine machine cuts sheet metal. (3 marks)

b) Name three main parts of a guillotine machine. (3 marks)

c) State two safety precautions to observe when using a guillotine machine. (2 marks)

**QUESTION 5: BENDING MACHINES (9 MARKS)**

a) Define the term bending as used in metalwork. (2 marks)

b) Identify three types of bending machines. (3 marks)

c) Explain the meaning of springback in metal bending. (2 marks)

d) State two factors that influence the bending of metal. (2 marks)

**QUESTION 6: MACHINE SELECTION, SAFETY AND MAINTENANCE (9 MARKS)**

a) State three factors to consider when selecting a machine tool for a particular task. (3 marks)

b) Explain three general safety precautions to observe when operating machine tools. (3 marks)

c) State three benefits of maintaining machine tools regularly. (3 marks)

**ANSWERS AND MARKING SCHEME**

**SECTION A: MULTIPLE-CHOICE ANSWERS**

| Question | Answer | Question | Answer |
|---|---|---|---|
| 1 | B | 16 | C |
| 2 | C | 17 | B |
| 3 | B | 18 | C |
| 4 | A | 19 | B |
| 5 | C | 20 | B |
| 6 | B | 21 | B |
| 7 | C | 22 | B |
| 8 | A | 23 | C |
| 9 | B | 24 | A |
| 10 | C | 25 | B |
| 11 | B | 26 | B |
| 12 | B | 27 | A |
| 13 | A | 28 | A |
| 14 | B | 29 | B |
| 15 | C | 30 | C |

**SECTION B: SUGGESTED MARKING SCHEME**

**QUESTION 1 (8 MARKS)**

a) A machine tool is a powered mechanical device used to cut, shape, drill, form or finish materials into required dimensions and shapes. (2 marks)

b) Any four:

- Sawing machine. (1)
- Drilling machine. (1)
- Grinding machine. (1)
- Guillotine machine. (1)
- Bending machine. (1)

Award any four. (4 marks)

c) Any two:

- Increases production speed.
- Improves accuracy.
- Reduces physical effort.
- Improves product quality.
- Reduces material wastage.
- Increases production capacity.

(2 marks)

**QUESTION 2 (8 MARKS)**

a) Any two:

- Cutting metal bars.
- Cutting pipes.

- Cutting angle irons.
- Preparing metal sections for fabrication.
- Cutting steel rods to required lengths.

(2 marks)

b) Any three:

- Base.
- Column.
- Worktable.
- Drill head.
- Electric motor.
- Spindle.
- Chuck.
- Feed handle.
- Drill bit.

(3 marks)

c) Any three explained:

- Secure the workpiece firmly to prevent it from rotating during drilling.
- Wear safety goggles to protect the eyes from flying particles.
- Remove the chuck key before starting the machine to prevent it from being thrown out.
- Avoid loose clothing to prevent entanglement.
- Switch off the machine before changing drill bits.
- Remove swarf using a brush to prevent cuts.

(3 marks)

**QUESTION 3 (8 MARKS)**

a) Grinding is the process of removing small amounts of material from a workpiece using a rotating abrasive wheel to achieve a required shape, dimension or surface finish. (2 marks)

b) Any three:

- Sharpening cutting tools.
- Removing burrs.
- Smoothing metal surfaces.
- Removing excess weld metal.
- Finishing machined surfaces.
- Removing unwanted material.

(3 marks)

c) Any three explained:

- Clean the machine after use to remove accumulated dust and particles.

- Inspect the grinding wheel to identify cracks or damage.
- Replace damaged wheels to prevent accidents.
- Check wheel guards to ensure they are correctly fitted.
- Inspect electrical cables to identify defects.
- Check the tool rest to ensure correct adjustment.
- Lubricate appropriate moving components.

(3 marks)

**QUESTION 4 (8 MARKS)**

a) A guillotine machine cuts sheet metal through shearing action. The sheet is positioned between the upper and lower blades. The clamping system holds it firmly, and the upper blade moves downwards past the lower blade, separating the material along the cutting line. (3 marks)

b) Any three:

- Frame.
- Upper blade.
- Lower blade.
- Worktable.
- Back gauge.
- Clamping system.
- Operating lever.
- Motor.
- Hydraulic system.
- Safety guards.

(3 marks)

c) Any two:

- Keep hands away from the cutting blades.
- Ensure machine guards are in position.
- Do not exceed the rated cutting capacity.
- Position the sheet correctly.
- Isolate the machine before maintenance.
- Do not remove offcuts while the blades are moving.

(2 marks)

**QUESTION 5 (9 MARKS)**

a) Bending is the process of changing the shape of a metal workpiece by applying force along a predetermined line without intentionally removing material. (2 marks)

b) Any three:

- Manual bending machine.

- Mechanical bending machine.
- Hydraulic press brake.
- Roll bending machine.

(3 marks)

c) Springback is the tendency of metal to recover partially towards its original shape after the bending force is removed. (2 marks)

d) Any two:

- Type of metal.
- Thickness of material.
- Bending angle.
- Bend radius.
- Ductility of the material.
- Grain direction.
- Type of tooling.
- Amount of bending force.

(2 marks)

**QUESTION 6 (9 MARKS)**

a) Any three:

- Nature of the operation.
- Type of material.
- Thickness of material.
- Size of workpiece.
- Accuracy required.
- Production quantity.
- Available power.
- Machine capacity.
- Cost of operation.
- Safety requirements.

(3 marks)

b) Any three explained:

- Wear suitable PPE to protect the body from workshop hazards.
- Inspect machines before use to identify faults.
- Use machine guards to prevent contact with moving parts.
- Secure workpieces firmly to prevent movement.
- Avoid loose clothing near rotating parts.
- Operate machines only after receiving proper training.

- Switch off machines before making adjustments.
- Keep the workshop clean to prevent accidents.

(3 marks)

c) Any three:

- Extends machine lifespan.
- Improves machine accuracy.
- Reduces breakdowns.
- Improves operator safety.
- Reduces repair costs.
- Improves productivity.
- Reduces material wastage.
- Maintains product quality.

(3 marks)

**COMPETENCY-BASED PRACTICAL LEARNING ACTIVITIES**

The following activities can be used by teachers to assess learners' practical competencies.

**Activity 1: Identification of Machine Tools**

**Task:** Visit a metalwork workshop and identify five machine tools.

Learners should:

1. Observe the machines.
2. Record their names.
3. Identify their main parts.
4. State their uses.
5. Identify safety features.

**Activity 2: Practical Drilling**

**Task:** Under qualified supervision, produce a hole in a suitable mild steel workpiece using a drilling machine.

Learners should demonstrate:

- Correct selection of drill bit.
- Accurate marking.
- Secure clamping.
- Correct machine settings.
- Safe drilling.
- Proper finishing.
- Machine care.

**Activity 3: Practical Metal Bending**

**Task:** Bend a suitable sheet-metal sample to a specified angle using a bending machine.

Learners should demonstrate:

- Accurate measurement.
- Correct positioning.
- Appropriate machine selection.
- Safe operation.
- Accurate bending.
- Inspection of the finished workpiece.

**Activity 4: Machine Maintenance**

**Task:** Prepare a maintenance checklist for a machine tool.

Learners should:

- Inspect the machine.
- Identify visible defects.
- Clean appropriate surfaces.

- Identify lubrication points.
- Record maintenance observations.
- Report defects requiring technical attention.

**Activity 5: Community-Based Learning**

**Task:** Visit a local Jua Kali workshop or metal fabrication enterprise.

Learners should investigate:

1. Types of machine tools available.
2. Products manufactured.
3. Materials commonly used.
4. Safety procedures followed.
5. Maintenance practices.
6. Challenges faced by artisans.
7. Opportunities for employment and entrepreneurship.

**STRAND 2.0: TOOLS AND MATERIALS IN METALWORK**

**SUB-STRAND 2.3: ALLOY STEELS**

**1.0 Introduction to Alloy Steels**

Metalworking industries require materials with different properties depending on the products being manufactured. Some products require metals that are extremely hard, while others require metals that are strong, tough, resistant to corrosion or capable of withstanding high temperatures.

Ordinary carbon steel is useful in many metalworking applications. However, it may not possess all the properties required for specialised industrial applications. To improve its properties, manufacturers add controlled quantities of other elements to steel during production.

The resulting materials are known as **alloy steels**.

Alloy steels are widely used in manufacturing industries, motor vehicle production, construction, agricultural machinery, engineering workshops, toolmaking and the manufacture of industrial equipment.

**1.1 Definition of Alloy Steel**

**Alloy steel** is a type of steel made by adding one or more alloying elements, apart from carbon, to iron in controlled proportions to improve its mechanical, physical and chemical properties.

The common alloying elements include:

1. Chromium.
2. Nickel.
3. Molybdenum.
4. Manganese.
5. Tungsten.
6. Cobalt.
7. Vanadium.
8. Silicon.

The quantity and combination of alloying elements determine the properties and applications of the resulting steel.

**Examples of alloy steels include:**

- Stainless steel.
- High-speed steel.
- Silver steel.
- High-tensile steel.
- Chromium steel.
- Nickel steel.
- Manganese steel.
- Tungsten steel.







**1.2 Importance of Alloy Steels in Metalworking**

Alloy steels are important in metalworking because they:

1. **Improve strength:** They can withstand heavy loads without easily breaking or permanently deforming.

2. **Increase hardness:** Some alloy steels resist scratching, indentation and surface wear.
3. **Improve toughness:** They can withstand sudden impacts without fracturing easily.
4. **Increase corrosion resistance:** Certain alloy steels resist rusting and chemical attack.
5. **Improve heat resistance:** Some retain their hardness and strength at high temperatures.
6. **Improve wear resistance:** They are suitable for components exposed to friction and continuous movement.
7. **Improve machinability:** Certain alloy compositions make steel easier to machine using suitable cutting tools and conditions.
8. **Improve service life:** Components made from appropriate alloy steels can last longer under demanding working conditions.

**Examples in the Kenyan context:**

- Stainless steel is used in food-processing equipment and hospital fittings.
- High-speed steel is used in cutting tools in engineering workshops.
- High-tensile steel is used in structural and engineering applications.
- Silver steel is used in the manufacture of precision tools and shafts.

**2.0 Classification of Alloy Steels**

Alloy steels are classified mainly according to the total percentage of alloying elements present in their composition.

The two main classes are:

1. Low-alloy steels.
2. High-alloy steels.

**2.1 Low-Alloy Steels**

**Definition:** Low-alloy steel is steel containing relatively small quantities of alloying elements, generally up to about 5% by mass in commonly used engineering classifications.

The alloying elements are added to improve the strength, toughness, hardenability and wear resistance of ordinary steel.

**Characteristics of low-alloy steels**

1. They contain a relatively small proportion of alloying elements.
2. They generally retain many characteristics of ordinary carbon steel.
3. They have improved strength compared with similar unalloyed steels.
4. They can have improved toughness and fatigue resistance.
5. Some grades can be heat-treated to achieve desired mechanical properties.
6. They are often more economical than highly alloyed steels.
7. Their corrosion resistance varies depending on their composition.

**Examples of low-alloy steels**

- Low-alloy chromium steel.
- Nickel-chromium steel.
- Chromium-molybdenum steel.
- Manganese steel.

- High-strength low-alloy (HSLA) steel.



**Applications of low-alloy steels**

- Manufacture of vehicle axles.
- Production of gears and shafts.
- Construction of bridges and structural components.
- Manufacture of agricultural machinery.
- Production of pressure vessels.
- Manufacture of heavy engineering components.
- Production of machine frames and transmission parts.

**2.2 High-Alloy Steels**

**Definition:** High-alloy steel is steel containing a relatively high proportion of alloying elements, commonly more than 5% by mass.

The high proportion of alloying elements gives the steel specialised properties such as high corrosion resistance, heat resistance and exceptional wear resistance.

**Characteristics of high-alloy steels**

1. They contain relatively large quantities of alloying elements.
2. They may have excellent resistance to corrosion.
3. Some grades withstand high working temperatures.
4. They can possess high hardness and wear resistance.
5. They are used in specialised engineering applications.
6. Some grades retain their mechanical properties under extreme working conditions.
7. They are generally more expensive than low-alloy steels.

**Examples of high-alloy steels**

- Stainless steel.
- High-speed steel.
- High-chromium steel.

- Certain heat-resistant alloy steels.



**Applications of high-alloy steels**

- Manufacture of chemical-processing equipment.
- Production of surgical and medical instruments.
- Manufacture of food-processing machinery.
- Production of cutting tools.
- Manufacture of furnace components.
- Production of corrosion-resistant pipes and tanks.
- Manufacture of industrial blades and specialised machine parts.

**2.3 Differences Between Low-Alloy and High-Alloy Steels**

| Low-alloy steels | High-alloy steels |
|---|---|
| Contain relatively small amounts of alloying elements. | Contain relatively large amounts of alloying elements. |
| Generally have up to about 5% alloying elements. | Generally contain more than about 5% alloying elements. |
| Often less expensive. | Often more expensive. |
| Commonly used in structural and engineering components. | Commonly used in specialised industrial applications. |
| Corrosion resistance varies with composition. | Some grades have excellent corrosion resistance. |
| Examples include chromium-molybdenum steel. | Examples include stainless steel and high-speed steel. |

*Note:* These percentage limits are useful general engineering guidelines. Exact classification conventions may vary between standards and steel specifications.

**3.0 Types of Alloy Steels Used in Metalworking Industries**

There are several types of alloy steels used in metalworking depending on the required properties and intended applications.

The main types covered in this sub-strand are:

1. Stainless steel.
2. High-speed steel.
3. Silver steel.
4. High-tensile steel.

**3.1 Stainless Steel**







**Definition:** Stainless steel is an alloy steel containing at least approximately 10.5% chromium by mass, which gives it improved resistance to corrosion.

Chromium reacts with oxygen in the atmosphere to form a very thin protective oxide layer on the surface of the steel. This layer prevents further corrosion under suitable conditions.

Nickel, molybdenum, carbon and other elements may also be added to improve particular properties.

**Composition of stainless steel**

The main constituents include:

- Iron – forms the main base metal.

- Chromium – improves corrosion resistance.
- Nickel – improves toughness, ductility and corrosion resistance in many grades.
- Molybdenum – improves resistance to pitting and crevice corrosion.
- Carbon – influences hardness and strength.

**Properties of stainless steel**

1. **Corrosion resistance:** It resists rusting and chemical attack better than ordinary carbon steel.
2. **Strength:** It can withstand considerable mechanical loads depending on its grade.
3. **Toughness:** Many grades can withstand impact without breaking easily.
4. **Ductility:** Some grades can be bent and formed into different shapes without cracking.
5. **Attractive appearance:** It has a clean, bright and smooth surface when properly finished.
6. **Hygienic properties:** Its smooth surface can be cleaned easily, making it suitable for food-processing equipment.
7. **Heat resistance:** Certain grades withstand elevated temperatures.
8. **Durability:** It can provide a long service life when correctly selected and maintained.
9. **Recyclability:** It can be recycled and used to manufacture new products.

**Types of stainless steel**

a) Austenitic stainless steel

- Contains chromium and usually nickel.
- Generally has excellent corrosion resistance.
- Is usually non-magnetic in the annealed condition.
- Has good ductility and formability.
- Is widely used in food-processing equipment, sinks and kitchen utensils.

Example: Grade 304 stainless steel.

b) Ferritic stainless steel

- Contains chromium as the main alloying element.
- Usually contains little or no nickel.
- Is generally magnetic.
- Has good resistance to corrosion in suitable environments.
- Is used in vehicle exhaust components and household appliances.

c) Martensitic stainless steel

- Contains chromium and relatively more carbon than many other stainless-steel grades.
- Can be hardened through heat treatment.
- Has good strength and wear resistance.
- Is used in blades, knives and engineering components.

d) Duplex stainless steel

- Has a mixed austenitic and ferritic structure.



- Has high strength.
- Has good resistance to stress corrosion cracking.
- Is used in chemical-processing equipment and marine applications.

**Applications of stainless steel**

1. Manufacture of kitchen sinks.
2. Production of cooking utensils.
3. Manufacture of surgical instruments.
4. Construction of food-processing equipment.
5. Manufacture of storage tanks.
6. Production of water pipes and fittings.
7. Manufacture of chemical-processing equipment.
8. Production of vehicle exhaust components.
9. Manufacture of handrails and architectural fittings.
10. Production of marine equipment.

**Advantages of stainless steel**

- Resists corrosion.
- Has an attractive appearance.
- Is easy to clean and maintain.
- Has good durability.
- Can be recycled.
- Is available in different grades for different industrial applications.

**Limitations of stainless steel**

- Some grades are expensive.
- Certain grades are difficult to machine.
- Some grades work-harden during forming.
- Special welding procedures may be required.
- It can still corrode under unsuitable environmental conditions.

**3.2 High-Speed Steel (HSS)**





**Definition:** High-speed steel is a special alloy tool steel designed to maintain its hardness and cutting ability even when exposed to the high temperatures generated during high-speed machining operations.

It is commonly used in the manufacture of cutting tools.

**Main alloying elements in high-speed steel**

1. Tungsten – improves hot hardness and wear resistance.
2. Molybdenum – improves hardness and high-temperature performance.
3. Chromium – improves hardenability and wear resistance.
4. Vanadium – improves hardness and resistance to abrasion.
5. Cobalt – improves hot hardness in certain grades.
6. Carbon – contributes to the formation of hard carbides and high hardness.

**Properties of high-speed steel**

1. **High hardness:** It can be hardened to resist deformation and wear.
2. **Hot hardness:** It retains much of its hardness at elevated cutting temperatures.
3. **Wear resistance:** It resists wearing away during cutting operations.
4. **Toughness:** It can withstand some shocks and vibrations during machining.
5. **Cutting ability:** It can cut many metals effectively.
6. **Heat-treatment response:** It can be hardened and tempered to achieve suitable working properties.
7. **Strength:** It can withstand cutting forces during machining.

**Types of high-speed steel**

a) Tungsten high-speed steel

- Contains tungsten as an important alloying element.
- Has good hot hardness.
- Resists wear during cutting.
- Used in drills, milling cutters and other cutting tools.

b) Molybdenum high-speed steel

- Uses molybdenum as a major alloying element.
- Has good toughness and cutting performance.
- Is commonly used in general-purpose cutting tools.
- Can be used in drill bits and milling cutters.

c) Cobalt high-speed steel

- Contains cobalt to improve hot hardness.
- Maintains cutting performance at relatively high temperatures.
- Is suitable for demanding cutting operations.
- Used in specialised drills and milling cutters.

**Applications of high-speed steel**

1. Twist drills.
2. Milling cutters.
3. Lathe cutting tools.
4. Reamers.
5. Taps and dies.
6. Broaches.
7. Gear-cutting tools.
8. Metal-cutting saw blades.

**Advantages of high-speed steel**

- Retains hardness at high cutting temperatures.
- Has good wear resistance.
- Can be resharpened.
- Is tougher than many cemented carbide cutting materials.
- Can be used for a wide range of machining operations.

**Limitations of high-speed steel**

- Generally wears faster than cemented carbide in many high-production cutting applications.
- Can lose hardness if overheated beyond its working limits.
- Requires correct heat treatment.
- May be expensive compared with ordinary carbon tool steel.

**3.3 Silver Steel**



**Definition:** Silver steel is a high-carbon tool steel supplied mainly in precision-ground round bars. It is commonly used for making small cutting tools, punches, drills and other precision engineering components.

It is called silver steel because of its bright, silvery appearance after grinding and polishing. It does not contain silver as an alloying element.

**Composition of silver steel**

Silver steel commonly contains:

- Iron – the main constituent.

- Carbon – provides hardness after heat treatment.
- Chromium – improves hardenability and wear resistance.
- Manganese – improves strength and hardenability.

The exact composition depends on the steel grade and manufacturer's specification.

**Properties of silver steel**

1. **High hardness:** It can be hardened to resist indentation and deformation.
2. **Good wear resistance:** It withstands friction and surface wear.
3. **Good machinability before hardening:** It can be shaped and machined in its supplied condition.
4. **Precision dimensions:** It is commonly supplied in accurately ground sizes.
5. **Good strength:** It can withstand mechanical forces in small engineering components.
6. **Heat-treatment capability:** It can be hardened and tempered to achieve desired properties.
7. **Good surface finish:** It is supplied with a smooth and bright surface.

**Applications of silver steel**

1. Manufacture of punches.
2. Production of small drills.
3. Manufacture of reamers.
4. Production of precision shafts.
5. Manufacture of dowel pins.
6. Production of gauges.
7. Manufacture of lathe tools.
8. Production of springs and small engineering components where the specified grade is suitable.

**Advantages of silver steel**

- Easy to machine before hardening.
- Can achieve high hardness.
- Has good wear resistance.
- Is supplied in precision-ground sizes.
- Is suitable for small precision engineering work.

**Limitations of silver steel**

- Can become brittle if excessively hardened.
- May require careful heat treatment.
- Is not suitable for every heavy-duty application.
- Its corrosion resistance is limited compared with stainless steel.

### 3.4 High-Tensile Steel







**Definition:** High-tensile steel is steel designed to have high tensile strength, enabling it to withstand large pulling forces before breaking.

It is produced by controlling its chemical composition and manufacturing processes, including the addition of alloying elements and suitable heat treatment or controlled rolling.

**Common alloying elements**

- Manganese.
- Chromium.
- Nickel.
- Molybdenum.

- Vanadium.
- Niobium.
- Titanium.

**Properties of high-tensile steel**

1. **High tensile strength:** It can withstand considerable pulling forces before failure.
2. **High yield strength:** It can support high loads before permanent deformation occurs.
3. **Good toughness:** Many grades can absorb energy during impact.
4. **Fatigue resistance:** Suitable grades can withstand repeated loading.
5. **Good strength-to-weight ratio:** Some grades provide high strength without requiring excessively thick sections.
6. **Weldability:** Some grades can be welded successfully using appropriate procedures.
7. **Durability:** It can withstand demanding working conditions when correctly selected.

**Applications of high-tensile steel**

1. Manufacture of bridges.
2. Construction of buildings.
3. Manufacture of vehicle chassis.
4. Production of heavy-duty bolts and fasteners.
5. Manufacture of cranes and lifting equipment.
6. Construction of storage tanks.
7. Production of railway components.
8. Manufacture of agricultural machinery.
9. Production of pressure vessels using suitable grades.
10. Manufacture of heavy engineering structures.

**Advantages of high-tensile steel**

- Supports heavy loads.
- Provides high strength.
- Can reduce the amount of material required in some structures.
- Has good fatigue resistance in suitable grades.
- Is useful in demanding engineering applications.

**Limitations of high-tensile steel**

- Some grades are difficult to weld.
- Special fabrication procedures may be required.
- Some grades are more expensive than ordinary carbon steel.
- Incorrect heat treatment can affect its mechanical properties.
- High strength does not automatically mean high toughness.

**4.0 Alloying Elements Used in the Production of Alloy Steels**

Alloying elements are additional chemical elements deliberately introduced into molten steel during manufacture to improve its properties.

Each alloying element has a particular effect on the performance of steel. The manufacturer selects the elements and their quantities according to the intended application.

**4.1 Chromium (Cr)**



**Definition:** Chromium is a metallic alloying element added to steel to improve corrosion resistance, hardness and wear resistance.

**Functions of chromium in steel**

1. Improves resistance to corrosion and rusting.
2. Increases hardness after suitable heat treatment.
3. Improves resistance to abrasion and wear.
4. Increases hardenability.
5. Improves oxidation resistance at elevated temperatures.
6. Helps stainless steel develop a protective chromium oxide layer.
7. Improves the durability of machine components.

**Applications of chromium-alloyed steel**

- Stainless steel kitchen equipment.
- Cutting tools.
- Bearings.
- Vehicle components.
- Industrial shafts.
- Corrosion-resistant pipes.

**4.2 Nickel (Ni)**



**Definition:** Nickel is a metallic alloying element added to steel to improve toughness, strength and corrosion resistance.

**Functions of nickel**

1. Improves toughness, particularly at low temperatures.
2. Improves resistance to corrosion.
3. Increases strength.
4. Improves ductility.
5. Improves the performance of steel under impact loading.
6. Helps stabilise the austenitic structure in stainless steel.
7. Improves the suitability of steel for demanding engineering applications.

**Applications**

- Stainless steel manufacture.
- Vehicle components.
- Pressure vessels.
- Marine engineering equipment.
- Industrial machinery.
- Structural engineering components.

**4.3 Molybdenum (Mo)**



**Definition:** Molybdenum is an alloying element used to improve the strength, hardenability, wear resistance and high-temperature performance of steel.

**Functions of molybdenum**

1. Improves high-temperature strength.
2. Increases hardenability.
3. Improves wear resistance.
4. Helps prevent softening during tempering.
5. Improves resistance to pitting corrosion in certain stainless steels.
6. Improves the performance of tool steels.
7. Increases the suitability of steel for heavy engineering work.

**Applications**

- High-speed cutting tools.
- Automotive components.
- Pressure vessels.
- Industrial machinery.
- Stainless steel equipment.
- High-temperature engineering components.

**4.4 Manganese (Mn)**



**Definition:** Manganese is an alloying element added to steel to improve strength, hardenability and toughness.

**Functions of manganese**

1. Increases the strength of steel.
2. Improves hardenability.
3. Combines with sulphur to reduce harmful effects associated with iron sulphide.
4. Improves wear resistance in certain steel grades.
5. Improves the performance of steel during heat treatment.
6. Contributes to toughness depending on the composition and processing.
7. Helps produce specialised wear-resistant manganese steels.

**Applications**

- Railway components.
- Heavy-duty machinery.
- Gears.
- Agricultural equipment.
- Construction machinery.
- High-wear industrial components.

**4.5 Tungsten (W)**




**Definition:** Tungsten is a hard metallic alloying element used mainly in tool steels to improve hot hardness, wear resistance and cutting performance.

**Functions of tungsten**

1. Improves hardness.
2. Increases resistance to wear.
3. Improves hot hardness.
4. Helps steel retain its cutting edge at elevated temperatures.
5. Forms hard carbides that resist abrasion.
6. Improves the performance of high-speed cutting tools.

**Applications**

- High-speed drills.
- Milling cutters.
- Lathe cutting tools.
- Industrial cutting blades.
- Specialised engineering tools.

**4.6 Cobalt (Co)**



**Definition:** Cobalt is a metallic alloying element added to certain tool steels to improve hot hardness and maintain cutting performance at elevated temperatures.

**Functions of cobalt**

1. Improves hot hardness.

2. Helps cutting tools retain their hardness at high temperatures.
3. Improves the performance of high-speed steel.
4. Increases the suitability of cutting tools for demanding machining operations.
5. Helps improve the performance of specialised heat-resistant alloys.

**Applications**

- High-speed cutting tools.
- Milling cutters.
- Specialised drills.
- High-temperature engineering materials.

**4.7 Vanadium (V)**



**Definition:** Vanadium is an alloying element used to improve the strength, hardness, wear resistance and grain structure of steel.

**Functions of vanadium**

1. Forms hard vanadium carbides.
2. Improves wear resistance.
3. Increases hardness.
4. Helps refine the grain structure of steel.
5. Improves strength.
6. Improves the performance of tool steels.
7. Contributes to improved fatigue resistance in suitable steel grades.

**Applications**

- High-speed steel.
- Cutting tools.
- Springs.
- Automotive components.
- High-strength structural steel.
- Industrial machine parts.

**4.8 Silicon (Si)**



**Definition:** Silicon is an alloying element used in steelmaking as a deoxidiser and to improve certain mechanical and electrical properties of steel.

**Functions of silicon**

1. Acts as a deoxidiser during steel production.
2. Improves strength.
3. Improves elastic properties in suitable grades.
4. Contributes to oxidation resistance in certain steels.
5. Improves magnetic properties in electrical steels.
6. Helps improve the performance of spring steels.

**Applications**

- Spring steel.
- Electrical steel.
- Transformer cores.
- Specialised engineering components.
- Heat-resistant steel applications.

**4.9 Summary of Alloying Elements and Their Functions**

| Alloying element | Main function | Common application |
|---|---|---|
| Chromium | Corrosion resistance and hardness | Stainless steel |
| Nickel | Toughness and corrosion resistance | Stainless steel |
| Molybdenum | High-temperature strength and hardenability | Tool steel |
| Manganese | Strength and hardenability | Heavy machinery |
| Tungsten | Hot hardness and wear resistance | High-speed tools |
| Cobalt | Hot hardness | Specialised cutting tools |
| Vanadium | Hardness and grain refinement | Tool and spring steels |
| Silicon | Deoxidation and elastic properties | Spring and electrical steel |

**5.0 Properties of Alloy Steels Used in Metalworking**

The properties of alloy steels determine their suitability for different engineering and manufacturing operations.

A metalworker must understand these properties before selecting steel for a particular task.

The main properties include:

1. Strength.

2. Hardness.
3. Ductility.
4. Toughness.
5. Corrosion resistance.
6. Machinability.

**5.1 Strength**

**Definition:** Strength is the ability of a material to withstand an applied force without failing.

Strength determines the amount of load a steel component can carry before it deforms or breaks.

**Types of strength**

a) Tensile strength

- Ability of steel to withstand pulling forces before breaking.
- Important in cables, structural members and fasteners.
- High-tensile steel is commonly selected where high tensile strength is required.

b) Compressive strength

- Ability of steel to withstand forces that attempt to squeeze or shorten it.
- Important in columns, supports and machine components.

c) Shear strength

- Ability of steel to resist forces acting parallel to a surface.
- Important in bolts, rivets, pins and fastening components.

**Factors affecting the strength of alloy steel**

1. Type and quantity of alloying elements.
2. Carbon content.
3. Heat treatment.
4. Grain structure.
5. Manufacturing method.
6. Working temperature.

**Applications where strength is important**

- Bridges.
- Building structures.
- Vehicle chassis.
- Machine frames.
- Heavy-duty bolts.
- Agricultural machinery.

**5.2 Hardness**

**Definition:** Hardness is the ability of a material to resist indentation, scratching, abrasion and local deformation.

Hardness is important when manufacturing cutting tools and components exposed to continuous friction.

**Characteristics of hard alloy steel**

1. Resists scratching.
2. Resists indentation.
3. Maintains a cutting edge.
4. Resists surface wear.
5. Can withstand repeated contact with other materials.

**Factors affecting hardness**

- Carbon content.
- Alloying elements.
- Heat treatment.
- Cooling rate during hardening.
- Tempering temperature.
- Microstructure.

**Methods of testing hardness**

a) Brinell hardness test



- Uses a hard ball-shaped indenter.
- The indenter is pressed into the material under a specified load.
- The diameter of the indentation is measured.
- Commonly used for testing metals.

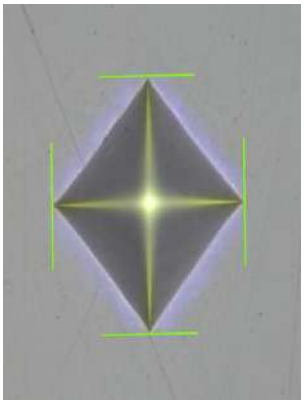
b) Rockwell hardness test




- Uses a diamond cone or hardened ball indenter depending on the scale.
- Measures the depth of indentation.

- Commonly used in engineering workshops because it is relatively quick.

c) Vickers hardness test



- Uses a diamond pyramid-shaped indenter.
- The diagonals of the indentation are measured.
- Suitable for different hardness levels and small test areas.

**Applications where hardness is important**

- Drill bits.
- Milling cutters.
- Lathe tools.
- Dies and punches.
- Bearings.
- Machine components exposed to friction.

**5.3 Ductility**

**Definition:** Ductility is the ability of a material to undergo considerable plastic deformation under tensile loading before breaking.

A ductile material can be stretched or drawn into a wire without breaking easily.

**Characteristics of ductile alloy steel**

1. Can be drawn into wires.
2. Can undergo plastic deformation.
3. Can be formed into different shapes.
4. Can withstand some stretching before fracture.
5. Is suitable for manufacturing components requiring forming operations.

**Factors affecting ductility**

- Chemical composition.
- Temperature.
- Heat treatment.
- Grain structure.
- Manufacturing process.

**Applications of ductile steel**

- Wire production.
- Metal sheet forming.
- Automobile body components.
- Structural fabrication.
- Metal containers.
- Engineering fasteners.



**5.4 Toughness**

**Definition:** Toughness is the ability of a material to absorb energy and resist fracture when subjected to impact or sudden loading.

Tough materials are important in engineering applications where components experience shocks, vibration and sudden forces.

**Characteristics of tough alloy steel**

1. Resists sudden fracture.
2. Absorbs impact energy.
3. Can withstand repeated mechanical shocks.
4. Performs well under demanding working conditions.
5. Is suitable for components subjected to dynamic loading.

**Factors affecting toughness**

- Chemical composition.
- Heat treatment.
- Temperature.
- Grain size.
- Internal defects.
- Manufacturing processes.

**Applications**

- Vehicle axles.
- Gears.
- Railway components.
- Heavy machinery.
- Cranes.
- Industrial shafts.

**Difference between hardness and toughness**

| Hardness | Toughness |
|---|---|
| Resistance to indentation and scratching. | Resistance to fracture under impact or loading. |
| Important in cutting tools. | Important in impact-loaded components. |
| Often increased through hardening. | Depends on strength, ductility and microstructure. |
| Example: hardened cutting tool. | Example: tough vehicle axle. |

**5.5 Corrosion Resistance**

**Definition:** Corrosion resistance is the ability of a material to withstand deterioration caused by chemical or electrochemical reactions with its surroundings.

Steel may corrode when exposed to moisture, oxygen, acids, salts and other aggressive substances.

Chromium, nickel and molybdenum are among the elements used to improve the corrosion resistance of steel.

**Factors that affect corrosion**

1. Presence of moisture.
2. Exposure to oxygen.
3. Presence of salts.
4. Exposure to acids and chemicals.
5. Temperature.
6. Chemical composition of the steel.
7. Surface condition.
8. Environmental conditions.

**Ways of improving corrosion resistance**

- Selecting suitable stainless steel grades.
- Applying protective paint.
- Applying galvanised coatings where appropriate.
- Using protective metal coatings.
- Regular cleaning and maintenance.
- Preventing prolonged exposure to corrosive substances.
- Using suitable protective oils or coatings.

**Applications requiring corrosion resistance**

- Water storage tanks.

- Food-processing equipment.
- Hospital equipment.
- Chemical-processing plants.
- Marine equipment.
- Kitchen fittings.





**5.6 Machinability**

**Definition:** Machinability is the ease with which a material can be cut, drilled, turned, milled or shaped using machine tools to produce the required dimensions and surface finish.

A steel with good machinability can be processed efficiently with suitable cutting tools and machining conditions.

**Characteristics of steel with good machinability**

1. Can be cut without excessive tool wear.
2. Produces manageable chips.
3. Requires reasonable cutting forces.
4. Can produce a satisfactory surface finish.
5. Allows efficient machining.
6. Can reduce production costs.

**Factors affecting machinability**

- Chemical composition.
- Hardness.
- Microstructure.
- Heat treatment.
- Cutting speed.
- Feed rate.
- Cutting tool material.
- Use of cutting fluids.
- Type of machining operation.

**Methods of improving machinability**

1. Selecting a suitable steel grade.
2. Using appropriate cutting tools.
3. Maintaining correct cutting speeds.

4. Applying suitable cutting fluids.
5. Ensuring correct machine settings.
6. Using proper work-holding devices.
7. Carrying out suitable heat treatment where required.

**Examples of machining operations**







- Turning.
- Drilling.
- Milling.
- Reaming.
- Grinding.
- Boring.

## 6.0 Processes of Alloy Steel Production

Alloy steel production involves several stages through which raw materials are converted into finished steel products with the required composition and properties.

The production process must be carefully controlled to ensure the steel meets the intended industrial specifications.

## 6.1 Raw Materials Used in Alloy Steel Production

The main raw materials include:

1. **Iron ore:** Provides iron used in steel production.
2. **Scrap steel:** Recycled steel used as a raw material.
3. **Coke or other reducing agents:** Used in ironmaking processes.
4. **Limestone:** Used as a flux to help remove impurities during certain steelmaking processes.
5. **Alloying elements:** Such as chromium, nickel, manganese and molybdenum.
6. **Oxygen:** Used in steelmaking to oxidise unwanted elements.
7. **Refractory materials:** Used to line furnaces and withstand high temperatures.







## 6.2 Main Stages in the Production of Alloy Steel

### Stage 1: Preparation of raw materials

- Iron ore, scrap steel and other raw materials are collected

- The materials are sorted and prepared.
- Impurities and unwanted materials are removed where necessary.
- Alloying materials are identified according to the required steel grade.

**Stage 2: Melting**

- The prepared metallic materials are charged into a suitable furnace.
- High temperatures are applied to melt the materials.
- The molten metal is collected for further processing.
- Furnace conditions are controlled to obtain the required molten metal.

**Stage 3: Primary steelmaking**

- The molten iron or scrap is processed to reduce unwanted elements.
- Oxygen may be introduced to remove excess carbon and other impurities.
- Slag is formed to help remove unwanted substances.
- The chemical composition of the steel is controlled.

**Stage 4: Addition of alloying elements**

- Selected alloying elements are added in measured quantities.
- The elements are introduced according to the required grade.
- The molten steel is mixed to distribute the alloying elements uniformly.
- Chemical analysis is carried out to confirm the composition.

**Stage 5: Refining**

- Dissolved gases and unwanted impurities are reduced using suitable refining techniques.
- The chemical composition is adjusted.
- The cleanliness of the molten steel is improved.
- The steel is prepared for casting.

**Stage 6: Casting**

- Molten steel is poured into moulds or passed through continuous casting equipment.
- The steel cools and solidifies.
- Semi-finished products such as billets, blooms and slabs are produced.

**Stage 7: Rolling and forming**

- The solidified steel is heated where necessary.
- It is passed through rolling mills to obtain the required dimensions.
- It may be formed into plates, sheets, rods, bars and structural sections.

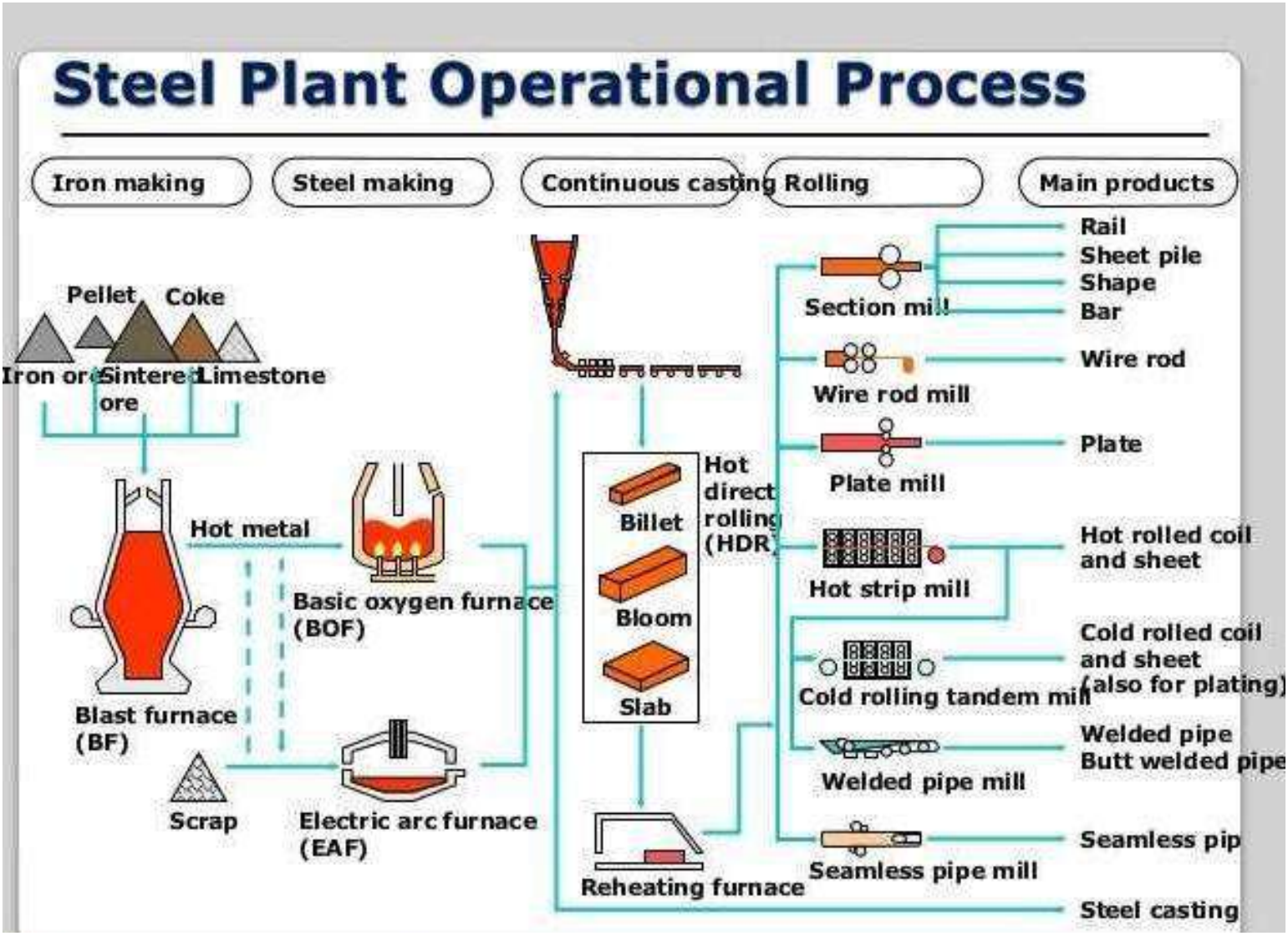
**Stage 8: Heat treatment**

- The steel is heated to a specified temperature.
- It is held at that temperature for a suitable period.
- It is cooled under controlled conditions.

- Hardening, tempering, annealing or normalising may be carried out depending on the required properties.

**Stage 9: Finishing and inspection**

- The steel is cut to the required dimensions.
- Surfaces are cleaned and finished.
- The products are inspected for defects.
- Mechanical and chemical tests are conducted.
- Approved products are labelled and prepared for distribution.




**6.3 Flow Chart of Alloy Steel Production**

**Raw material preparation**

Iron ore, scrap steel and alloying elements

**Melting in a suitable furnace**

**Primary steelmaking and refining**

**Addition of alloying elements**

**Casting and solidification**

**Rolling and forming**

**Heat treatment**

**Finishing, testing and inspection**

Finished alloy steel products

**7.0 Types of Furnaces Used in Steel Production**

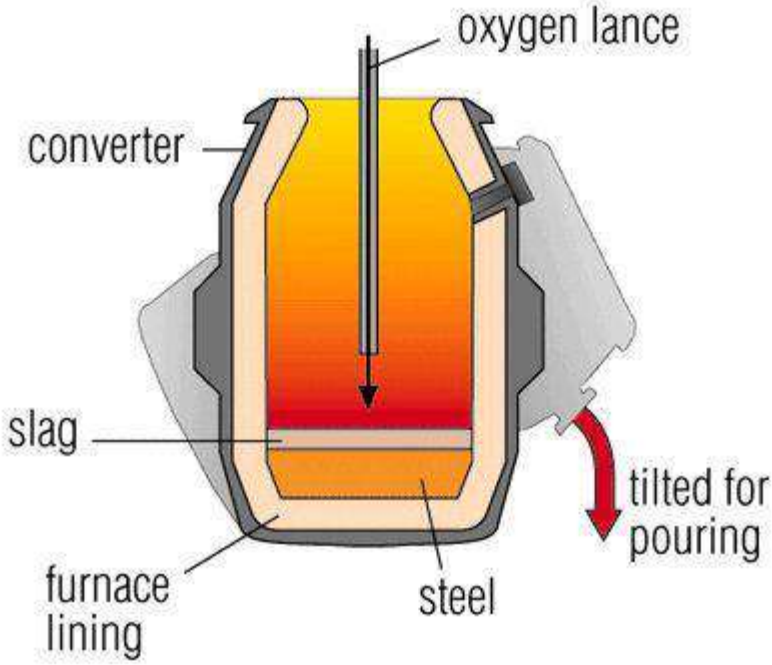
A furnace is an industrial heating device used to produce and maintain high temperatures required for melting, refining and processing metals.

Different types of furnaces are used in steel production depending on the raw materials, production capacity, energy source and required quality of steel.

The main furnaces in this sub-strand are:

1. Basic oxygen furnace.
2. Bessemer converter.
3. Open-hearth furnace.
4. Electric furnace.

**7.1 Basic Oxygen Furnace (BOF)**




**Definition:** A basic oxygen furnace is a steelmaking vessel in which high-purity oxygen is blown onto molten iron to reduce the carbon content and remove other unwanted elements.

**Main parts of a basic oxygen furnace**

1. Steel vessel.
2. Refractory lining.
3. Oxygen lance.
4. Tilting mechanism.
5. Molten metal charging opening.
6. Slag removal arrangement.

**Working principle**

The furnace works through oxidation reactions. Oxygen reacts with carbon, silicon, manganese and other unwanted elements in molten iron.

**Production process**

1. Molten iron is charged into the furnace.
2. Scrap steel may be added to regulate temperature and recycle materials.
3. A water-cooled oxygen lance is lowered into the vessel.
4. High-purity oxygen is blown onto the molten metal.
5. Carbon and other elements are oxidised.
6. Slag forms and helps remove impurities.
7. The required steel composition is achieved.
8. The molten steel is tapped into a ladle.
9. Alloying elements are added or adjusted during subsequent refining.

**Advantages**

- High production rate.
- Suitable for large-scale steel production.
- Uses oxygen efficiently.
- Can process substantial quantities of molten iron.
- Produces steel with controlled carbon content.

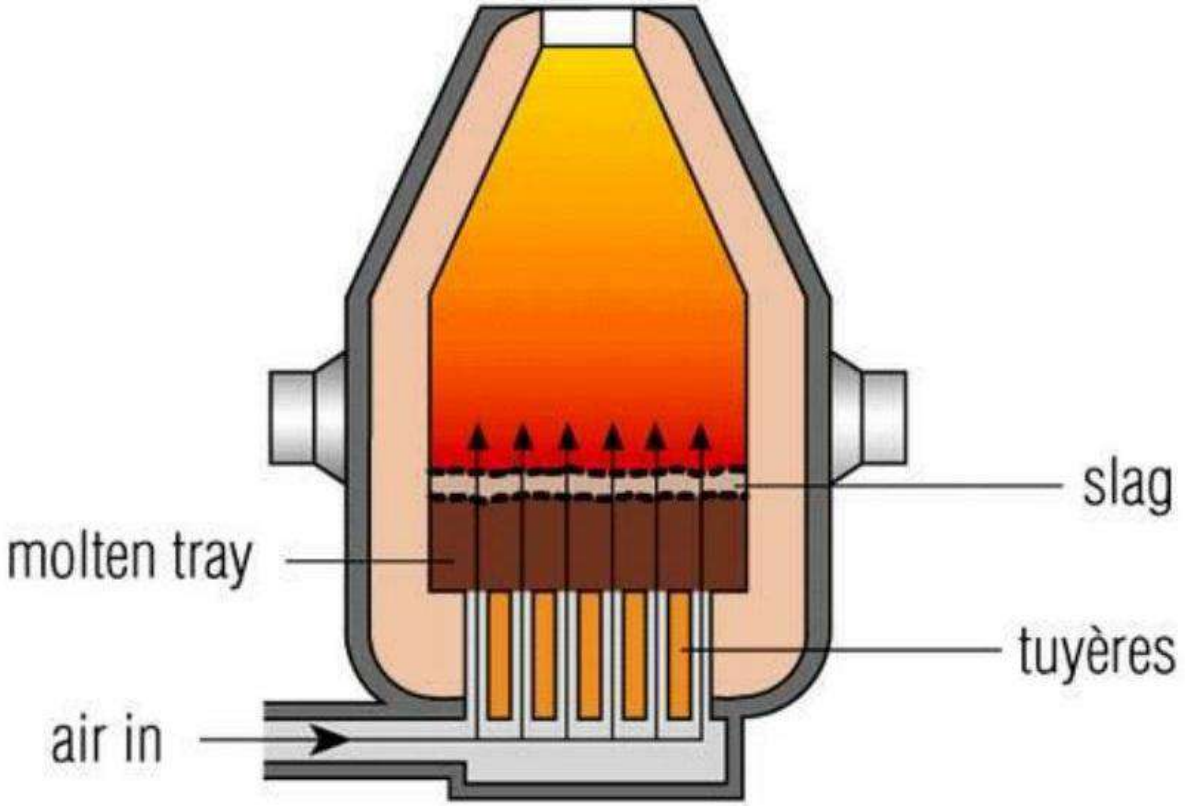
**Limitations**

- Requires molten iron as a major input.
- Requires specialised industrial equipment.
- Not as flexible as some electric furnaces for high-scrap-based production.
- Requires careful control of chemical composition.

**Applications**

- Production of structural steel.
- Manufacture of engineering steel.
- Production of steel plates and sheets.
- Manufacture of steel for industrial applications.

**7.2 Bessemer Converter**




**Definition:** A Bessemer converter is a steelmaking vessel in which air is blown through molten pig iron to oxidise impurities and reduce the carbon content.

It is an important historical steelmaking process that contributed to the development of mass steel production.

**Main parts**

1. Steel vessel.
2. Refractory lining.
3. Air blast arrangement.
4. Tuyeres (air openings).
5. Tilting mechanism.
6. Charging and pouring opening.

**Working process**

1. Molten pig iron is charged into the converter.
2. Air is forced through tuyeres at the bottom.
3. Oxygen in the air reacts with impurities.
4. Carbon, silicon and manganese are oxidised.
5. Heat generated by the oxidation reactions helps maintain the high temperature.
6. Slag forms and is removed.
7. The molten steel is poured out.
8. The required composition is adjusted where neces

**Advantages**

- Fast steelmaking process.
- Historically enabled mass production of steel.
- Does not require an external fuel source during the main blowing stage.
- Uses oxidation reactions to remove impurities.

**Limitations**

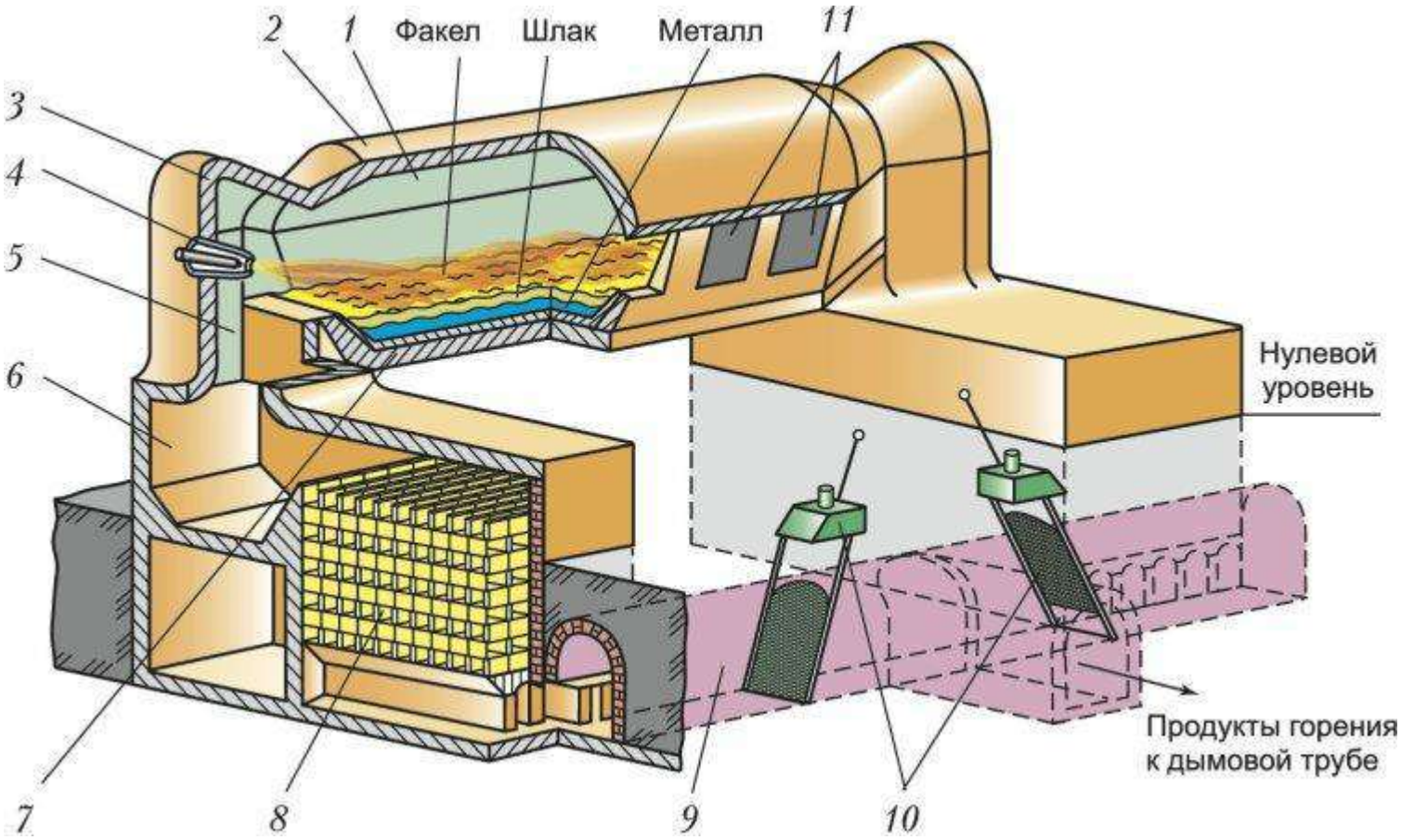
- Conventional air blowing introduces nitrogen into the steel.
- Difficult to control the final composition compared with modern processes.
- Not suitable for all steel grades.
- Conventional Bessemer practice has largely been replaced by modern steelmaking technologies.

**Applications**

- Historical production of construction steel.
- Historical production of railway steel.
- Historical manufacture of general-purpose steel products.

**Important note:** The Bessemer converter is mainly studied for its historical and metallurgical importance rather than as the main modern method of producing alloy steel.

**7.3 Open-Hearth Furnace**




**Definition:** An open-hearth furnace is a regenerative furnace that uses fuel combustion and preheated air to melt and refine pig iron and scrap steel.

It is also known as the Siemens-Martin furnace.

**Main parts**

1. Furnace chamber.
2. Refractory lining.
3. Charging doors.
4. Fuel and air inlets.
5. Regenerative chambers.
6. Flues and chimneys.
7. Tapping opening.

**Working process**

1. Pig iron and scrap steel are charged into the furnace.
2. Fuel is burnt to generate heat.
3. Preheated air supports combustion.
4. The metallic materials melt.
5. Oxidation reactions reduce unwanted elements.
6. Slag is formed and removed.
7. The chemical composition is adjusted.
8. The finished molten steel is tapped from the furnace.

**Advantages**

- Can use pig iron and scrap steel.
- Allows careful control of steel composition.
- Can produce different grades of steel.
- Historically useful for large-scale steel production.

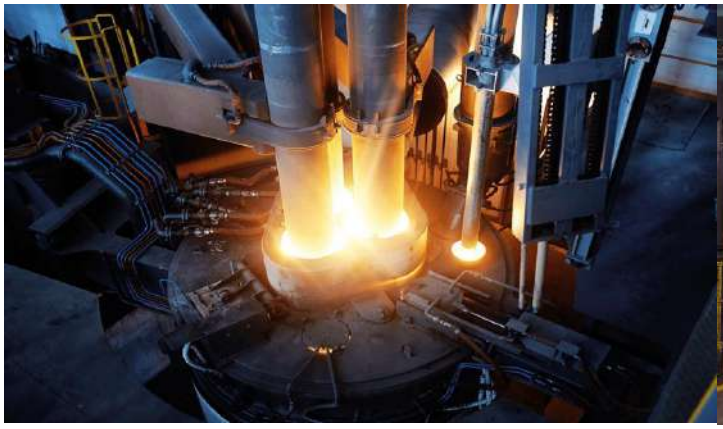
**Limitations**

- Requires a long production time.
- Uses considerable energy.
- Has relatively high operating costs.
- Has largely been replaced by more efficient modern steelmaking methods.

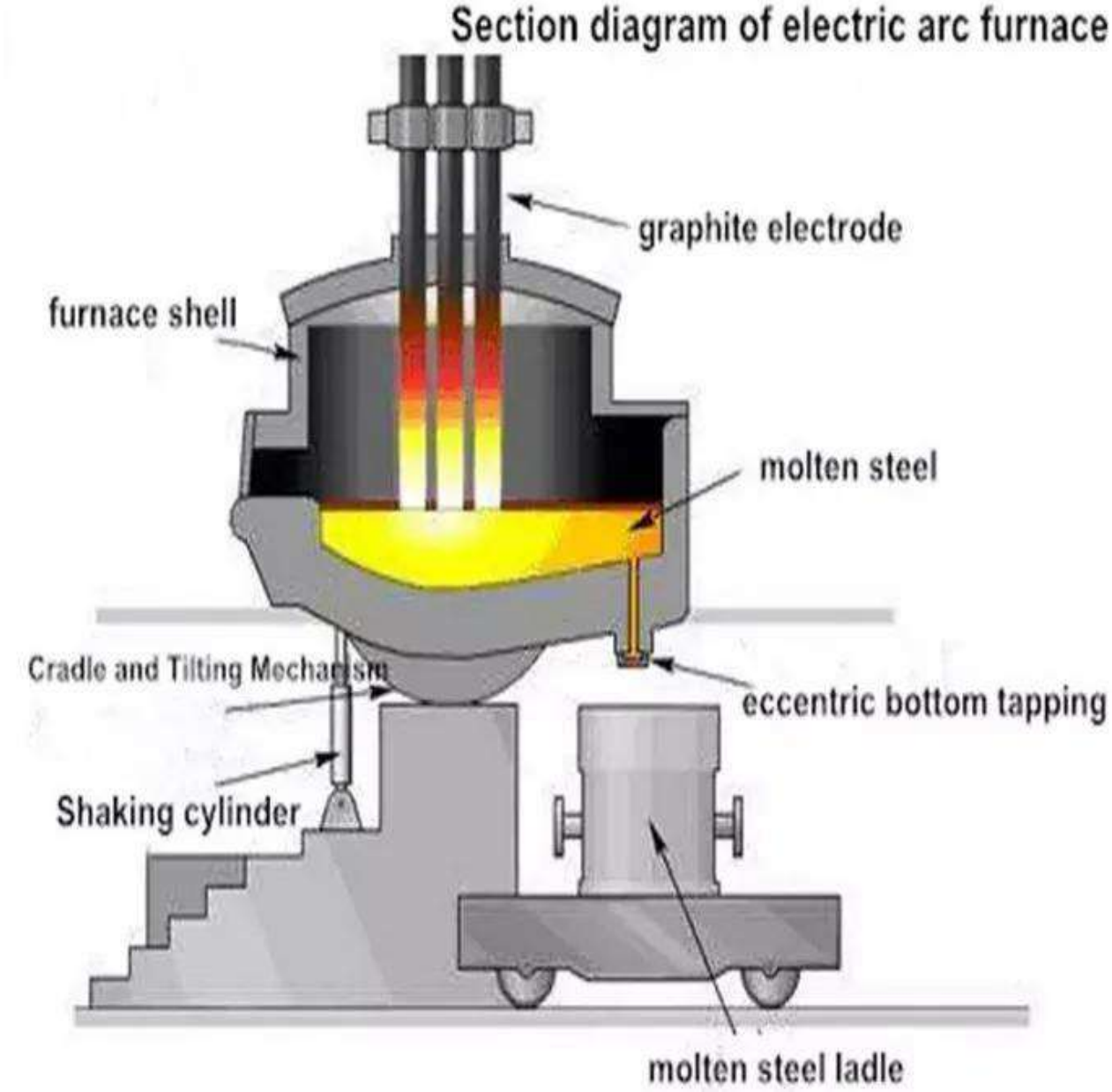
**Applications**

- Historical production of structural steel.
- Production of general engineering steel.
- Manufacture of steel plates and sections.

**7.4 Electric Furnace**








**Definition:** An electric furnace is a furnace that uses electrical energy to generate heat for melting and processing metals.

Two important types used in metal industries are:

a) Electric arc furnace (EAF)

- Uses an electric arc between graphite electrodes and the metal charge to generate intense heat.
- Commonly uses scrap steel and may use direct reduced iron or other metallic inputs.
- Allows the production of different steel grades.
- Is widely used in modern steel recycling and steelmaking.

b) Electric induction furnace

- Uses electromagnetic induction to generate heat in the metal charge.
- Does not require direct contact between the heating coil and the molten metal.
- Is commonly used in foundries and specialised metal-melting operations.
- Offers good control of melting conditions.

**Main parts of an electric arc furnace**

1. Furnace shell.
2. Refractory lining.
3. Graphite electrodes.
4. Electrode holders.
5. Charging system.
6. Power supply.
7. Slag removal arrangement.
8. Tapping opening.

**Working process of an electric arc furnace**

1. Scrap steel or other metallic materials are charged into the furnace.
2. The furnace lid is closed.
3. Graphite electrodes are lowered.
4. An electric arc is generated.
5. The intense heat melts the metallic materials.
6. Oxygen and other refining agents may be used to remove impurities.
7. Slag is formed and removed.
8. Alloying elements are added in controlled quantities.
9. The chemical composition is tested and adjusted.
10. Molten steel is tapped into a ladle for further processing.

**Advantages of electric furnaces**

- Can produce specialised steel grades.
- Offer good temperature control.
- Can use recycled scrap steel.
- Allow accurate composition adjustment.

- Are suitable for alloy steel production.
- Can produce high-quality steel when properly operated.

**Limitations**

- Require a reliable electricity supply.
- Have high initial installation costs.
- Require skilled operators.
- Electricity costs can affect production expenses.

**Applications**

- Production of stainless steel.
- Manufacture of tool steel.
- Production of high-speed steel.
- Manufacture of specialised engineering steel.
- Recycling of scrap steel.

**7.5 Comparison of the Four Steelmaking Furnaces**

| Furnace | Main heat/working principle | Important feature |
|---|---|---|
| Basic oxygen furnace | Oxygen blown into molten iron | Rapid oxidation and refining |
| Bessemer converter | Air blown through molten pig iron | Historical mass steel production |
| Open-hearth furnace | Fuel combustion and regenerative heating | Slow refining with composition control |
| Electric furnace | Electrical energy | Suitable for specialised grades and scrap-based production |

**Important distinction:** The furnaces listed above are not interchangeable. The basic oxygen furnace, Bessemer converter and open-hearth furnace are primarily associated with primary steelmaking. Electric furnaces can be used for melting, refining and producing specialised alloy steels. Alloy additions and final composition adjustment may take place in secondary steelmaking operations.

**8.0 Selection of Appropriate Alloy Steels for Specified Metalworking Tasks**

The selection of alloy steel is the process of identifying and choosing the most suitable steel grade for a particular manufacturing or engineering task.

A metalworker must consider the working conditions, required properties, cost and manufacturing processes before selecting a material.

**8.1 Factors to Consider When Selecting Alloy Steel**

**1. Strength requirements**

- The material should withstand the expected working loads.
- High-tensile steel is suitable for components exposed to high tensile forces.
- Low-strength materials should not be used where heavy loads are expected.

**2. Hardness requirements**

- Components exposed to abrasion require suitable hardness.
- High-speed steel is suitable for cutting tools.
- Hardened silver steel can be used for precision punches and small tools.

**3. Corrosion resistance**

- Materials used in wet or chemical environments should resist corrosion.
- Stainless steel is suitable for many food-processing and kitchen applications.

**4. Toughness**

- Components exposed to shock and impact require good toughness.
- Suitable alloy steels are used for gears, axles and machine parts.

**5. Operating temperature**

- Some components operate at high temperatures.
- High-speed steel is suitable for cutting operations because it retains hot hardness.
- Heat-resistant alloy grades are selected for furnaces and industrial heating equipment.

**6. Machinability**

- The material should be suitable for the intended machining operations.
- The machinability of a steel grade influences cutting speed, tool selection and production cost.

**7. Availability**

- The selected steel should be readily available in the required size and form.
- The metalworker should consider local suppliers and the cost of transportation.

**8. Cost**

- The cost of the material should be considered against its expected service life.
- Expensive alloy steel may be economical where it provides longer service and reduced maintenance.

**9. Weldability**

- Some components require joining through welding.
- The selected steel must have suitable weldability and the correct welding procedure.

**10. Working environment**

- Exposure to water, chemicals, dust, friction and changing temperatures influences the selection.

**8.2 Selection of Alloy Steel for Different Tasks**

| Metalworking task | Recommended steel | Reason |
|---|---|---|
| Manufacture of food-processing equipment | Stainless steel | Corrosion resistance and ease of cleaning |
| Manufacture of drill bits | High-speed steel | Hot hardness and wear resistance |
| Manufacture of precision punches | Silver steel | Hardness and precision-ground supply |
| Manufacture of heavily loaded structural components | Suitable high-tensile steel | High strength |
| Manufacture of milling cutters | High-speed steel | Retains cutting hardness |
| Manufacture of chemical storage equipment | Suitable stainless steel | Resistance to chemical corrosion |
| Manufacture of heavy-duty gears | Suitable alloy steel | Strength, toughness and wear resistance |
| Manufacture of precision shafts | Suitable silver steel or alloy steel | Dimensional accuracy and strength |

**8.3 Practical Examples of Material Selection**

**Example 1: Manufacturing a drill bit**

A metalworker is required to manufacture a drill bit for drilling steel plates.

Suitable material: High-speed steel.

Reasons:

1. It has high hardness.
2. It retains hardness at elevated cutting temperatures.
3. It has good wear resistance.
4. It can maintain a cutting edge during drilling.

**Example 2: Manufacturing a kitchen sink**

A metalworker is required to manufacture a kitchen sink for a hotel.

Suitable material: Stainless steel.

Reasons:

1. It resists corrosion.
2. It can be cleaned easily.
3. It has an attractive appearance.
4. It is durable.
5. It is suitable for hygienic applications.

**Example 3: Manufacturing a precision punch**

A workshop requires a small punch for marking metal surfaces.

Suitable material: Silver steel.

Reasons:

1. It can be machined before hardening.
2. It can achieve high hardness.
3. It has good wear resistance.
4. It is available in precision-ground round bars.

**Example 4: Manufacturing a heavy-duty bridge component**

A manufacturer is required to produce a structural member that will carry heavy loads.

Suitable material: Appropriate high-tensile structural steel.

Reasons:

1. It has high yield strength.
2. It can withstand substantial loads.
3. Suitable grades have good toughness.
4. It can reduce structural weight in some designs.

**9.0 Heat Treatment of Alloy Steels**

Heat treatment is the controlled heating and cooling of steel to change its mechanical properties and improve its suitability for particular applications.

Alloy steels are heat-treated to obtain the required hardness, toughness, strength and ductility.

**9.1 Annealing**

**Definition:** Annealing is a heat-treatment process in which steel is heated to a suitable temperature, held for a specified period and cooled slowly, usually in the furnace.

**Purposes**

1. Softens steel.
2. Improves machinability.
3. Reduces internal stresses.
4. Improves ductility.
5. Refines the microstructure under suitable conditions.
6. Prepares steel for further manufacturing operations.

**9.2 Normalising**

**Definition:** Normalising is a heat-treatment process in which steel is heated to the appropriate temperature, held and allowed to cool in still air.

**Purposes**

- Refines grain structure.
- Improves uniformity of mechanical properties.
- Improves strength and toughness in suitable grades.
- Reduces some internal stresses.
- Prepares steel for further heat treatment.

**9.3 Hardening**

**Definition:** Hardening is a heat-treatment process in which steel is heated to the appropriate temperature and rapidly cooled using a suitable quenching medium to increase its hardness.

**Quenching media include:**

1. Water.
2. Oil.
3. Air.
4. Specialised quenching solutions.

**Purposes**

- Increases hardness.
- Improves wear resistance.
- Improves cutting performance.
- Produces a harder surface or structure depending on the treatment.

### 9.4 Tempering

**Definition:** Tempering is the reheating of hardened steel to a temperature below its critical transformation temperature, followed by controlled cooling.

**Purposes**

1. Reduces brittleness.
2. Improves toughness.
3. Reduces internal stresses.
4. Adjusts hardness to the required level.
5. Improves the service performance of hardened steel components.




### 9.5 Comparison of Heat-Treatment Processes

| Process | Main purpose | Typical cooling method |
|---|---|---|
| Annealing | Softening and stress relief | Slow furnace cooling |
| Normalising | Grain refinement and property uniformity | Still-air cooling |
| Hardening | Increasing hardness | Rapid quenching |
| Tempering | Reducing brittleness and improving toughness | Controlled cooling |

### 10.0 Safety Precautions When Working with Alloy Steels

Metalworking involves tools, machines, heat and heavy materials. Proper safety precautions must be followed to prevent accidents and injuries.

### 10.1 Personal Protective Equipment (PPE)

The following protective equipment should be used:





1. **Safety goggles:** Protect the eyes from flying metal particles and sparks.
2. **Face shield:** Protects the face during grinding and cutting.
3. **Safety boots:** Protect the feet from falling metal objects.
4. **Protective gloves:** Protect hands when handling sharp or hot materials, but should not be worn near rotating machinery where they could become entangled.
5. **Overalls:** Protect the body from dirt, sparks and hot particles.
6. **Ear protection:** Reduces exposure to excessive machine noise.
7. **Respiratory protection:** Protects against harmful metal dust and fumes where required.

### 10.2 General Workshop Safety Rules

1. Inspect machines before use.
2. Use the correct tools for each operation.
3. Ensure workpieces are properly secured.
4. Keep hands away from rotating parts.
5. Do not wear loose clothing near moving machines.
6. Maintain a clean and organised workshop.
7. Remove metal chips using a suitable brush or tool, not bare hands.
8. Follow the manufacturer's operating instructions.
9. Use appropriate lifting equipment when handling heavy steel.
10. Report damaged equipment immediately.
11. Keep flammable materials away from hot-working areas.
12. Ensure adequate ventilation during welding and heat treatment.
13. Never handle hot steel without appropriate equipment.
14. Keep fire extinguishers and first-aid facilities accessible.

### 10.3 Environmental Considerations in Alloy Steel Production

Alloy steel production and metalworking activities can affect the environment.

**Possible environmental effects**

- Air pollution from industrial emissions.

- Noise pollution from heavy machinery.
- High energy consumption.
- Wastewater contamination.
- Generation of metal scrap.
- Production of furnace slag and dust.

**Ways of reducing environmental pollution**

1. Recycle steel scrap.
2. Use energy-efficient furnaces.
3. Install suitable emission-control equipment.
4. Treat industrial wastewater before discharge.
5. Dispose of slag and other industrial waste responsibly.
6. Maintain machines to reduce energy wastage.
7. Use dust extraction systems.
8. Reduce unnecessary material wastage.
9. Reuse suitable materials where possible.
10. Comply with applicable environmental regulations in Kenya.

**11.0 Practical Learning Activities**

**Activity 1: Identification of Alloy Steels**

**Learning task:** Identify different types of alloy steels used in metalworking.

**Materials required**

- Stainless steel sample.
- High-speed steel drill bit.
- Silver steel rod.
- High-tensile steel sample.
- Magnifying glass.
- Identification chart.

**Procedure**

1. Collect samples of different types of alloy steels.
2. Observe their physical appearance.
3. Examine their surface finishes.
4. Identify the possible type of steel.
5. Discuss their properties.
6. Record their industrial applications.

**Expected learning outcome:** The learner should be able to identify different alloy steels and explain their uses.

**Activity 2: Comparing the Properties of Alloy Steels**

**Procedure**

1. Obtain suitable samples of different steel grades.
2. Observe their physical characteristics.
3. Use appropriate supervised laboratory tests to compare hardness and other properties.
4. Record the observations.
5. Discuss why different steels are selected for different applications.

**Expected learning outcome:** The learner should be able to explain the properties of different alloy steels.

**Activity 3: Furnace Observation**

**Procedure**

1. Visit a suitable metalworking industry or foundry.
2. Observe the available metal-melting equipment.
3. Identify the type of furnace.
4. Observe the safety measures used.
5. Discuss how alloying elements are introduced.
6. Record the production stages observed.

**Expected learning outcome:** The learner should be able to describe steel production processes and identify different types of furnaces.

**Activity 4: Material Selection Exercise**

A local workshop wants to manufacture:

- A kitchen sink.
- A metal-cutting drill.
- A precision punch.
- A heavy-duty machine shaft.

**Task:** Select a suitable steel for each product and justify your choices using the properties of the material.

**Activity 5: Digital Research**

Use textbooks, reliable online resources and educational videos to investigate:

1. Different alloying elements.
2. Their functions in steel production.
3. The operation of electric arc furnaces.
4. The production of stainless steel.
5. Industrial applications of high-speed steel.

Present your findings to the class.

**12.0 Appreciation of Alloy Steels in Manufacturing Industries**

Alloy steels contribute significantly to industrial development and technological advancement.

Their importance includes:

1. Supporting the manufacture of durable machinery.

2. Improving the quality of engineering products.
3. Supporting the construction industry.
4. Improving the performance of agricultural equipment.
5. Supporting vehicle and transport manufacturing.
6. Promoting industrial innovation.
7. Improving the reliability of manufacturing equipment.
8. Supporting food-processing and medical industries.
9. Reducing equipment replacement costs when appropriate grades are used.
10. Supporting recycling and sustainable material use.

**Kenyan industrial examples**

- Construction companies use suitable high-strength steels in structural applications.
- Engineering workshops use high-speed steel drills and cutting tools.
- Food-processing industries use stainless steel equipment.
- Agricultural machinery workshops use alloy steel components in gears, shafts and other machine parts.
- Fabrication workshops use different steel grades for gates, tanks, machinery and equipment.

**13.0 Key Terms and Definitions**

| Term | Meaning |
|---|---|
| Alloy | A material made by combining two or more elements, at least one of which is a metal. |
| Alloy steel | Steel containing intentionally added alloying elements apart from carbon. |
| Chromium | An alloying element that improves corrosion resistance and hardness. |
| Nickel | An alloying element that improves toughness and corrosion resistance. |
| Molybdenum | An alloying element that improves hardenability and high-temperature performance. |
| Tungsten | An element used to improve hot hardness and wear resistance. |
| Cobalt | An element used to improve hot hardness in specialised tool steels. |
| Vanadium | An element that improves hardness and grain refinement. |
| Manganese | An element that improves strength and hardenability. |
| Silicon | An element used in deoxidation and in improving certain steel properties. |
| Hardness | Ability to resist indentation and scratching. |
| Toughness | Ability to absorb energy and resist fracture. |
| Ductility | Ability to undergo plastic deformation under tensile loading before breaking. |
| Strength | Ability to withstand applied forces without failure. |
| Corrosion | Deterioration of a material through chemical or electrochemical reactions. |
| Machinability | Ease with which a material can be machined. |
| Furnace | Equipment used to generate heat for melting or processing materials. |
| Casting | The process of pouring molten metal into a mould to solidify into a required shape. |
| Quenching | Rapid cooling of heated metal using a suitable medium. |
| Tempering | Reheating hardened steel to reduce brittleness and improve toughness. |
| Heat treatment | Controlled heating and cooling of metals to modify their properties. |

**REVISION QUESTIONS**

**SUBSTRAND: ALLOY STEELS**

**Assessment and Practice**

The following questions assess the learner's understanding of alloy steels, their classification, properties, production processes, furnaces and applications in metalworking industries.

**SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)**

Instructions: Answer all questions by selecting the correct answer from the alternatives A, B, C and D.

1. What is an alloy steel?

A. Steel containing only iron and carbon.
B. Steel containing controlled quantities of additional alloying elements.
C. Steel produced without heating.
D. Steel containing only chromium.

2. Which of the following is a major alloying element used in stainless steel production?

A. Lead.
B. Tin.
C. Chromium.
D. Zinc.

3. The main purpose of adding chromium to steel is to improve its:

A. Electrical conductivity.
B. Corrosion resistance.
C. Weight.
D. Melting point only.

4. Which of the following is classified as a high-alloy steel?

A. Ordinary mild steel.
B. Plain carbon steel.
C. Stainless steel.
D. Low-carbon steel.

5. High-speed steel is mainly used in the manufacture of:

A. Roofing sheets.
B. Cutting tools.
C. Water storage tanks.
D. Decorative furniture.

6. Which alloying element improves the hot hardness of high-speed steel?

A. Tungsten.
B. Lead.
C. Zinc.
D. Tin.

7. Silver steel is commonly supplied in the form of:

A. Large cast blocks.
B. Precision-ground round bars.
C. Corrugated sheets.
D. Hollow concrete sections.

8. Why is silver steel suitable for manufacturing precision punches?

A. It has low strength.
B. It has poor wear resistance.
C. It can be hardened to achieve high hardness.
D. It cannot undergo heat treatment.

9. High-tensile steel is mainly selected for applications requiring:

A. Low tensile strength.
B. High tensile strength.
C. Low hardness only.
D. Poor toughness.

10. Which alloying element improves the toughness of many steel grades, particularly at low temperatures?

A. Nickel.
B. Lead.
C. Tin.
D. Zinc.

11. Which property describes the ability of steel to resist indentation and scratching?

A. Ductility.
B. Toughness.
C. Hardness.
D. Elasticity.

12. The ability of steel to absorb energy and resist fracture under impact is known as:

A. Machinability.
B. Toughness.
C. Corrosion.
D. Conductivity.

13. Which property enables steel to be drawn into wires without breaking easily?

A. Hardness.
B. Brittleness.
C. Ductility.
D. Corrosion resistance.

14. The ability of steel to resist deterioration caused by chemical reactions with its surroundings is known as:

A. Machinability.
B. Corrosion resistance.
C. Tensile strength.
D. Plasticity.

15. Which alloying element is commonly used to improve the high-temperature performance of steel?

A. Molybdenum.
B. Lead.
C. Tin.
D. Aluminium.

16. Which element is particularly important in improving the hot hardness of specialised high-speed steels?

A. Cobalt.
B. Copper.
C. Zinc.
D. Lead.

17. Which alloying element helps refine the grain structure of steel?

A. Vanadium.
B. Tin.
C. Lead.
D. Zinc.

18. Silicon is commonly used during steel production as a:

A. Corrosion-producing agent.
B. Deoxidiser.
C. Cooling lubricant.
D. Surface coating.

19. Which furnace uses high-purity oxygen blown onto molten iron?

A. Open-hearth furnace.
B. Electric induction furnace.
C. Basic oxygen furnace.
D. Cupola furnace.

20. The Bessemer converter uses which substance during the steelmaking process?

A. Compressed air.
B. Pure nitrogen.
C. Water vapour.
D. Carbon dioxide only.

21. Which furnace is also known as the Siemens-Martin furnace?

A. Basic oxygen furnace.
B. Open-hearth furnace.
C. Electric arc furnace.
D. Induction furnace.

22. Which furnace uses electrical energy to generate heat through an electric arc?

A. Bessemer converter.
B. Open-hearth furnace.
C. Electric arc furnace.
D. Basic oxygen furnace.

23. What is the main purpose of adding alloying elements to molten steel?

A. To reduce its quality.
B. To improve its required properties.
C. To make it lighter than aluminium.
D. To prevent it from melting.

24. Which process involves pouring molten steel into moulds to produce solid shapes?

A. Casting.
B. Tempering.
C. Quenching.
D. Machining.

25. Which of the following heat-treatment processes involves slow cooling, usually inside a furnace?

A. Hardening.
B. Quenching.
C. Annealing.
D. Normalising.

26. What is the main purpose of tempering hardened steel?

A. To increase brittleness.
B. To reduce brittleness and improve toughness.
C. To convert steel into aluminium.
D. To remove all alloying elements.

27. Which steel would be most suitable for manufacturing a kitchen sink?

A. Silver steel.
B. High-speed steel.
C. Stainless steel.
D. Ordinary tool steel.

28. Which factor should be considered when selecting alloy steel for a particular metalworking task?

A. Material colour only.
B. Required mechanical properties.
C. The learner's age.
D. The shape of the workshop roof.

29. Which safety equipment protects the eyes against flying metal particles during grinding?

A. Safety goggles.
B. Safety boots.
C. Overalls.
D. Ear plugs.

30. Which practice promotes environmental sustainability in the steel industry?

A. Dumping scrap steel in rivers.
B. Burning all metal waste in open spaces.
C. Recycling scrap steel.
D. Discharging untreated industrial wastewater.

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

Instructions:

1. Answer all questions.
2. Write your answers clearly and systematically.
3. Use appropriate examples where necessary.
4. Draw well-labelled diagrams where required.

**QUESTION 1: INTRODUCTION AND CLASSIFICATION OF ALLOY STEELS (8 MARKS)**

a) Define the term alloy steel. (2 marks)

b) State the two main classifications of alloy steels according to their alloying element content. (2 marks)

c) Give three examples of alloy steels used in metalworking industries. (3 marks)

d) State one importance of alloy steels in manufacturing industries. (1 mark)

**QUESTION 2: TYPES OF ALLOY STEELS (8 MARKS)**

a) Identify four types of alloy steels used in metalworking industries. (4 marks)

b) State two properties of stainless steel that make it suitable for manufacturing kitchen equipment. (2 marks)

c) Give two applications of high-speed steel in metalworking. (2 marks)

**QUESTION 3: ALLOYING ELEMENTS AND THEIR FUNCTIONS (9 MARKS)**

a) State five alloying elements used in the production of alloy steels. (5 marks)

b) Explain the functions of the following alloying elements in steel production:

i. Chromium. (1 mark)

ii. Nickel. (1 mark)

iii. Tungsten. (1 mark)

iv. Vanadium. (1 mark)

**QUESTION 4: PROPERTIES OF ALLOY STEELS (8 MARKS)**

a) Define the following properties of alloy steels:

i. Hardness. (1 mark)

ii. Toughness. (1 mark)

iii. Ductility. (1 mark)

iv. Machinability. (1 mark)

b) Explain two factors that influence the selection of alloy steel for a particular metalworking task. (4 marks)

**QUESTION 5: PRODUCTION OF ALLOY STEELS AND FURNACES (9 MARKS)**

a) Outline five major stages involved in the production of alloy steels. (5 marks)

b) Identify four types of furnaces used in steel production. (4 marks)

**QUESTION 6: SELECTION AND APPLICATION OF ALLOY STEELS (8 MARKS)**

a) Select the most appropriate alloy steel for each of the following applications and give a reason for your choice:

i. Manufacture of a metal-cutting drill bit. (2 marks)

ii. Manufacture of a kitchen sink. (2 marks)

iii. Manufacture of a precision punch. (2 marks)

b) State two safety precautions that should be observed when working with alloy steels in a metalwork workshop. (2 marks)

**SECTION A: ANSWER KEY (30 MARKS)**

TEACHER'S MARKING KEY

| Question | Answer | Question | Answer | Question | Answer |
|---|---|---|---|---|---|
| 1 | B | 11 | C | 21 | B |
| 2 | C | 12 | B | 22 | C |
| 3 | B | 13 | C | 23 | B |
| 4 | C | 14 | B | 24 | A |
| 5 | B | 15 | A | 25 | C |
| 6 | A | 16 | A | 26 | B |
| 7 | B | 17 | A | 27 | C |
| 8 | C | 18 | B | 28 | B |
| 9 | B | 19 | C | 29 | A |
| 10 | A | 20 | A | 30 | C |

**MARKING SCHEME FOR SECTION B**

FOR TEACHER'S REFERENCE

**Question 1 (8 marks)**

a) Alloy steel is steel containing iron, carbon and controlled quantities of additional alloying elements to improve its properties. (2)

b)

- Low-alloy steels. (1)
- High-alloy steels. (1)

c) Any three:

- Stainless steel.
- High-speed steel.
- Silver steel.
- High-tensile steel.
- Chromium steel.
- Nickel steel. (3)

d) Improves the strength, durability, hardness or corrosion resistance of manufactured products. (1)

**Question 2 (8 marks)**

a) Any four:

- Stainless steel.
- High-speed steel.
- Silver steel.

- High-tensile steel. (4)

b) Any two:

- Good corrosion resistance.
- Easy to clean.
- Attractive appearance.
- Good durability. (2)

c) Any two:

- Drills.
- Milling cutters.
- Reamers.
- Taps.
- Dies.
- Lathe cutting tools. (2)

**Question 3 (9 marks)**

a) Any five:

- Chromium.
- Nickel.
- Molybdenum.
- Manganese.
- Tungsten.
- Cobalt.
- Vanadium.
- Silicon. (5)

b)

i. Chromium: Improves corrosion resistance and hardness. (1)

ii. Nickel: Improves toughness and corrosion resistance. (1)

iii. Tungsten: Improves hot hardness and wear resistance. (1)

iv. Vanadium: Improves hardness and refines grain structure. (1)

**Question 4 (8 marks)**

a)

i. Hardness: Ability to resist indentation and scratching. (1)

ii. Toughness: Ability to absorb energy and resist fracture. (1)

iii. Ductility: Ability to undergo plastic deformation under tensile loading before breaking. (1)

iv. Machinability: Ease with which a material can be cut or machined. (1)

b) Any two explained factors:

- Strength requirements: Steel should withstand the expected working loads without failing.
- Corrosion resistance: Steel should resist rusting and chemical attack in its working environment.
- Hardness: Steel should possess suitable hardness for the intended application.
- Toughness: Steel should resist impact and sudden loading.
- Cost: The material should be economical for the intended application.
- Availability: The required grade and dimensions should be accessible.
- Weldability: The steel should be suitable for the intended joining process.

(2 × 2 = 4 marks)

**Question 5 (9 marks)**

a) Any five stages:

1. Preparation of raw materials.
2. Melting.
3. Primary steelmaking.
4. Addition of alloying elements.
5. Refining.
6. Casting.
7. Rolling and forming.
8. Heat treatment.
9. Finishing and inspection.

(5 marks)

b)

- Basic oxygen furnace. (1)
- Bessemer converter. (1)
- Open-hearth furnace. (1)
- Electric furnace. (1)

**Question 6 (8 marks)**

a)

i. High-speed steel – retains hardness at high cutting temperatures and has good wear resistance. (2)

ii. Stainless steel – resists corrosion and is easy to clean. (2)

iii. Silver steel – can be hardened and has good wear resistance. (2)

b) Any two:

- Wear safety goggles when grinding or cutting.
- Wear safety boots when handling heavy metal.
- Use appropriate protective clothing.
- Secure workpieces before machining.

- Keep hands away from rotating machinery.
- Use appropriate lifting equipment.
- Ensure adequate ventilation during welding.
- Use suitable protective equipment when handling hot metal.

(2 marks)

**STRAND 2.0: TOOLS AND MATERIALS IN METALWORK**

**SUB-STRAND 2.4: PROJECT**

**1.0 Introduction to the project**

A project in Metal Technology is a practical activity in which learners apply the knowledge, skills, techniques and safety practices acquired in metalwork to identify and solve real-life problems.

Metalwork projects involve designing, planning, selecting materials, preparing tools, measuring, marking out, cutting, shaping, joining, finishing and evaluating metal products.

In Grade 11, learners are expected to go beyond performing isolated workshop operations. They should identify challenges within their communities and develop useful metal products that address those challenges.

For example, learners in a Kenyan community may identify the following problems:

- Inadequate waste disposal facilities in schools and markets.
- Lack of secure storage facilities for tools in workshops.
- Poorly constructed cooking equipment.
- Lack of metal drying racks for homes and institutions.
- Inadequate water storage and distribution equipment.
- Lack of suitable metal furniture in schools.
- Poor security of doors, windows and gates.
- Lack of suitable farming and livestock-handling equipment.

Through Metal Technology, learners can design and fabricate suitable products to address these challenges.

**Importance of project work in Metal Technology**

1. It develops practical metalworking skills.
2. It encourages creativity and innovation.
3. It promotes problem-solving and critical thinking.
4. It enables learners to apply classroom knowledge to real-life situations.
5. It promotes responsible use of locally available materials.
6. It develops entrepreneurial and income-generating skills.
7. It encourages teamwork and cooperation.
8. It promotes environmental conservation through recycling and reuse of metals.
9. It prepares learners for further technical training and employment.
10. It develops confidence in designing and making useful products.

**2.0 Curriculum learning expectations**

**2.1 Specific learning outcomes**

By the end of this sub-strand, the learner should be able to:

a) Identify a problem in the community that can be solved using knowledge and skills acquired in the study of Metalwork.

b) Propose an item that can be made to solve the identified problem.

c) Fabricate an item that can be used to solve the identified problem in the community.

d) Appreciate the item made to solve problems within the community.

**2.2 Suggested learning experiences**

The learner should be guided to:

1. Brainstorm on problems in the locality that can be solved using skills acquired in the study of Metalwork.
2. Discuss possible items that can be made to solve identified community problems.
3. Select an item that can be made using locally available resources.
4. Develop a fabrication procedure for the selected item, including materials, tools, steps and safety considerations.
5. Use locally available resources to make the selected item in a metal workshop.
6. Present the fabricated item to the class.
7. Demonstrate how the fabricated item can be used to generate income through sales, services or local exhibitions.

**2.3 Key inquiry question**

**What are some of the applications of metals in the locality?**

Other guiding questions include:

- Which problems in our community can be solved using metal products?
- How can locally available metals be used to make useful products?
- What factors should be considered when selecting a metalwork project?
- How can a fabricated metal product improve people's lives?
- How can metalwork projects create employment and income?

**3.0 Identification of community problems that can be solved using Metal Technology**

**3.1 Meaning of a community problem**

A community problem is a challenge or difficulty experienced by people living in a particular area that affects their daily activities, safety, health, productivity or general well-being.

Metal Technology provides knowledge and practical skills that can be used to design and fabricate products that address some of these challenges.

Learners should observe their immediate environment, identify challenges and propose suitable metal products to solve them.

**3.2 Examples of community problems and possible metalwork solutions**

| Community problem | Possible metalwork solution |
|---|---|
| Poor waste disposal | Metal litter bins |
| Inadequate school furniture | Metal desks and chairs |
| Insecurity in homes | Security gates and window grills |
| Poor storage of tools | Metal tool cabinets |
| Lack of clothes-drying facilities | Metal drying racks |
| Inadequate cooking facilities | Improved metal cooking stoves |
| Poor storage of water | Metal water tanks and stands |
| Inadequate farming equipment | Hoes, wheelbarrows and hand tools |
| Poor organisation of books | Metal book shelves |
| Inadequate market display facilities | Metal display stands |
| Lack of livestock feeding equipment | Metal feeding troughs |

| | |
|---|---|
| Poor storage of fuel | Suitable metal storage cabinets |

**3.3 Sources of information when identifying community problems**

A learner can obtain information about community challenges through:

1. **Observation:** Looking at the surroundings to identify problems that require practical solutions.
2. **Interviews:** Asking community members about challenges they experience.
3. **Questionnaires:** Preparing questions to collect information from people.
4. **Community discussions:** Engaging parents, teachers, farmers, traders and other stakeholders.
5. **School visits:** Observing problems experienced in classrooms, laboratories, workshops and school compounds.
6. **Market visits:** Identifying challenges affecting traders and customers.
7. **Research:** Reading books, technical publications and other reliable sources of information.

**3.4 Factors to consider when identifying a community problem**

- The seriousness of the problem.
- The number of people affected.
- Whether the problem can be solved through Metal Technology.
- Availability of suitable materials.
- Availability of tools and equipment.
- Cost of producing the proposed solution.
- Safety during fabrication and use.
- Durability of the proposed product.
- Environmental impact.
- Possibility of producing the item within the available time.

**Example:**

Learners observe that rubbish is scattered around their school compound because there are inadequate waste collection facilities.

The identified problem is poor waste disposal.

A possible solution is to fabricate metal litter bins and install them at strategic locations within the school.

**4.0 Proposing an item to solve an identified community problem**

**4.1 Meaning of a project proposal**

A project proposal is a written description of a proposed product or activity, explaining the problem to be addressed, the intended solution, resources required and the procedure for carrying out the project.

In Metal Technology, a project proposal guides the learner before beginning fabrication.

**4.2 Importance of preparing a project proposal**

1. It provides a clear direction for the project.
2. It helps identify the problem being addressed.
3. It identifies the materials and tools required.
4. It assists in estimating the cost of production.

5. It helps determine the time needed to complete the project.
6. It identifies possible risks and safety precautions.
7. It reduces wastage of materials.
8. It provides a basis for evaluating the finished product.

**4.3 Characteristics of a good metalwork project**

A good metalwork project should:

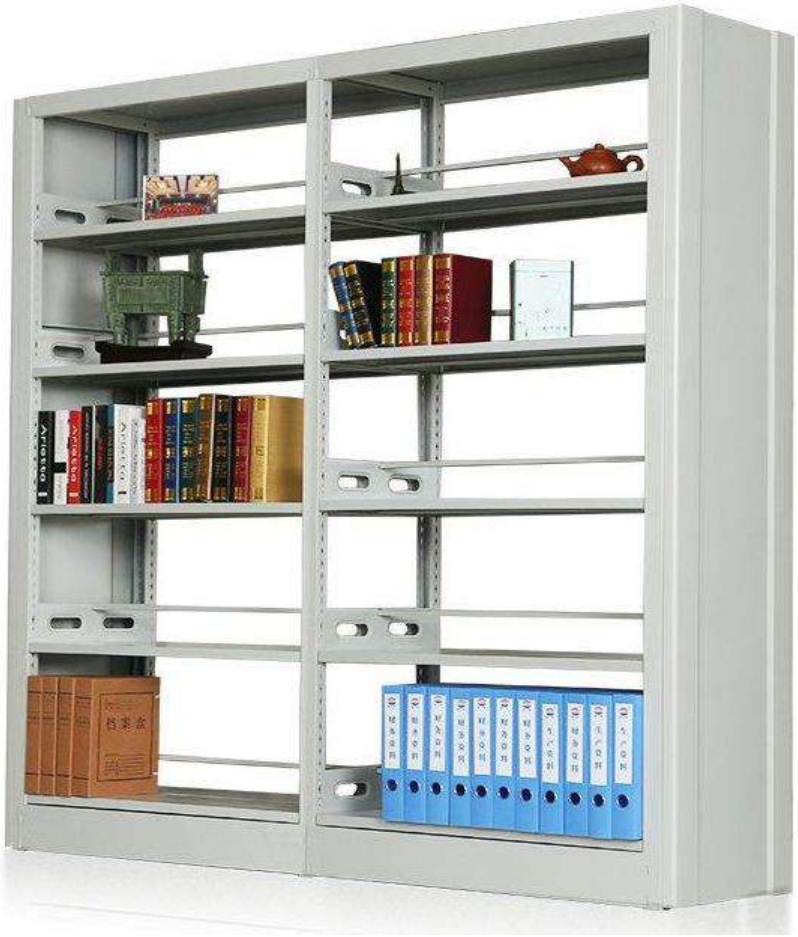
- Solve a genuine community problem.
- Be practical and achievable.
- Be affordable to fabricate.
- Use locally available materials where possible.
- Be safe during fabrication and use.
- Be durable and reliable.
- Be easy to maintain and repair.
- Have an appropriate size and shape.
- Be environmentally friendly.
- Have potential economic value.

**4.4 Examples of suitable Grade 11 Metal Technology projects**



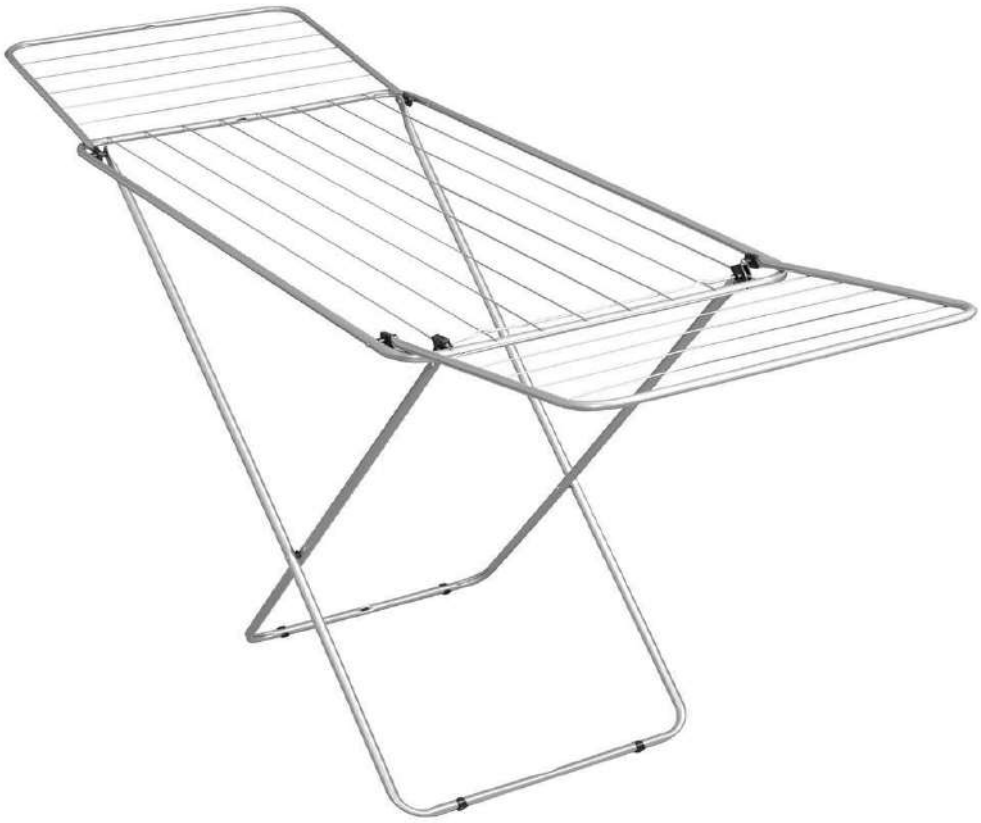
**1. Metal litter bin**

Used for collecting waste in schools, homes, markets and public places. It can be fabricated from mild steel sheet.



**2. Metal bookshelf**

Provides organised storage for books in classrooms, libraries and offices.



**3. Metal clothes-drying rack**

Provides a strong and reusable structure for drying clothes in homes and institutions.



**4. Metal tool cabinet**

Provides secure storage for workshop tools, equipment and accessories.



**5. Metal wheelbarrow**

Helps farmers, builders and other community members transport materials.



**6. Metal livestock feeding trough**

Provides a durable feeding facility for livestock farmers.

**4.5 Factors to consider when selecting a project**

The learner should consider the following:

1. **Availability of materials:** Materials should be readily available locally.
2. **Availability of tools:** The workshop should have the necessary tools and machines.
3. **Level of difficulty:** The project should match the learner's knowledge and practical ability.
4. **Cost:** The total cost should be affordable.
5. **Time:** The project should be completed within the allocated learning period.
6. **Usefulness:** The item should address an actual community need.
7. **Safety:** The project should not expose learners or users to unnecessary danger.
8. **Durability:** The finished product should withstand normal use.
9. **Environmental considerations:** Materials should be used efficiently and waste managed responsibly.
10. **Economic value:** The item should have potential for sale or commercial production.

**5.0 Project planning in Metal Technology**

**5.1 Meaning of project planning**

Project planning is the process of organising activities, resources, materials, tools, labour and time required to complete a project successfully.

It is an important stage because it ensures that fabrication is carried out systematically.

**5.2 Main stages of project planning**

1. Identification of the community problem.
2. Investigation of the problem.
3. Generation of possible solutions.
4. Selection of the most suitable solution.
5. Preparation of design sketches.
6. Determination of dimensions.
7. Selection of suitable materials.
8. Identification of tools and equipment.
9. Preparation of a fabrication procedure.
10. Estimation of material and production costs.
11. Identification of safety precautions.
12. Preparation of a work schedule.

**5.3 Preparation of a design sketch**

A design sketch is a drawing that shows the proposed appearance, shape and main features of the product to be fabricated.

A good design sketch should show:

- General shape of the product.
- Main components.
- Approximate dimensions.
- Positions of joints.
- Material thickness where necessary.
- Important construction details.
- Any special features.

**Importance of design sketches**

- They communicate the intended design.
- They guide material preparation.
- They help determine dimensions.
- They reduce fabrication errors.
- They assist in estimating material requirements.
- They provide a reference during fabrication.

### 5.4 Preparation of a fabrication procedure

A fabrication procedure is a systematic sequence of operations followed when making a metal product.

It should indicate:

- The operation to be performed.
- Materials required.
- Tools and equipment required.
- Safety precautions.
- Expected outcome of each operation.

**Example: Fabrication procedure for a metal litter bin**

| Stage | Operation | Tools/equipment |
|---|---|---|
| 1 | Study the design | Drawing instruments |
| 2 | Select and prepare materials | Steel rule, measuring tools |
| 3 | Measure and mark out | Scriber, steel rule, try square |
| 4 | Cut the sheet metal | Tin snips or suitable cutting machine |
| 5 | Form the body | Folding bars, mallet |
| 6 | Prepare the base | Measuring and cutting tools |
| 7 | Join the components | Welding machine or suitable mechanical fasteners |
| 8 | Smooth sharp edges | File and suitable grinder |
| 9 | Prepare and fit the lid | Hand tools and hinges |
| 10 | Clean and finish | Wire brush, paintbrush |
| 11 | Inspect the product | Measuring and inspection tools |

## 6.0 Selection of materials for metalwork projects

### 6.1 Meaning of materials

Materials are the substances used to manufacture or construct an item.

In Metal Technology, materials may include metals, non-metals, fasteners, finishing materials and other supporting components.

### 6.2 Common materials used in metalwork projects

**A. Mild steel**

Mild steel is a low-carbon steel that is widely used in metal fabrication.

Properties:

- It is relatively easy to cut and shape.
- It can be welded using appropriate methods.
- It is readily available.
- It is relatively affordable.
- It has good strength for many general fabrication applications.
- It can corrode when exposed to moisture unless protected.

Uses:

- Fabrication of gates.
- Construction of shelves.
- Making litter bins.

- Making furniture frames.
- Manufacturing tool cabinets.

**B. Stainless steel**

Stainless steel is an alloy of iron containing chromium and other elements that improve its resistance to corrosion.

Properties:

- It has good corrosion resistance.
- It is strong and durable.
- It has an attractive appearance.
- It is generally more expensive than mild steel.
- It requires appropriate fabrication techniques.

Uses:

- Kitchen equipment.
- Food-processing equipment.
- Hospital fittings.
- Water-related equipment.

**C. Aluminium**

Aluminium is a lightweight, silvery metal.

Properties:

- It has low density.
- It is resistant to corrosion due to its protective oxide layer.
- It is relatively easy to form.
- It conducts heat and electricity well.
- Some joining processes require specialised techniques.

Uses:

- Window frames.
- Light structures.
- Roofing components.
- Containers.
- Certain furniture components.

**D. Copper**

Copper is a reddish-brown metal with excellent electrical and thermal conductivity.

Properties:

- It conducts electricity very well.
- It conducts heat effectively.
- It is ductile.

- It is relatively resistant to corrosion.
- It is more expensive than ordinary mild steel in many applications.

Uses:

- Electrical wiring.
- Plumbing fittings.
- Heat exchangers.
- Electrical components.

**E. Galvanised steel**

Galvanised steel is steel coated with zinc to protect it against corrosion.

Uses:

- Roofing sheets.
- Water-related structures.
- Outdoor metal fittings.
- Some storage containers.

**6.3 Factors influencing material selection**

1. Strength requirements.
2. Corrosion resistance.
3. Availability.
4. Cost.
5. Ease of fabrication.
6. Weight.
7. Appearance.
8. Durability.
9. Intended use.
10. Maintenance requirements.

**6.4 Reusing and recycling materials**

Recycling is the process of converting used materials into new products.

Reuse involves using an existing material or component again for another suitable purpose.

Examples of materials that may be reused in metalwork projects include:

- Suitable steel offcuts.
- Old metal pipes.
- Used metal angles.
- Scrap sheet metal.
- Reusable bolts and nuts.
- Old metal frames.

**Benefits of recycling and reuse**

- Reduces the cost of projects.
- Minimises environmental pollution.
- Reduces demand for newly extracted raw materials.
- Encourages resource conservation.
- Promotes creativity.
- Provides opportunities for small-scale businesses.

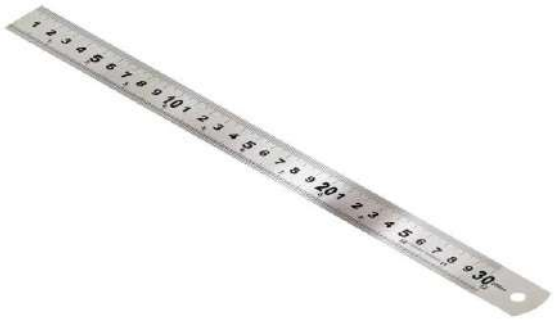
**Important:** Scrap materials must be inspected for cracks, excessive corrosion, contamination, structural weakness and other defects before reuse. Containers that previously held hazardous chemicals should not be reused without proper assessment and safe handling.

**7.0 Selection and use of tools and equipment**

**7.1 Meaning of tools**

Tools are implements used to perform specific operations during the fabrication of metal products.

**7.2 Common hand tools used in project fabrication**



**Steel rule**

Used for measuring short lengths and marking dimensions.



**Try square**

Used for checking and marking right angles.



**Scriber**

Used for scratching fine marking lines on metal surfaces.



**Tin snips**

Used for cutting thin sheet metal.




**Hammer**

Used for striking, shaping and forming metal.



**Bench vice**

Used for holding workpieces securely during operations.




**File**

Used for removing small amounts of metal and smoothing edges.




**Hacksaw**

Used for cutting metal bars, rods and tubes.

**7.3 Workshop machines and equipment**

**1. Drilling machine**

A drilling machine is used to produce circular holes in metal workpieces.

Applications:

- Making holes for bolts and screws.
- Preparing holes for rivets.
- Producing holes in metal brackets.
- Preparing components for assembly.

**2. Welding machine**

A welding machine supplies the electrical energy required for certain welding processes.

Applications:

- Joining metal frames.
- Fabricating gates.
- Joining metal brackets.
- Making furniture structures.

**3. Angle grinder**

An angle grinder is a portable power tool used for grinding, cutting and surface preparation with suitable attachments.

Applications:

- Removing weld irregularities.
- Smoothing sharp edges.
- Cutting suitable metal sections.
- Cleaning metal surfaces.

**4. Power hacksaw**

A power hacksaw is used for cutting metal bars, rods and other suitable sections.

**5. Bench grinder**

A bench grinder is used for grinding, sharpening and removing small amounts of material.

**6. Sheet-metal folding machine**

A folding machine is used for bending sheet metal to the required angles.

**7. Lathe machine**

A lathe is used to produce cylindrical components through operations such as turning, facing and drilling.

**7.4 Factors to consider when selecting tools and machines**

- Nature of the operation.
- Type of material.
- Size of the workpiece.
- Accuracy required.

- Availability of equipment.
- Condition of the tool.
- Operator's skill level.
- Safety requirements.
- Production time.

**8.0 Fabrication of a metalwork project**

**8.1 Meaning of fabrication**

Fabrication is the process of converting raw materials into finished products through operations such as measuring, marking out, cutting, shaping, joining and finishing.

It involves applying practical workshop skills to produce useful metal items.

**8.2 Main fabrication operations**

**A. Measuring**

Measuring is the process of determining the dimensions of a workpiece using appropriate measuring instruments.

Examples of measuring instruments:

- Steel rule.
- Measuring tape.
- Vernier calliper.
- Micrometer.
- Outside callipers.

Importance:

1. Ensures dimensional accuracy.
2. Reduces material wastage.
3. Ensures components fit correctly.
4. Improves product quality.

**B. Marking out**

Marking out is the process of transferring dimensions and shapes from a design or drawing onto the surface of a workpiece.

Common marking-out tools:

- Scriber.
- Steel rule.
- Try square.
- Dividers.
- Centre punch.
- Surface gauge.

**C. Cutting**

Cutting is the process of separating metal into the required shapes and sizes.

Methods include:

- Hacksawing.
- Shearing.
- Snipping.
- Grinding.
- Sawing.
- Machine cutting.

**D. Shaping and forming**

Shaping is the process of changing the form or geometry of a metal workpiece to obtain the required shape.

Examples:

- Bending.
- Folding.
- Rolling.
- Hammering.
- Drawing.
- Pressing.

**E. Joining**

Joining is the process of connecting two or more metal components to form a complete product.

Methods of joining include:

1. Welding.
2. Riveting.
3. Bolting.
4. Screwing.
5. Brazing.
6. Soldering.

**F. Finishing**

Finishing involves improving the appearance, surface quality and resistance to deterioration of a fabricated product.

Examples:

- Filing.
- Grinding.
- Polishing.
- Painting.
- Applying protective coatings.
- Removing burrs.

**9.0 Project demonstration: Fabrication of a metal litter bin**



**9.1 Project title**

Fabrication of a mild steel litter bin for use in a school or local community.

**9.2 Problem identified**

The school compound experiences poor waste disposal because there are inadequate waste collection facilities.

**9.3 Proposed solution**

Fabricate a durable metal litter bin that can be placed at strategic locations within the school compound.

**9.4 Objectives of the project**

By completing this project, the learner should be able to:

1. Identify a waste disposal problem in the community.
2. Prepare a simple design of a metal litter bin.
3. Select appropriate sheet metal.
4. Use measuring and marking-out tools correctly.
5. Cut and form sheet metal.
6. Join the components using suitable methods.
7. Apply appropriate surface finishing.
8. Observe workshop safety procedures.
9. Evaluate the finished product.
10. Explain how the product can generate income.

**9.5 Materials required**

| Material | Purpose |
|---|---|
| Mild steel sheet | Making the body and base |
| Mild steel strip | Making supporting edges or handles |
| Hinges | Attaching the lid |
| Mild steel rod or strip | Making handles |

| | |
|---|---|
| Welding electrodes | Joining components where welding is used |
| Primer | Protecting the surface |
| Paint | Improving appearance and protection |
| Bolts and nuts | Mechanical fastening where appropriate |

**9.6 Tools and equipment required**

- Steel rule.
- Measuring tape.
- Scriber.
- Try square.
- Centre punch.
- Tin snips or suitable cutting machine.
- Bench vice.
- Mallet.
- Welding machine.
- Welding helmet.
- Angle grinder.
- Files.
- Paintbrush.
- Drill and suitable drill bits.

**9.7 Design considerations**

The learner should consider:

- Suitable height and capacity.
- Stability when placed on the ground.
- Smooth edges to prevent injuries.
- A suitable opening for waste disposal.
- A removable or hinged lid.
- Ease of emptying and cleaning.
- Resistance to corrosion.
- Proper ventilation where appropriate.
- Safe handling and transportation.

**9.8 Fabrication procedure**

**Step 1: Prepare the design**

- Draw the proposed litter bin.
- Indicate the dimensions.
- Identify the body, base, lid and handles.
- Determine the method of joining.

**Step 2: Select materials**

- Select suitable mild steel sheet.
- Check for cracks, excessive rust and other defects.
- Determine the required sheet thickness based on the intended use.

**Step 3: Measure and mark out**

- Place the sheet on a suitable workbench.
- Use a steel rule and scriber to mark the required dimensions.
- Use a try square to ensure accurate right-angle markings.
- Mark cutting lines clearly.

**Step 4: Cut the metal**

- Secure the workpiece appropriately.
- Cut along the marked lines using suitable cutting equipment.
- Remove sharp burrs carefully.

**Step 5: Form the body**

- Bend the sheet metal to obtain the required shape.
- Use appropriate folding equipment.
- Ensure that the corners are properly aligned.

**Step 6: Prepare the base**

- Cut the base to the required dimensions.
- Position it correctly.
- Check that it fits the body.

**Step 7: Join the components**

- Use suitable welding or mechanical fastening methods.
- Ensure that the joints are strong and properly aligned.
- Allow welded components to cool safely.

**Step 8: Make and attach the lid**

- Prepare the lid according to the design.
- Attach suitable hinges.
- Check that the lid opens and closes smoothly.

**Step 9: Smooth and clean the product**

- Remove sharp edges and burrs.
- Grind or file rough areas.
- Remove dirt, oil and loose rust.

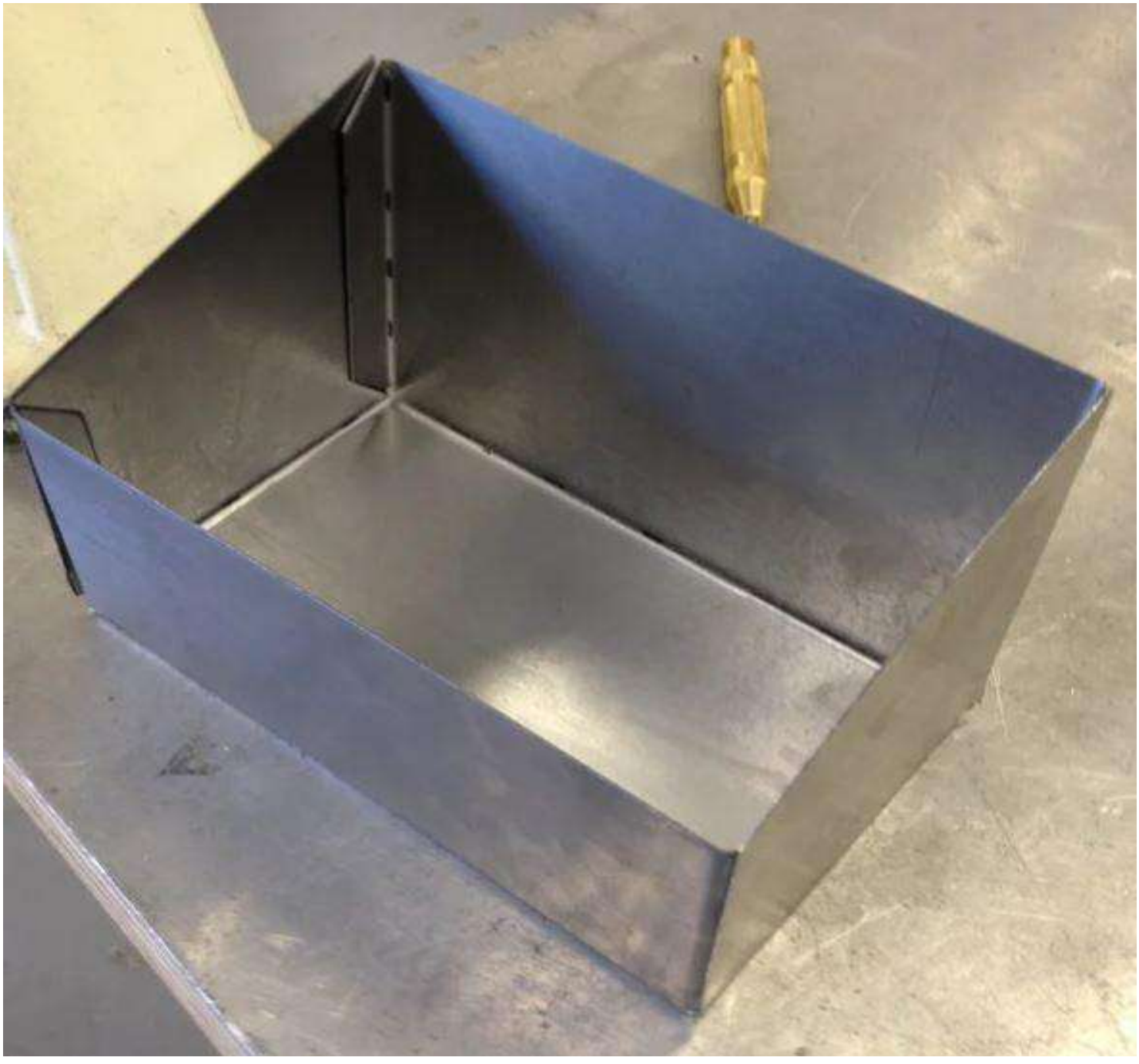
**Step 10: Apply surface finishing**

- Apply a suitable metal primer.

- Allow it to dry as recommended.
- Apply the appropriate paint.
- Allow the paint to cure properly.

**Step 11: Inspect and test the product**

- Check the dimensions.
- Check the stability.
- Inspect the joints.
- Test the lid.
- Check for sharp edges.
- Confirm that the litter bin is suitable for its intended purpose.






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**9.9 Expected outcome**

A strong, stable and durable metal litter bin that can be used to collect waste in the school or community.

**10.0 Workshop safety during project fabrication**

**10.1 Meaning of workshop safety**

Workshop safety refers to the rules, procedures and precautions followed to prevent accidents, injuries and damage to property during metalworking activities.

Safety is essential because metal fabrication involves sharp tools, heavy materials, electricity, heat, sparks and moving machinery.

**10.2 Personal protective equipment (PPE)**



Personal protective equipment refers to clothing and equipment worn to protect the body from workplace hazards.

| PPE | Purpose |
|---|---|
| Safety goggles | Protect the eyes from flying particles |
| Welding helmet | Protects the face and eyes from welding radiation and sparks |
| Leather gloves | Protect the hands from heat, sharp edges and abrasion |
| Safety boots | Protect the feet from falling objects and sharp materials |
| Overalls | Protect the body and clothing |
| Ear defenders | Reduce exposure to excessive noise |
| Respirator | Protects against specified airborne contaminants when correctly selected |

**10.3 General workshop safety precautions**

1. Wear appropriate protective clothing.
2. Keep the workshop clean and organised.

3. Use the correct tool for each operation.
4. Inspect tools and machines before use.
5. Do not operate machines without proper training and supervision.
6. Secure workpieces before cutting, drilling or grinding.
7. Keep hands away from moving machine parts.
8. Use machine guards where provided.
9. Keep flammable materials away from welding and grinding sparks.
10. Ensure proper workshop ventilation.
11. Switch off machines after use.
12. Do not wear loose clothing or jewellery near rotating machines.
13. Report accidents and damaged equipment immediately.
14. Follow the teacher's instructions.
15. Keep fire extinguishers and first-aid equipment accessible.

**10.4 Safety precautions during welding**

- Wear an appropriate welding helmet.
- Use suitable leather gloves and protective clothing.
- Ensure adequate ventilation or appropriate fume extraction.
- Inspect welding cables and connections.
- Keep combustible materials away from the welding area.
- Use welding screens to protect nearby people from arc radiation.
- Ensure proper electrical earthing and equipment condition.
- Do not touch hot metal with bare hands.
- Keep suitable fire-fighting equipment nearby.

**10.5 Safety precautions during grinding**

- Wear appropriate eye and face protection.
- Inspect the grinding disc before use.
- Ensure the correct disc is fitted for the operation.
- Never exceed the disc's rated speed.
- Keep the machine guard in position.
- Hold the grinder firmly with both hands where required.
- Direct sparks away from people and flammable materials.
- Allow the disc to stop completely before putting the machine down.

**10.6 Importance of observing workshop safety**

- Prevents accidents.
- Reduces injuries.

- Protects equipment.
- Promotes efficient working.
- Improves product quality.
- Develops responsible working habits.
- Creates a safe learning environment.

**11.0 Evaluation and testing of the finished project**

**11.1 Meaning of project evaluation**

Project evaluation is the process of examining a completed product to determine whether it meets the intended purpose and required quality standards.

It helps the learner identify strengths, weaknesses and areas that require improvement.

**11.2 Factors considered when evaluating a metalwork product**

1. **Accuracy:** Whether the product has the correct dimensions.
2. **Strength:** Whether it can withstand the intended loads.
3. **Stability:** Whether it stands firmly during use.
4. **Functionality:** Whether it performs the intended task.
5. **Appearance:** Whether it has an acceptable finish.
6. **Safety:** Whether it has sharp edges or other hazards.
7. **Durability:** Whether it can withstand normal use.
8. **Cost:** Whether the cost of production was reasonable.
9. **Workmanship:** Whether the joints and components are properly made.
10. **Environmental suitability:** Whether the product can be used and maintained without unnecessary environmental harm.

**11.3 Methods of testing a fabricated product**

- Visual inspection.
- Dimensional inspection.
- Functional testing.
- Stability testing.
- Joint inspection.
- Surface-finish inspection.
- Appropriate load testing.

Testing should be conducted under controlled conditions and within the safe design limits of the product.

**11.4 Importance of evaluating a project**

- Identifies fabrication errors.
- Ensures the product meets user requirements.
- Improves workmanship.
- Promotes quality control.

- Identifies areas for modification.
- Increases customer satisfaction.
- Develops critical thinking and problem-solving skills.

**12.0 Presentation of the fabricated item**

**12.1 Meaning of project presentation**

Project presentation is the process of displaying and explaining a completed product to an audience.

In Metal Technology, learners present their fabricated items to classmates, teachers and other relevant community members.

**12.2 Information to include during presentation**

The learner should explain:

1. The name of the project.
2. The community problem identified.
3. Why the problem was selected.
4. The proposed solution.
5. The materials used.
6. The tools and equipment used.
7. The fabrication procedures followed.
8. The safety precautions observed.
9. The challenges experienced.
10. How the challenges were addressed.
11. The functions of the finished product.
12. Possible improvements.
13. The estimated cost of production.
14. How the product can benefit the community.

**12.3 Importance of presenting a project**

- Develops communication skills.
- Builds confidence.
- Encourages sharing of ideas.
- Promotes peer learning.
- Provides an opportunity to receive feedback.
- Demonstrates practical competence.
- Encourages innovation.

**13.0 Entrepreneurship and income generation through Metal Technology projects**

**13.1 Meaning of entrepreneurship**

Entrepreneurship is the process of identifying business opportunities, organising resources and undertaking activities to produce goods or services for economic and social benefit.

Metal Technology provides opportunities for learners to develop entrepreneurial skills through fabrication, repair and maintenance of metal products.

**13.2 Ways of generating income through metalwork**

**1. Selling fabricated products**

Learners or trained artisans can make and sell products such as:

- Metal chairs.
- Tables.
- Gates.
- Litter bins.
- Bookshelves.
- Tool cabinets.
- Clothes-drying racks.
- Livestock equipment.

**2. Offering repair services**

Metalworkers can earn income by repairing:

- Broken metal gates.
- Damaged furniture.
- Metal doors.
- Farm implements.
- Metal containers.
- Wheelbarrows.

**3. Offering fabrication services**

Customers may provide specifications for products they want fabricated.

Examples include:

- Making window grills.
- Constructing metal shelves.
- Fabricating metal frames.
- Making security gates.
- Making metal stands.

**4. Participating in exhibitions**

Learners can display their products during:

- School open days.
- Agricultural shows.
- County exhibitions.
- Community innovation events.
- Technical education exhibitions.

**5. Producing customised products**

Metalworkers can make products according to customers' preferences, measurements and requirements.

**13.3 Entrepreneurial skills developed through Metal Technology**

- Creativity.
- Innovation.
- Communication.
- Financial management.
- Customer care.
- Problem-solving.
- Marketing.
- Time management.
- Decision-making.
- Record keeping.

**13.4 Factors to consider when pricing a fabricated product**

The selling price should take into consideration:

1. Cost of raw materials.
2. Labour costs.
3. Electricity and other energy costs.
4. Transport costs.
5. Tool and equipment maintenance.
6. Finishing costs.
7. Other overhead expenses.
8. Desired profit.

**Example of costing a metal litter bin**

The following is an illustrative costing exercise.

| Item | Estimated cost (KSh) |
|---|---|
| Mild steel sheet | 1,500 |
| Hinges and fasteners | 250 |
| Welding consumables | 300 |
| Primer and paint | 450 |
| Labour | 700 |
| Transport and other costs | 300 |
| Total production cost | 3,500 |

If the product is sold at KSh 4,200:

Profit = Selling price − Total production cost

Profit = 4,200 − 3,500

**Profit = KSh 700**

The actual cost will depend on material prices, dimensions, design and labour requirements in the locality.

**14.0 Challenges experienced during metalwork projects and possible solutions**

| Challenge | Possible solution |
|---|---|
| High cost of materials | Use suitable reusable materials and minimise wastage |
| Inadequate tools | Share available tools under supervision or seek access to suitable equipment |
| Lack of fabrication skills | Practise and seek guidance from qualified instructors |
| Incorrect measurements | Use appropriate measuring instruments and verify dimensions |
| Material wastage | Prepare a cutting list before cutting |
| Poor-quality joints | Practise correct joining procedures and inspect joints |
| Corrosion | Apply suitable protective coatings |
| Insufficient working time | Prepare a realistic work schedule |
| Equipment breakdown | Conduct regular inspection and maintenance |
| Safety risks | Follow workshop safety procedures and use appropriate PPE |

**15.0 Environmental conservation in metalwork projects**

Environmental conservation involves protecting natural resources and reducing harmful effects of human activities on the environment.

Metalwork projects can contribute to environmental conservation through:

1. Reusing suitable metal offcuts.
2. Recycling scrap metals.
3. Minimising material wastage.
4. Collecting and disposing of metal waste responsibly.
5. Preventing oil and chemical spills.
6. Using materials efficiently.
7. Applying environmentally appropriate finishing products.
8. Maintaining equipment to reduce unnecessary energy consumption.
9. Keeping workshops clean.
10. Separating recyclable waste from general waste.

**Importance of environmental conservation in Metal Technology**

- Reduces pollution.
- Conserves natural resources.
- Reduces production costs.
- Promotes sustainable development.
- Encourages responsible use of materials.
- Creates opportunities for recycling businesses.

**16.0 Documentation and record keeping in project work**

Project documentation involves recording important information about the planning, fabrication, testing and presentation of a project.

**16.1 Important project records**

A learner should maintain:

- Project proposal.
- Problem identification report.

- Design sketches.
- Working drawings.
- Materials list.
- Tools and equipment list.
- Cost estimate.
- Fabrication procedure.
- Work schedule.
- Safety checklist.
- Progress report.
- Testing and evaluation report.
- Final project presentation.

**16.2 Importance of project documentation**

1. Provides evidence of work completed.
2. Helps monitor project progress.
3. Makes it easier to identify mistakes.
4. Supports accurate costing.
5. Provides information for future improvements.
6. Helps assess individual contribution.
7. Develops organisational skills.

**GRADE 11 METAL TECHNOLOGY**

**STRAND 2.0: TOOLS AND MATERIALS IN METALWORK**

**SUB-STRAND 2.4: PROJECT**

**Time:** 1 Hour 30 Minutes

**Total Marks:** 80

**Instructions to learners**

1. Answer all questions in Section A.
2. Answer all questions in Section B.
3. Write your answers clearly.
4. Observe the numbering of questions.
5. Draw neat, labelled sketches where necessary.

**SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)**

Choose the correct answer from the alternatives A, B, C and D.

**1.** What is a metalwork project?

A. An activity involving only the sharpening of tools.

B. A practical activity involving the application of metalworking skills to produce a useful item.

C. An activity involving the purchase of finished metal products.

D. A process of storing metals in a workshop.

**2.** Which of the following is an example of a community problem that can be solved using Metal Technology?

A. Lack of rainfall.

B. Inadequate waste collection facilities.

C. High population growth.

D. Soil erosion caused by heavy rainfall.

**3.** Which of the following is the most appropriate source of information when identifying problems in a community?

A. Guessing.

B. Copying unrelated designs.

C. Interviewing community members.

D. Avoiding community interaction.

**4.** A learner identifies poor waste disposal in school as a community problem. Which item would be most appropriate to fabricate?

A. Metal litter bin.

B. Metal bookshelf.

C. Metal ruler.

D. Metal window frame.

**5.** What is a project proposal?

A. A report written after selling a product.

B. A description of a proposed project and how it will be carried out.

C. A list of finished products in a workshop.

D. A record of machine breakdowns.

**6.** Which factor is most important when selecting a suitable community metalwork project?

A. The colour of the workshop walls.

B. The popularity of the learner.

C. Its ability to address a genuine community need.

D. The number of machines in the school office.

**7.** Which metal is commonly preferred for general fabrication because it is relatively easy to weld and form?

A. Mild steel.

B. Gold.

C. Silver.

D. Lead.

**8.** The main purpose of preparing a design sketch is to:

A. Increase the cost of production.

B. Guide the fabrication process.

C. Replace all workshop tools.

D. Eliminate the need for measurements.

**9.** Which of the following is used for marking fine lines on a metal surface?

A. Hammer.

B. Scriber.

C. File.

D. Chisel.

**10.** Which tool is suitable for checking right angles during marking out?

A. Try square.

B. Divider.

C. Centre punch.

D. Hacksaw.

**11.** Which of the following tools is mainly used for cutting thin sheet metal?

A. Tin snips.

B. Bench vice.

C. Mallet.

D. Steel rule.

**12.** What is the main function of a bench vice?

A. Measuring dimensions.

B. Holding a workpiece securely.

C. Producing holes.

D. Painting metal surfaces.

**13.** Which machine is mainly used to produce circular holes in metal?

A. Lathe.

B. Drilling machine.

C. Bench grinder.

D. Power hacksaw.

**14.** Which of the following is a metal joining process?

A. Filing.

B. Grinding.

C. Welding.

D. Measuring.

**15.** What is the main purpose of applying primer to a mild steel product?

A. To increase its weight.

B. To provide a protective base for the finishing coat.

C. To make the metal softer.

D. To reduce its dimensions.

**16.** Which property makes stainless steel suitable for many kitchen applications?

A. High corrosion resistance.

B. Poor strength.

C. High rust formation.

D. Low durability.

**17.** What is the main advantage of using aluminium in some metalwork projects?

A. It is extremely heavy.

B. It is lightweight and corrosion-resistant.

C. It rusts easily.

D. It cannot be shaped.

**18.** What is recycling?

A. Throwing away all scrap materials.

B. Converting used materials into new products.

C. Burning metal waste.

D. Storing waste indefinitely.

**19.** Which of the following is a suitable method of reducing material wastage?

A. Cutting without measurements.

B. Preparing a cutting list.

C. Ignoring the design.

D. Using defective materials.

**20.** Which PPE is specifically designed to protect the eyes and face during arc welding?

A. Cotton cap.

B. Welding helmet.

C. Safety sandals.

D. Ordinary spectacles.

**21.** Why should a workpiece be secured before drilling?

A. To increase vibration.

B. To prevent movement and improve safety.

C. To make the drill blunt.

D. To reduce the machine speed automatically.

**22.** Which of the following is an appropriate finishing operation?

A. Polishing.

B. Measuring.

C. Marking out.

D. Drilling.

**23.** What is the purpose of project evaluation?

A. To identify the quality and effectiveness of the finished product.

B. To increase the number of workshop accidents.

C. To avoid testing the product.

D. To prevent learners from making improvements.

**24.** Which of the following is an example of an income-generating activity in Metal Technology?

A. Disposing of all workshop tools.

B. Selling fabricated metal furniture.

C. Avoiding customer interaction.

D. Destroying unused metal products.

**25.** A metalworker fabricates gates according to customers' measurements. This is an example of:

A. Customised fabrication.

B. Material disposal.

C. Metal recycling only.

D. Workshop cleaning.

**26.** Which of the following should be considered when estimating the selling price of a metal product?

A. Material costs only.

B. Labour costs only.

C. Production costs and desired profit.

D. The colour of the product only.

**27.** Which document shows the sequence of operations to be followed when making a product?

A. Fabrication procedure.

B. Attendance register.

C. Shopping receipt.

D. Sales poster.

**28.** Why is project presentation important?

A. It prevents learners from explaining their work.

B. It provides an opportunity to demonstrate and communicate the project's value.

C. It eliminates the need for fabrication.

D. It discourages feedback.

**29.** Which of the following is an environmental conservation practice in Metal Technology?

A. Dumping metal waste in rivers.

B. Burning painted metal waste in open spaces.

C. Reusing suitable metal offcuts.

D. Allowing oil to drain into the soil.

**30.** Which core competency is mainly developed when learners work together to fabricate a metal product?

A. Communication and collaboration.

B. Memorisation only.

C. Competition without cooperation.

D. Isolation.

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

Answer all questions.

**1. Identification of community problems (8 marks)**

a) Define the term community problem as used in Metal Technology. (2 marks)

b) State three problems in your locality that can be solved through metal fabrication. (3 marks)

c) State three methods that can be used to identify community problems. (3 marks)

**2. Project selection and planning (8 marks)**

a) What is a project proposal? (2 marks)

b) State four factors that should be considered when selecting a suitable Metal Technology project. (4 marks)

c) Give two reasons why a design sketch is important before starting fabrication. (2 marks)

**3. Materials and tools (8 marks)**

a) State four materials that may be used when fabricating a metal litter bin. (4 marks)

b) State four tools or equipment that may be required when fabricating a metal litter bin. (4 marks)

**4. Fabrication procedures (10 marks)**

A group of Grade 11 learners decides to fabricate a metal bookshelf for their school library.

a) State four important operations involved in fabricating the bookshelf. (4 marks)

b) Explain three factors that should be considered when selecting materials for the bookshelf. (3 marks)

c) State three quality checks that should be conducted on the completed bookshelf. (3 marks)

**5. Workshop safety and environmental conservation (8 marks)**

a) State four safety precautions that should be observed during metal fabrication. (4 marks)

b) State four ways of promoting environmental conservation during metalwork project activities. (4 marks)

**6. Project evaluation and entrepreneurship (8 marks)**

A learner fabricates a metal wheelbarrow to help farmers transport farm produce.

a) State three ways of evaluating the finished wheelbarrow. (3 marks)

b) Explain two ways in which the learner can generate income from the fabricated wheelbarrow. (2 marks)

c) State three factors that should be considered when determining the selling price of the wheelbarrow. (3 marks)

**TEACHER'S MARKING SCHEME**

**SECTION A: MULTIPLE-CHOICE ANSWERS**

| Question | Answer | Question | Answer |
|---|---|---|---|
| 1 | B | 16 | A |
| 2 | B | 17 | B |
| 3 | C | 18 | B |
| 4 | A | 19 | B |
| 5 | B | 20 | B |
| 6 | C | 21 | B |
| 7 | A | 22 | A |
| 8 | B | 23 | A |
| 9 | B | 24 | B |
| 10 | A | 25 | A |
| 11 | A | 26 | C |
| 12 | B | 27 | A |
| 13 | B | 28 | B |
| 14 | C | 29 | C |
| 15 | B | 30 | A |

30 marks

Each correct answer earns 1 mark.

**SECTION B: SUGGESTED ANSWERS AND MARKING GUIDE**

**Question 1. Identification of community problems (8 marks)**

**a) Definition (2 marks)**

A community problem is a challenge or difficulty experienced by people in a particular locality that affects their daily activities, safety, productivity or well-being.

**b) Problems (3 marks)**

Any three:

- Inadequate waste collection facilities.
- Lack of school furniture.
- Inadequate storage facilities.
- Poor security gates.
- Lack of suitable farming equipment.
- Inadequate livestock feeding equipment.
- Lack of clothes-drying facilities.

Award 1 mark each.

**c) Methods of identification (3 marks)**

Any three:

- Observation.
- Interviews.
- Questionnaires.
- Community discussions.
- School visits.
- Market visits.
- Research.

Award 1 mark each.

**Question 2. Project selection and planning (8 marks)**

**a) Project proposal (2 marks)**

A project proposal is a written description of a planned project indicating the problem to be addressed, the proposed solution and the resources and procedures required to complete it.

**b) Factors (4 marks)**

Any four:

- Availability of materials.
- Availability of tools and machines.
- Cost of production.
- Time available.
- Level of difficulty.
- Safety.
- Usefulness to the community.
- Durability.
- Environmental impact.

Award 1 mark each.

**c) Importance of a design sketch (2 marks)**

Any two:

- Guides the fabrication process.
- Shows the shape and appearance of the product.
- Helps establish dimensions.
- Reduces fabrication errors.
- Helps estimate material requirements.

Award 1 mark each.

**Question 3. Materials and tools (8 marks)**

**a) Materials (4 marks)**

Any four:

- Mild steel sheet.
- Mild steel strip.
- Hinges.
- Welding electrodes.
- Bolts and nuts.
- Primer.
- Paint.
- Mild steel rods.

Award 1 mark each.

**b) Tools and equipment (4 marks)**

Any four:

- Steel rule.
- Scriber.
- Try square.
- Tin snips.
- Hacksaw.
- Bench vice.
- Welding machine.
- Angle grinder.
- File.
- Measuring tape.

Award 1 mark each.

**Question 4. Fabrication procedures (10 marks)**

**a) Fabrication operations (4 marks)**

Any four:

- Measuring.

- Marking out.
- Cutting.
- Drilling.
- Bending.
- Welding.
- Bolting.
- Filing.
- Grinding.
- Painting.

Award 1 mark each.

**b) Material selection factors (3 marks)**

Any three, with appropriate explanations:

1. **Strength:** The material should support the weight of books without excessive bending.
2. **Durability:** The material should withstand regular use.
3. **Cost:** The material should be affordable.
4. **Availability:** The material should be locally accessible.
5. **Corrosion resistance:** The material should resist rusting or be capable of suitable protection.
6. **Workability:** The material should be easy to cut, shape and join using available equipment.

Award 1 mark each.

**c) Quality checks (3 marks)**

Any three:

- Check dimensional accuracy.
- Check the strength of joints.
- Check stability.
- Check surface finish.
- Check for sharp edges.
- Check alignment of shelves.
- Check that the bookshelf can support its intended load.

Award 1 mark each.

**Question 5. Workshop safety and environmental conservation (8 marks)**

**a) Safety precautions (4 marks)**

Any four:

- Wear appropriate PPE.
- Use the correct tool for each operation.
- Secure workpieces before cutting or drilling.

- Keep the workshop clean.
- Inspect machines before use.
- Ensure adequate ventilation.
- Keep flammable materials away from sparks.
- Switch off machines after use.
- Avoid loose clothing near rotating machinery.
- Follow instructor instructions.

Award 1 mark each.

**b) Environmental conservation (4 marks)**

Any four:

- Reuse suitable metal offcuts.
- Recycle scrap metals.
- Minimise material wastage.
- Dispose of waste responsibly.
- Prevent oil and chemical spills.
- Use environmentally appropriate finishing materials.
- Maintain machines to reduce energy wastage.
- Keep the workshop clean.

Award 1 mark each.

**Question 6. Project evaluation and entrepreneurship (8 marks)**

**a) Evaluation methods (3 marks)**

Any three:

- Checking the dimensions.
- Testing the stability.
- Inspecting the joints.
- Checking the strength.
- Testing the functionality.
- Inspecting the surface finish.

Award 1 mark each.

**b) Income generation (2 marks)**

Any two:

- Selling the wheelbarrow to farmers.
- Making wheelbarrows according to customer orders.
- Offering wheelbarrow repair services.
- Producing wheelbarrows for agricultural shops.

Award 1 mark each.

**c) Selling price factors (3 marks)**

Any three:

- Cost of materials.
- Labour costs.
- Electricity and energy costs.
- Transport costs.
- Finishing costs.
- Overhead expenses.
- Desired profit.

Award 1 mark each.

**19.0 Practical learner activity**

**Activity: Design and fabricate a useful metal product for your community.**

In groups, identify a problem in your school or local community that can be solved using Metal Technology.

Choose one suitable product and undertake the following activities:

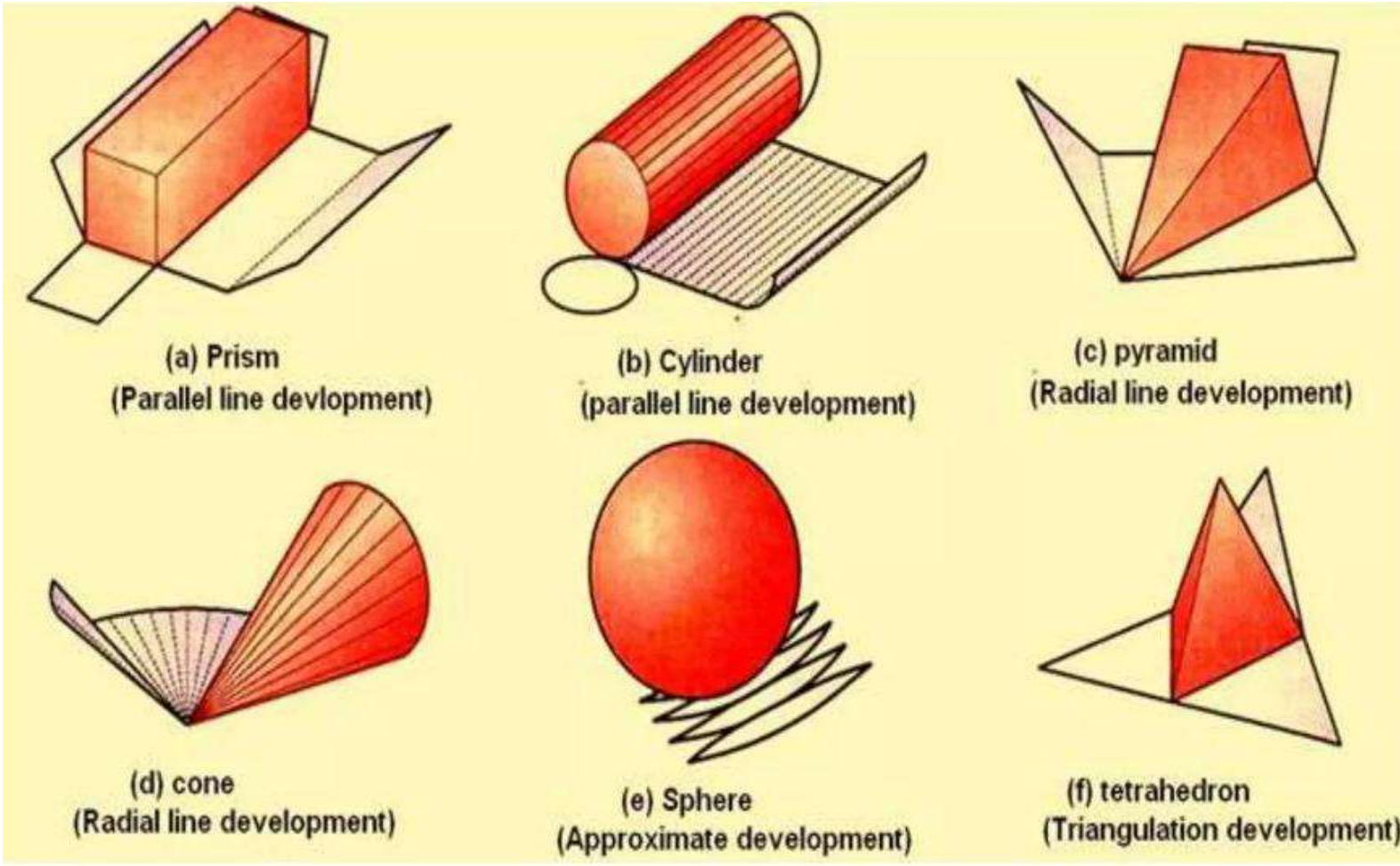
1. Investigate and describe the problem.
2. Propose a suitable metal product.
3. Prepare a labelled design sketch.
4. Identify the materials required.
5. List the tools and equipment required.
6. Prepare a fabrication procedure.
7. Identify possible hazards and safety precautions.
8. Fabricate the product under the teacher's supervision.
9. Test and evaluate the completed product.
10. Present the product to the class.
11. Explain how the product can be marketed and sold.

**Expected evidence of learning**

- Project proposal.
- Design sketch.
- Materials and tools list.
- Fabrication procedure.
- Safety checklist.
- Completed metal product.
- Project evaluation report.
- Oral presentation.

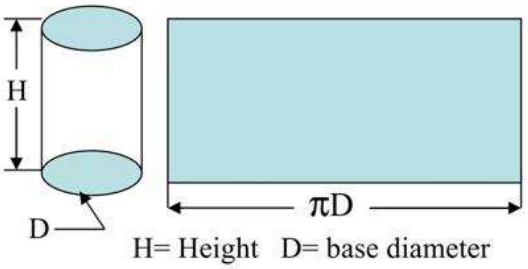
**STRAND 3.0: RELATED DRAWING IN METALWORK**

**SUB-STRAND 3.1: SURFACE DEVELOPMENT**



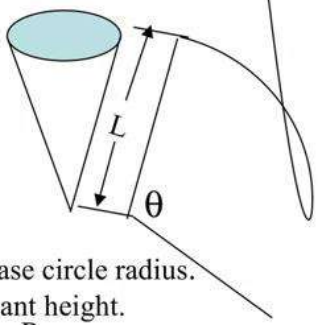
Development of lateral surfaces of different solids.
(Lateral surface is the surface excluding top & base)

*Cylinder:* A Rectangle




H= Height D= base diameter

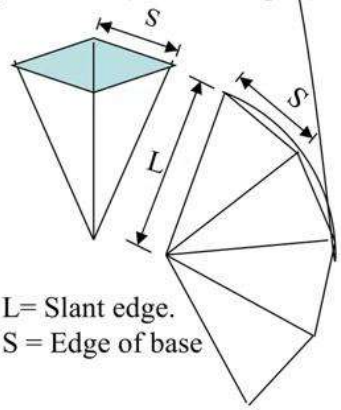
*Cone:* (Sector of circle)




R=Base circle radius.
L=Slant height.

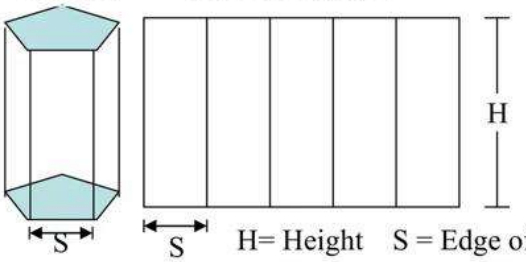
$$\theta = \frac{R}{L} \times 360^0$$

*Pyramids*: (No.of triangles)



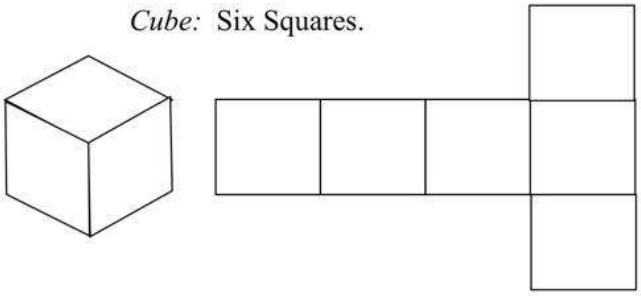

L= Slant edge.
S = Edge of base

*Prisms*: No.of Rectangles

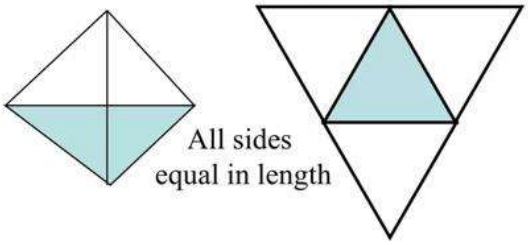


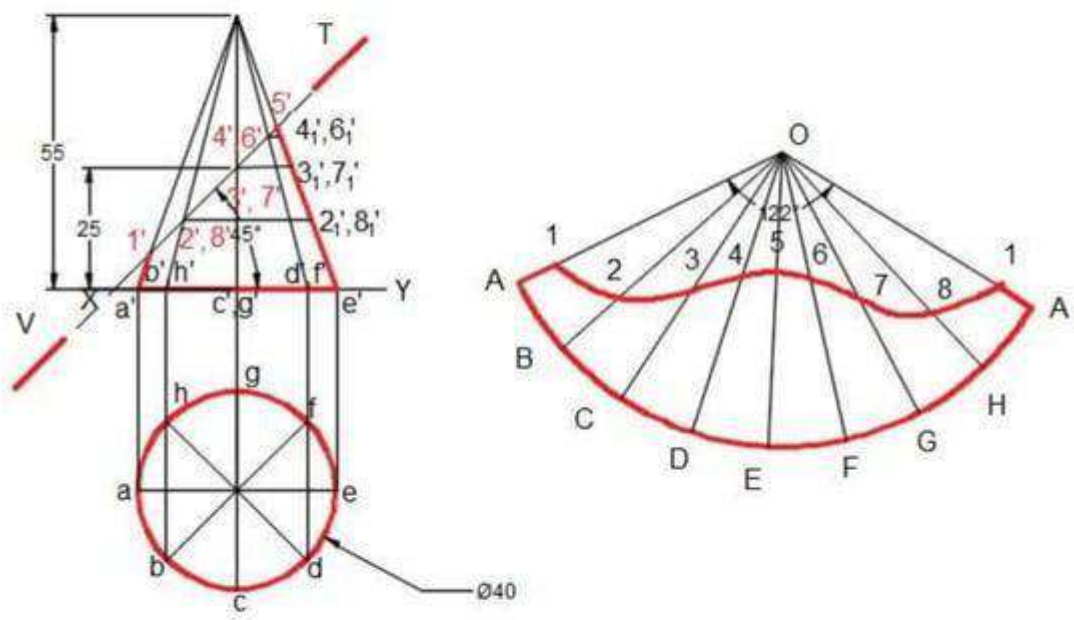

H= Height S = Edge of base

*Cube:* Six Squares.



*Tetrahedron:* Four Equilateral Triangles






## 1.0 INTRODUCTION TO SURFACE DEVELOPMENT

Surface development is an important aspect of related drawing in Metal Technology. It involves unfolding the surfaces of three-dimensional objects onto a flat plane to produce two-dimensional patterns that can be used to cut and fabricate sheet metal components.

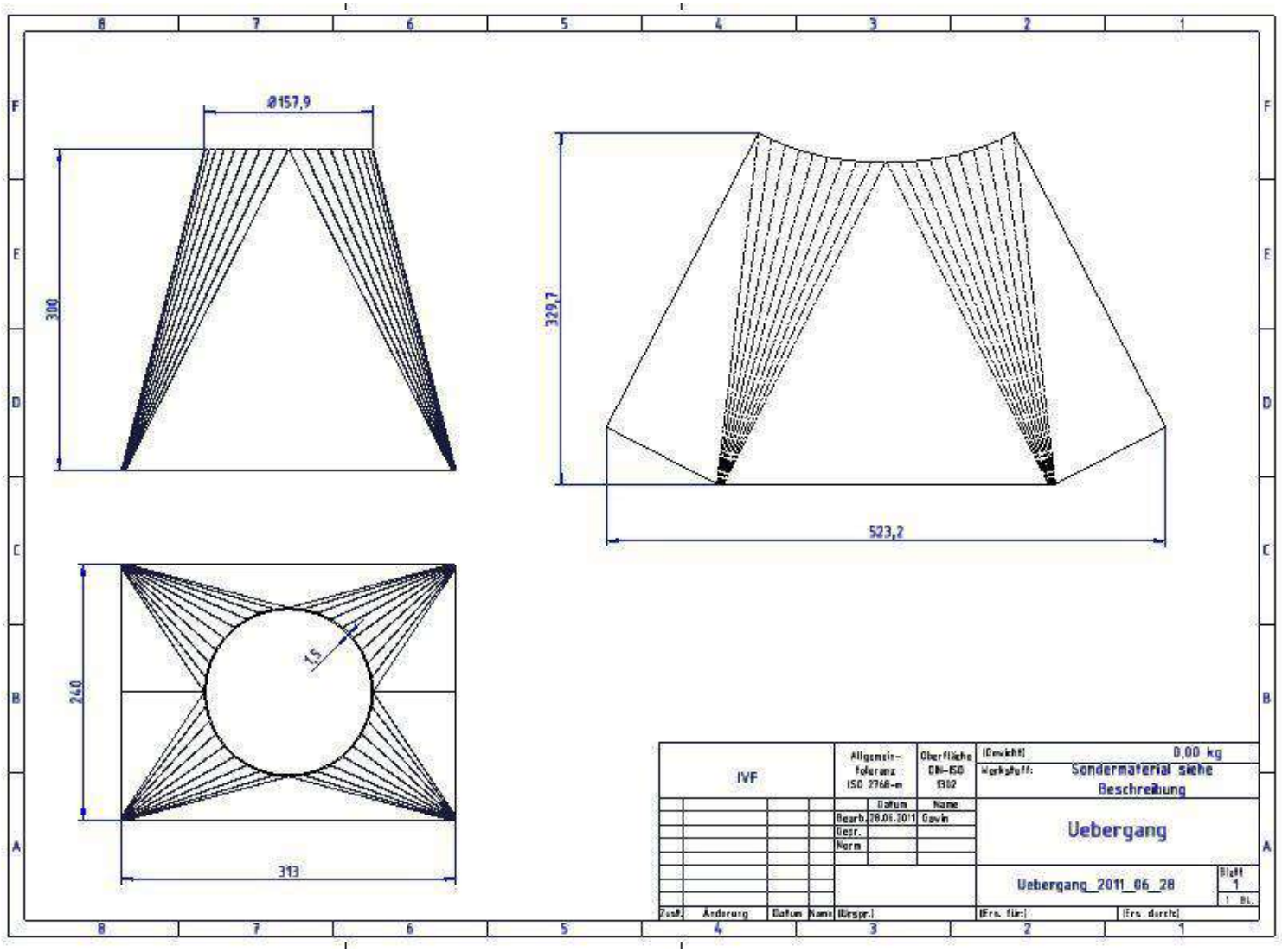
In metal fabrication, many products are first designed as three-dimensional objects but are manufactured from flat sheets of metal. The metalworker must therefore determine how the flat sheet should be marked, cut, folded, bent or joined to produce the required object.

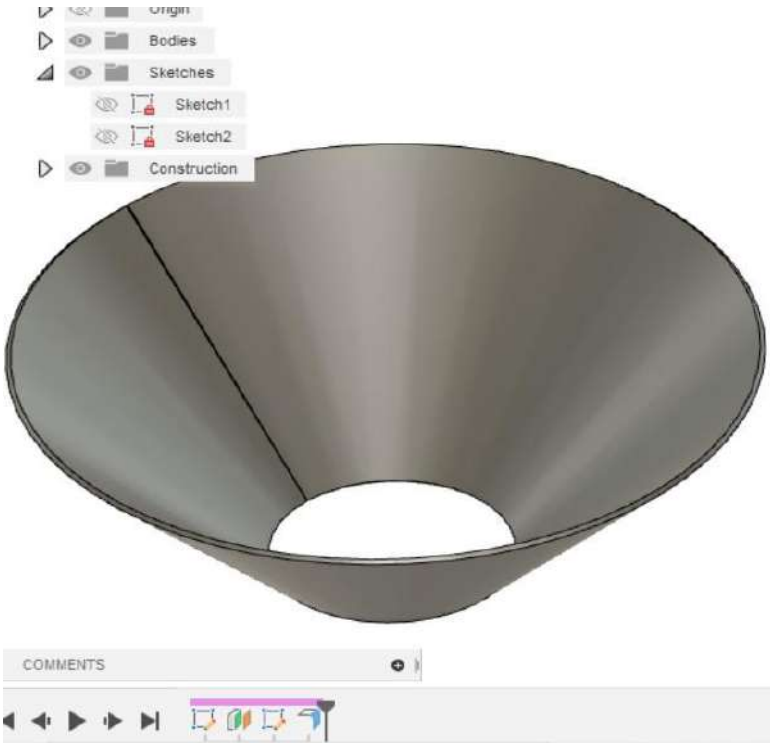
Surface development provides the necessary information for producing accurate sheet metal patterns before fabrication begins.

Examples of products made using surface development include:

1. Water tanks.
2. Metal funnels.
3. Ventilation ducts.
4. Metal buckets.
5. Cooking pots.
6. Roofing gutters.
7. Chimney pipes.
8. Metal containers.
9. Hoppers.
10. Machine covers.

11. Storage bins.
12. Sheet metal trays.





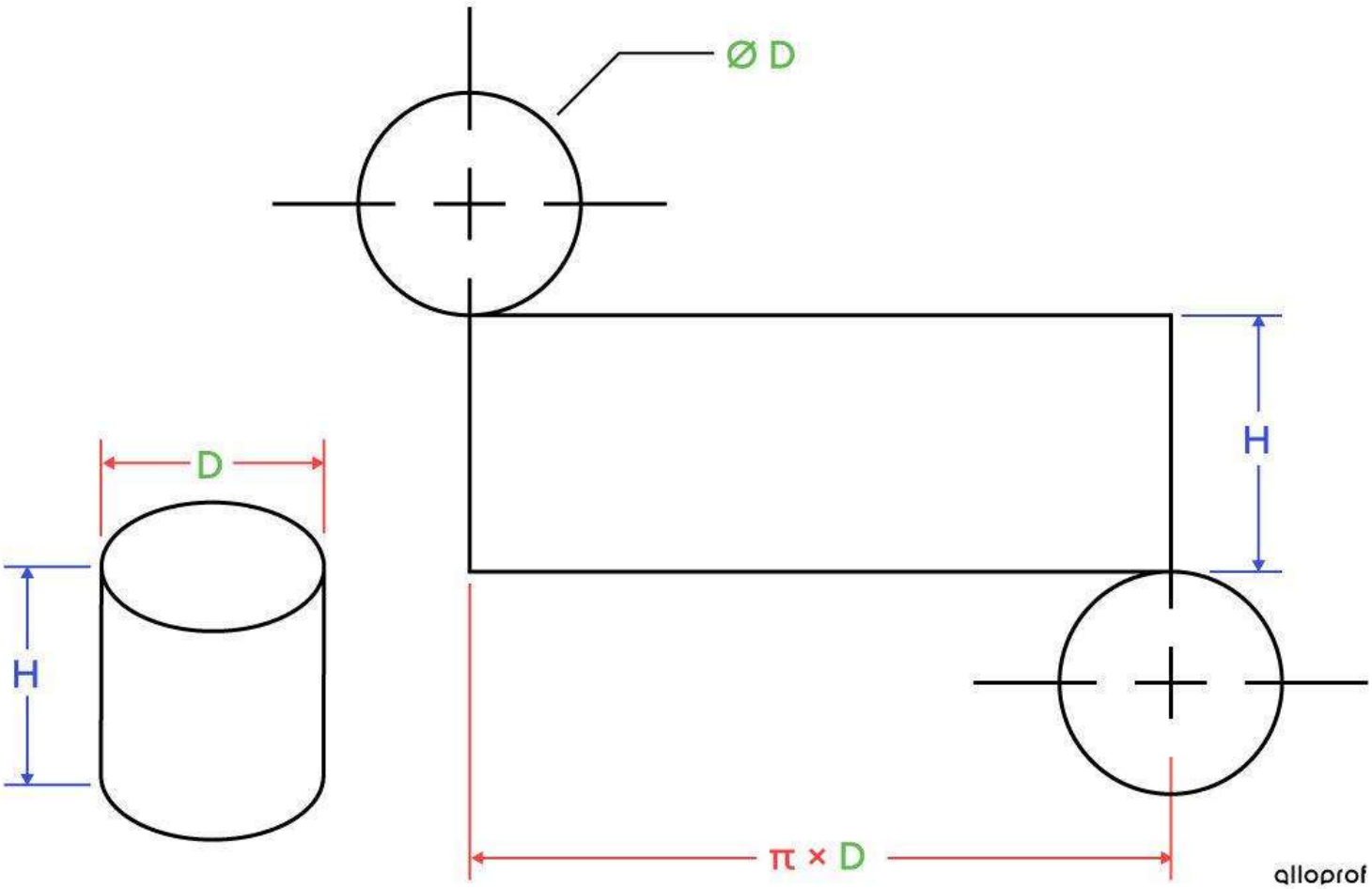

### 1.1 Definition of Surface Development

Surface development is the process of unfolding or laying out the surfaces of a three-dimensional solid onto a flat two-dimensional plane to obtain a pattern that can be used in manufacturing the object.

In simple terms, it is the process of converting the outside surfaces of a solid object into a flat pattern without changing their actual surface dimensions.

**Example:**

A cylindrical water tank is made from a rectangular sheet of metal rolled into a cylinder and joined along its vertical edges. The rectangular sheet represents the developed curved surface of the cylinder.




### 1.2 Important Terms Used in Surface Development

**a) Development**

The unfolded representation of the surface of a three-dimensional object on a flat plane.

**b) Pattern**

A flat shape produced through surface development. It is used as a guide when marking out and cutting sheet metal.

**c) Generator**

A straight line that moves along a defined path to produce a surface.

For example, a vertical straight line moving around a circular path generates a cylindrical surface.

**d) Seam**

A joint formed when two edges of sheet metal are connected during fabrication.

Examples include:

- Lap seam.
- Grooved seam.
- Locked seam.
- Riveted seam.

**e) Fold line**

A line marked on sheet metal to indicate where the material should be bent or folded.

**f) Cutting line**

A line that indicates where sheet metal should be cut to obtain the required pattern.

**g) True length**

The actual length of a line or edge of an object.

**h) Truncation**

The process of cutting off part of a solid object using a plane that does not necessarily pass through its complete length or height.

**i) Intersection**

The line or curve formed where two or more surfaces meet or penetrate one another.

**j) Allowance**

Additional material provided on a developed pattern to facilitate joining, folding, bending or finishing.

## 2.0 IMPORTANCE OF SURFACE DEVELOPMENT IN METALWORK

Surface development is important in metal fabrication because it enables metalworkers to prepare accurate patterns before cutting and assembling sheet metal.

The importance includes:

### 2.1 Accurate production of metal components

- It enables metalworkers to obtain accurate dimensions when marking out sheet metal.
- It ensures that the developed pattern corresponds to the required shape and size.
- It reduces errors during fabrication.
- It helps components fit together correctly.

### 2.2 Minimising material wastage

- Accurate patterns help metalworkers use sheet metal economically.
- They reduce unnecessary cutting and trimming.
- They help arrange patterns efficiently on available sheets.
- This reduces production costs.

### 2.3 Saving time during fabrication

- Development allows patterns to be prepared before the actual fabrication process.
- It reduces repeated measuring and trial fitting.
- It makes production faster and more organised.

**2.4 Production of complex shapes**

Surface development enables metalworkers to manufacture components with different geometrical shapes, such as:

- Cylinders.
- Cones.
- Pyramids.
- Prisms.
- Transition pieces.
- Intersecting pipes.

**2.5 Improving the quality of finished products**

- Accurate development improves the fitting of edges and joints.
- It reduces gaps and unnecessary distortions.
- It helps produce components with the required dimensions.

**2.6 Supporting mass production**

- The same accurate pattern can be used to manufacture many identical components.
- It promotes consistency in the dimensions of manufactured products.
- It makes standardisation easier.

**2.7 Promoting safety**

- Correctly developed patterns reduce the need for excessive adjustment during fabrication.
- They help minimise poorly fitted joints and unstable components.

**2.8 Supporting creativity and innovation**

- Metalworkers can design and manufacture different products.
- It encourages problem-solving and creative thinking.
- It enables the production of customised metal components.

**Kenyan workshop applications**

Surface development is used in:

- Fabrication of water tanks in local metal workshops.
- Production of metal roofing accessories.
- Manufacturing of jikos and cooking equipment.
- Construction of ventilation systems in buildings.
- Fabrication of agricultural equipment and storage containers.

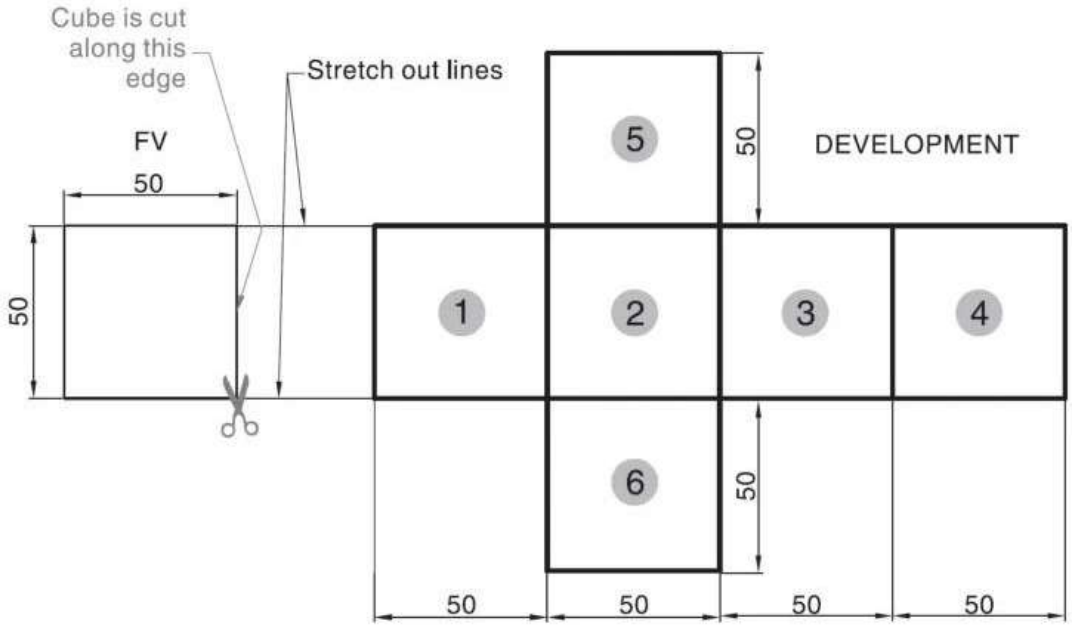
**3.0 METHODS OF SURFACE DEVELOPMENT**

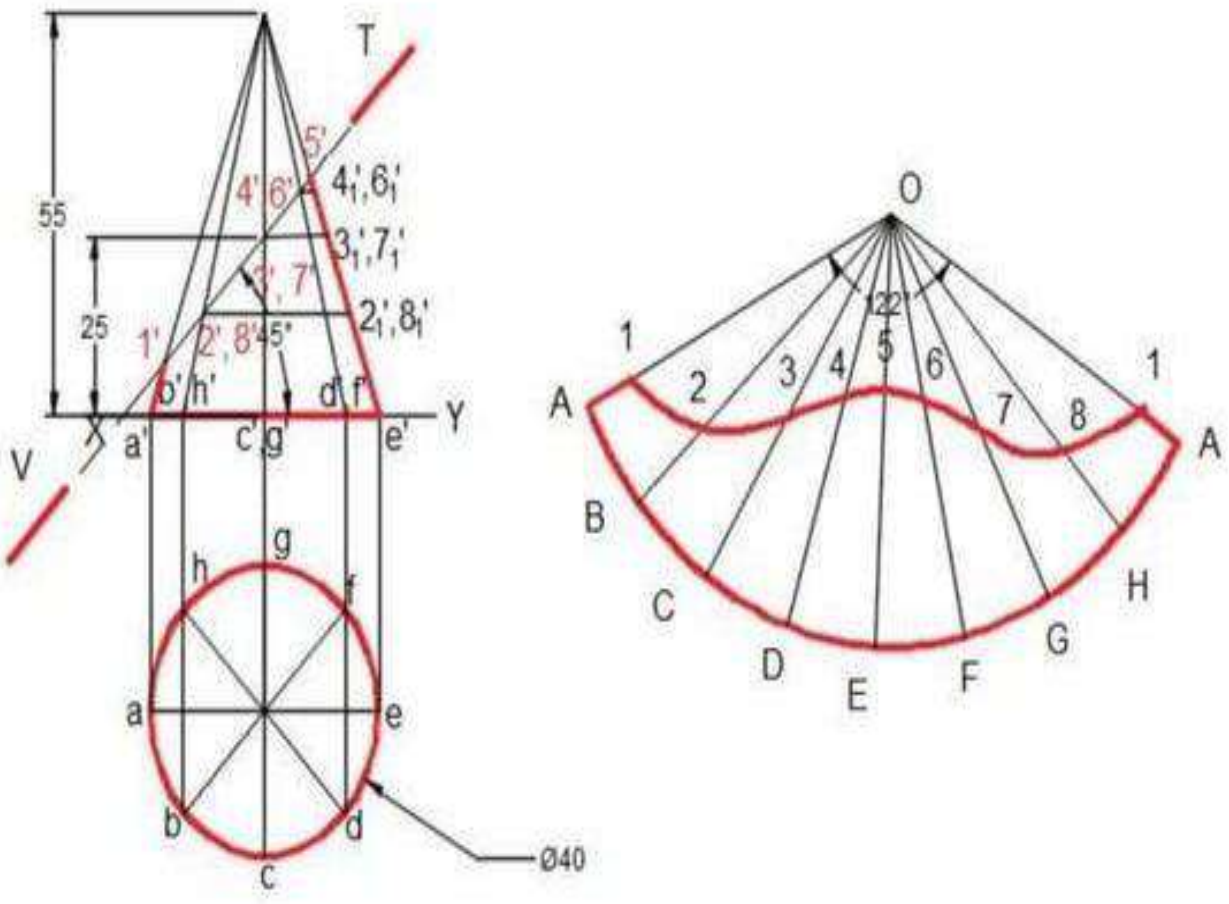
There are four main methods of surface development used in Metal Technology.

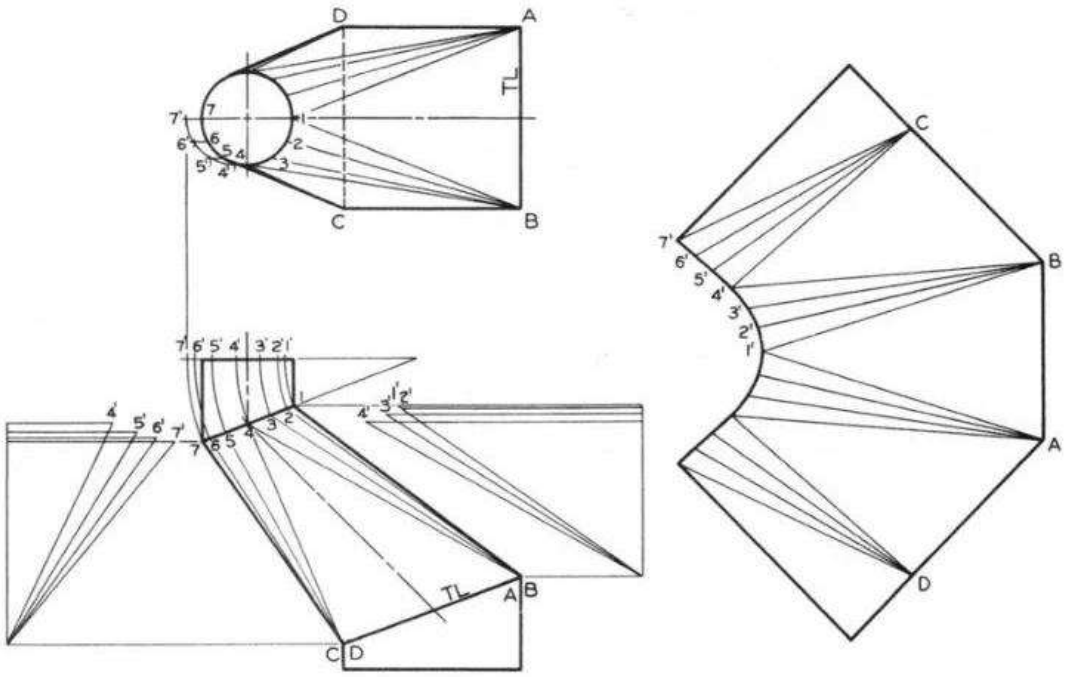
1. Parallel-line development.
2. Radial-line development.
3. Triangulation development.

4. Approximate development.

Transition development is also an important application of surface development, particularly when connecting components of different shapes or sizes.






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**3.1 Parallel-Line Development**

**Definition**

Parallel-line development is a method of surface development in which the surfaces of an object are unfolded by drawing a series of parallel lines called generators.

The generators remain parallel to one another throughout the development.

This method is mainly used for objects having parallel sides or surfaces.

**Objects developed using the parallel-line method**

1. Cylinders.
2. Square prisms.
3. Rectangular prisms.
4. Hexagonal prisms.
5. Other prismatic objects.

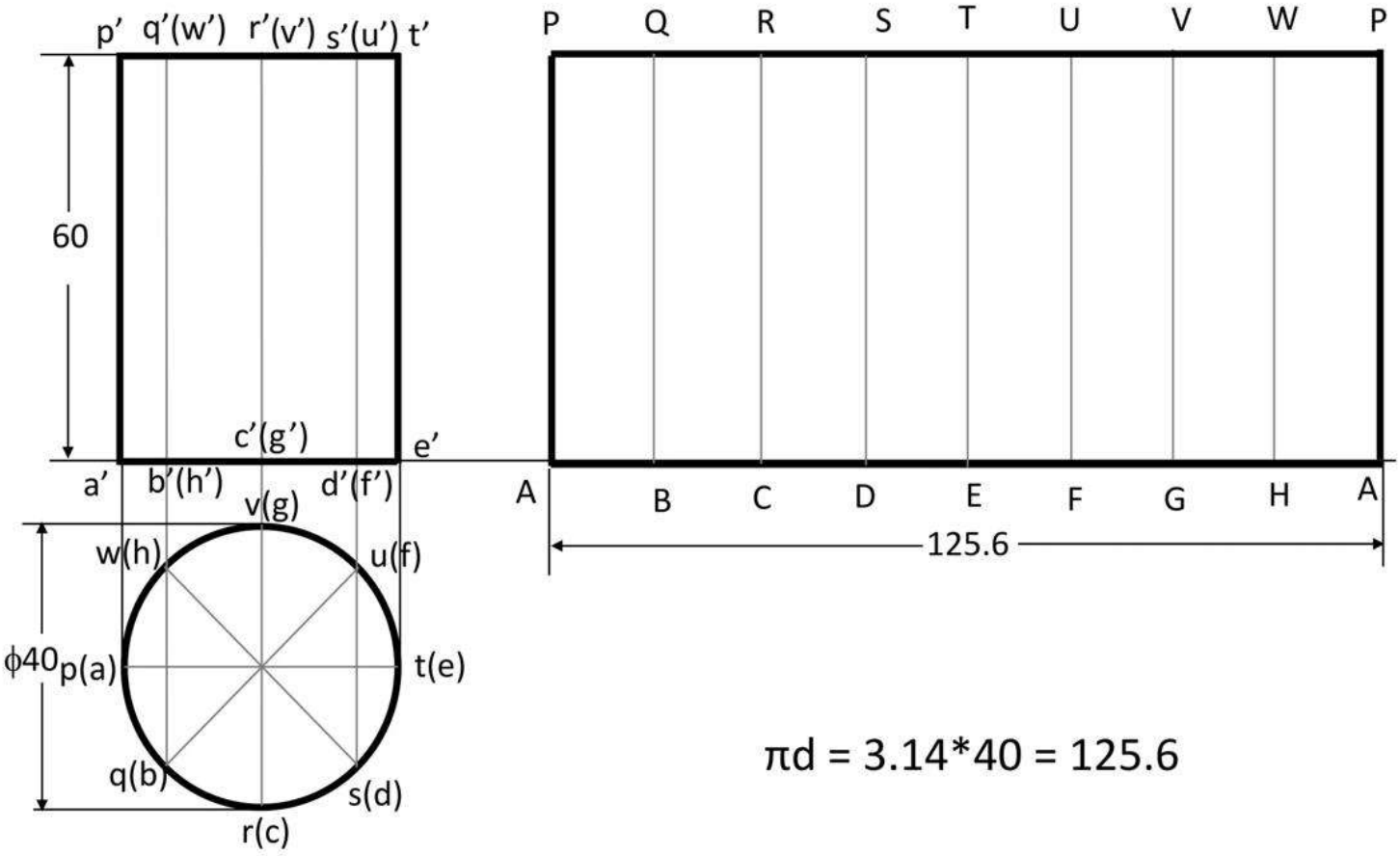
**Characteristics of parallel-line development**

- It uses parallel generators.
- The generators have equal spacing where the surface is divided equally.
- The developed pattern is generally rectangular or a series of connected rectangles.
- It is suitable for objects with straight parallel generators.
- It maintains the actual lengths of the generators.

**Procedure for developing a cylinder using parallel-line development**

**Example:** Developing the curved surface of a cylindrical water tank.

## 12. Draw the development of the lateral surfaces of a right cylinder of diameter 40 mm and height 60 mm long




Step 1: Draw the front elevation of the cylinder showing its height and diameter.

Step 2: Draw the circular plan of the cylinder.

Step 3: Divide the circular plan into a convenient number of equal parts, for example, 12.

Step 4: Number the division points from 1 to 12.

Step 5: Project the division points onto the front elevation where necessary.

Step 6: Calculate the circumference of the cylinder using:

$C=\pi D$

Where:

- $C$ = circumference.
- $D$ = diameter.
- $\pi$ = 3.142 approximately.

Step 7: Draw a rectangle whose:

- Length equals the circumference of the cylinder.
- Height equals the height of the cylinder.

Step 8: Divide the length of the rectangle into 12 equal parts.

Step 9: Mark the fold, seam or joining allowance where required.

Step 10: Draw the cutting outline to complete the developed pattern.

**Worked example 1**

A cylindrical tank has a diameter of 280 mm and a height of 400 mm. Calculate the dimensions of its curved surface development, ignoring joining allowances.

**Solution**

Given:

- Diameter = 280 mm.
- Height = 400 mm.
- $\pi=3.142$

Circumference:

$C=\pi D$

$C=3.142\times280$

$C=879.76$ mm

Therefore:

- Length of development = 879.76 mm.
- Width of development = 400 mm.

Answer

The developed curved surface is approximately 880 mm × 400 mm.

**Advantages of parallel-line development**

1. It is easy to understand and apply.
2. It is suitable for cylindrical and prismatic objects.
3. It provides accurate surface dimensions.
4. It reduces errors in marking out.
5. It is useful in the production of ducts and tanks.

**Limitations**

1. It is not suitable for all curved and irregular surfaces.
2. Complex shapes may require other methods.
3. Accurate division of the original surface is necessary.

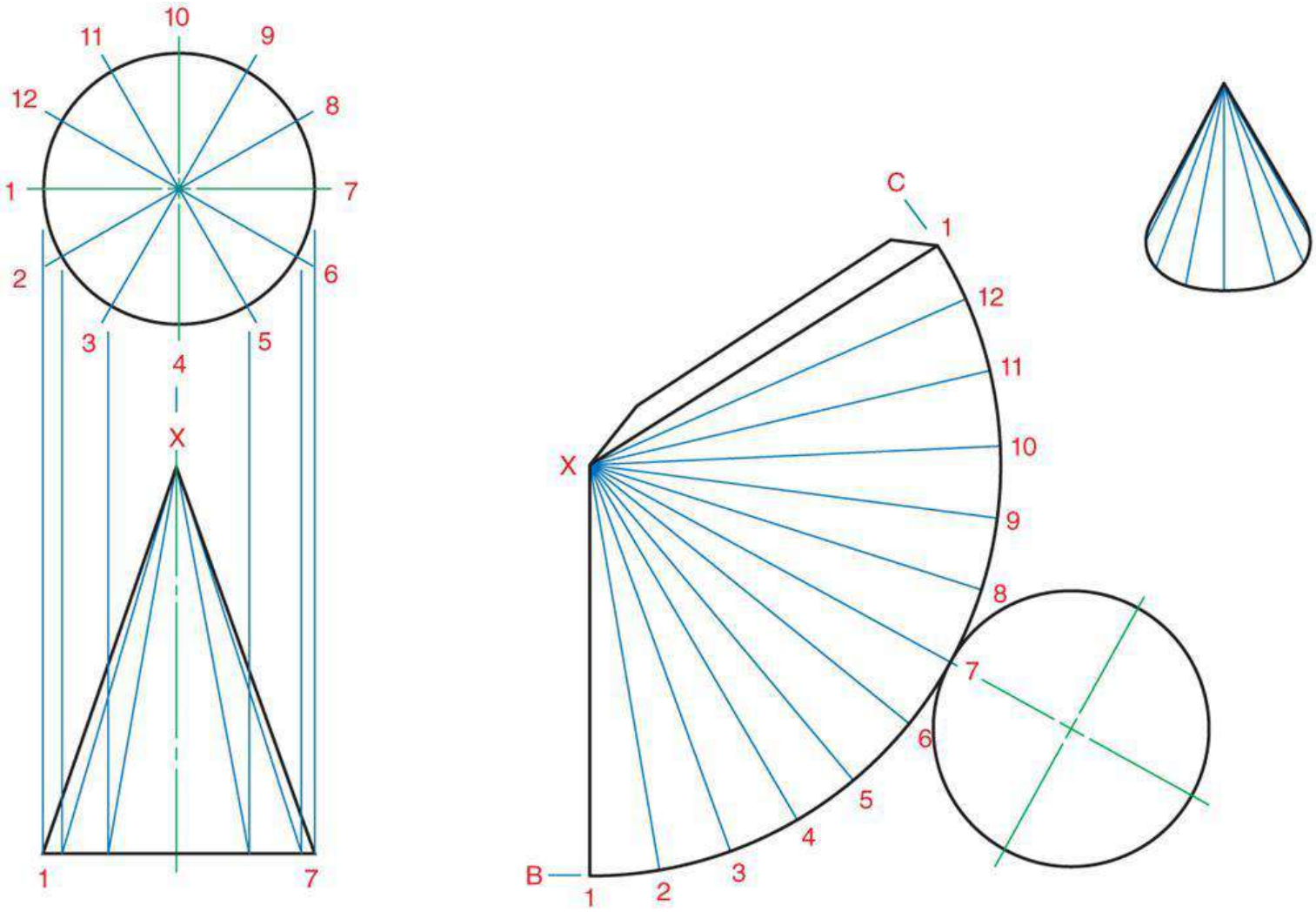
**3.2 Radial-Line Development**

**Definition**

Radial-line development is a method of developing surfaces in which the generators of the object meet at a common point called the apex.

It is mainly used for developing cones and pyramids.

The generators radiate from a single point, forming a fan-shaped development.




**Objects developed using radial-line development**

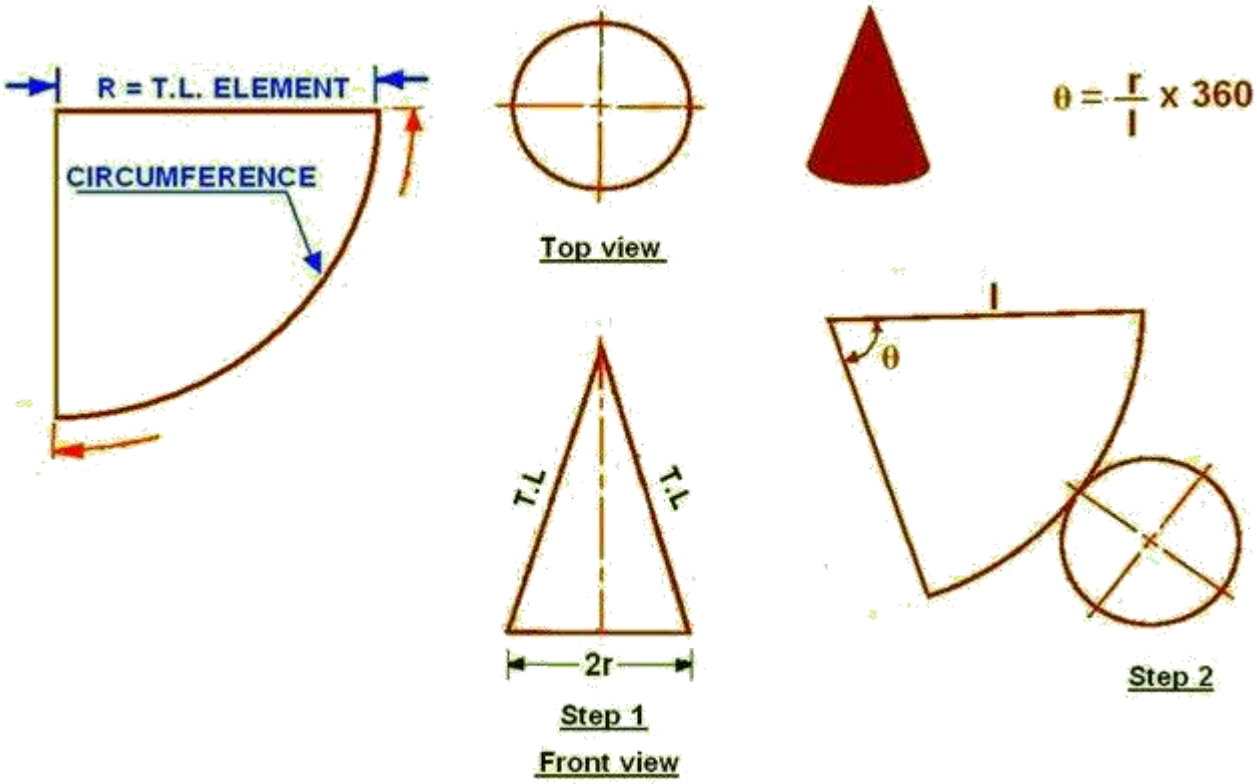
1. Right circular cones.
2. Pyramids.
3. Conical hoppers.
4. Metal funnels.
5. Conical roof sections.
6. Tapered sheet metal components.

**Characteristics of radial-line development**

- The generators converge at one common point.
- It is suitable for conical and pyramidal surfaces.
- The development is normally sector-shaped or fan-shaped.
- True lengths of the generators are required.
- The developed pattern can be marked directly onto sheet metal.

**Procedure for developing a cone using radial-line development**

**Example:** Developing a right circular cone for a metal funnel.




Step 1: Draw the elevation of the cone showing its height and base diameter.

Step 2: Draw the plan showing the circular base.

Step 3: Determine the true slant height of the cone.

The slant height is calculated using:

L=h2+r2

Where:

- L = slant height.
- h = vertical height.
- r = base radius.

Step 4: Calculate the circumference of the base.

C=2πr

Step 5: Using the slant height as the radius, draw an arc from the apex.

Step 6: Calculate the included angle of the development using:

θ=360∘rL$\theta$=$L$360∘$r$

Step 7: Draw the two radial lines forming the sector angle.

Step 8: Complete the sector using the arc.

Step 9: Add any required joining allowance.

Step 10: Mark the cutting outline.

**Worked example 2**

A conical funnel has a base radius of 70 mm and a vertical height of 240 mm. Determine its slant height and the angle of its development.

**Solution**

Given:

- Radius = 70 mm.
- Height = 240 mm.

**Step 1: Calculate slant height.**

**Solution**

**Given:**

- Radius, $r = 70\ \text{mm}$
- Vertical height, $h = 240\ \text{mm}$

**Step 1: Calculate the slant height**

Using Pythagoras' theorem:

$$L = \sqrt{h^2 + r^2}$$

Substituting the values:

$$L = \sqrt{240^2 + 70^2}$$

$$L = \sqrt{57600 + 4900}$$

$$L = \sqrt{62500}$$

$$\boxed{L = 250\ \text{mm}}$$

**Step 2: Calculate the development angle**

The formula for the development angle is:

$$\theta = \frac{360^\circ \times r}{L}$$

Substituting the values:

$$\theta = \frac{360^\circ \times 70}{250}$$

$$\theta = \frac{25200}{250}$$

$$\boxed{\theta = 100.8^\circ}$$

The development is a sector of a circle with a radius of 250 mm and an included angle of 100.8°.

**Advantages of radial-line development**

1. It is suitable for cones and pyramids.
2. It produces accurate developments of simple radial surfaces.
3. It is useful in making funnels and hoppers.
4. It is relatively easy to construct using drawing instruments.
5. It reduces unnecessary material wastage.

**Limitations**

1. It is not suitable for cylindrical surfaces.
2. It requires accurate determination of true lengths.
3. Complicated transition pieces may require triangulation.

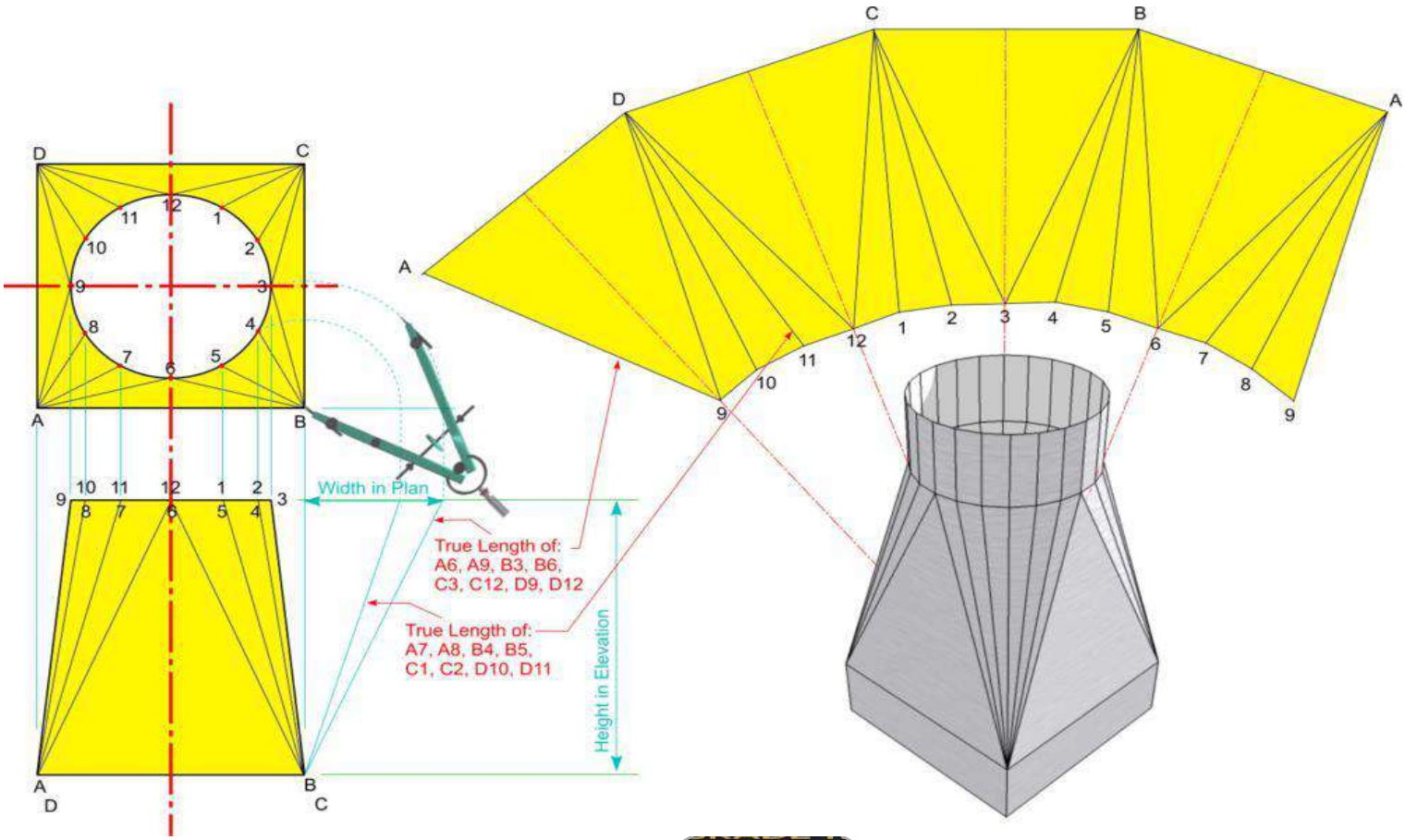
**3.3 Triangulation Development**

**Definition**

Triangulation development is a method of surface development in which a complicated surface is divided into a number of triangles.

The true lengths of the sides of the triangles are determined and transferred onto a flat plane to form the complete development.

It is particularly useful for developing transition pieces and irregular sheet metal shapes.



**Applications of triangulation development**

It is used in developing:

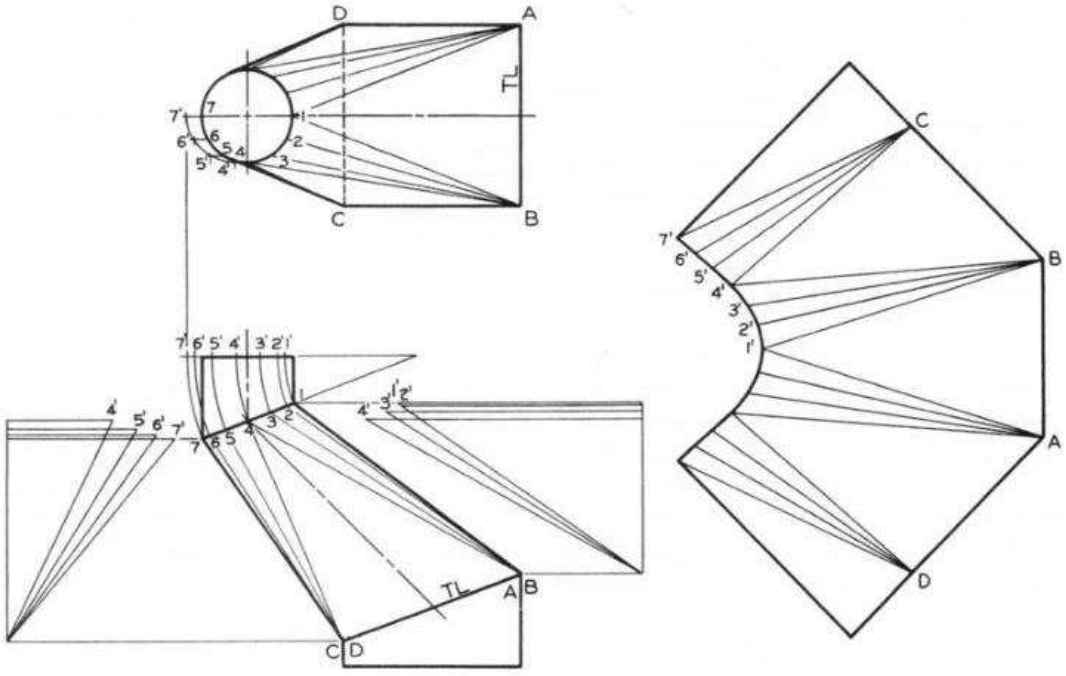
1. Square-to-round transition ducts.
2. Rectangular-to-circular duct connections.
3. Unequal pipe connections.
4. Irregular hoppers.
5. Sheet metal ventilation fittings.
6. Offset transition pieces.
7. Components with inclined surfaces.

**Characteristics of triangulation development**

- The surface is divided into triangular sections.
- True lengths of the triangle sides are determined.
- The triangles are transferred onto a flat plane.
- It can be applied to irregular surfaces.
- It is useful where parallel-line and radial-line methods are unsuitable.

**Procedure for triangulation development**

**Example:** Developing a transition piece connecting a square duct to a circular duct.




Step 1: Draw the top and bottom shapes of the transition piece.

Step 2: Draw the elevation and plan of the object.

Step 3: Divide the circular end into equal sections.

Step 4: Join corresponding division points to the corners or edges of the other end.

Step 5: Divide the surfaces into triangular sections.

Step 6: Determine the true lengths of the triangle sides using suitable projection or geometrical construction.

Step 7: Transfer the true lengths to the development drawing.

Step 8: Construct the triangles one after another.

Step 9: Join the outer points to obtain the complete cutting outline.

Step 10: Add joining allowances and identify the cutting and folding lines.

**Advantages of triangulation development**

1. It is useful for complicated sheet metal components.
2. It can develop irregular surfaces.
3. It is suitable for transition pieces.
4. It provides a practical method for developing non-parallel surfaces.
5. It is widely used in ventilation and duct fabrication.

**Limitations**

1. It requires accurate geometrical construction.
2. It may involve many calculations.
3. It is more time-consuming than parallel-line development.
4. Errors in true lengths can affect the final pattern.

**3.4 Approximate Development**

**Definition**

Approximate development is a method of developing a surface where the exact development is difficult to obtain or where a small degree of approximation is acceptable.

It is applied to certain curved or irregular surfaces.

**Applications**

- Irregular sheet metal components.
- Certain curved transition pieces.
- Complex fabricated covers.
- Components whose surfaces cannot easily be developed using simple geometrical methods.

**Characteristics**

1. It uses approximate measurements or geometrical constructions.
2. It may divide curved surfaces into smaller sections.
3. It is useful where exact construction is complicated.
4. The degree of accuracy depends on the method used and the intended application.

**Important:** Approximate development should only be used where the required manufacturing tolerance permits it. Components requiring high accuracy should use an appropriate exact or more accurate development method.

## 4.0 DEVELOPMENT OF DIFFERENT GEOMETRICAL SHAPES

Surface development involves unfolding the surfaces of different geometrical solids.

The main shapes studied at this level include:

1. Cube.
2. Pyramid.
3. Cylinder.
4. Cone.

### 4.1 Development of a Cube

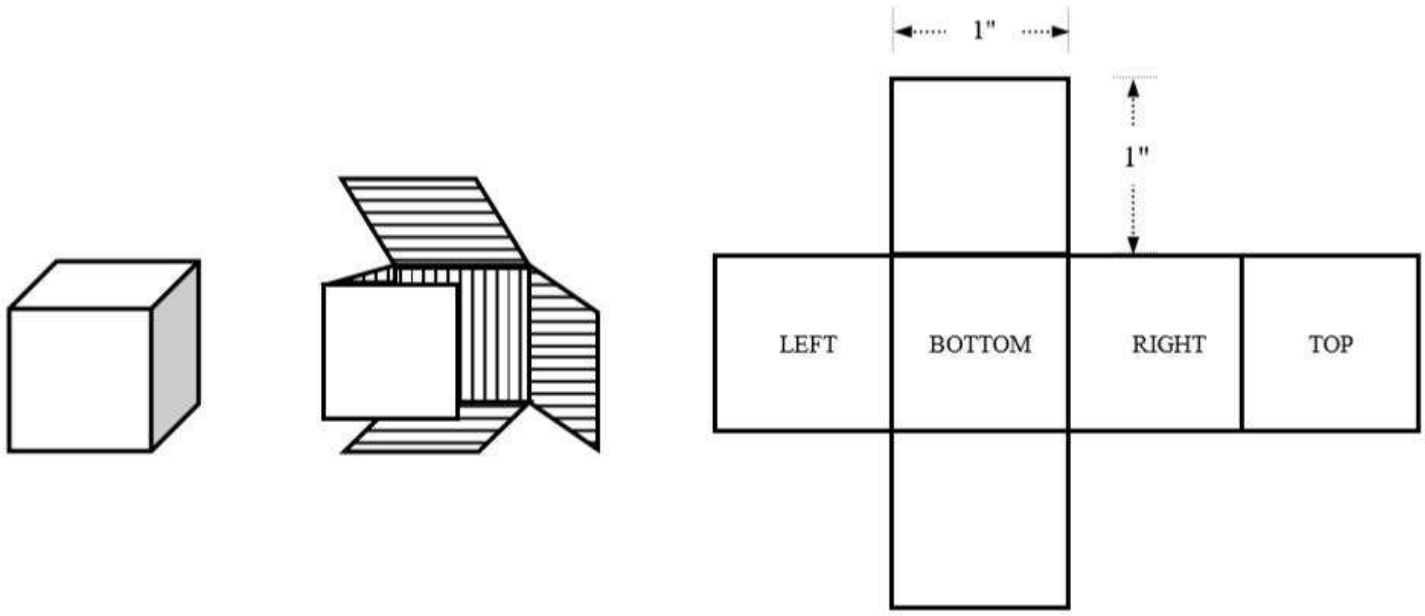
**Definition of a cube**

A cube is a three-dimensional solid having six equal square faces, twelve equal edges and eight vertices.

All the faces are equal in size.

Examples of cube-shaped metal products include:

- Metal storage boxes.
- Square metal containers.
- Small sheet metal enclosures.
- Square fabrication boxes.




**Characteristics of a cube**

1. It has six square faces.
2. It has twelve equal edges.
3. It has eight vertices.
4. All interior angles are 90°.
5. All faces have equal dimensions.

**Method of developing a cube**

A cube is developed using the parallel-line method.

**Procedure**

Step 1: Determine the length of one edge of the cube.

Step 2: Draw four equal squares in a straight row.

Step 3: Attach one square above the second square.

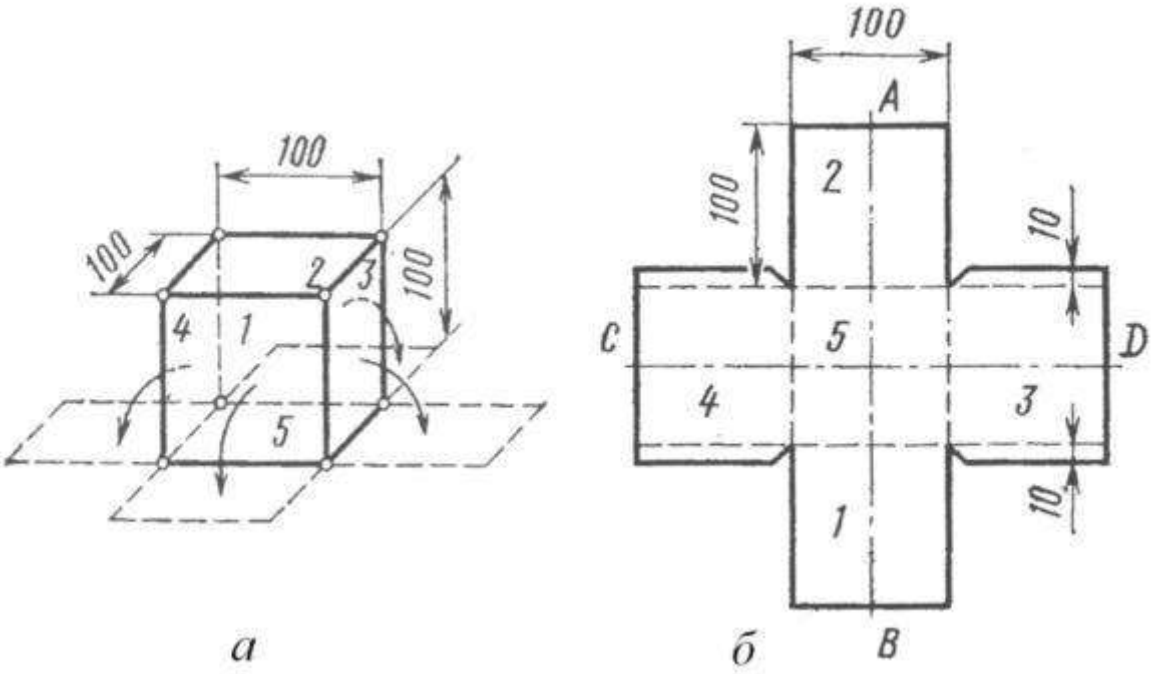
Step 4: Attach another square below the second square.

Step 5: Ensure that all six squares have equal dimensions.

Step 6: Draw the outer cutting boundary.

Step 7: Mark the folding lines between the squares.

Step 8: Add joining allowances where necessary.




**Worked example 3**

Develop a cube with an edge length of 80 mm.

**Solution**

Each of the six faces must measure:

80 mm×80 mm80 mm×80 mm

The total surface area is:

A=6a2$A = 6a^2$

A=6×802$A = 6 \times 80^2$

A=6×6400$A = 6 \times 6400$

A=38400 mm2$A = 38400$ mm2

Therefore, the development consists of six squares, each measuring 80 mm by 80 mm.

**Applications of cube development**

- Metal storage containers.

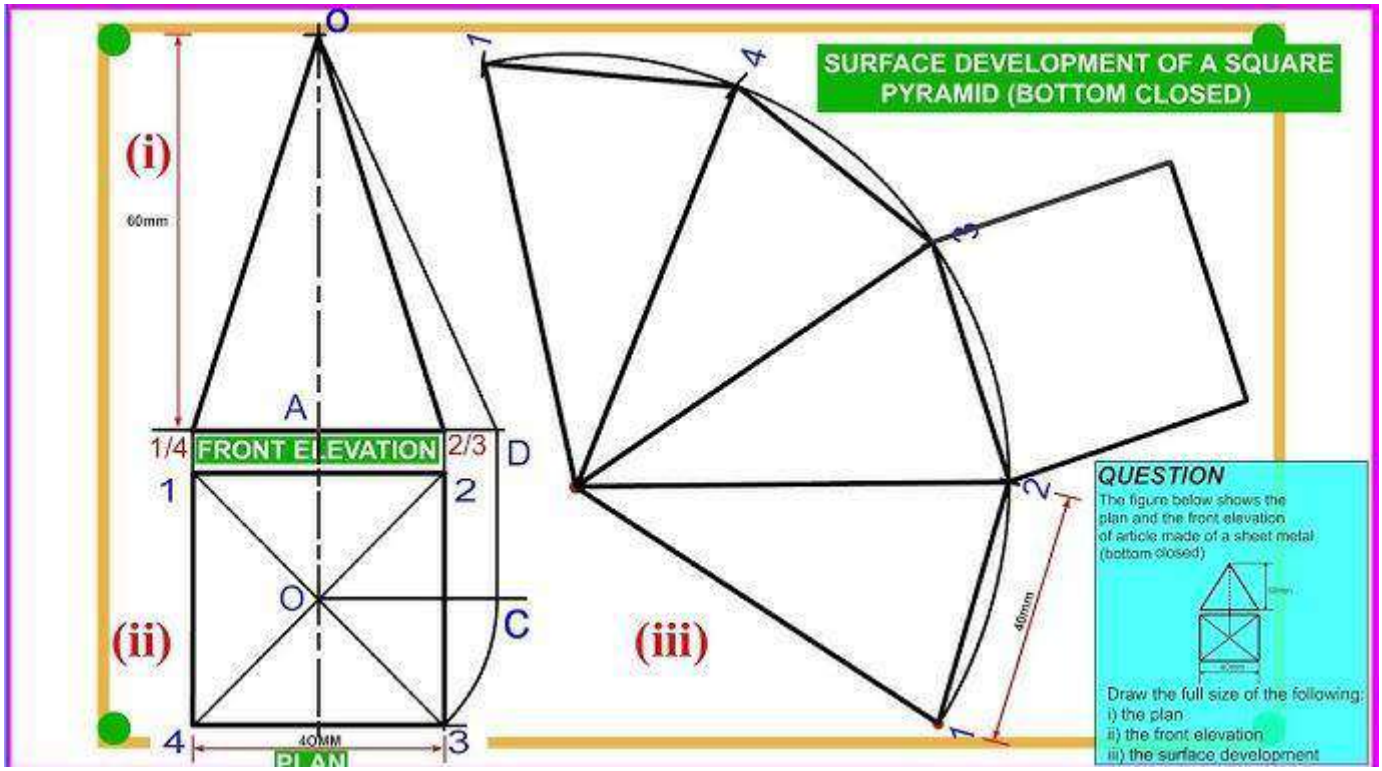
- Square boxes.
- Electrical enclosures.
- Sheet metal cabinets.
- Fabricated metal casings.

**4.2 Development of a Pyramid**

**Definition of a pyramid**

A pyramid is a solid geometrical object with a polygonal base and triangular faces that meet at a common point called the apex.

The most common type studied in basic surface development is the square-based pyramid.

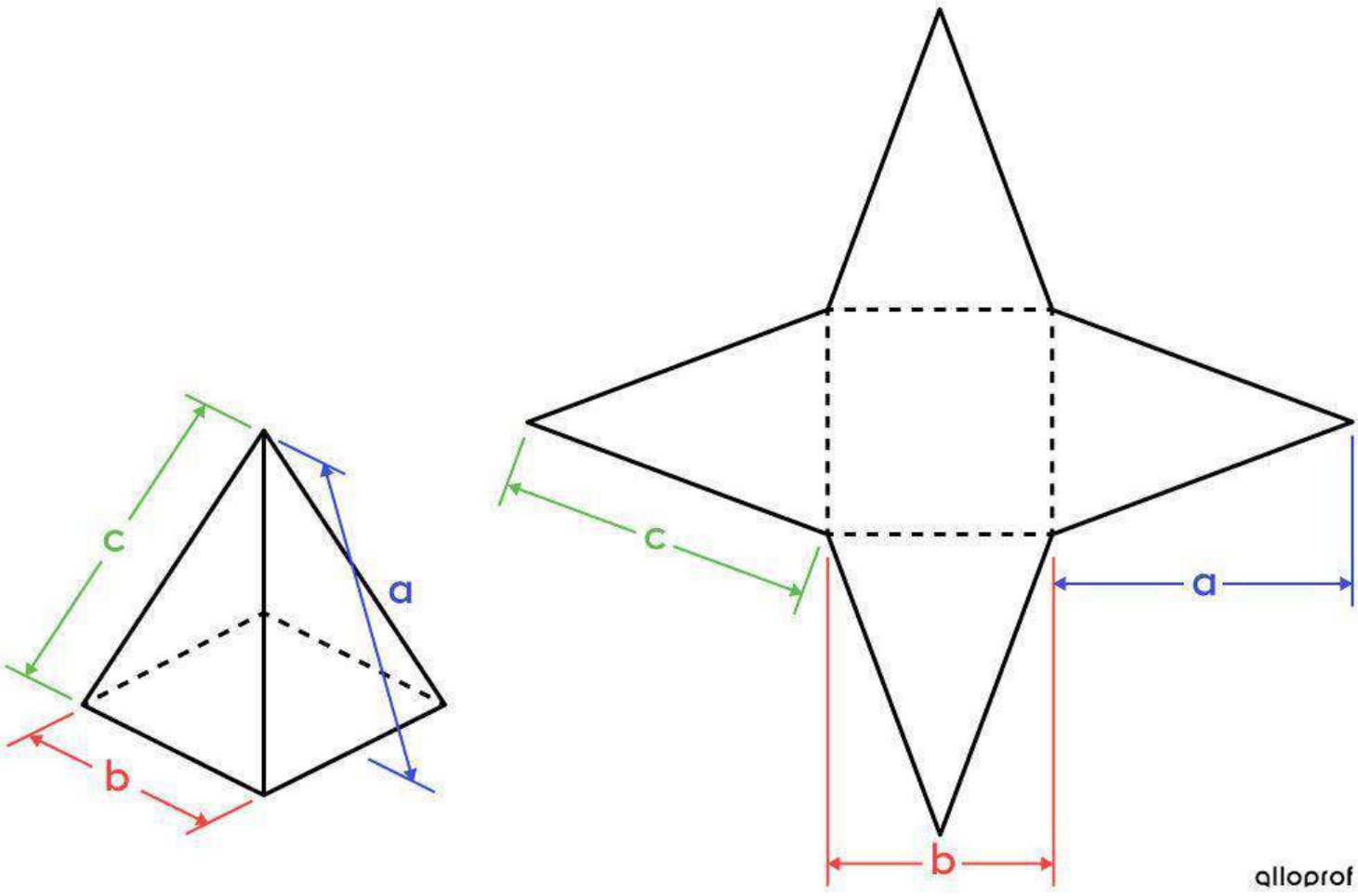



**Parts of a square-based pyramid**

1. Base: The square bottom face.
2. Apex: The top point where all triangular faces meet.
3. Slant edge: An edge joining the apex to a base corner.
4. Slant height: The perpendicular distance measured along a triangular face from the apex to the midpoint of a base edge.
5. Base edge: One of the four equal sides of the square base.

**Development of a square-based pyramid**

A square-based pyramid is developed using the radial-line method.




**Procedure**

Step 1: Draw the plan of the square-based pyramid.

Step 2: Draw the elevation showing the apex and base.

Step 3: Determine the true length of the slant edges.

Step 4: Using the apex as the centre, draw an arc with the true slant-edge length as the radius.

Step 5: Step off four equal base-edge lengths along the arc using a compass.

Step 6: Join the division points to the apex.

Step 7: Add the square base to one of the triangular faces if a complete closed-surface net is required.

Step 8: Draw the outer cutting outline.

Step 9: Indicate folding and joining allowances.

**Worked example 4**

A square-based pyramid has a base edge of 100 mm and a vertical height of 120 mm. Determine the slant edge length.

**Solution**

**Step 1: Calculate the horizontal distance from the centre of the square base to one corner.**

Using the formula:

$$r = \frac{a\sqrt{2}}{2}$$

Substituting the values:

$$r = \frac{100\sqrt{2}}{2}$$

$$r = \frac{141.42}{2}$$

$$\boxed{r = 70.71 \text{ mm}}$$

**Step 2: Calculate the slant edge length.**

Using Pythagoras' theorem:

$$L = \sqrt{h^2 + r^2}$$

Substituting the values:

$$L = \sqrt{120^2 + 70.71^2}$$

$$L = \sqrt{14400 + 4999.90}$$

$$L = \sqrt{19399.90}$$

$$\boxed{L \approx 139.28 \text{ mm}}$$

Therefore, the slant edge is approximately 139.28 mm.

**Applications of pyramid development**

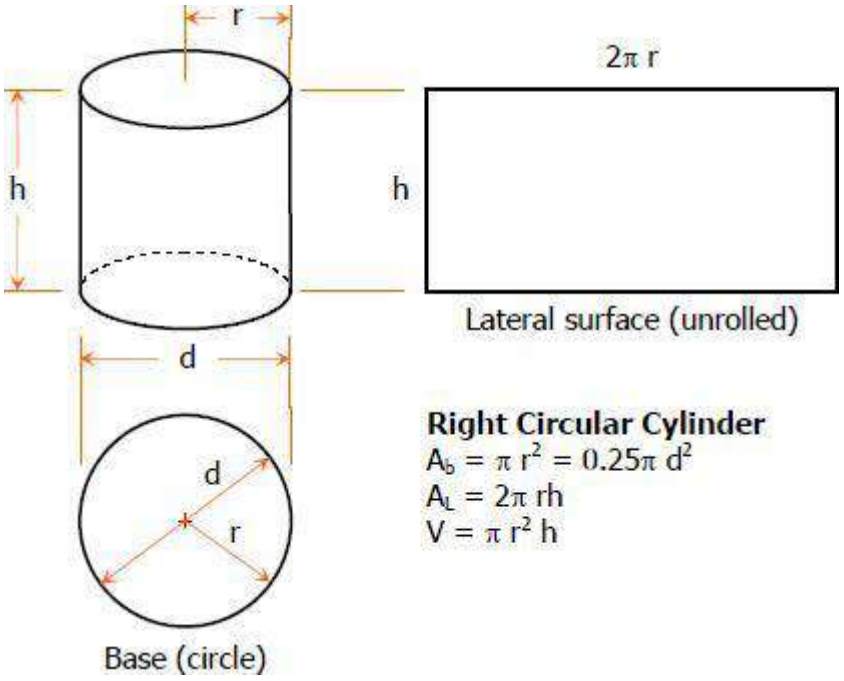
1. Decorative metal roofs.
2. Metal hoppers.
3. Sheet metal covers.

4. Industrial chutes.
5. Decorative metal structures.

**4.3 Development of a Cylinder**

**Definition of a cylinder**

A cylinder is a three-dimensional solid with two equal and parallel circular bases joined by one continuous curved surface.




**Parts of a cylinder**

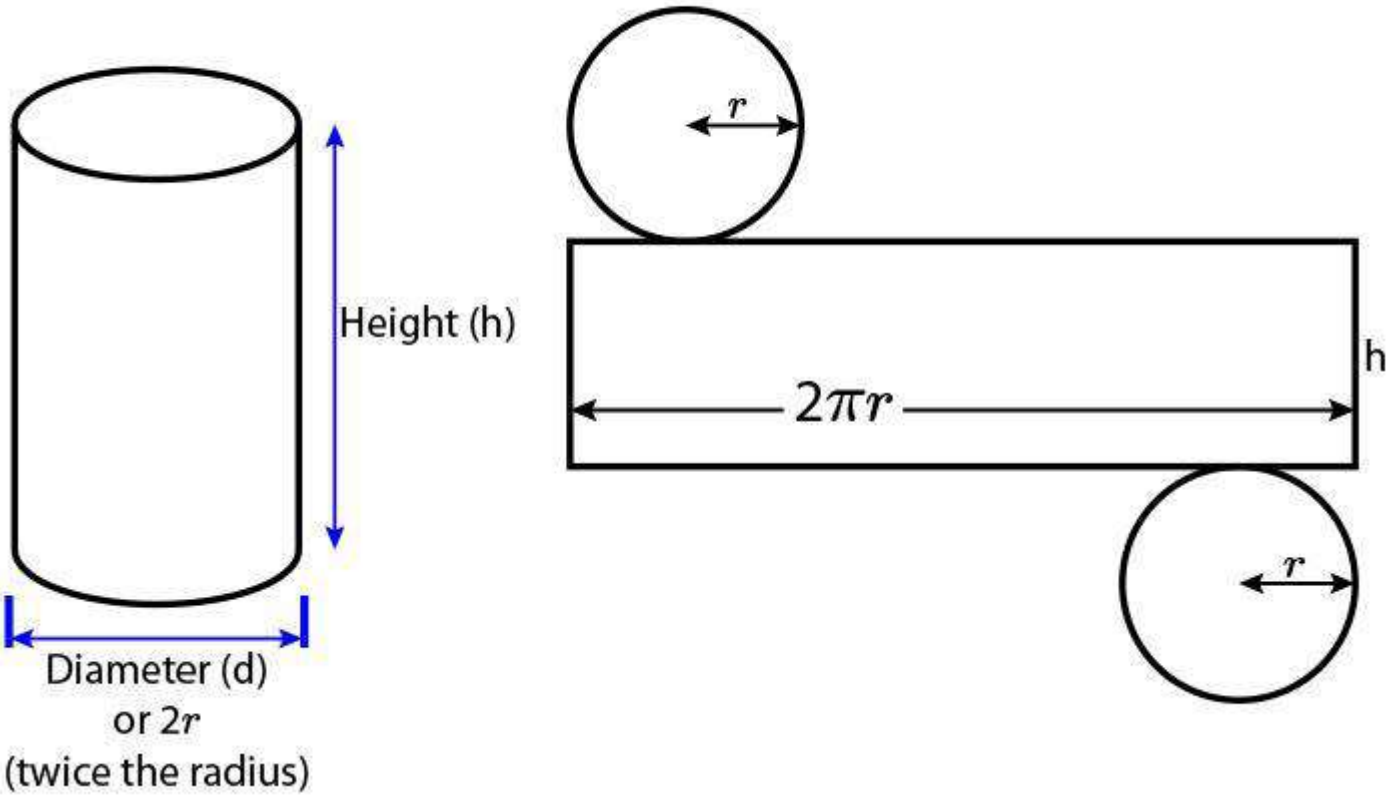
1. Circular base.
2. Top circular face.
3. Curved surface.
4. Radius.
5. Diameter.
6. Height.
7. Axis.

**Development of a cylinder**

The curved surface of a cylinder develops into a rectangle.

When both circular ends are included, the complete development consists of:

- One rectangle.
- Two equal circles.




**Procedure**

Step 1: Draw the front elevation of the cylinder.

Step 2: Draw the circular plan.

Step 3: Divide the circular plan into 12 equal parts.

Step 4: Draw the rectangular development.

Step 5: Calculate the circumference of the cylinder.

C=πDC=$\pi D$

Step 6: Make the length of the rectangle equal to the circumference.

Step 7: Make the height of the rectangle equal to the cylinder height.

Step 8: Divide the rectangle into 12 equal sections.

Step 9: Draw the two circular ends separately if required.

Step 10: Add joining allowances.

**Worked example 5**

A cylindrical container has a diameter of 160 mm and a height of 300 mm. Determine the dimensions of the curved surface development.

**Solution**

C=πDC=$\pi D$

C=3.142×160

C=502.72 mm

Therefore:

- Length = 502.72 mm.
- Height = 300 mm.

The developed curved surface is approximately 503 mm × 300 mm.

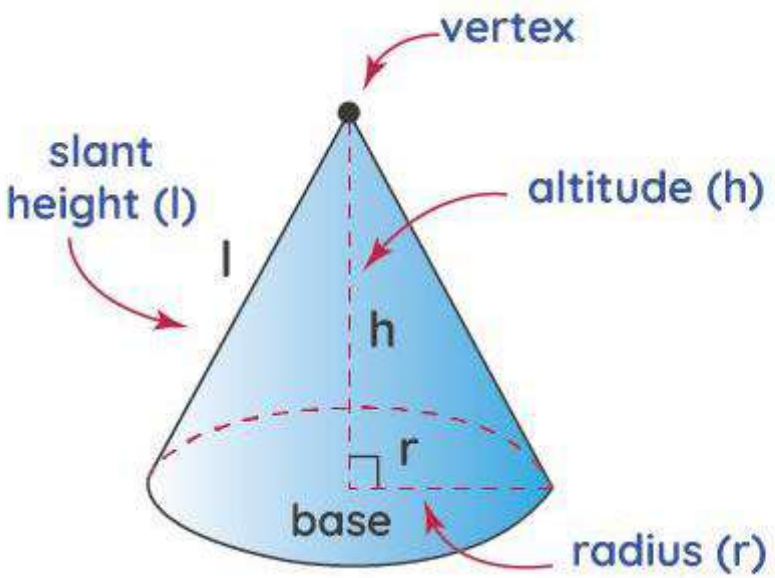
**Applications of cylinder development**

- Water tanks.
- Chimneys.
- Metal pipes.
- Cooking cylinders.
- Ventilation ducts.
- Storage drums.
- Metal buckets.

**4.4 Development of a Cone**

**Definition of a cone**

A cone is a three-dimensional solid having a circular base and a curved surface that tapers uniformly to a single point called the apex.




**Parts of a cone**

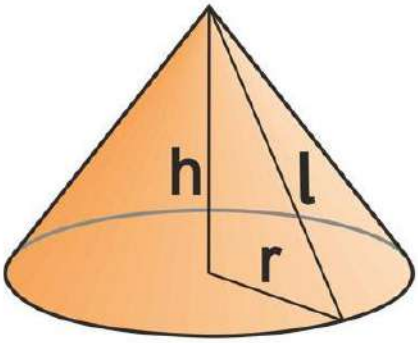
1. Apex.
2. Circular base.
3. Curved surface.
4. Radius.
5. Diameter.
6. Vertical height.
7. Slant height.
8. Axis.

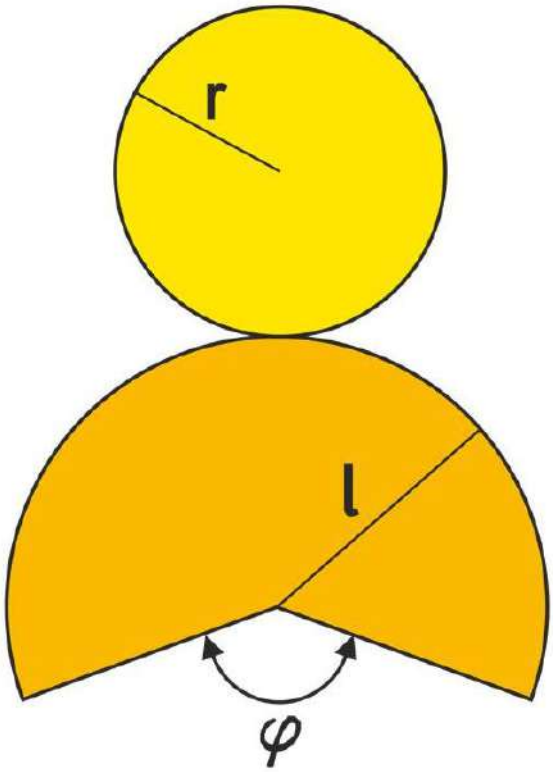
**Development of a cone**

The curved surface of a cone develops into a sector of a circle.

The radius of the sector is equal to the slant height of the cone.

The arc length of the sector is equal to the circumference of the circular base.




$$l = \sqrt{h^2 + r^2}$$

$$\varphi = \frac{2\pi r}{l}$$

**Procedure**

Step 1: Draw the elevation and plan of the cone.

Step 2: Determine the radius of the circular base.

Step 3: Calculate the slant height.

$L = h^2 + r^2$

Step 4: Calculate the circumference of the base.

$C = 2\pi r$

Step 5: Calculate the sector angle.

$\theta = 360 \circ rL$

Step 6: Draw an arc using the slant height as the radius.

Step 7: Construct the sector angle.

Step 8: Join the two radial lines to complete the development.

Step 9: Add allowances for joining.

**Applications of cone development**

1. Metal funnels.
2. Conical hoppers.
3. Chimney tops.

4. Industrial exhaust fittings.
5. Conical roofing structures.
6. Metal feeding equipment.

## 5.0 DEVELOPMENT OF INTERSECTING SURFACES

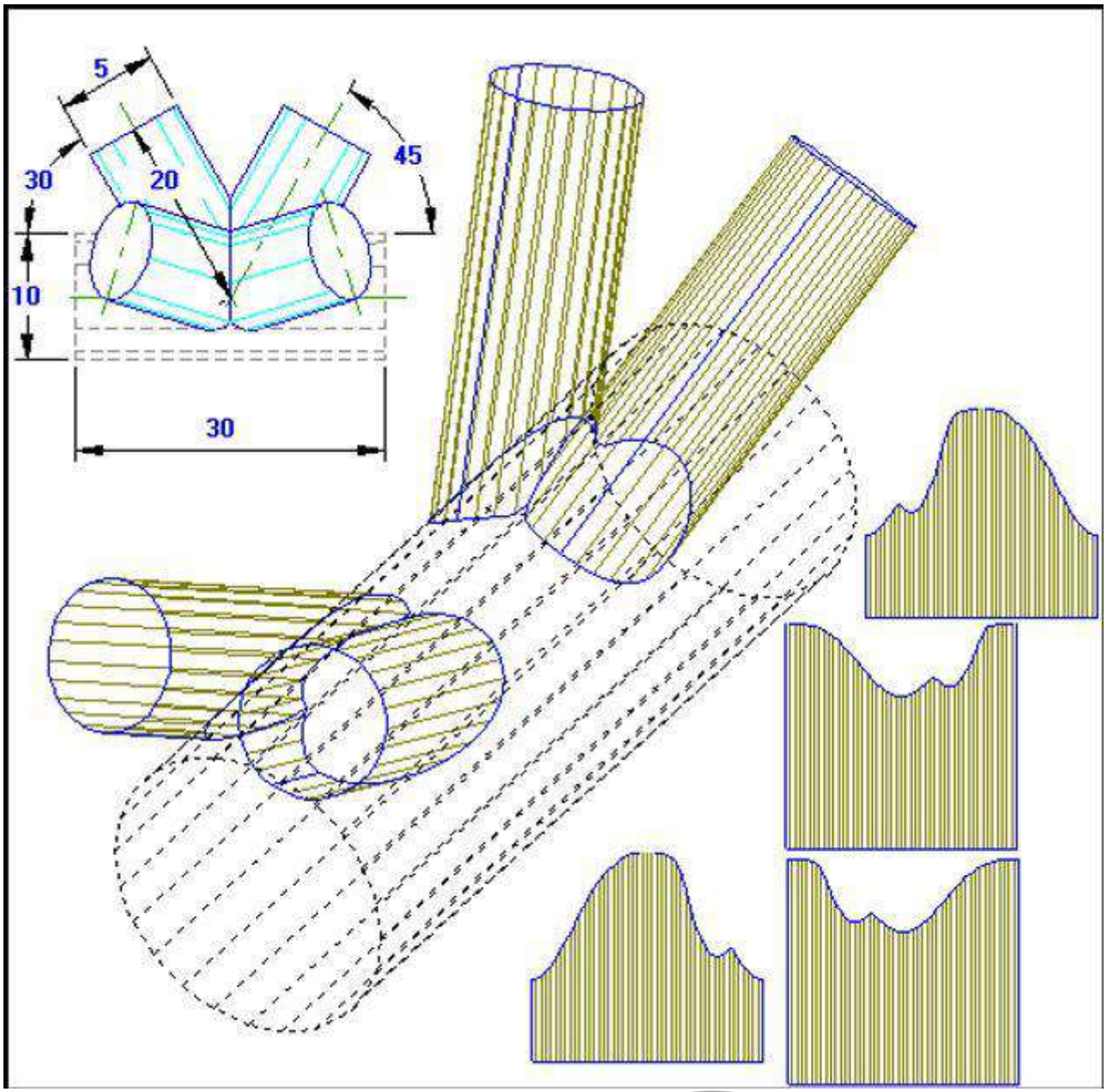
### 5.1 Meaning of Intersecting Surfaces

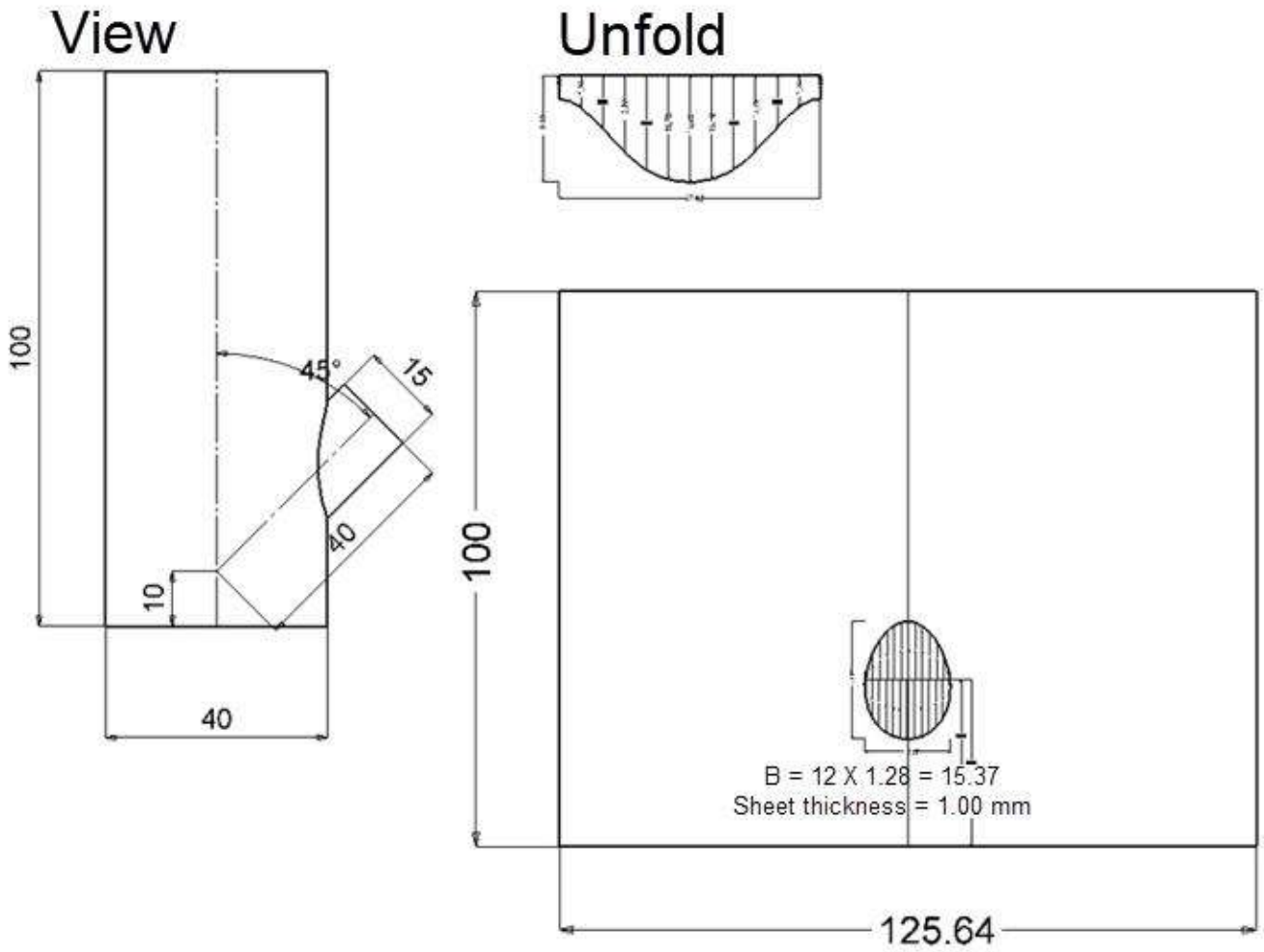
Intersecting surfaces are two or more surfaces that meet or penetrate one another to form a common boundary known as the line of intersection.

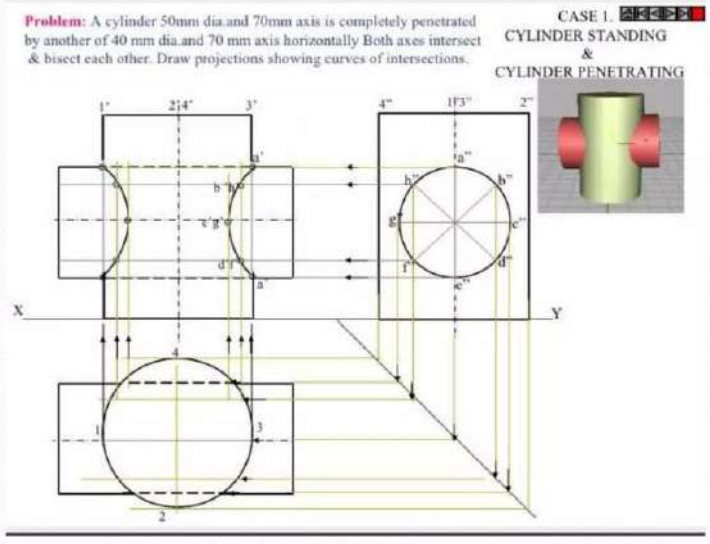
In sheet metal fabrication, intersecting surfaces are common where one pipe or duct connects to another.

Examples include:

- A small pipe entering a large pipe.
- A branch duct connecting to a main ventilation duct.
- A cylindrical chimney connected to another cylindrical section.
- A pipe connected to a tank.





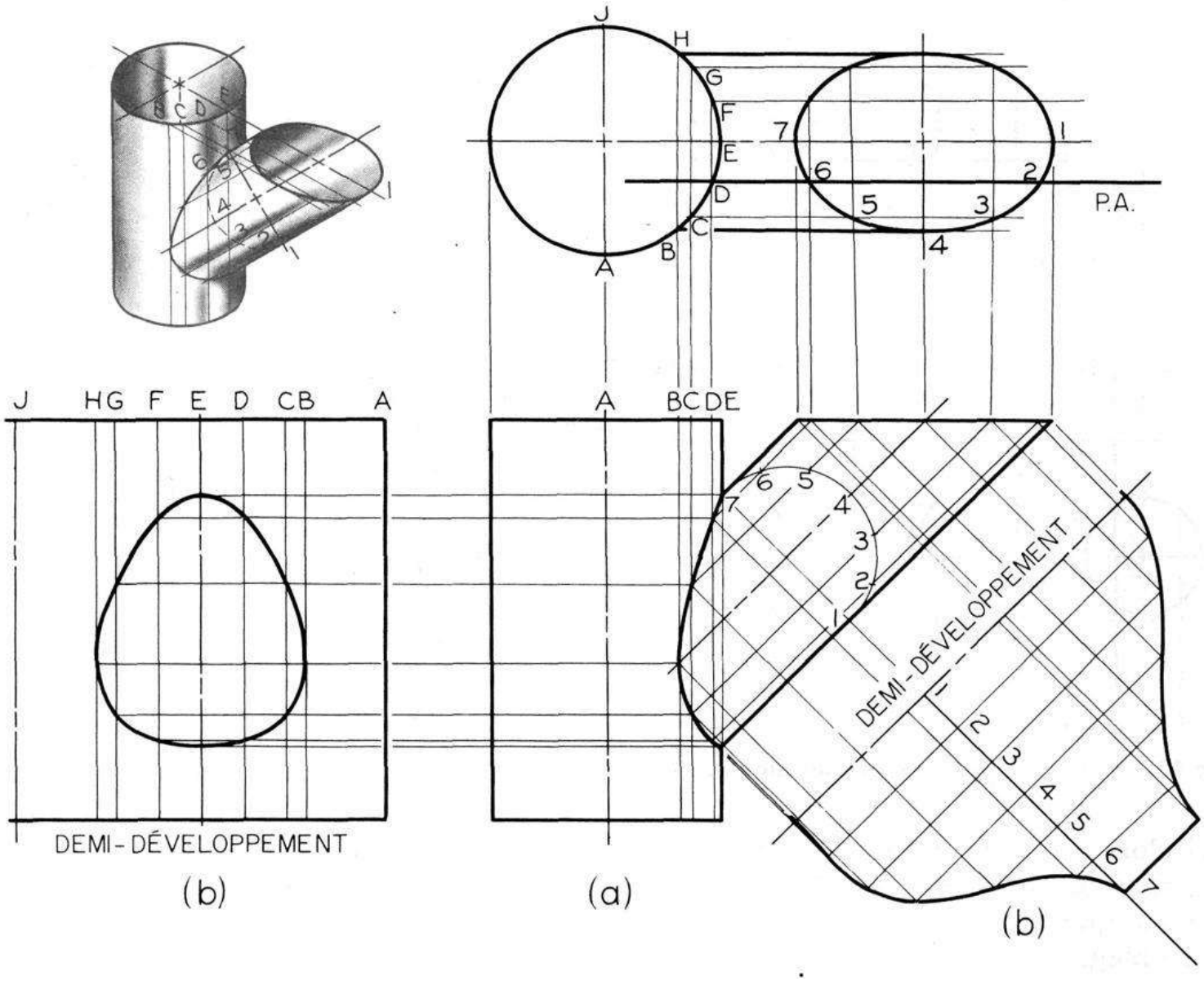

- First draw the Top View make 50mm diameter circle and project all axis line for the side view and front view
- Make 70mm axis height of front view and side view
- From center of rectangular side view make 40mm circle this is the intersect cylinder and make its projection for top view and draw the intersect cylinder in top view with 70mm horizontal line and 40mm diameter of circle.
- Project the line for intersect cylinder in front view help of top view
- Using all intersect point match all projection with the help of naming
- This id the Cylinder to cylinder intersection

**5.2 Types of Intersections in Metalwork**

**a) Cylinder intersecting cylinder**

This occurs when one cylindrical surface meets or penetrates another cylindrical surface.

Example: A smaller ventilation pipe connecting to a larger circular duct.




**b) Cylinder intersecting cone**

This occurs when a cylindrical surface penetrates a conical surface.

Example: A pipe connection entering a conical hopper.

**c) Cylinder intersecting prism**

This occurs when a cylindrical object penetrates a prismatic surface.

Example: A circular pipe entering a square sheet metal duct.

**d) Prism intersecting prism**

This occurs when two prismatic objects meet or penetrate each other.

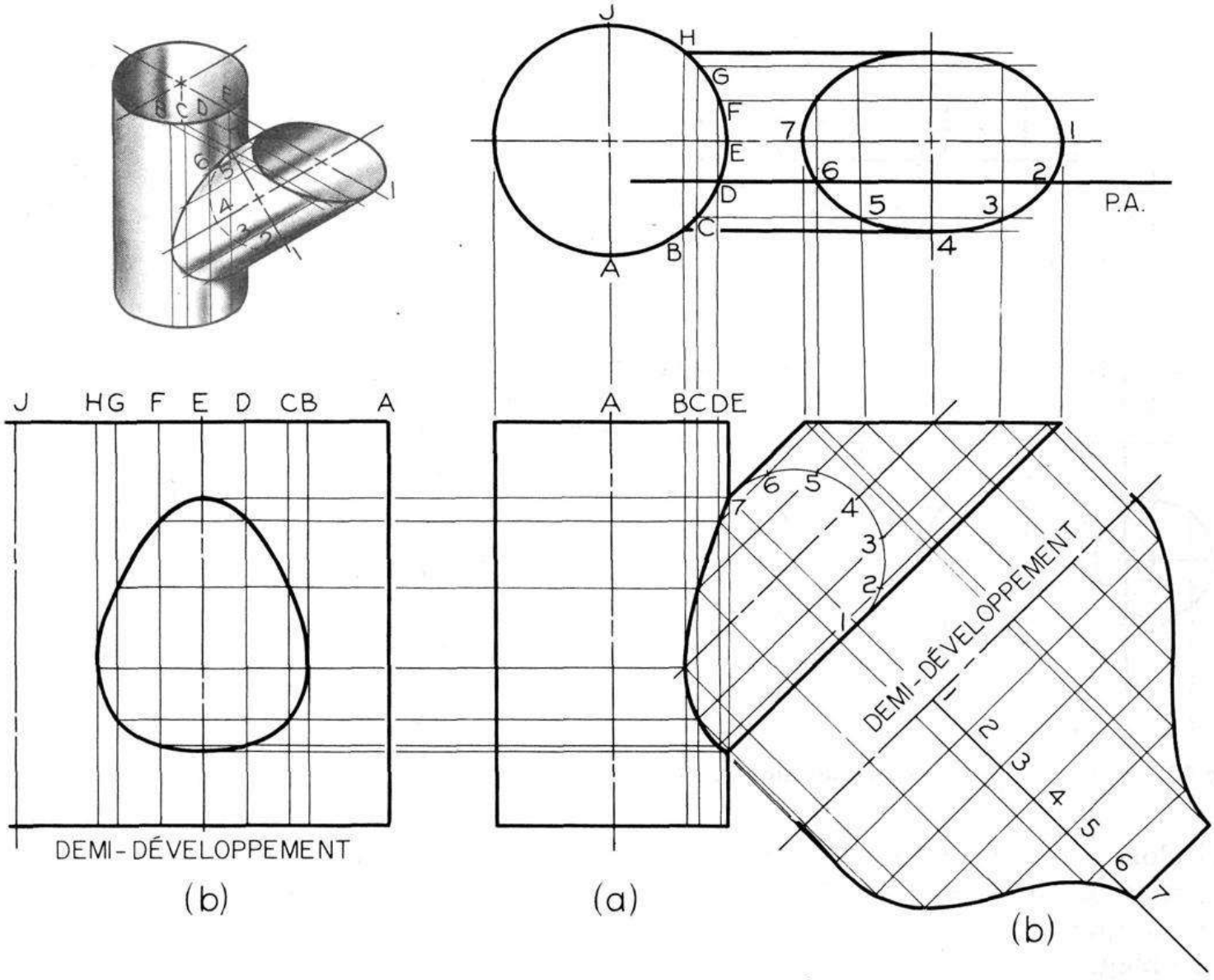
Example: Two rectangular ventilation ducts connected at an angle.

**5.3 Importance of Drawing Intersecting Surfaces**

1. It enables accurate fabrication of pipe connections.
2. It ensures that connecting surfaces fit properly.
3. It helps determine the shape of the cutting outline.
4. It reduces unnecessary material wastage.

5. It improves the quality of joints.
6. It supports fabrication of ventilation systems.
7. It makes it easier to manufacture complex sheet metal products.

**5.4 General Procedure for Drawing Intersecting Cylinders**




Step 1: Draw the elevation of the two cylinders in their required positions.

Step 2: Draw the plan showing the relative positions of the cylinders.

Step 3: Divide the circular end of the intersecting cylinder into equal parts.

Step 4: Number the division points.

Step 5: Project the division points to the elevation.

Step 6: Identify the points where the two surfaces meet.

Step 7: Transfer the intersection points to the developed surface of the cylinder.

Step 8: Join the transferred points using a smooth curve.

Step 9: Complete the cutting outline.

Step 10: Check the dimensions before cutting the sheet metal.

**Note:** The exact shape of the intersection curve depends on the diameters, relative positions and angles of the intersecting components.

## 6.0 DEVELOPMENT OF TRUNCATED SURFACES

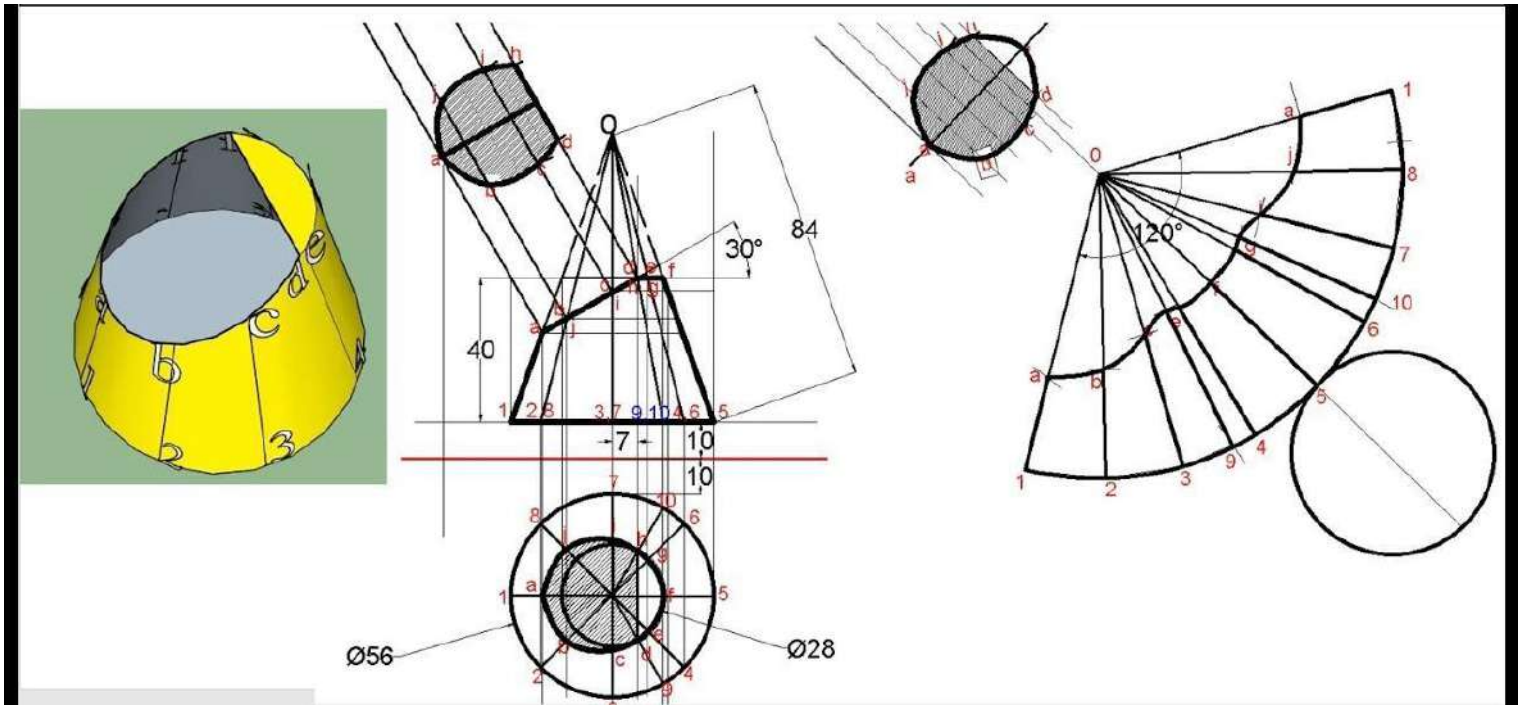
### 6.1 Definition of Truncation

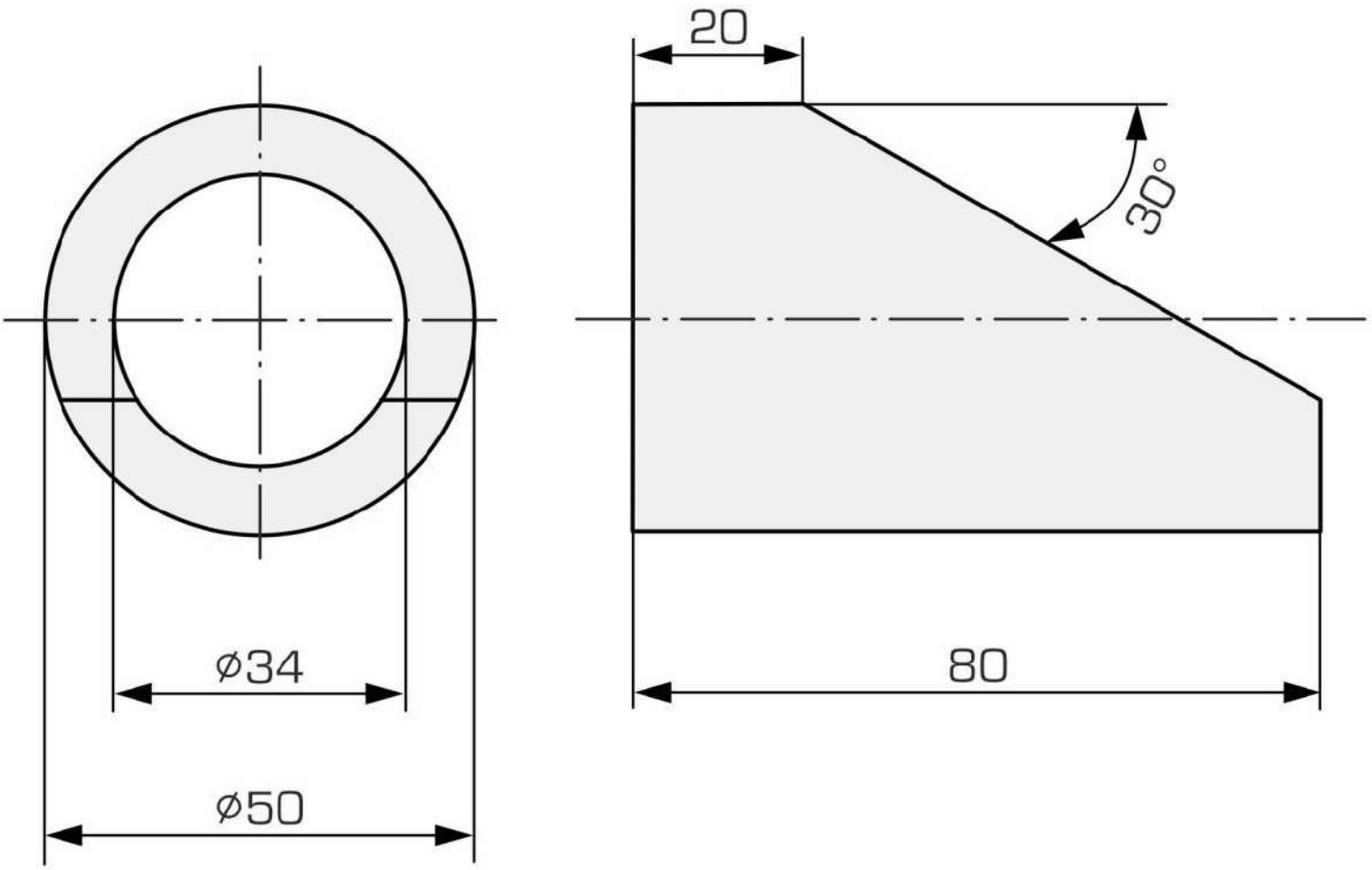
Truncation is the process of cutting off part of a solid object using a plane, thereby producing a new surface.

In Metal Technology, truncated surfaces are important when manufacturing components that have inclined, sloping or angled ends.

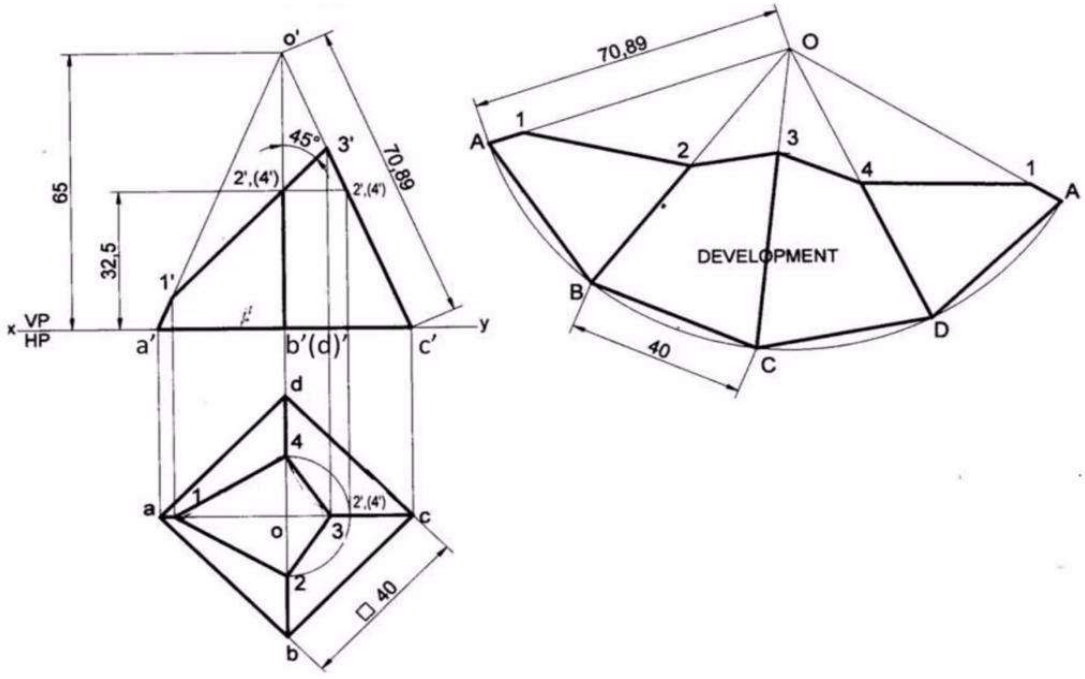
Examples include:

1. Sloping ventilation ducts.
2. Angled pipe ends.
3. Metal hoppers.
4. Chimney sections.
5. Tapered metal covers.
6. Inclined sheet metal outlets.






17) A square pyramid base 40mm side and axis 65mm long has its **base on HP and all the edges of the base are equally inclined to VP.** It is cut to with an inclined section plane so as the truncated surface at **45⁰ to its axis bisecting it**. Draw the development of the truncated pyramid. **Cutting plane leans upward right.**

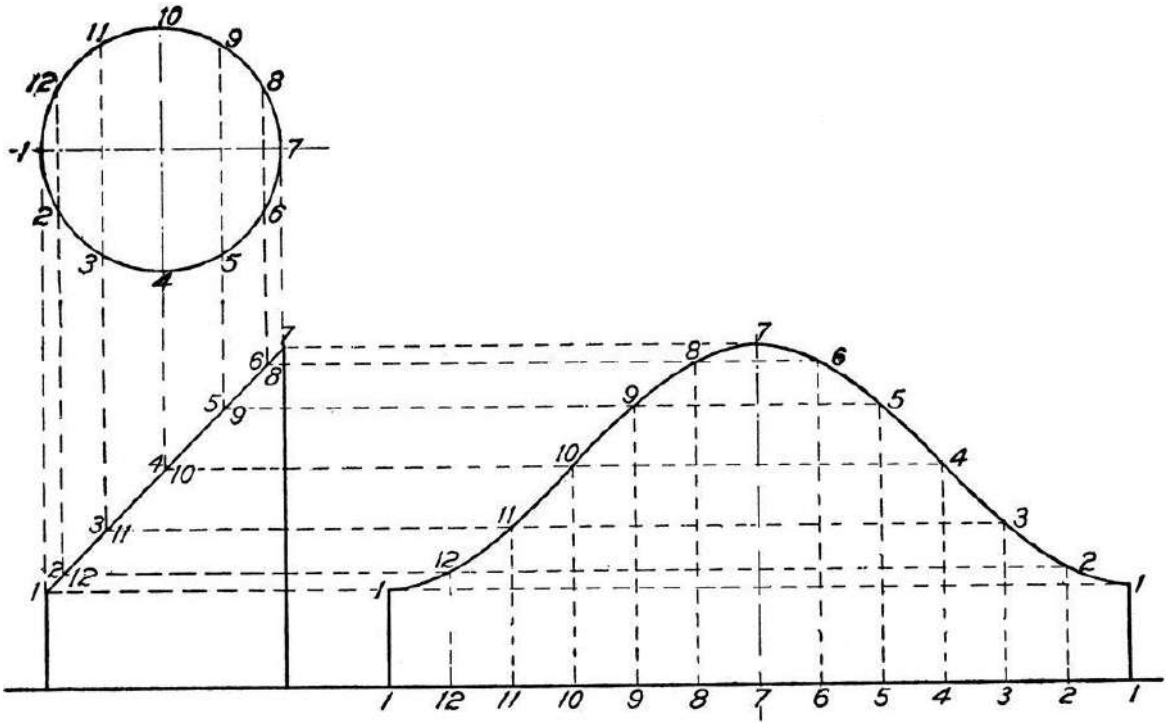



**6.2 Types of Truncated Surfaces**

**a) Truncated cylinder**

A truncated cylinder is a cylinder whose top or bottom portion has been cut off by an inclined or angled plane.

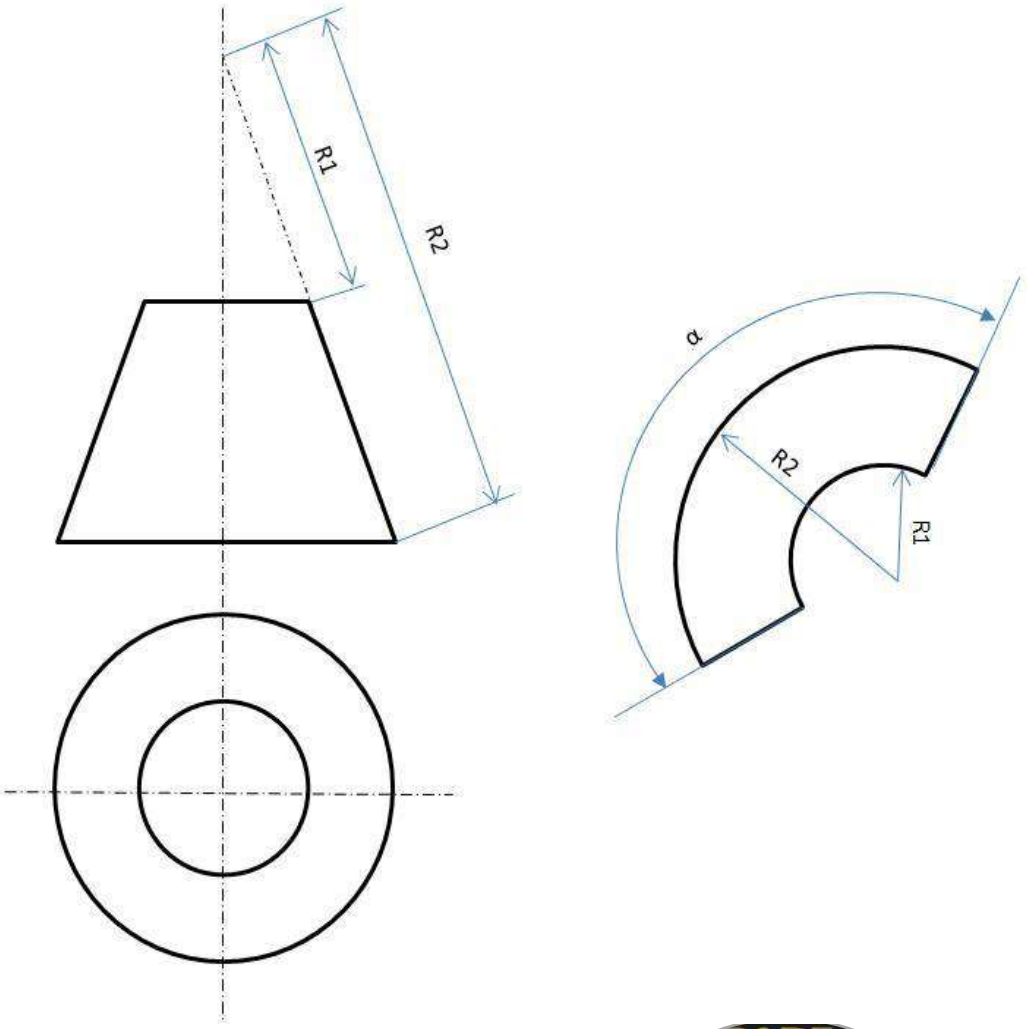
Example: An inclined-ended ventilation pipe.



**b) Truncated cone**

A truncated cone is a cone whose apex or part of its height has been removed by a cutting plane.

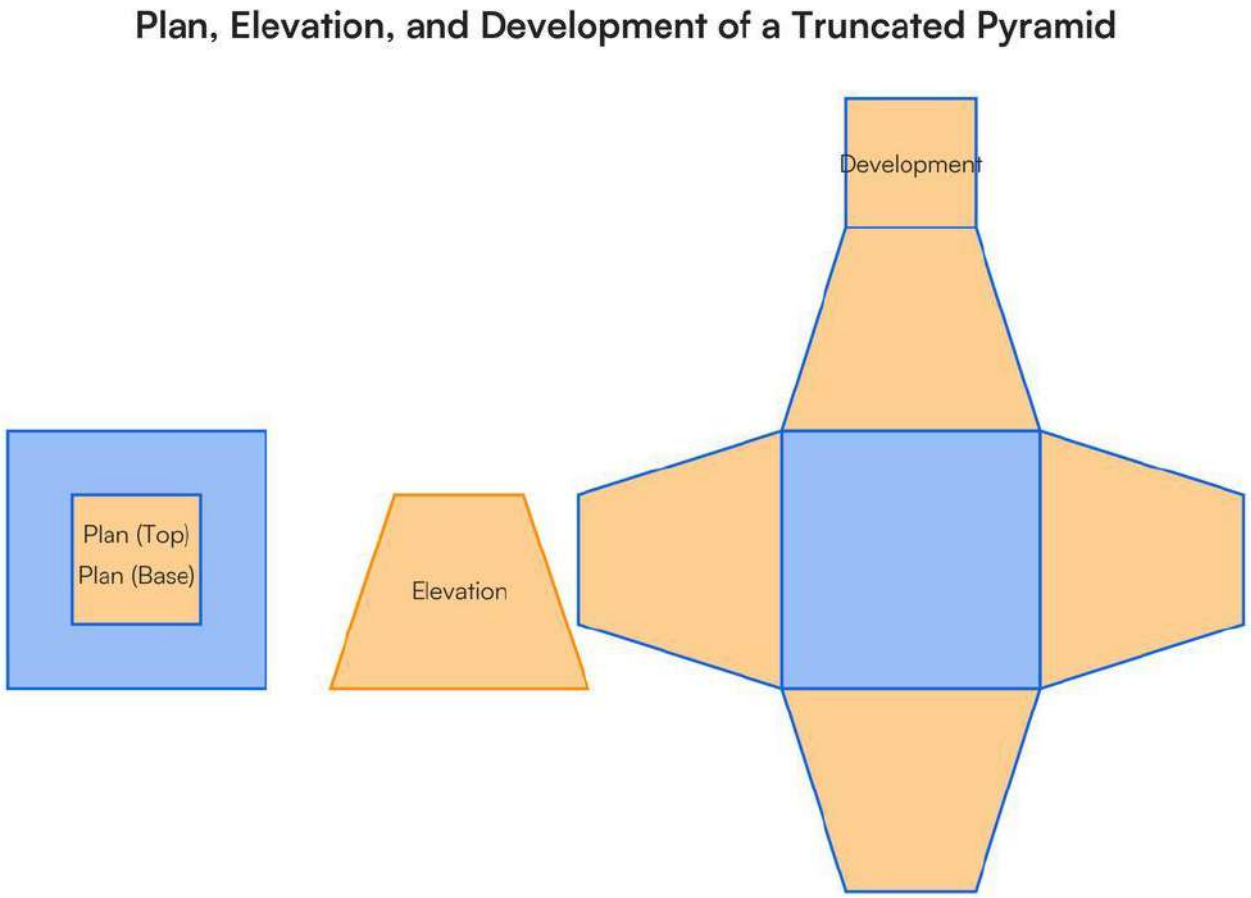
Example: A conical hopper with its top removed.



**c) Truncated pyramid**

A truncated pyramid is a pyramid whose apex or upper portion has been removed by a cutting plane.

Example: A square-based metal hopper with an open top.




**6.3 Procedure for Drawing a Truncated Cylinder**

Step 1: Draw the elevation of the cylinder.

Step 2: Draw the plan of the cylinder.

Step 3: Draw the inclined cutting plane in the elevation.

Step 4: Divide the circular plan into equal parts, for example, 12.

Step 5: Project the division points onto the elevation.

Step 6: Identify the points where the cutting plane intersects the generators.

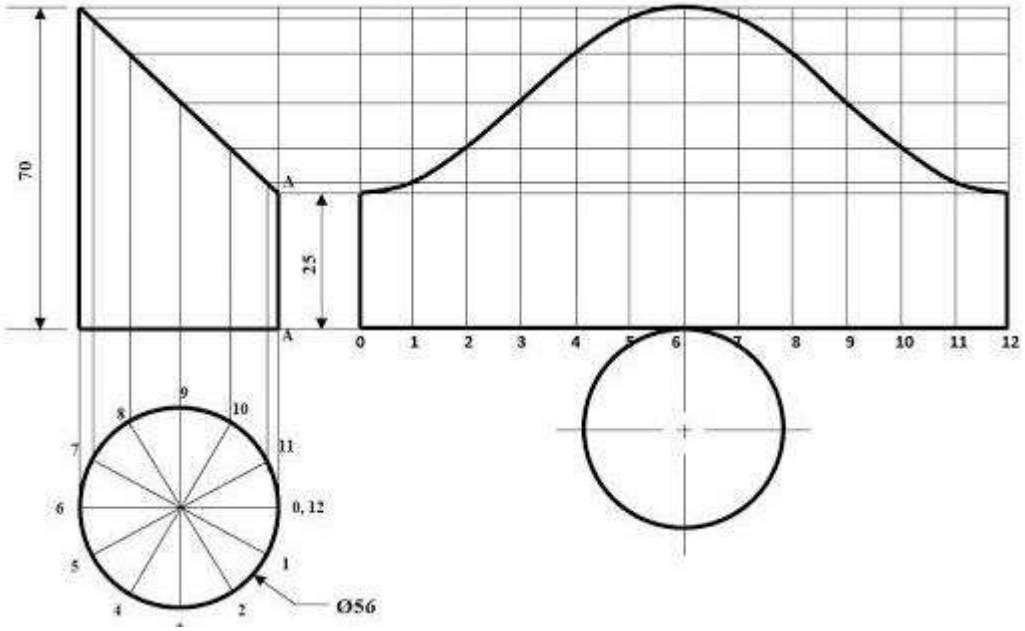
Step 7: Draw the rectangular development of the cylinder.

Step 8: Divide the length of the rectangle into the same number of equal parts used in the plan.

Step 9: Transfer the heights of the intersection points to their corresponding positions on the development.

Step 10: Join the transferred points with a smooth curve.

Step 11: Complete the cutting boundary and add joining allowances.




**6.4 Procedure for Drawing a Truncated Cone**

Step 1: Draw the elevation and plan of the cone.

Step 2: Draw the cutting plane at the required angle.

Step 3: Divide the circular base into equal parts.

Step 4: Project the division points onto the elevation.

Step 5: Determine the points where the cutting plane intersects the generators.

Step 6: Determine the true lengths of the generators up to the cutting plane.

Step 7: Draw the full radial development of the cone.

Step 8: Transfer the true lengths of the truncated generators onto their corresponding radial lines.

Step 9: Join the transferred points with a smooth curve.

Step 10: Add joining allowances and complete the cutting outline.

**6.5 Importance of Truncated Surface Development**

1. It enables production of components with angled ends.
2. It ensures accurate fitting of connecting parts.
3. It helps in producing sloping metal structures.
4. It reduces material wastage.
5. It supports production of specialised ventilation components.
6. It improves accuracy during marking out and cutting.

**7.0 DEVELOPMENT OF TRANSITION PIECES**

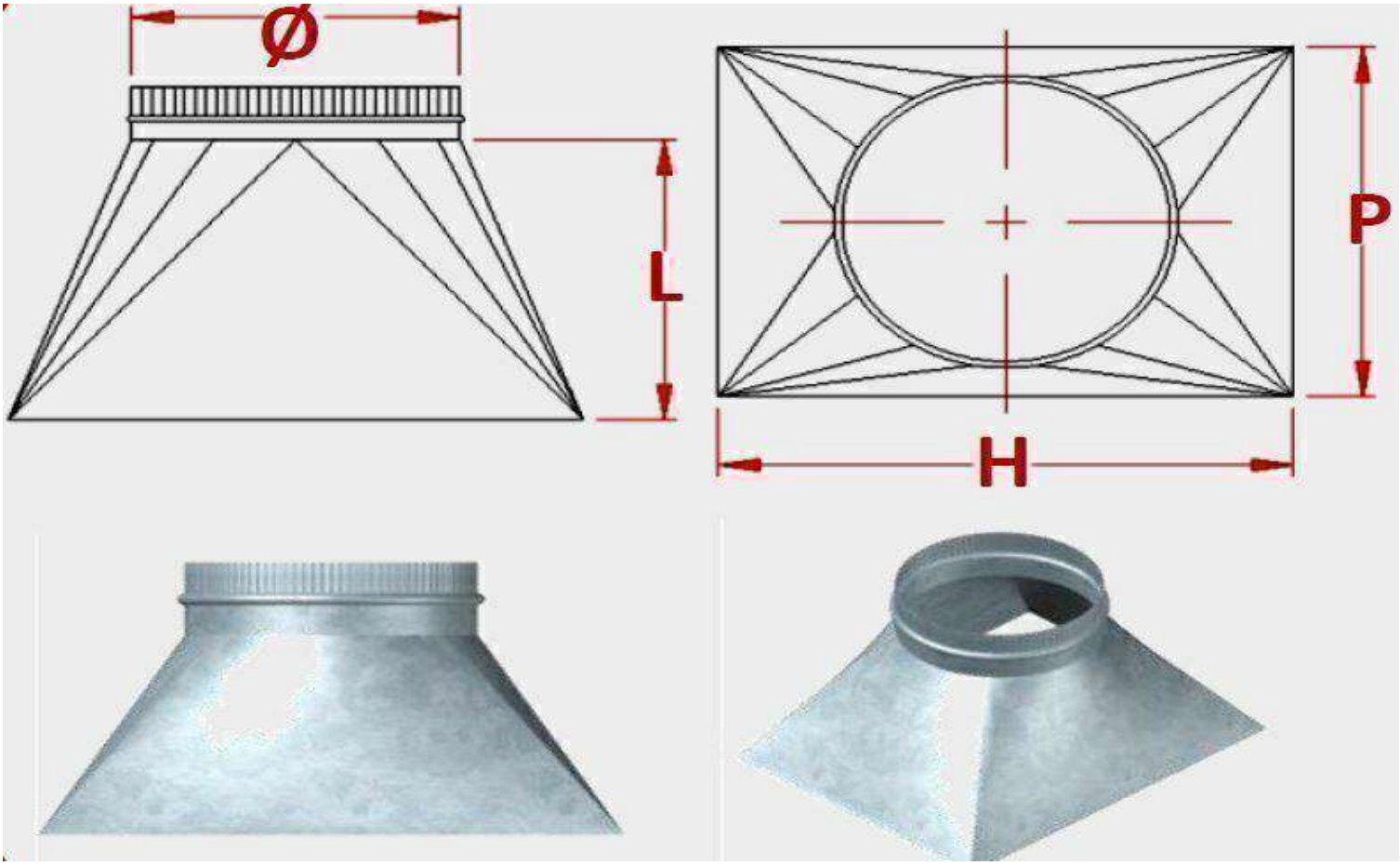
**7.1 Meaning of a Transition Piece**

A transition piece is a sheet metal component used to connect two openings, ducts or pipes of different shapes or sizes.

It allows a gradual change from one cross-sectional shape to another.

Examples include:

- Square-to-round transition.
- Rectangular-to-round transition.
- Large-to-small circular duct.
- Rectangular-to-rectangular tapered duct.








**7.2 Applications of Transition Pieces**

1. Ventilation systems in buildings.
2. Air-conditioning installations.
3. Industrial dust extraction systems.
4. Agricultural processing equipment.
5. Metal hoppers and chutes.
6. Industrial exhaust systems.

**7.3 Methods Used in Developing Transition Pieces**

The method depends on the shape and geometry of the transition.

- Parallel-line development: Suitable for certain transitions involving prismatic surfaces.
- Radial-line development: Suitable for transitions involving surfaces that converge towards a common apex.
- Triangulation development: Suitable for irregular transitions between different shapes.

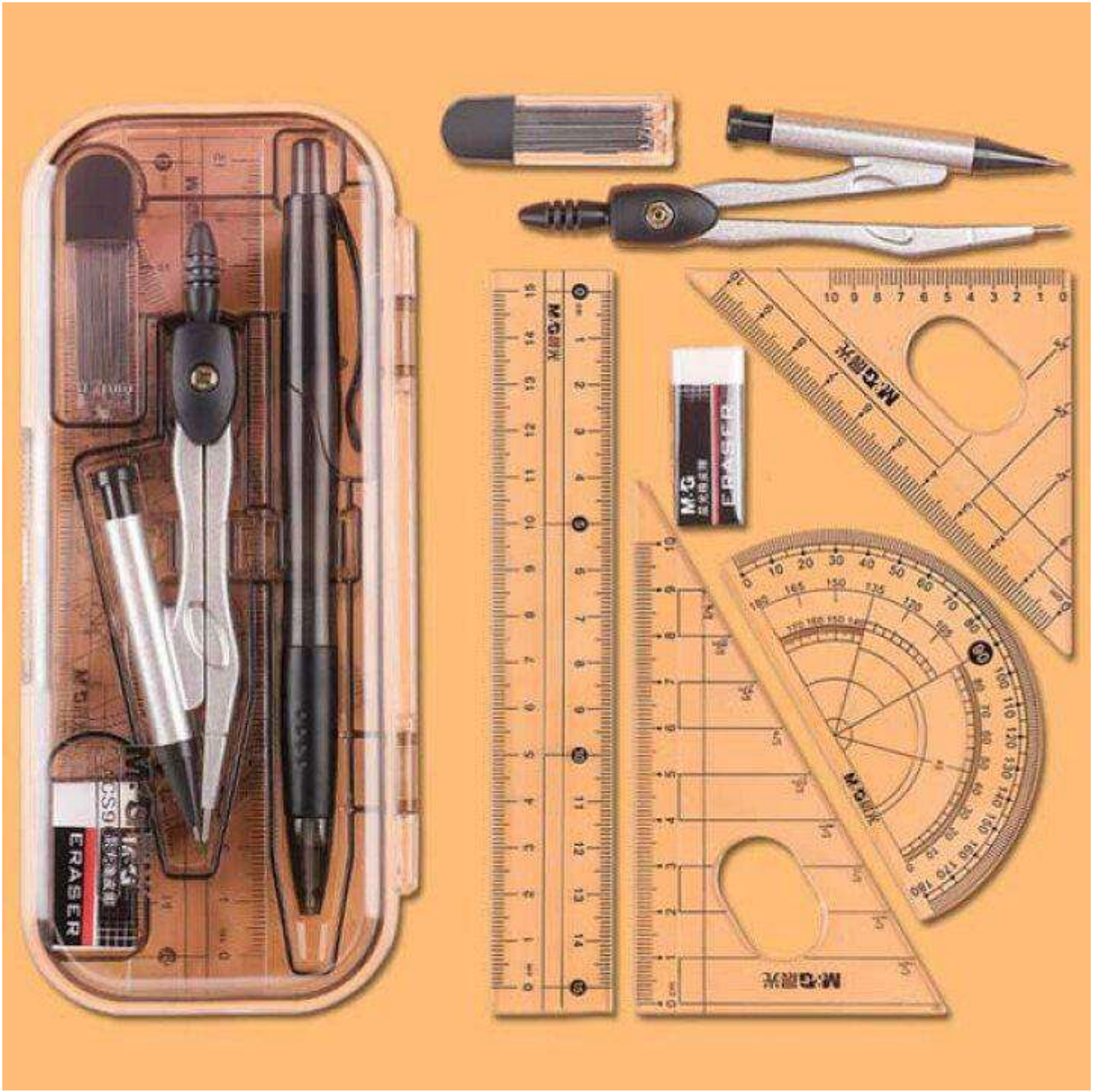
**7.4 Qualities of a Good Transition Development**

1. Accurate dimensions.

2. Proper alignment of connecting ends.
3. Smooth transition between sections.
4. Correct joining allowances.
5. Minimum material wastage.
6. Suitable shape for the intended application.

**8.0 DRAWING INSTRUMENTS AND EQUIPMENT USED IN SURFACE DEVELOPMENT**

Accurate surface development requires appropriate drawing instruments and workshop equipment.








**8.1 Drawing Board**

A flat board used to support drawing paper during technical drawing.

**Uses:**

- Provides a stable drawing surface.

- Supports accurate construction of geometrical shapes.
- Holds the drawing paper in position.

**8.2 T-square**

An instrument used to draw horizontal parallel lines.

**Uses:**

- Drawing horizontal construction lines.
- Supporting set squares.
- Producing accurate technical drawings.

**8.3 Set Square**

A triangular drawing instrument used for drawing vertical and inclined lines.

**Types:**

- 45° set square.
- 30°–60° set square.

**Uses:**

- Drawing perpendicular lines.
- Constructing angles.
- Drawing parallel inclined lines.

**8.4 Compass**

A drawing instrument used for drawing circles and arcs.

**Uses:**

- Drawing circular bases.
- Constructing sector developments.
- Transferring measurements.
- Dividing circles into equal sections.

**8.5 Divider**

An instrument with two pointed legs used for transferring measurements and dividing distances.

**Uses:**

- Stepping off equal divisions.
- Transferring measurements.
- Dividing circles and arcs.

**8.6 Protractor**

An instrument used for measuring and constructing angles.

**Uses:**

- Measuring sector angles.
- Constructing inclined cutting lines.

- Checking angular dimensions.

**8.7 Steel Rule**

A graduated measuring instrument used for measuring and marking dimensions.

**Uses:**

- Measuring lengths.
- Checking dimensions.
- Marking out sheet metal.

**8.8 Scriber**

A sharp-pointed marking tool used to make fine lines on metal surfaces.

**Uses:**

- Marking cutting lines.
- Marking folding lines.
- Transferring patterns onto metal.

**8.9 Try Square**

A tool used to mark and check right angles.

**Uses:**

- Checking perpendicular edges.
- Marking 90° lines.
- Checking accuracy of fabricated components.

**8.10 Sheet Metal Snips**

Hand-operated cutting tools used for cutting thin sheet metal.

**Types:**

- Straight snips.
- Left-cut snips.
- Right-cut snips.

**Uses:**

- Cutting developed patterns.
- Trimming sheet metal edges.
- Cutting curved and straight outlines.

**8.11 Folding Bars and Folding Machines**

Used to bend sheet metal along predetermined lines.

**Uses:**

- Forming bends.
- Producing flanges.
- Making rectangular and angular components.

## 9.0 MATERIALS USED IN SURFACE DEVELOPMENT AND SHEET METAL FABRICATION

Different materials are used depending on the intended application of the finished product.








**9.1 Mild Steel Sheets**

- Made mainly from iron and carbon.
- Easy to cut, bend and shape.
- Used in making tanks, containers and equipment covers.
- Requires protection against corrosion.

**9.2 Galvanised Steel Sheets**

- Steel sheets coated with zinc.
- Have improved resistance to corrosion.
- Commonly used in roofing and ventilation ducts.
- Suitable for many indoor and outdoor sheet metal applications.

**9.3 Aluminium Sheets**

- Lightweight.
- Resistant to corrosion.
- Easy to form.
- Used in ventilation systems, containers and lightweight covers.

**9.4 Stainless Steel Sheets**

- Resistant to rust and corrosion.
- Durable and easy to clean.
- Used in food-processing equipment, kitchen equipment and specialised containers.

**9.5 Copper Sheets**

- Good electrical and thermal conductivity.
- Easy to form.
- Used in roofing accessories, decorative items and specialised metal components.

**10.0 SAFETY PRECAUTIONS DURING SURFACE DEVELOPMENT AND FABRICATION**

Safety is important when preparing patterns and converting sheet metal into finished products.



**10.1 Personal Protective Equipment (PPE)**

Metalworkers should use:

1. Safety goggles to protect the eyes from flying particles.
2. Protective gloves suitable for handling sheet metal.
3. Safety boots to protect the feet from falling objects.
4. Overalls or protective clothing.
5. Hearing protection when operating noisy machinery.

**10.2 Safe handling of sheet metal**

- Handle sheet metal carefully because its edges may be sharp.
- Avoid sliding bare hands along cut edges.
- Store sheets in a stable position.
- Use suitable lifting methods when handling large sheets.
- Keep walkways free from metal offcuts.

**10.3 Safe use of drawing and marking tools**

- Keep scribers and compasses in safe conditions.
- Do not leave sharp tools carelessly on drawing boards.
- Store instruments properly after use.
- Use the correct tool for the intended operation.

**10.4 Safe use of cutting tools**

- Use the correct type of snips.
- Keep hands away from cutting edges.
- Secure material where necessary.
- Do not use damaged cutting tools.
- Collect and dispose of sharp offcuts safely.

**10.5 Workshop housekeeping**

- Keep the work area clean.
- Return tools to their proper storage positions.
- Remove unnecessary materials from working surfaces.
- Dispose of metal scraps appropriately.
- Maintain clear emergency exits.

## 11.0 QUALITY CONTROL IN SURFACE DEVELOPMENT

Quality control involves checking the accuracy and suitability of developed patterns before and during fabrication.

**Important quality checks**

1. Confirm that the dimensions are correct.
2. Check the accuracy of geometrical constructions.
3. Ensure that the correct development method has been used.
4. Check the positions of fold lines.
5. Confirm that joining allowances are adequate.
6. Ensure that cutting lines are clearly marked.
7. Check that corresponding edges fit correctly.
8. Inspect the finished component for distortion.
9. Ensure that the finished product meets the required specifications.

**Common errors in surface development**

| Error | Possible cause | Correction |
|---|---|---|
| Incorrect pattern size | Wrong measurements | Recheck dimensions |
| Uneven divisions | Inaccurate marking | Use compass and divider |
| Poorly fitting joints | Incorrect allowances | Check joining edges |
| Distorted development | Incorrect projections | Repeat construction carefully |
| Wrong sector angle | Calculation error | Recalculate the angle |
| Uneven cutting outline | Poor marking | Use appropriate drawing instruments |

## 12.0 PRACTICAL LEARNING ACTIVITIES

Learners should undertake practical activities to develop the skills and competencies required in surface development.

**Activity 1: Developing a cube**

**Requirements:**

- Drawing paper.
- Drawing board.
- T-square.
- Set square.
- Compass.
- Steel rule.
- Pencil.

**Task:**

Construct the complete development of a cube with an edge length of 60 mm.

**Expected outcome:**

A correctly constructed net consisting of six equal squares.

**Activity 2: Developing a cylinder**

**Task:**

Develop the curved surface of a cylinder having:

- Diameter: 100 mm.
- Height: 200 mm.

Calculate the circumference and draw the rectangular development.

**Activity 3: Developing a cone**

**Task:**

Develop a right circular cone with:

- Base radius: 60 mm.
- Vertical height: 80 mm.

Determine:

- Slant height.
- Sector angle.
- Shape of the development.

**Activity 4: Developing a transition piece**

**Task:**

Prepare a development of a transition piece connecting a square opening to a circular opening.

Use triangulation and show all the construction lines.

**Activity 5: Truncated cylinder**

**Task:**

Draw the development of a cylinder cut by an inclined plane.

Show:

- Elevation.
- Plan.
- Division points.
- Generators.
- Development.
- Cutting outline.

**Activity 6: Classroom exhibition**

Learners should display their completed developments and explain:

1. The type of object developed.
2. The development method used.
3. The drawing instruments used.
4. The dimensions of the development.
5. The application of the developed pattern in metal fabrication.

**REVISION QUESTIONS**

SECTION A: MULTIPLE-CHOICE QUESTIONS

**Instructions:** Answer all questions. Choose the correct answer from the alternatives A, B, C and D.

**1.** What is surface development in Metal Technology?

A. Joining two metal surfaces permanently.

B. Unfolding the surfaces of a three-dimensional object onto a flat plane.

C. Painting the surface of a metal object.

D. Measuring the weight of a metal object.

**2.** Which of the following is the main purpose of surface development?

A. To increase the weight of sheet metal.

B. To determine the colour of a metal component.

C. To obtain accurate flat patterns for fabrication.

D. To harden sheet metal.

**3.** Which development method is suitable for a cylinder?

A. Radial-line development.

B. Parallel-line development.

C. Approximate development only.

D. Freehand development.

**4.** Which development method is mainly used for cones?

A. Parallel-line development.

B. Radial-line development.

C. Freehand development.

D. Sectional development.

**5.** A generator in surface development refers to:

A. A machine used to produce electricity.

B. A straight line that produces a surface as it moves along a path.

C. A line used only for colouring drawings.

D. A line representing a cutting tool.

**6.** Which geometrical shape has six equal square faces?

A. Cylinder.

B. Cone.

C. Cube.

D. Pyramid.

**7.** The flat development of the curved surface of a cylinder is:

A. A triangle.

B. A rectangle.

C. A circle.

D. A sector.

**8.** The development of the curved surface of a cone is:

A. A rectangle.

B. A square.

C. A sector of a circle.

D. A hexagon.

**9.** Which instrument is used for drawing circles and arcs?

A. T-square.

B. Compass.

C. Try square.

D. Steel rule.

**10.** Which instrument is used to measure and construct angles?

A. Divider.

B. Scriber.

C. Protractor.

D. Try square.

**11.** What is the common point where the generators of a cone meet called?

A. Base.

B. Axis.

C. Apex.

D. Radius.

**12.** Which method involves dividing a complicated surface into triangular sections?

A. Parallel-line development.

B. Radial-line development.

C. Triangulation development.

D. Folding development.

**13.** Which of the following is an application of radial-line development?

A. Developing a cylindrical tank.

B. Developing a conical funnel.

C. Developing a rectangular duct.

D. Developing a square box.

**14.** The circumference of a cylinder is calculated using:

A. $C = \pi D$

B. $C = 2\pi D$

C. $C = \pi r^2$

D. $C = \frac{D}{2}$

**15.** What does truncation mean?

A. Joining two equal surfaces.

B. Cutting off part of a solid using a plane.

C. Painting a metal surface.

D. Increasing the diameter of a cylinder.

**16.** Which of the following is an example of intersecting surfaces?

A. Two separate metal sheets.

B. A branch pipe entering a main pipe.

C. Two unrelated circles.

D. A flat rectangular plate.

**17.** Which of the following materials is commonly used in ventilation duct fabrication?

A. Paper.

B. Timber.

C. Galvanised steel sheet.

D. Cardboard.

**18.** What is a seam in sheet metal fabrication?

A. A measuring instrument.

B. A joint formed by connecting sheet metal edges.

C. A type of drawing paper.

D. A metal cutting machine.

**19.** Which instrument is used to transfer measurements and divide distances?

A. Divider.

B. Protractor.

C. T-square.

D. Set square.

**20.** Which of the following is an advantage of accurate surface development?

A. Increased material wastage.

B. Increased production errors.

C. Reduced material wastage.

D. Poor fitting of components.

**21.** What is the slant height of a right circular cone?

A. The diameter of its base.

B. The distance along its curved surface from the apex to the base edge.

C. The circumference of its base.

D. The vertical diameter of its base.

**22.** Which of the following is used to mark fine lines on a metal surface?

A. Compass.

B. Scriber.

C. Protractor.

D. Drawing board.

**23.** A transition piece is mainly used to:

A. Connect two components of different shapes or sizes.

B. Increase the hardness of steel.

C. Paint metal surfaces.

D. Sharpen cutting tools.

**24.** Which of the following is an example of a truncated surface?

A. An uncut cube.

B. A cylinder cut by an inclined plane.

C. A complete sphere.

D. A flat sheet of paper.

**25.** A school water tank is in the shape of a frustum of a cone. Its vertical height is 7.2 m, while the top and bottom radii are 6 m and 12 m respectively. Calculate the slant height of the tank, correct to one decimal place.

A. 7.8 m

B. 8.5 m

C. 9.4 m

D. 10.2 m

**26.** What is the main function of a folding machine?

A. To measure sheet metal.

B. To bend sheet metal along predetermined lines.

C. To paint sheet metal.

D. To divide circles.

**27.** Which PPE is essential for protecting the eyes during sheet metal cutting?

A. Safety goggles.

B. Safety boots.

C. Apron.

D. Overalls.

**28.** Which of the following is a characteristic of parallel-line development?

A. All generators meet at one apex.

B. The generators remain parallel.

C. It uses only circular arcs.

D. It is used only for pyramids.

**29.** What is the main purpose of adding a joining allowance to a developed pattern?

A. To increase the colour of the metal.

B. To provide material for joining the edges.

C. To reduce the thickness of the sheet.

D. To make the drawing more attractive.

**30.** Why should learners display their completed surface developments?

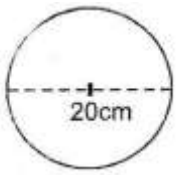
A. To avoid practical work.

B. To demonstrate their understanding and share their work.

C. To increase the weight of the drawing paper.

D. To replace all workshop activities.

**31.** What is the circumference of the figure below? (Take x = 3.14)




A. 62.58m

B. 62.58mm

C. 62.58cm

D. 62.58$m^2$

**SECTION B**

**QUESTION 1: INTRODUCTION TO SURFACE DEVELOPMENT (8 MARKS)**

a) Define surface development as used in Metal Technology. (2 marks)

b) State four reasons why surface development is important in sheet metal fabrication. (4 marks)

c) Identify two sheet metal products manufactured using surface development. (2 marks)

**QUESTION 2: METHODS OF SURFACE DEVELOPMENT (8 MARKS)**

a) Name four methods of surface development used in Metal Technology. (4 marks)

b) State one suitable application of each of the following methods:

i. Parallel-line development. (1 mark)

ii. Radial-line development. (1 mark)

c) Explain the principle of triangulation development. (2 marks)

**QUESTION 3: DEVELOPMENT OF GEOMETRICAL SHAPES (8 MARKS)**

a) State four characteristics of a cube. (4 marks)

b) Explain why the curved surface development of a cylinder takes the shape of a rectangle. (2 marks)

c) State two applications of cone development in sheet metal fabrication. (2 marks)

**QUESTION 4: CALCULATIONS IN SURFACE DEVELOPMENT (8 MARKS)**

a) A cylindrical metal tank has a diameter of 200 mm and a height of 350 mm.

Calculate:

i. The circumference of the tank. (2 marks)

ii. The dimensions of its curved surface development, ignoring joining allowances. (2 marks)

b) A conical funnel has a base radius of 60 mm and a vertical height of 80 mm.

Calculate:

i. Its slant height. (2 marks)

ii. The sector angle of its development. (2 marks)

Use $\pi=3.142$

**QUESTION 5: INTERSECTING AND TRUNCATED SURFACES (9 MARKS)**

a) Define the term intersection as used in Metal Technology. (2 marks)

b) State three examples of intersecting surfaces found in sheet metal fabrication. (3 marks)

c) Explain the procedure for developing a truncated cylinder. (4 marks)

**QUESTION 6: TOOLS, SAFETY AND PRACTICAL APPLICATIONS (9 MARKS)**

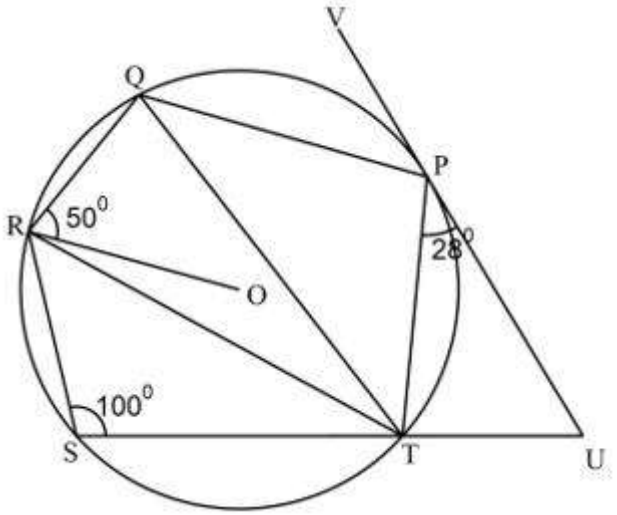
a) State four drawing instruments used in surface development and give one use of each. (4 marks)

b) State three safety precautions to observe when handling sheet metal. (3 marks)

c) Explain two applications of transition pieces in metal fabrication. (2 marks)

**QUESTION 7:**

In the figure below, P,Q,R,S and T lie on the circumference of a circle centre O. Line UPV is a tangent to the circle at P. Chord ST of the circle is produced to intersect with the tangent at U. Angles UPT, RST and ORQ are $28^0$, $100^0$ and $50^0$ respectively.




(a) Determine the sizes of the following angles;

1. RTP (3 marks)
2. QTP (3 marks)

(b) Given that PQ = 6cm , calculate correct to 1 decimal place, the radius of the circle. (4 marks)

**MARKING SCHEME**

**SECTION A: ANSWER KEY**

| Question | Answer | Question | Answer |
|---|---|---|---|
| 1 | B | 16 | B |
| 2 | C | 17 | C |
| 3 | B | 18 | B |
| 4 | B | 19 | A |
| 5 | B | 20 | C |
| 6 | C | 21 | B |
| 7 | B | 22 | B |
| 8 | C | 23 | A |
| 9 | B | 24 | B |
| 10 | C | 25 | C |
| 11 | C | 26 | B |
| 12 | C | 27 | A |
| 13 | B | 28 | B |
| 14 | A | 29 | B |
| 15 | B | 30 | B |
| | | 31 | C |

**SECTION B: STRUCTURED QUESTIONS**

**SECTION B:**

**QUESTION 1 (8 MARKS)**

a) Surface development is the process of unfolding or laying out the surfaces of a three-dimensional solid onto a flat two-dimensional plane to obtain a pattern for fabrication. (2 marks)

b) Reasons for importance (any four, 1 mark each):

1. Promotes dimensional accuracy.

2. Minimises material wastage.
3. Saves fabrication time.
4. Improves the quality of finished products.
5. Enables production of complex shapes.
6. Promotes mass production.
7. Improves fitting of components.
8. Reduces fabrication errors.

c) Any two (1 mark each):

- Water tanks.
- Funnels.
- Metal buckets.
- Chimney pipes.
- Ventilation ducts.
- Metal containers.
- Hoppers.

**QUESTION 2 (8 MARKS)**

a) Four methods (1 mark each):

1. Parallel-line development.
2. Radial-line development.
3. Triangulation development.
4. Approximate development.

b)

i. Parallel-line development: Used for cylinders or prisms. (1 mark)

ii. Radial-line development: Used for cones or pyramids. (1 mark)

c) Triangulation development involves dividing a complicated surface into triangular sections, determining the true lengths of the sides and transferring the triangles onto a flat plane to obtain the required development. (2 marks)

**QUESTION 3 (8 MARKS)**

a) Characteristics of a cube (any four, 1 mark each):

1. It has six faces.
2. All faces are equal squares.
3. It has twelve equal edges.
4. It has eight vertices.
5. All interior angles are 90°.

b) The curved surface of a cylinder unfolds into a rectangle because its circumference becomes the length of the rectangle while its height remains the width. (2 marks)

c) Applications (any two, 1 mark each):

- Manufacturing funnels.
- Making conical hoppers.
- Making chimney tops.
- Manufacturing conical covers.
- Making industrial exhaust fittings.

**QUESTION 4 (8 MARKS)**

**a) Development of a Cylinder**

**Given:**

- Diameter, $D = 200\ \text{mm}$
- Height, $h = 350\ \text{mm}$

**i. Calculate the circumference. (2 marks)**

Using the formula:

$$C = \pi D$$

Substituting the values:

$$C = 3.142 \times 200$$

$$\boxed{C = 628.4\ \text{mm}}$$

**ii. State the dimensions of the development. (2 marks)**

The development of a cylinder is a rectangle.

- Length = Circumference = 628.4 mm.
- Width = Height = 350 mm.

**Answer:**

- Length = 628.4 mm.
- Width = 350 mm.

**b) Development of a Cone**

**Given:**

- Radius, $r = 60\ \text{mm}$
- Vertical height, $h = 80\ \text{mm}$

**i. Calculate the slant height. (2 marks)**

Using Pythagoras' theorem:

$$L = \sqrt{h^2 + r^2}$$

Substituting the values:

$$L = \sqrt{80^2 + 60^2}$$

$$L = \sqrt{6400 + 3600}$$

$$L = \sqrt{10000}$$

$$\boxed{L = 100\ \text{mm}}$$

**ii. Calculate the sector angle. (2 marks)**

Using the formula:

$$\theta = \frac{360^\circ \times r}{L}$$

Substituting the values:

$$\theta = \frac{360^\circ \times 60}{100}$$

$$\theta = \frac{21600}{100}$$

$$\boxed{\theta = 216^\circ}$$

**QUESTION 5 (9 MARKS)**

a) Intersection is the line or curve formed where two or more surfaces meet or penetrate one another. (2 marks)

b) Examples (any three, 1 mark each):

1. Cylinder intersecting cylinder.
2. Cylinder intersecting cone.
3. Cylinder intersecting prism.
4. Prism intersecting prism.

c) Procedure for developing a truncated cylinder (any four, 1 mark each):

1. Draw the elevation and plan of the cylinder.
2. Draw the inclined cutting plane in the elevation.
3. Divide the circular plan into equal parts.
4. Project the division points onto the elevation.
5. Determine the points where the cutting plane intersects the generators.
6. Draw the rectangular development.
7. Transfer the intersection heights onto the corresponding generators.
8. Join the points with a smooth curve to form the cutting outline.

**QUESTION 6 (9 MARKS)**

a) Drawing instruments and uses (any four, 1 mark each):

| **Instrument** | **Use** |
|---|---|
| Compass | Drawing circles and arcs |
| Divider | Transferring and dividing measurements |
| Steel rule | Measuring lengths |
| Protractor | Measuring and constructing angles |
| T-square | Drawing horizontal lines |
| Set square | Drawing vertical and inclined lines |
| Try square | Checking right angles |
| Scriber | Marking lines on metal |

b) Safety precautions (any three, 1 mark each):

1. Wear suitable protective gloves when handling sheet metal.
2. Wear safety goggles when cutting metal.
3. Avoid handling sharp edges with bare hands.
4. Store sheet metal safely.
5. Use appropriate cutting tools.
6. Dispose of sharp offcuts safely.

c) Applications of transition pieces (any two, 1 mark each):

1. Connecting rectangular ducts to circular ventilation ducts.
2. Connecting pipes or ducts of different diameters.

3. Connecting square openings to round openings.
4. Changing the cross-sectional dimensions of industrial air ducts.
5. Connecting different sections of hoppers and chutes.

**QUESTION 7**

a) (i) Angle RQT = 180° − 100° = 80° – opposite angles of cyclic quadrilateral QRST are supplementary

Angle TQP = Angle UPT = 28° – angle between a chord in alternate segment.

Angle RQP = 80° + 28° = 108°

Hence Angle RTP = 180° − 108° = 72° – opposite angles of cyclic quadrilateral QRTP are supplementary

(ii) Join O to Q and consider ΔRQO

Angle RQO = $50^0$ – base angles of isosceles ΔRQO

Angle ROQ = 180° − (2 × 50°) = 80° – sum of angles in ΔRQO is $180^0$

Angle RTQ = $\frac{1}{2} \times 80^0 = 40^0$ – angle at the centre is twice angle at the circumference Hence

Angle QTP= $72^0 - 40^0 = 32^0$

b) In $\Delta QPT, PQ = 6cm, \angle QPT = 120° \; and \; \angle QTP = 32°$

$$\frac{6}{\sin 32} = \frac{QT}{\sin 120}$$

$$QT = \frac{6 \times \sin 120}{\sin 32} = 9.806 \; cm$$

Let M be the midpoint of QT

MQ = $\frac{1}{2} \times 9.806 = 4.903$

Consider ΔOQM

$$\cos 30° = \frac{OQ}{4.903}$$

$$OQ = \frac{4.903}{\cos 30°} = 5.7 \; cm$$

**STRAND 3.0: RELATED DRAWING IN METALWORK**

**SUB-STRAND 3.1: SURFACE DEVELOPMENT**

## 1.0 INTRODUCTION TO SURFACE DEVELOPMENT

### 1.1 Meaning of surface development

Surface development is the process of representing the complete outer surface of a three-dimensional object on a flat, two-dimensional plane.

It involves unfolding or opening out the surfaces of a solid object so that they lie flat without overlapping.

The resulting flat pattern is called a **development**, **surface development** or **pattern**.

In metalwork, surface development is used to prepare flat sheet-metal patterns before cutting, folding, bending, rolling, joining or forming them into finished products.

For example, before making a cylindrical water tank, a metalworker develops the curved surface of the cylinder into a rectangle and the circular ends into circles.

### 1.2 Understanding surface development

A three-dimensional object has length, width, height and surfaces. However, sheet metal is supplied in flat sheets.

A metalworker therefore needs to determine how the flat sheet should be marked and cut so that it can be formed into the required shape.

The process involves:

1. Studying the shape and dimensions of the object.
2. Identifying all its surfaces.
3. Determining how the surfaces can be unfolded.
4. Drawing the developed pattern on a flat surface.
5. Adding allowances where necessary.
6. Cutting the pattern from sheet metal.
7. Folding, rolling or joining the metal to obtain the required object.

### 1.3 Examples of products made using surface development in Kenya

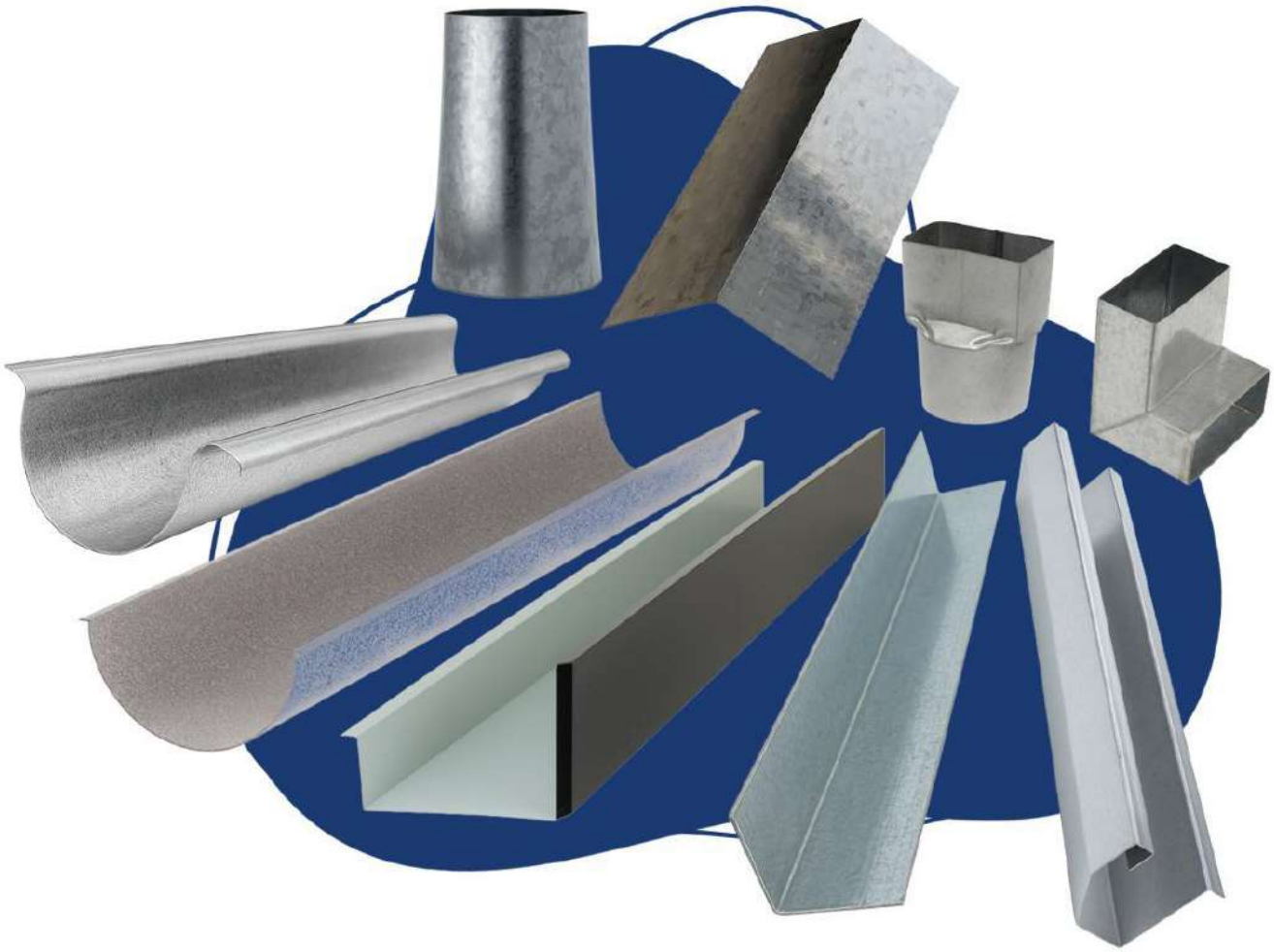
Surface development is applied when making:

- Water storage tanks.
- Metal buckets.
- Cooking pots.
- Milk cans.
- Metal funnels.
- Roofing accessories.
- Gutters and downpipes.
- Chimneys and ventilation ducts.
- Metal trays.
- Cooking jikos.
- Wheelbarrows.

- Metal cabinets.
- Grain storage containers.
- Metal roofing flashings.
- Agricultural equipment covers.







**1.4 Importance of studying surface development in metalwork**

Surface development is important because it enables a metalworker to:

1. **Prepare accurate patterns:** It helps in producing correct flat patterns before cutting sheet metal.
2. **Reduce material wastage:** Accurate patterns minimise unnecessary cutting and offcuts.
3. **Improve dimensional accuracy:** It ensures that the final product has the required dimensions.
4. **Save production time:** A correctly developed pattern reduces repeated measurements and adjustments.
5. **Improve product quality:** Proper development results in well-fitting joints and correctly shaped products.
6. **Determine material requirements:** It helps calculate the amount of sheet metal required.
7. **Produce complex shapes:** It makes it possible to manufacture cones, cylinders, pyramids and transition pieces.
8. **Improve workmanship:** It promotes neatness, accuracy and professional standards.
9. **Support mass production:** Standardised patterns can be reused when producing similar products.
10. **Promote economic use of resources:** It reduces production costs and unnecessary material losses.

**Kenyan context:** A fundi making metal water tanks, milk cans, gutters or cooking jikos in a local fabrication workshop uses surface development to ensure that the sheet metal is cut accurately before being formed and joined.

**2.0 BASIC TERMS USED IN SURFACE DEVELOPMENT**

Understanding the following terms is important when studying surface development.

**2.1 Development**

A flat representation of all the surfaces of a three-dimensional object, arranged so that they can be folded or formed into the original object.

**2.2 Pattern**

A template or outline drawn on sheet metal or another material to guide cutting and forming.

**2.3 Generator**

A straight line which moves along a particular path to generate a surface.

For example, a straight line moving parallel to the axis of a cylinder generates its curved surface.

**2.4 Seam**

A joint formed by joining two edges of sheet metal.

Examples include:

- Lap seam.
- Grooved seam.
- Wired seam.
- Riveted seam.

**2.5 Allowance**

Additional material provided on a developed pattern to facilitate joining, folding, bending or finishing.

Examples include:

- Seam allowance.
- Wiring allowance.
- Folding allowance.
- Hem allowance.

**2.6 True length**

The actual length of a line or edge in space, rather than its shortened projected length in a drawing.

**2.7 Lateral surface**

The side surface of a solid, excluding its base or bases.

**2.8 Truncation**

The process of cutting off part of a solid using a plane that removes a portion of the original object.

**2.9 Intersection**

The line or curve formed when two surfaces meet or pass through one another.

**2.10 Stretch-out**

The total distance required to unfold or develop a curved surface into a flat pattern.

For a cylinder, the stretch-out is equal to the circumference of its circular base.

$C=\pi D=2\pi r$

Where:

- CC = circumference.

- $D$ = diameter.
- $r$ = radius.
- $\pi$ = 3.142 approximately.

**3.0 PRINCIPLES OF SURFACE DEVELOPMENT**

Surface development is based on the idea that the surfaces of an object can be unfolded or transferred onto a flat plane.

**3.1 Main principles**

1. Every surface of the object must be represented in the development.
2. The dimensions of the developed surfaces must correspond to the actual dimensions of the object.
3. Curved surfaces must be developed using appropriate geometrical methods.
4. Edges that meet in the finished object must also meet correctly when the pattern is formed.
5. The development should avoid unnecessary overlapping of surfaces.
6. Allowances should be added where joining and folding are required.
7. Accurate geometrical construction is necessary to achieve a correctly fitting product.

**3.2 Types of surfaces commonly developed**

**A. Plane surfaces**

These are flat surfaces.

Examples:

- Square faces of a cube.
- Rectangular faces of a cuboid.
- Triangular faces of a pyramid.

**B. Curved surfaces**

These are surfaces that are not flat.

Examples:

- Curved surface of a cylinder.
- Curved surface of a cone.
- Curved surface of a transition duct.

**C. Combined surfaces**

These are objects containing both plane and curved surfaces.

Examples:

- A cylindrical container with a flat bottom.
- A funnel with a cylindrical outlet.
- A transition duct connecting two different-sized openings.

## 4.0 METHODS OF SURFACE DEVELOPMENT

There are different methods used to develop surfaces in sheet-metal work. The method selected depends on the shape of the object, the type of surface and the geometrical properties of the object.

The main methods are:

1. Parallel-line development.
2. Radial-line development.
3. Triangulation development.
4. Approximate development.

### 4.1 Parallel-line development method

**Definition**

Parallel-line development is a method of developing surfaces in which parallel generators are used to divide the surface into sections before transferring the sections onto a flat plane.

It is mainly used for objects whose surfaces are generated by parallel straight lines.

**Examples of objects developed using this method**

- Cylinders.
- Square ducts.
- Rectangular ducts.
- Prisms.
- Pipes.
- Uniform rectangular containers.

**Characteristics of parallel-line development**

1. The generators are parallel to one another.
2. The surface is divided into equal or convenient sections.
3. The distances between corresponding generators are maintained.
4. The true lengths of the generators are transferred to the development.
5. The method is suitable for cylindrical and prismatic objects.

**Procedure for developing a cylinder using parallel lines**

1. Draw the elevation of the cylinder.
2. Draw the plan showing its circular base.
3. Divide the circular base into a convenient number of equal parts, such as 12.
4. Project the division points onto the elevation.
5. Draw parallel generators through the corresponding points.
6. Draw a straight horizontal line equal to the circumference of the cylinder.
7. Divide the horizontal line into the same number of equal parts.
8. Transfer the corresponding generator lengths onto the development.
9. Join the transferred points to form the rectangular development.

10. Add the required seam allowance.

**Formula**

$L=\pi D$

Where:

- L = length of rectangular development.
- D = diameter of cylinder.

The width of the rectangle is equal to the height of the cylinder.

**Worked example 1**

A cylindrical container has a diameter of 140 mm and a height of 200 mm. Determine the dimensions of its lateral surface development.

Solution:

Given:

- Diameter = 140 mm.
- Height = 200 mm.
- $\pi=3.142\pi=3.142$.

Length of development:

$L=\pi D$

$L=3.142\times140$

$L=439.88$ mm

Width of development:

$W=200$ mm

Therefore, the lateral surface development is:

- Length = 439.88 mm.
- Width = 200 mm.

The rectangular pattern is approximately 439.88 mm by 200 mm, before adding seam and other allowances.

**Applications in Kenya**

- Making cylindrical water tanks.
- Fabricating metal drums.
- Making milk cans.
- Manufacturing cylindrical chimneys.
- Making metal pipes and ventilation ducts.

**4.2 Radial-line development method**

**Definition**

Radial-line development is a method of developing surfaces in which the generators of the object converge towards a common point called the apex.

It is mainly used for cones and pyramids.

**Examples**

- Conical funnels.
- Conical hoppers.
- Pyramids.
- Conical roofs.
- Sheet-metal funnels.
- Conical ventilation outlets.

**Characteristics**

1. The generators meet at a common apex.
2. The development is constructed using arcs drawn from the apex.
3. The true lengths of the slant edges are important.
4. It is suitable for conical and pyramidal surfaces.
5. The developed pattern is generally made up of triangular faces or a circular sector.

**Procedure for developing a cone**

1. Draw the elevation of the cone.
2. Draw the plan showing the circular base.
3. Determine the true slant height of the cone.
4. Calculate the circumference of the circular base.
5. Draw an arc with a radius equal to the slant height.
6. Calculate the included angle of the sector.
7. Draw the two radial sides of the sector.
8. Transfer the required angle and complete the circular sector.
9. Add allowances for joining.
10. Draw the circular base separately if the cone is closed at the bottom.

**Formula for the sector angle**

$$\theta = \frac{360^\circ \times r}{s}$$

Where:

- θ = angle of the developed sector.
- $r$ = radius of the cone base.
- $s$ = slant height.

**Worked example 2**

A cone has a base radius of 60 mm and a slant height of 150 mm. Determine the angle of its developed sector.

Solution

Given:

- Radius, $r = 60\ \text{mm}$
- Slant height, $s = 150\ \text{mm}$

Step 1: Write the formula.

$$\theta = \frac{360^\circ \times r}{s}$$

Step 2: Substitute the given values.

$$\theta = \frac{360^\circ \times 60}{150}$$

Step 3: Simplify.

$$\theta = \frac{21600}{150}$$

$$\boxed{\theta = 144^\circ}$$

Therefore, the developed curved surface is a sector of radius 150 mm and included angle 144°.

The circular base, where required, has a radius of 60 mm.

**Applications in Kenya**

- Making metal funnels.
- Fabricating conical water outlets.
- Making hoppers for grain handling.
- Manufacturing conical chimneys.
- Fabricating conical roofs for small structures.

**4.3 Triangulation development method**

**Definition**

Triangulation development is a method of developing surfaces by dividing them into a series of triangles and transferring the true lengths of the triangle sides onto a flat plane.

It is useful when dealing with objects whose surfaces cannot conveniently be developed using parallel-line or radial-line methods.

**Examples**

- Transition pieces.
- Connecting ducts of different cross-sections.

- Irregular sheet-metal fittings.
- Rectangular-to-circular transitions.
- Complex ventilation fittings.

**Characteristics**

1. The surface is divided into a number of triangular sections.
2. True lengths of the triangle sides are determined.
3. The triangles are transferred one after another onto a flat plane.
4. Accurate measurement is necessary.
5. It can be used for complicated and irregular shapes.

**Procedure**

1. Draw the elevation and plan of the object.
2. Identify the points that define the surface.
3. Divide the surface into triangular sections.
4. Determine the true lengths of all the required edges.
5. Draw the first triangle using its true side lengths.
6. Construct the next triangle using the shared edge.
7. Continue until all triangular sections have been completed.
8. Join the outer boundary points.
9. Check the dimensions and add necessary allowances.

**4.4 Approximate development method**

**Definition**

Approximate development is a method used to produce a close estimate of the flat pattern of a surface when an exact geometrical development is difficult or unnecessary.

It is commonly used for complex curved or irregular surfaces.

**Applications**

- Complex duct fittings.
- Irregular ventilation components.
- Certain sheet-metal transitions.
- Components with compound curves.

**Characteristics**

1. It involves approximations in measuring or transferring dimensions.
2. It is suitable for certain complicated shapes.
3. It may require trial fitting and adjustment.
4. It is less accurate than exact development methods.
5. It should be used only when acceptable for the required manufacturing tolerance.

### 4.5 Comparison of methods of surface development

| Method | Main feature | Examples |
|---|---|---|
| Parallel-line | Uses parallel generators | Cylinders, prisms |
| Radial-line | Generators meet at an apex | Cones, pyramids |
| Triangulation | Uses triangular sections | Transition pieces |
| Approximate | Uses estimated development | Complex irregular fittings |

## 5.0 DEVELOPMENT OF DIFFERENT GEOMETRICAL SOLIDS

### 5.1 Development of a cube

**Definition of a cube**

A cube is a three-dimensional solid having six equal square faces, twelve equal edges and eight vertices.

**Properties of a cube**

1. It has six faces.
2. All faces are squares.
3. All twelve edges have equal lengths.
4. All interior angles are 90°.
5. Opposite faces are parallel.
6. It has eight vertices.

**Applications in metalwork**

- Square metal containers.
- Sheet-metal boxes.
- Metal cabinets.
- Storage compartments.
- Square ducts.

**Method of development**

A cube is developed by unfolding its six square faces onto a flat plane.

**Construction procedure**

1. Draw a square representing the base of the cube.
2. Construct another square on each of the four sides of the base.
3. Construct the sixth square on the outer edge of one of the attached squares.
4. Check that all six squares have equal dimensions.
5. Add flaps where necessary for joining.
6. Darken the outlines of the completed development.

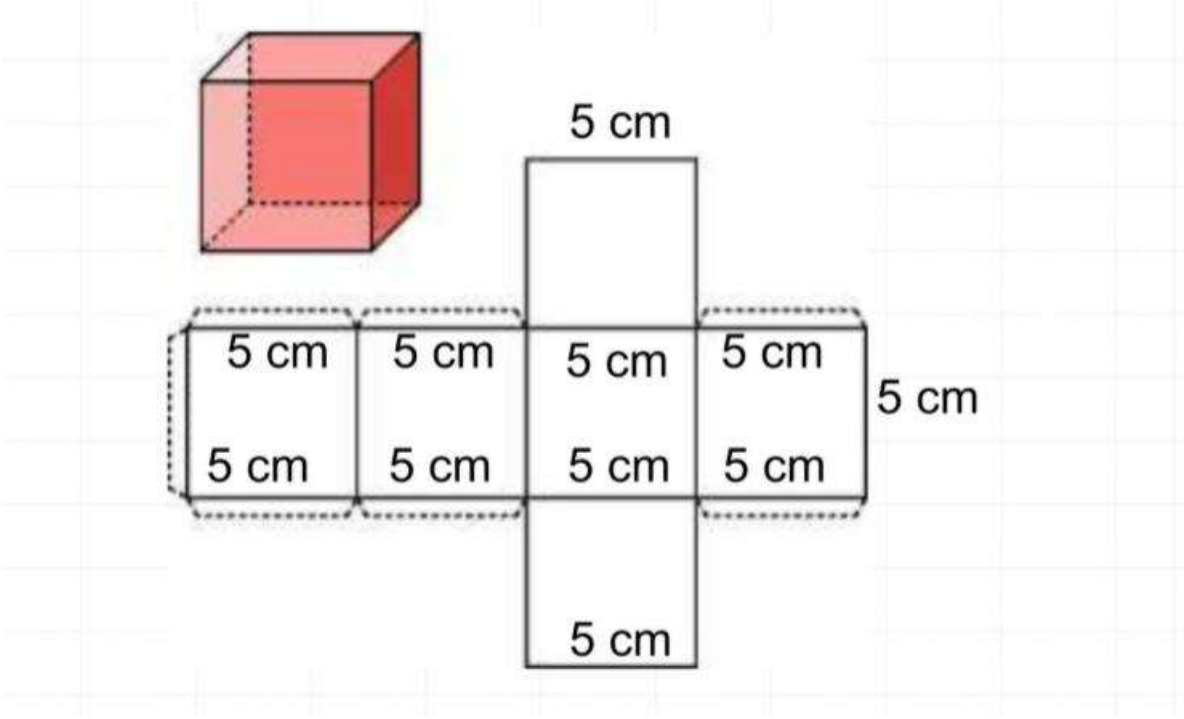
**Worked example**

Develop a cube whose edge measures 50 mm.

Each square face measures:

50×50 mm50×50 mm

The development consists of six squares, each measuring 50 mm by 50 mm.




The total surface area is:

The formula for the total surface area of a cube is:

$$A = 6a^2$$

Where:

- $A$ = Total surface area
- $a$ = Length of one edge

Substituting $a = 50$ mm:

$$A = 6(50)^2$$

$$A = 6 \times 50 \times 50$$

$$A = 6 \times 2500$$

$$\boxed{A = 15,000 \text{ mm}^2}$$

## 5.2 Development of a square pyramid

### Definition

A square pyramid is a solid having a square base and four triangular lateral faces meeting at a common point called the apex.

### Parts of a square pyramid

- Square base.
- Four triangular faces.
- Four slant edges.
- Four base edges.
- Apex.
- Slant height.

### Applications in metalwork

- Decorative metal covers.
- Pyramid-shaped hoppers.
- Roof ventilators.
- Decorative sheet-metal structures.
- Metal covers for equipment.

### Method of development

The square pyramid is developed using the radial-line method because its slant edges converge at a common apex.

### Construction procedure

1. Draw the plan of the square pyramid.
2. Draw its elevation.
3. Determine the true length of one slant edge.
4. Draw an arc using the true slant edge as the radius.
5. Mark off four base-edge lengths successively along the arc.
6. Join the marked points to the apex.
7. Complete the four triangular faces.
8. Draw the square base separately if it is required as a closed component.
9. Add joining allowances.

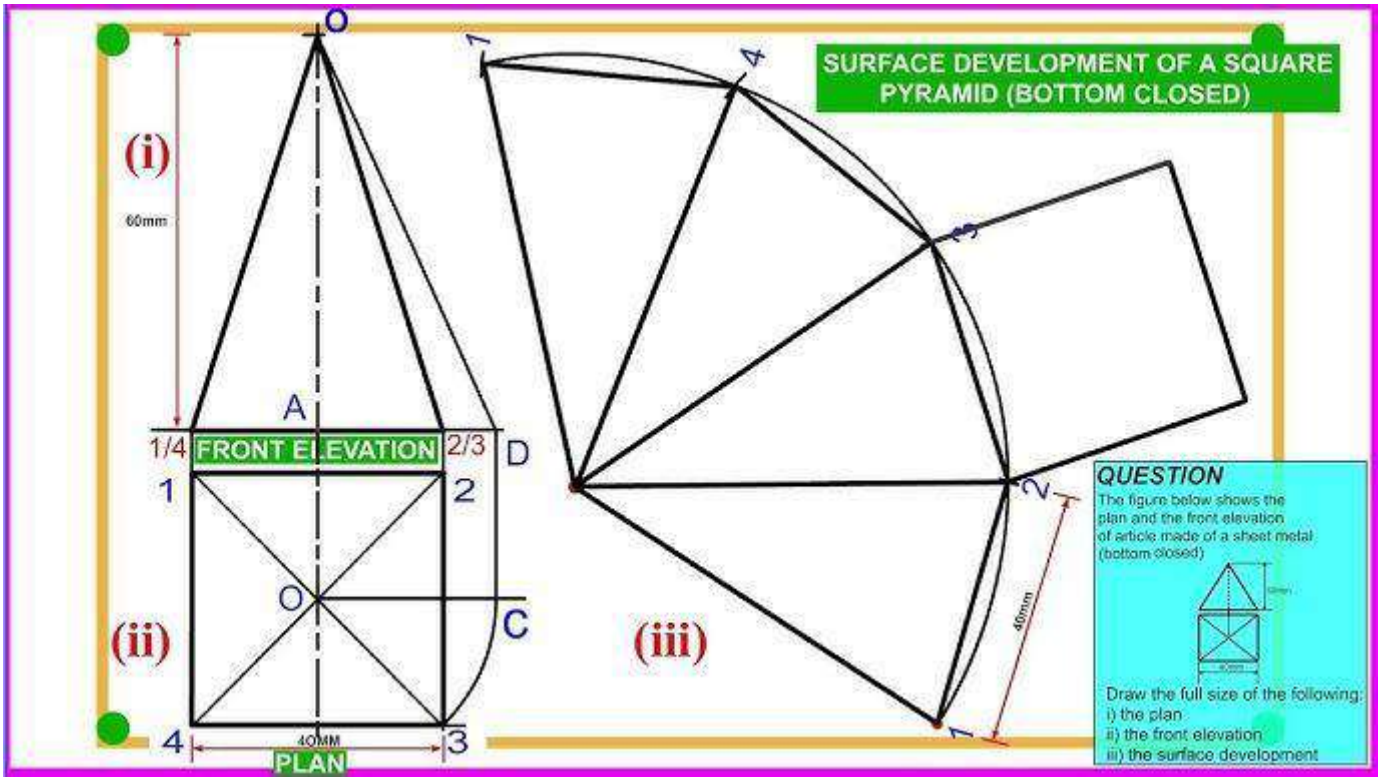
### Worked example

A square pyramid has a base measuring 60 mm by 60 mm. Each slant edge is 80 mm.

The development consists of:

- Four triangular faces.
- Each triangular face has a base of 60 mm.
- Each slant side measures 80 mm.

The four triangles are arranged around the apex to form the lateral surface pattern.




**5.3 Development of a cylinder**

**Definition**

A cylinder is a three-dimensional solid having two equal and parallel circular ends connected by one curved lateral surface.

**Parts of a cylinder**

1. Top circular face.
2. Bottom circular face.
3. Curved lateral surface.
4. Diameter.
5. Radius.
6. Height.
7. Axis.

**Applications**

- Water tanks.
- Metal drums.
- Chimneys.
- Pipes.
- Milk containers.
- Metal storage vessels.

**Method of development**

The cylinder is developed using the parallel-line method.

The curved surface becomes a rectangle while the circular ends remain circles.

**Construction procedure**

1. Draw the elevation of the cylinder.
2. Draw the plan showing its circular end.
3. Divide the circle into 12 equal parts.
4. Project the division points onto the elevation.
5. Draw the stretch-out line equal to the circumference.
6. Divide the stretch-out into 12 equal parts.
7. Draw perpendicular generators at each division.
8. Complete the rectangular development.
9. Add seam allowance.
10. Draw the circular ends separately.

**Formula**

L=πD

**Worked example**

A cylindrical water container has a diameter of 300 mm and a height of 400 mm. Calculate the dimensions of its lateral development.

**Step 1: Calculate the length.**

Using the formula:

$$L = \pi D$$

Substitute the given values:

$$L = 3.142 \times 300$$

$$L = 942.6 \text{ mm}$$

**Step 2: Determine the width.**

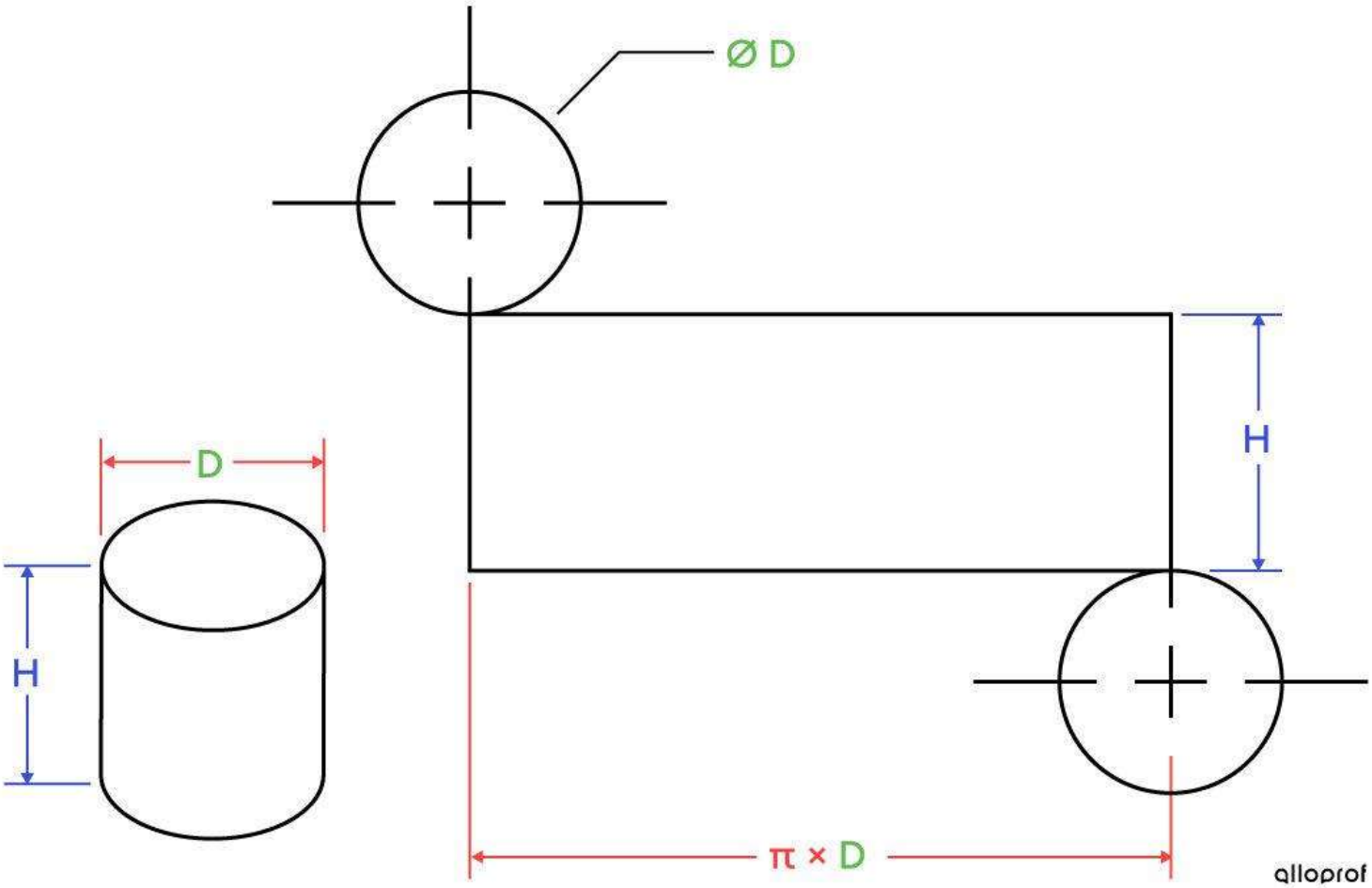
The width of the rectangular development is equal to the height of the cylinder.

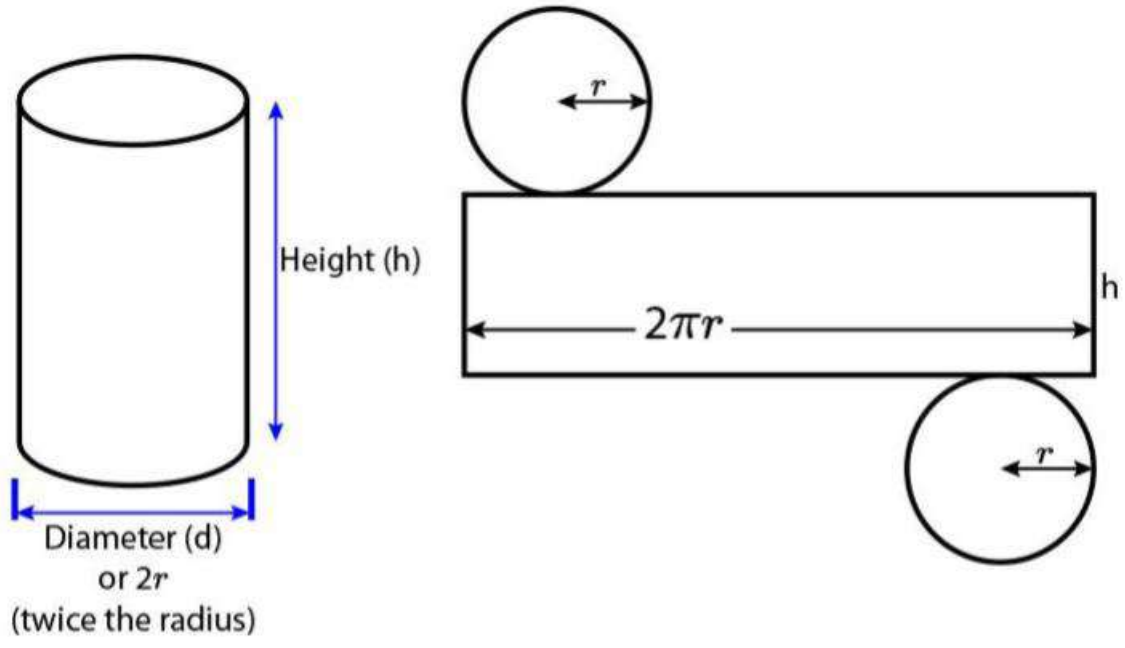
$$W = 400 \text{ mm}$$

Therefore:

- Length = 942.6 mm.
- Width = 400 mm.

The two circular ends each have a diameter of 300 mm.


Ø D
D
H
H
π × D
alloprof


Height (h)
Diameter (d)
or 2r
(twice the radius)
r
h
2πr
r

**5.4 Development of a cone**

**Definition**

A cone is a solid having one circular base and a curved surface that narrows towards a single point called the apex.

**Parts of a cone**

- Circular base.
- Apex.
- Radius.
- Diameter.
- Vertical height.
- Slant height.
- Curved surface.

**Applications in metalwork**

- Funnels.
- Conical hoppers.
- Chimney caps.
- Grain outlets.
- Sheet-metal reducers.

**Method of development**

The cone is developed using the radial-line method.

Its curved surface becomes a circular sector, while its base remains a circle.

**Construction procedure**

1. Draw the elevation of the cone.
2. Draw the plan showing the circular base.
3. Determine the true slant height.
4. Calculate the circumference of the base.
5. Draw an arc using the slant height as the radius.
6. Calculate the sector angle.
7. Construct the sector using a protractor or geometrical construction.
8. Complete the curved surface development.
9. Draw the circular base separately where necessary.
10. Add allowances for joining.

**Formula for the Sector Angle of a Cone**

The sector angle is calculated using:

$$\theta = \frac{360^\circ \times r}{l}$$

Where:

- $\theta$ = Sector angle.
- $r$ = Radius of the cone's base.
- $l$ = Slant height of the cone.

**Worked Example**

A cone has a base diameter of 100 mm and a slant height of 120 mm. Calculate the sector angle of its development.

**Step 1: Calculate the radius.**

$$r = \frac{D}{2}$$

$$r = \frac{100}{2} = 50 \text{ mm}$$

**Step 2: Calculate the sector angle.**

Using the formula:

$$\theta = \frac{360^\circ \times r}{l}$$

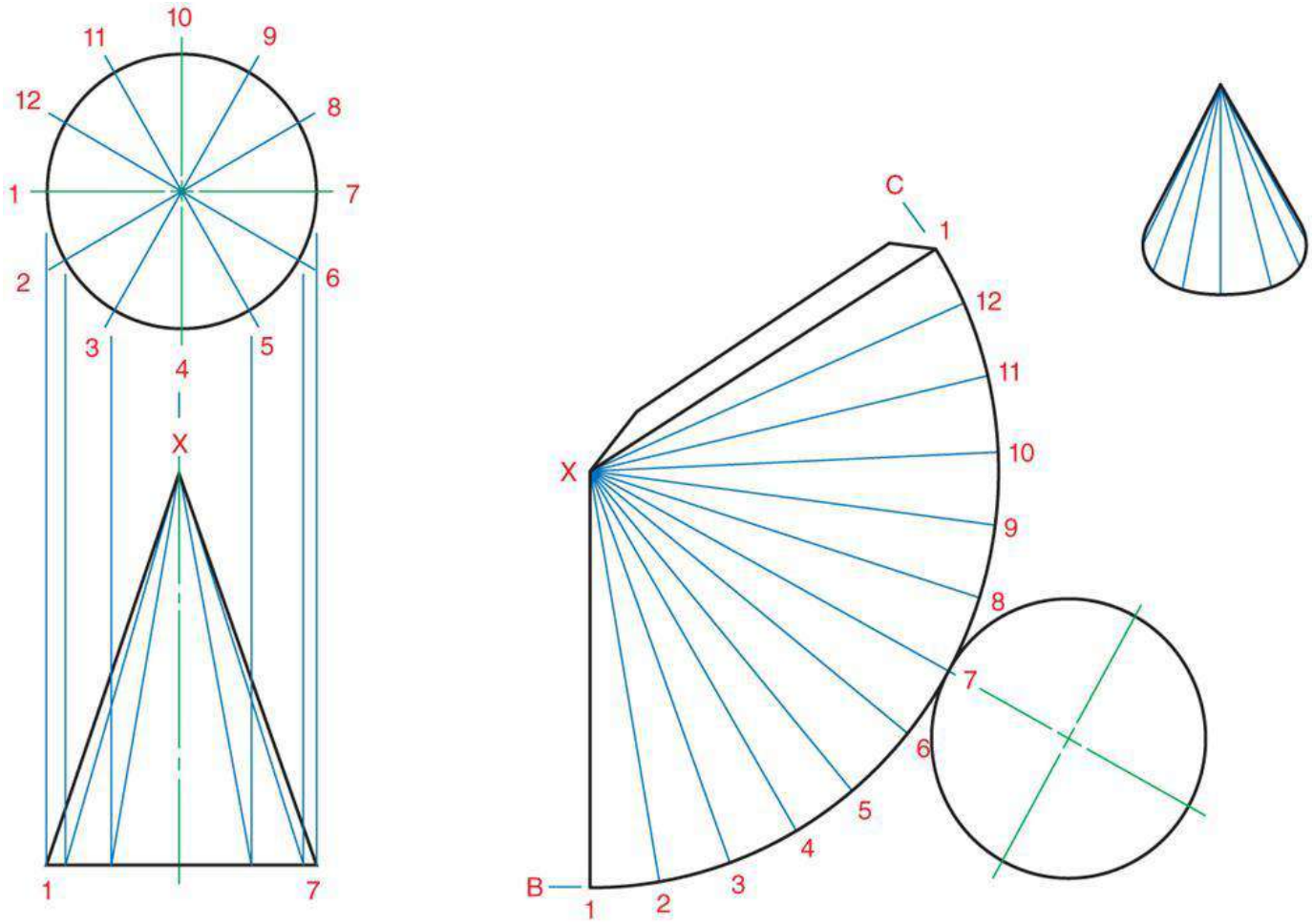
Substitute the given values:

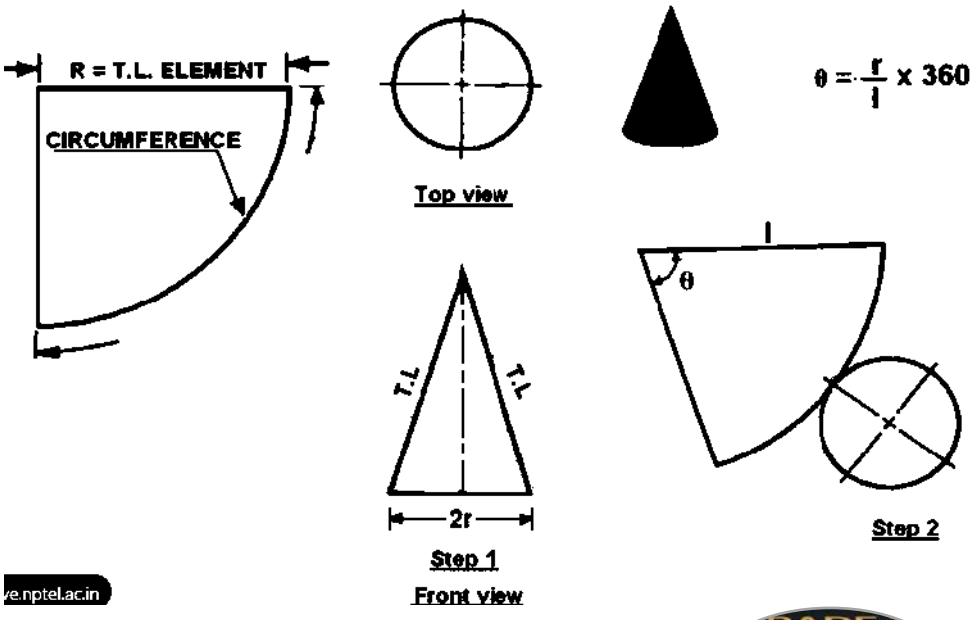
$$\theta = \frac{360^\circ \times 50}{120}$$

$$\theta = \frac{18000}{120}$$

$$\boxed{\theta = 150^\circ}$$

The development is a circular sector of radius 120 mm and angle 150°.



## 6.0 DEVELOPMENT OF INTERSECTING SURFACES

### 6.1 Meaning of intersecting surfaces

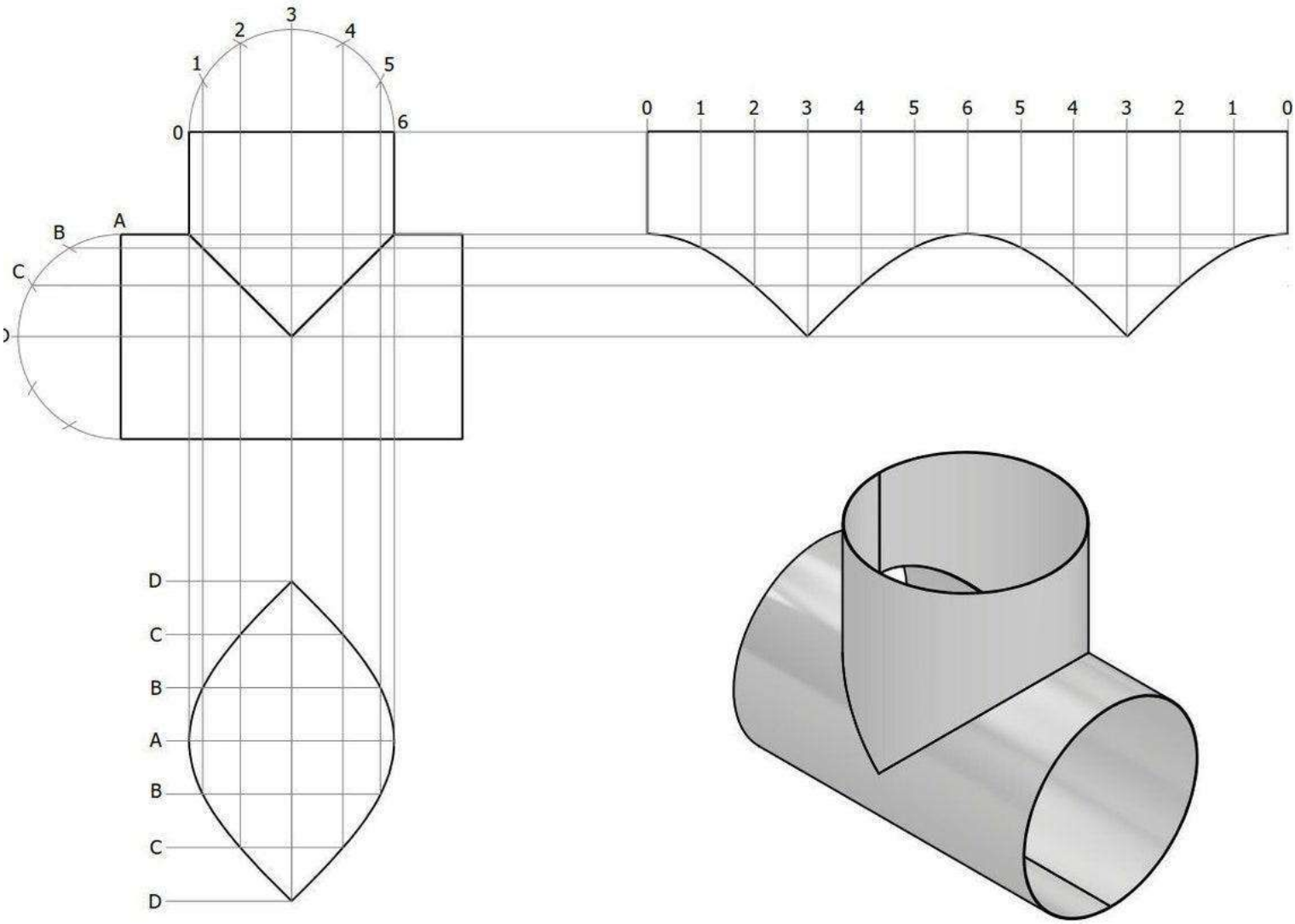
Intersection of surfaces is the line or curve formed when two or more solid surfaces meet or pass through one another.

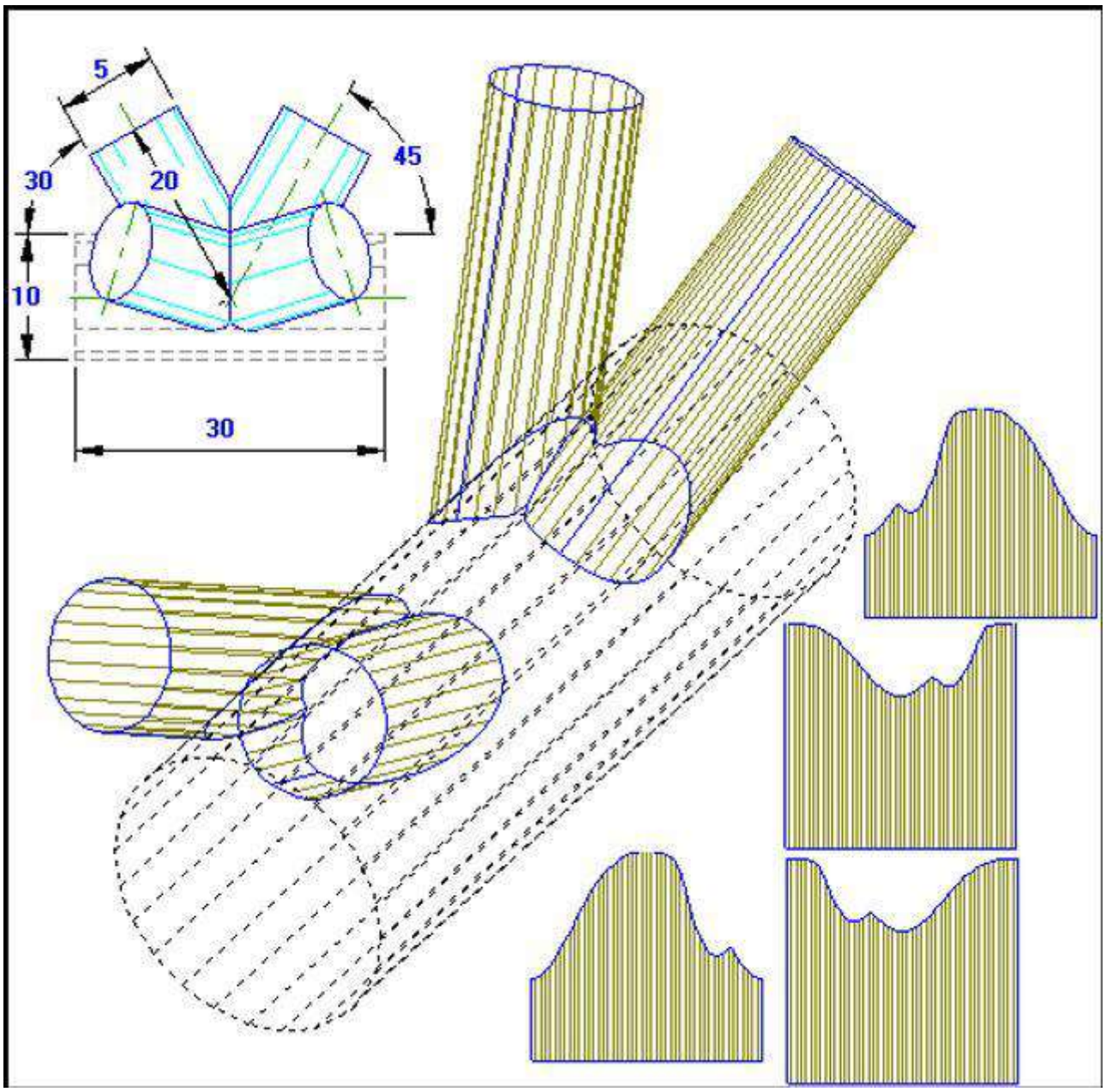
In metalwork, intersecting surfaces occur when pipes, ducts, cylinders, cones or other components are connected to form a complete structure.

The line formed where the surfaces meet is called the **line of intersection**.

### 6.2 Examples of intersecting surfaces in metalwork

- A smaller pipe entering a larger pipe.
- Two cylindrical ventilation ducts joining at an angle.
- A branch pipe joining a main pipe.
- A chimney pipe connected to another duct.
- A conical outlet joining a cylindrical pipe.
- Two metal cylinders intersecting at right angles.

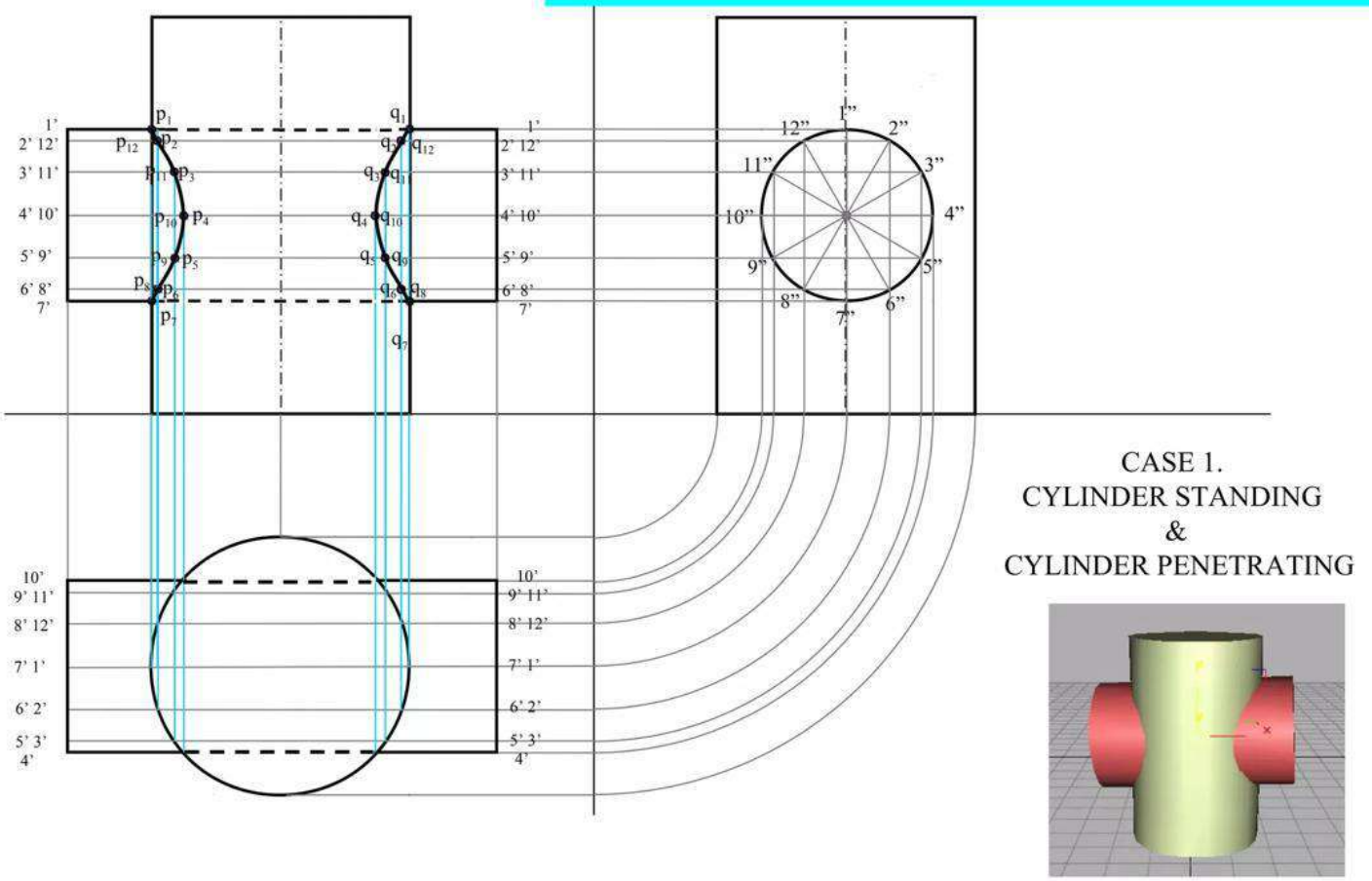



5
45
30
20
10
30

A vertical cylinder of 60 mm diameter is penetrated by another cylinder of 40 mm diameter, the axis of which bisects the axis of vertical cylinder. Draw projections showing curves of intersection.

Steps:

1. Draw the TV and FV of the vertical cylinder of 60 mm dia. and 100 mm length. Then also draw its side view.
2. Draw a circle of 40 mm dia in the side view with centre at the mid point of the axis. Then divide this circli\e in 12 equal parts, number them, first in the SV then i FV & TV.




CASE 1.
CYLINDER STANDING
&
CYLINDER PENETRATING



**6.3 Importance of drawing intersecting surfaces**

Drawing intersecting surfaces is important because it:

1. Determines the exact shape of the joint between two components.
2. Ensures that connecting parts fit together accurately.
3. Reduces gaps between intersecting components.
4. Minimises material wastage.
5. Improves the appearance of fabricated products.
6. Makes it easier to cut openings in pipes and ducts.
7. Helps in producing strong and reliable joints.
8. Reduces the need for repeated adjustments during fabrication.

**6.4 Methods used to draw intersections**

The following methods may be used:

**A. Generator method**

This method involves dividing one surface into a number of generators and locating the points where these generators meet the other surface.

Procedure:

1. Draw the elevation and plan of the intersecting objects.
2. Identify the surfaces that are intersecting.
3. Divide the circular or curved surface into equal parts.
4. Draw generators through the division points.
5. Project the generators onto the intersecting surface.
6. Mark the points where the generators meet the other surface.
7. Transfer the points to the required view.
8. Join the points using a smooth curve.
9. Check the accuracy of the intersection curve.

**B. Section-plane method**

This method uses imaginary cutting planes to determine the points of intersection between two surfaces.

Procedure:

1. Draw the views of the intersecting objects.
2. Select suitable cutting planes.
3. Determine the sectional points produced by each cutting plane.
4. Project the points onto the corresponding views.
5. Locate all the intersection points.
6. Join the points using a smooth curve.

**6.5 Development of a cylinder intersecting another cylinder**

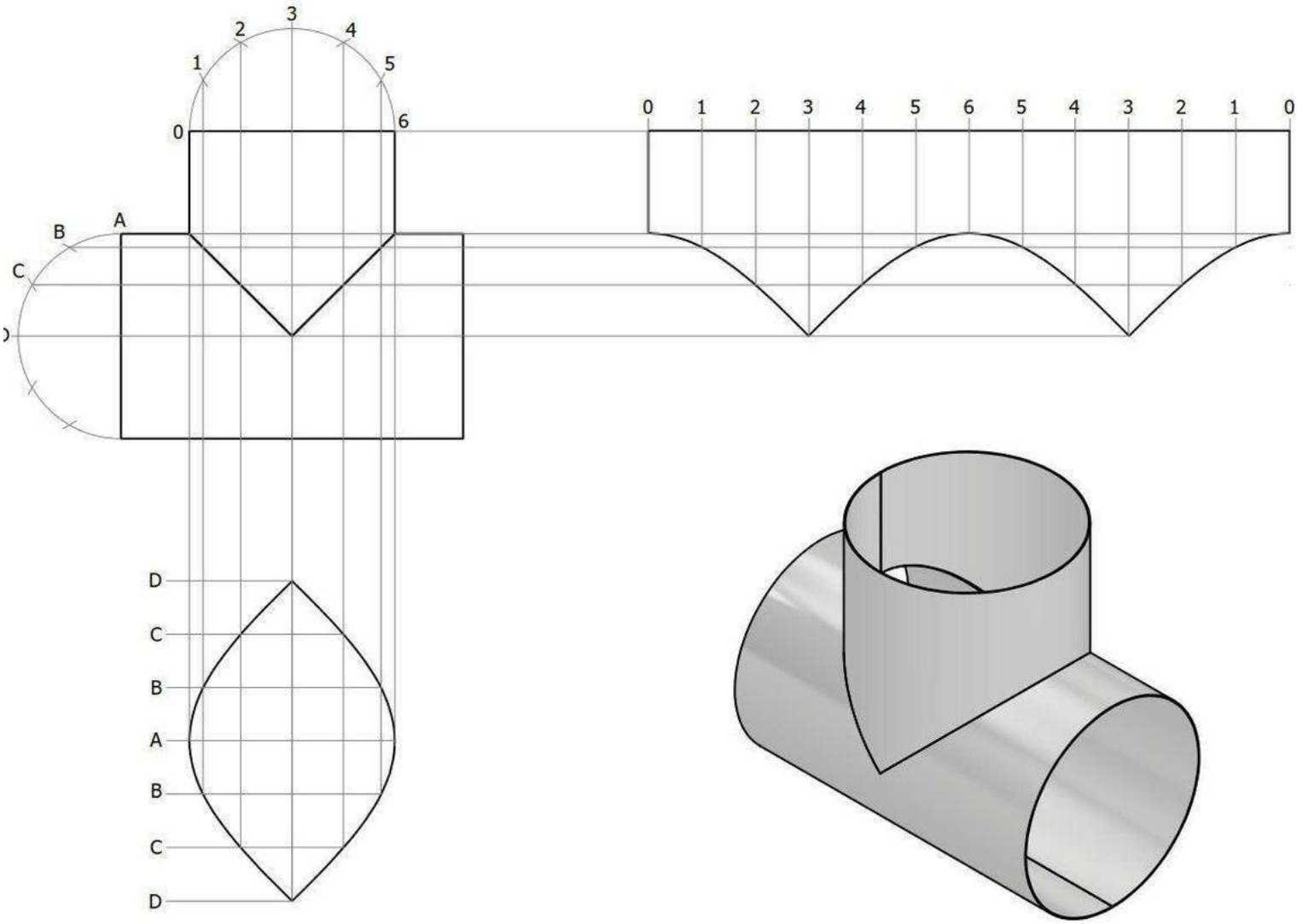
Consider a smaller cylindrical branch pipe joining a larger cylindrical pipe at right angles.

The branch pipe must have an opening that matches the curved surface of the main pipe.

**Construction procedure**

1. Draw the elevation showing the main cylinder and branch cylinder.
2. Draw the plan of the cylinders.
3. Divide the circular end of the branch cylinder into 12 equal parts.
4. Draw generators through the division points.
5. Project the generators onto the elevation.
6. Determine where each generator meets the surface of the main cylinder.
7. Mark the intersection points.
8. Draw the stretch-out of the branch cylinder using its circumference.
9. Divide the stretch-out into 12 equal parts.
10. Transfer the intersection points to the corresponding positions on the stretch-out.
11. Draw a smooth curve through the transferred points.
12. Complete the boundary of the developed pattern.
13. Add joining allowances where necessary.

The resulting pattern provides the shape of the opening that must be cut in the branch pipe.




**6.6 Applications of intersecting surfaces in Kenya**

Intersecting surfaces are commonly used in:

- Plumbing installations.
- Water supply systems.
- Ventilation systems.
- Industrial ductwork.
- Chimney construction.
- Agricultural processing equipment.
- Metal fabrication workshops.
- Exhaust systems.

**Practical activity**

Learners should observe two metal pipes joined at an angle in a workshop or plumbing installation. They should identify the line of intersection and explain how the opening in one pipe was prepared to fit the other pipe.

## 7.0 DEVELOPMENT OF TRUNCATED SURFACES

### 7.1 Meaning of truncation

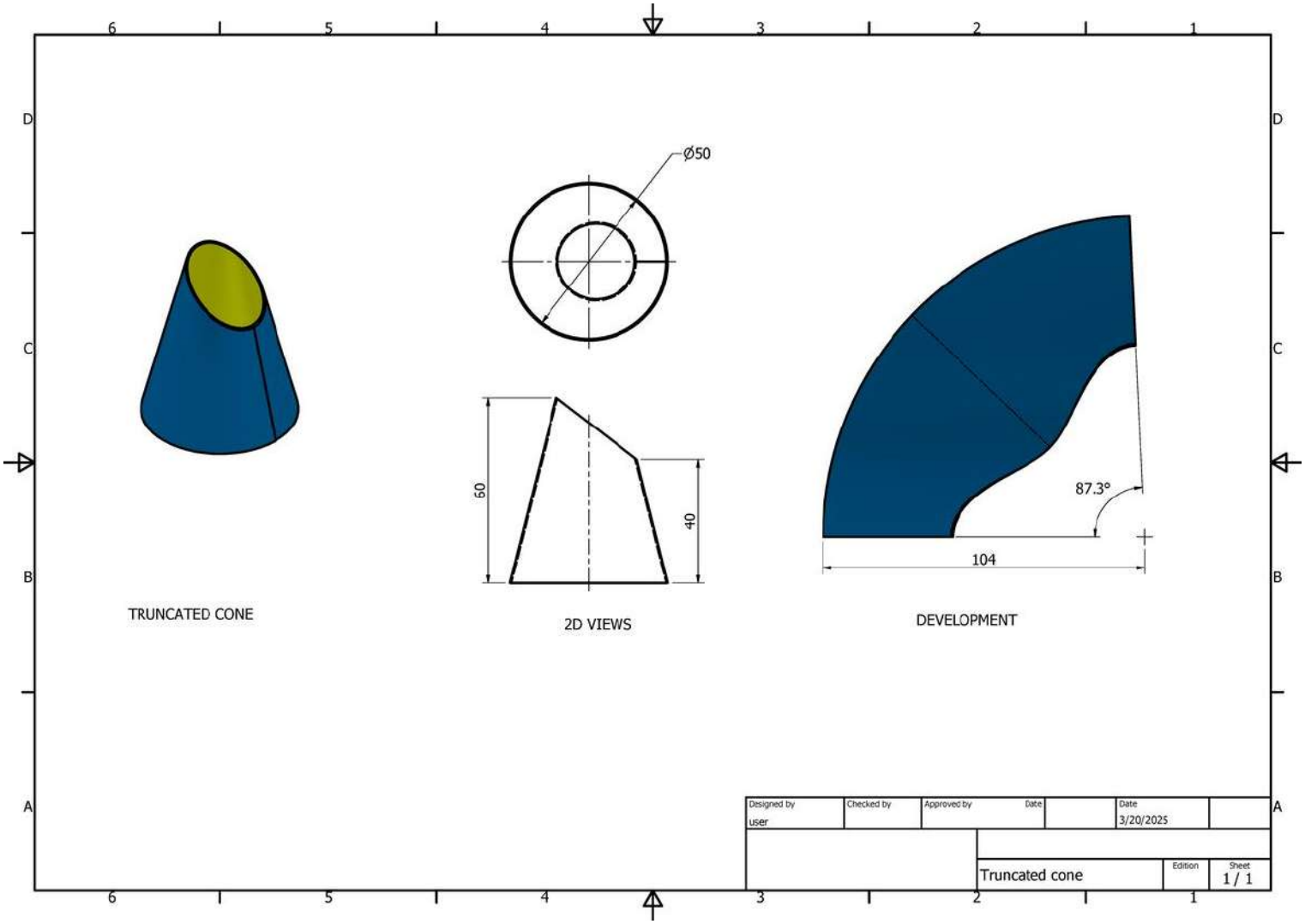
Truncation is the process of cutting off part of a solid using a plane that passes through the solid at an angle or position that is not necessarily perpendicular to its axis.

A truncated solid is therefore a solid whose original shape has been shortened or modified by cutting away a portion.

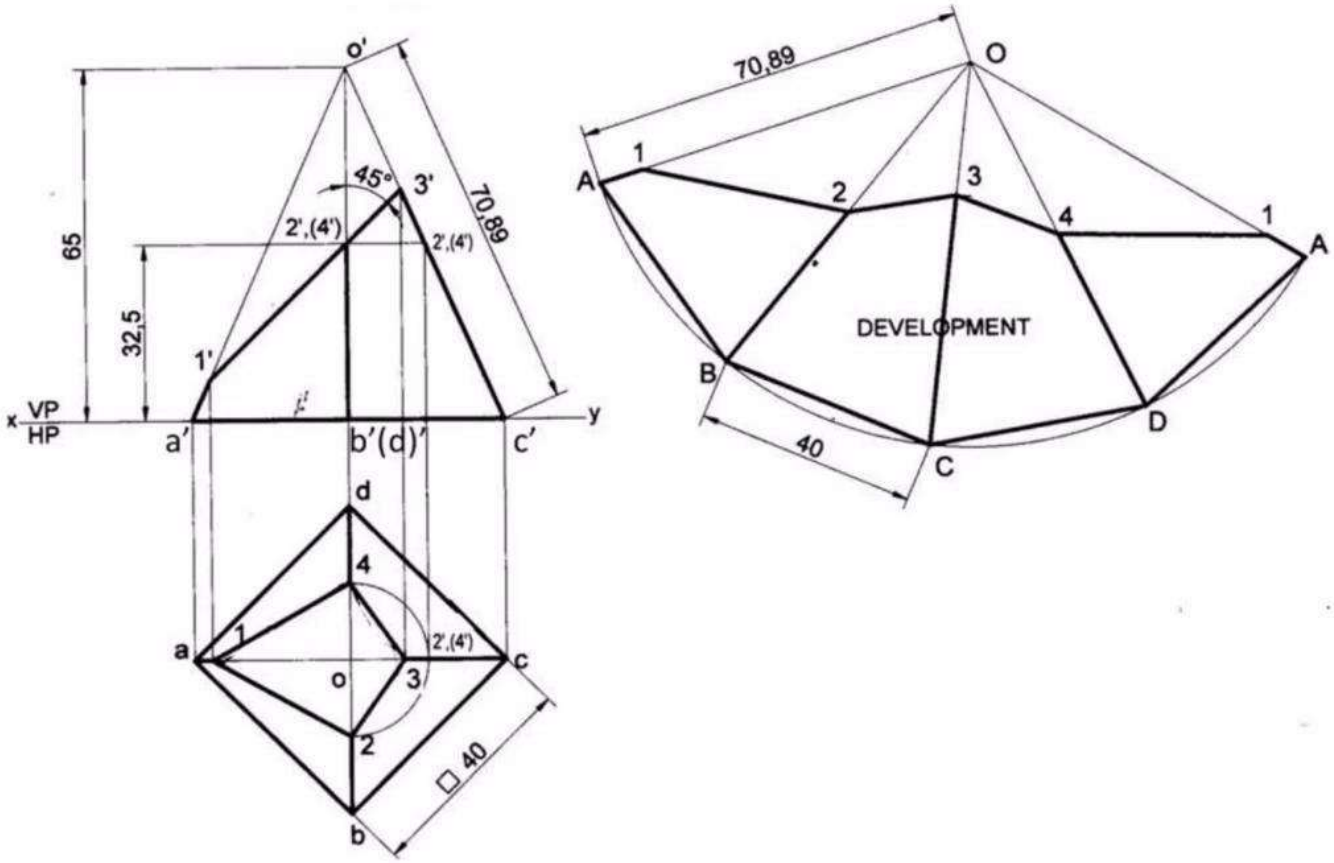
The line formed where the cutting plane meets the surface is called the **truncation line**.

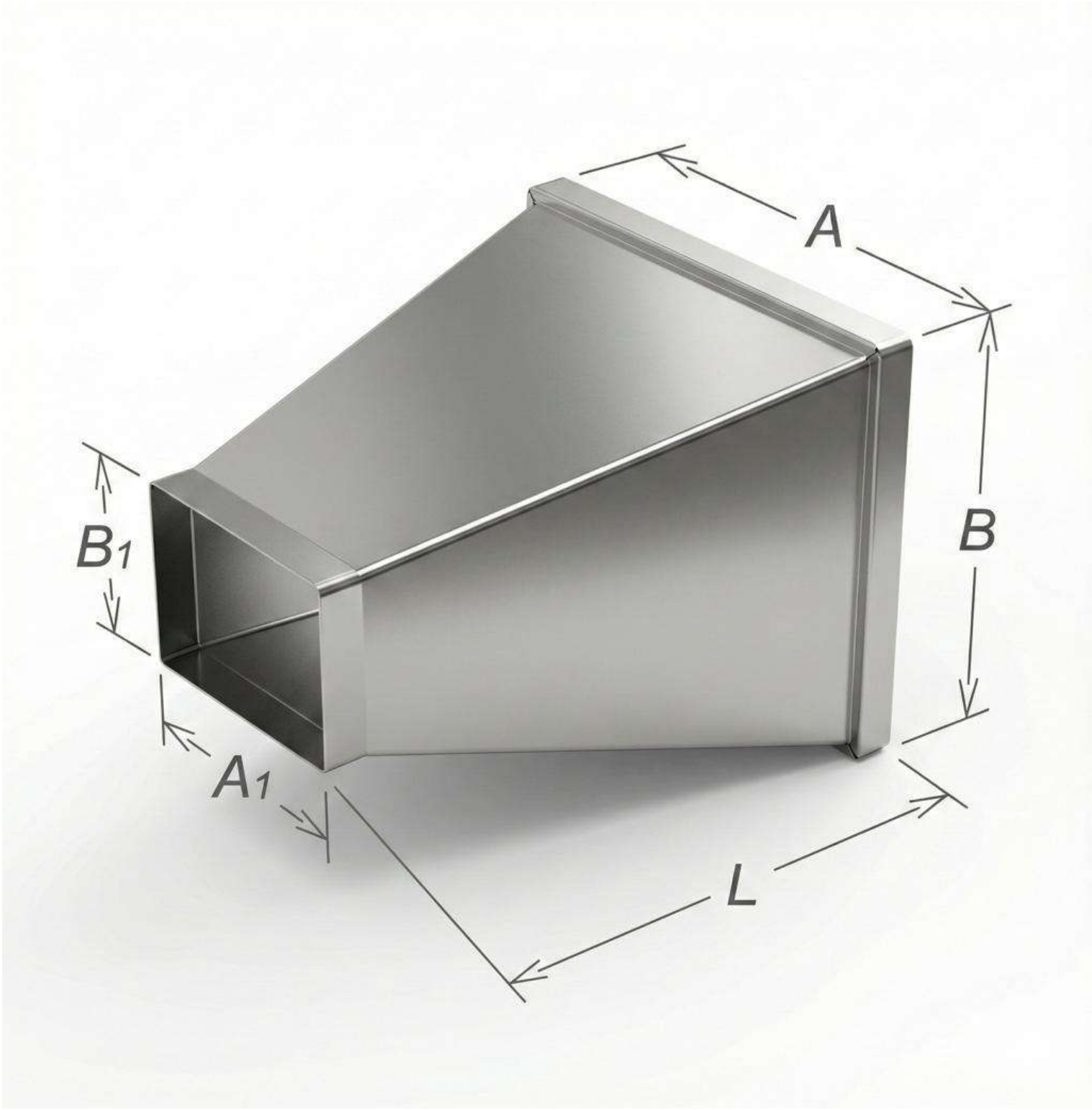
### 7.2 Examples of truncated objects in metalwork

- Truncated cones.
- Truncated pyramids.
- Sloping metal ducts.
- Hopper outlets.
- Chimney tops.
- Metal funnels with shortened tops.
- Sloping ventilation pipes.



17) A square pyramid base 40mm side and axis 65mm long has its **base on HP and all the edges of the base are equally inclined to VP.** It is cut to with an inclined section plane so as the truncated surface at **45⁰ to its axis bisecting it**. Draw the development of the truncated pyramid. **Cutting plane leans upward right.**






**7.3 Importance of drawing truncated surfaces**

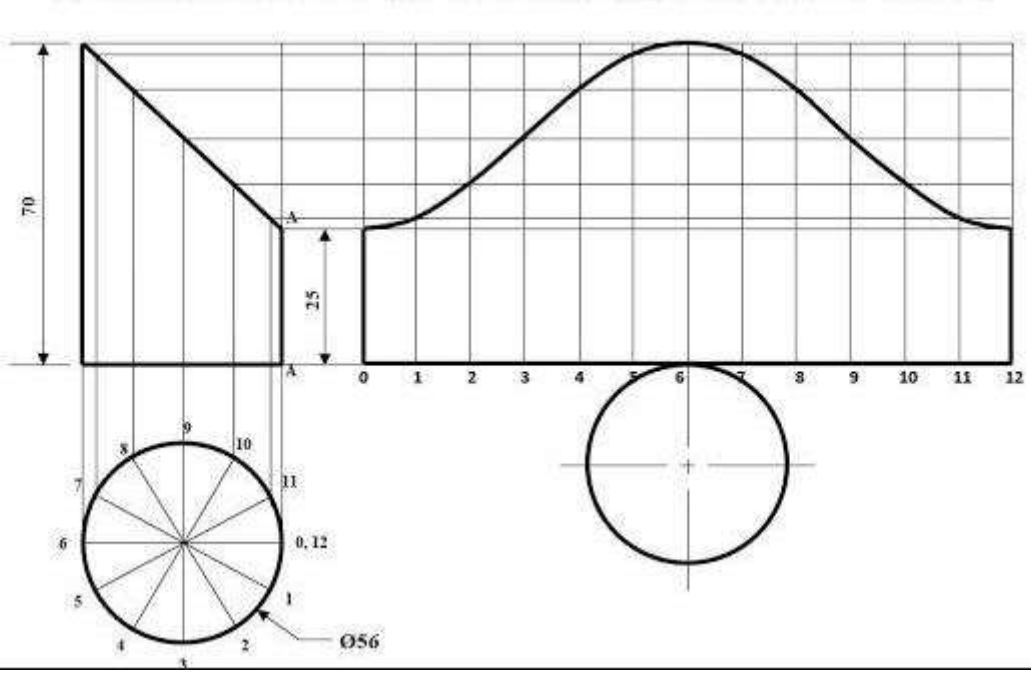
1. It helps determine the correct shape of a cut metal component.
2. It ensures that the final product has the required height and profile.
3. It assists in producing sloping surfaces.
4. It reduces errors when cutting sheet metal.
5. It improves the fitting of fabricated components.
6. It helps manufacture hoppers, ducts and metal outlets.
7. It reduces unnecessary material wastage.
8. It improves the accuracy of complex sheet-metal work.

### 7.4 Development of a truncated cylinder

A cylinder may be cut by a plane inclined to its base. The resulting upper boundary is an ellipse-like curve in the developed pattern.

**Construction procedure**

1. Draw the elevation of the cylinder.
2. Draw the inclined cutting plane.
3. Draw the plan showing the circular base.
4. Divide the circular base into 12 equal parts.
5. Project the division points onto the elevation.
6. Draw the corresponding generators.
7. Mark where each generator meets the inclined cutting plane.
8. Draw the stretch-out line equal to the circumference of the cylinder.
9. Divide the stretch-out into the same 12 equal parts.
10. Transfer the heights of the intersection points onto the corresponding generators of the development.
11. Join the transferred points using a smooth curve.
12. Complete the developed pattern.
13. Add the required cutting and joining allowances.




### 7.5 Development of a truncated cone

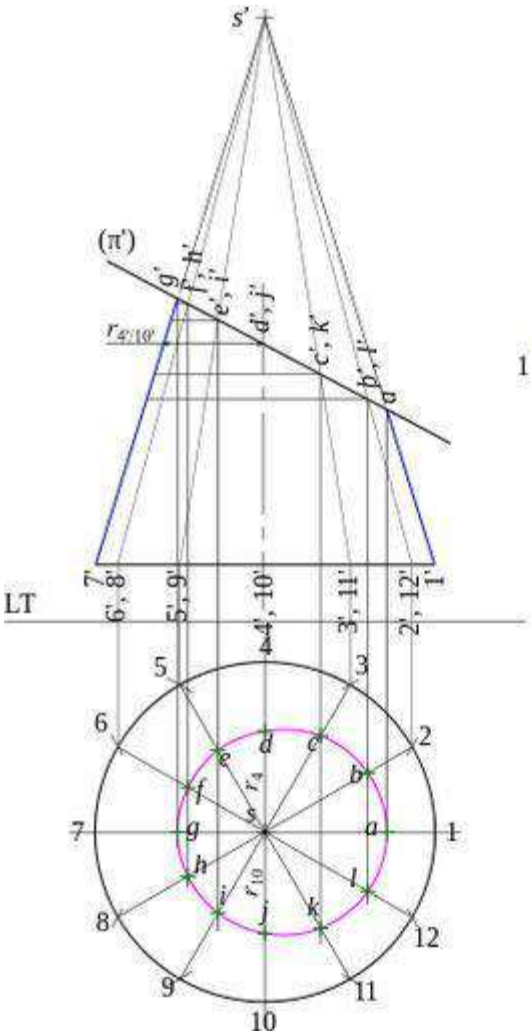
A truncated cone is a cone whose apex or upper portion has been removed by a cutting plane.

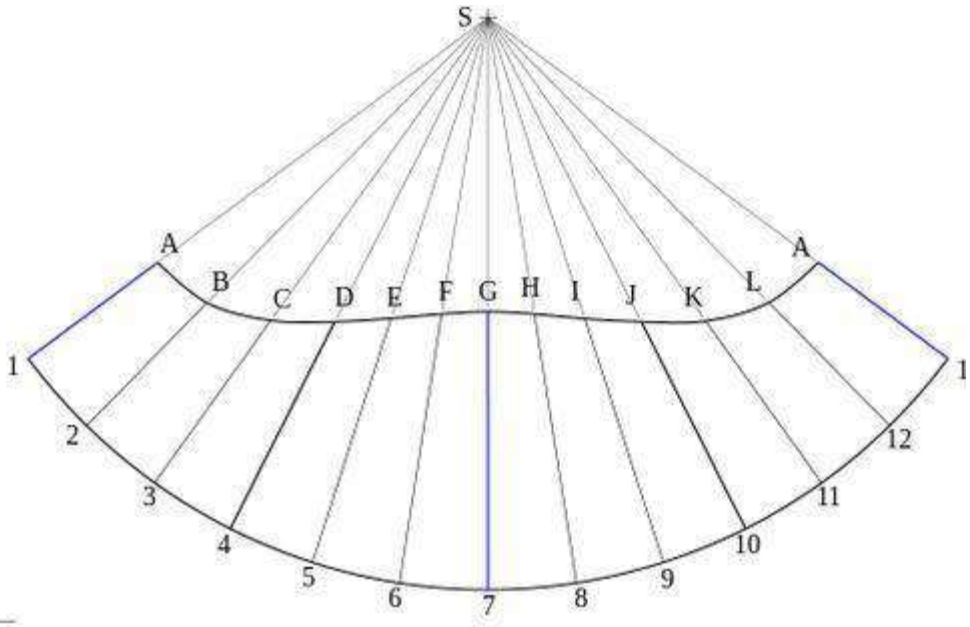
It is commonly used in sheet-metal fabrication where a larger opening needs to connect to a smaller opening.

**Construction procedure**

1. Draw the elevation of the cone.
2. Draw the plan showing the circular base.
3. Draw the cutting plane at the required angle.

4. Divide the circular base into equal parts.
5. Project the division points onto the elevation.
6. Draw the generators from the apex through the division points.
7. Mark where each generator intersects the cutting plane.
8. Determine the true lengths of the generators.
9. Draw the radial development using the slant length.
10. Transfer the corresponding generator lengths onto the development.
11. Join the transferred points using a smooth curve.
12. Complete the pattern.
13. Add the required joining allowances.




**7.6 Development of a truncated pyramid**

A truncated pyramid is formed when the upper part of a pyramid is removed by a cutting plane.

**Construction procedure**

1. Draw the plan and elevation of the pyramid.
2. Draw the required cutting plane.
3. Determine the points where the cutting plane intersects the slant edges.
4. Determine the true lengths of the truncated edges.

5. Develop the triangular faces using radial-line development.
6. Transfer the truncation points onto the corresponding developed edges.
7. Join the points to form the truncated boundary.
8. Complete the development of all the faces.
9. Add joining allowances.

**Applications**

- Fabricating square hoppers.
- Manufacturing metal roof ventilators.
- Making metal transition pieces.
- Producing sheet-metal covers.
- Making industrial containers.

## 8.0 DEVELOPMENT OF TRANSITION PIECES

### 8.1 Meaning of a transition piece

A transition piece is a sheet-metal component used to connect two openings or ducts of different sizes or shapes.

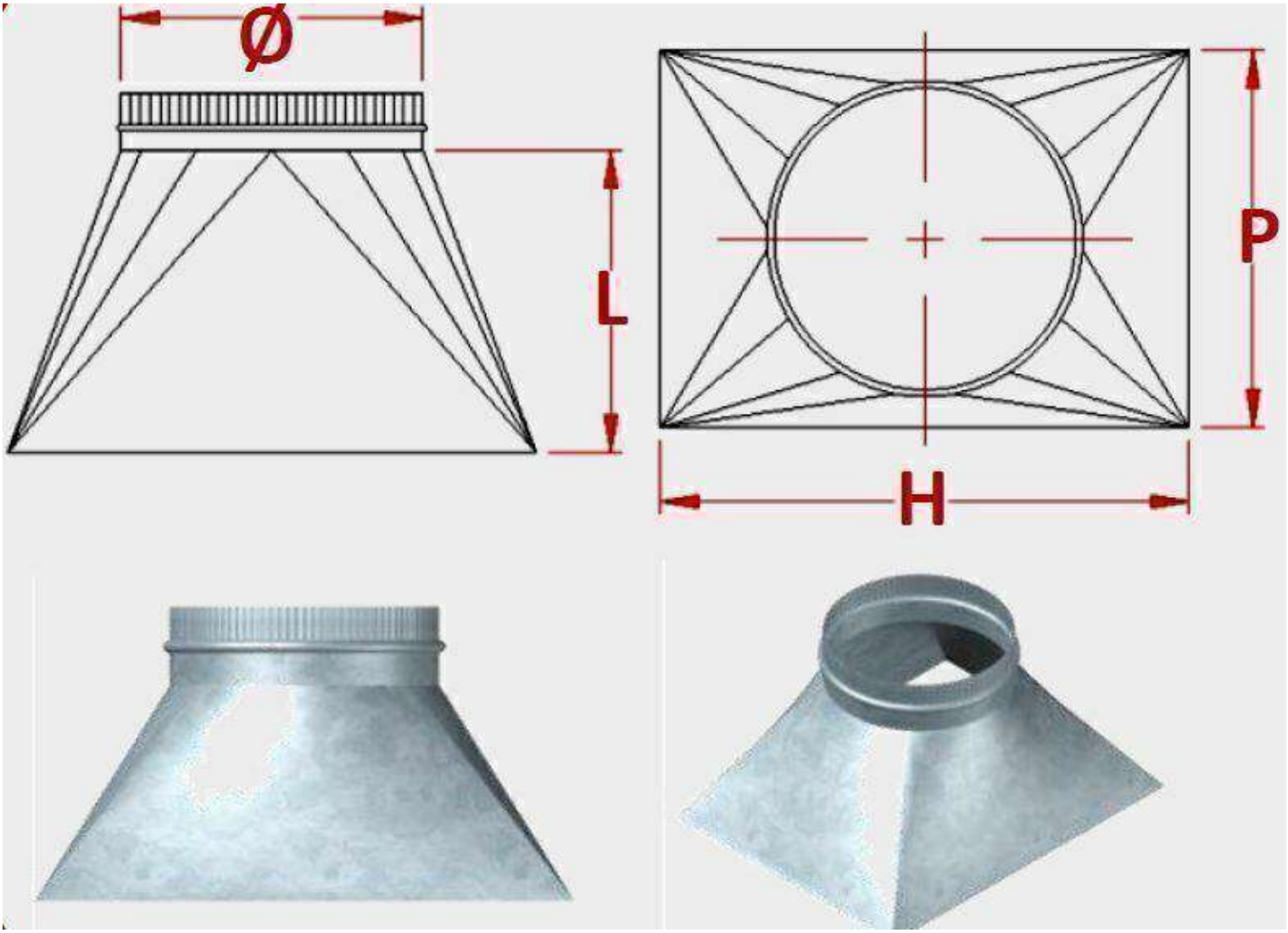
It allows a gradual change in cross-sectional area or shape.

For example, a transition piece may connect a large rectangular duct to a smaller rectangular duct or a circular pipe to a rectangular duct.

### 8.2 Examples of transition pieces

- Circular-to-square transition.
- Square-to-rectangular transition.
- Rectangular-to-circular transition.
- Large-to-small duct reducer.
- Conical pipe reducer.





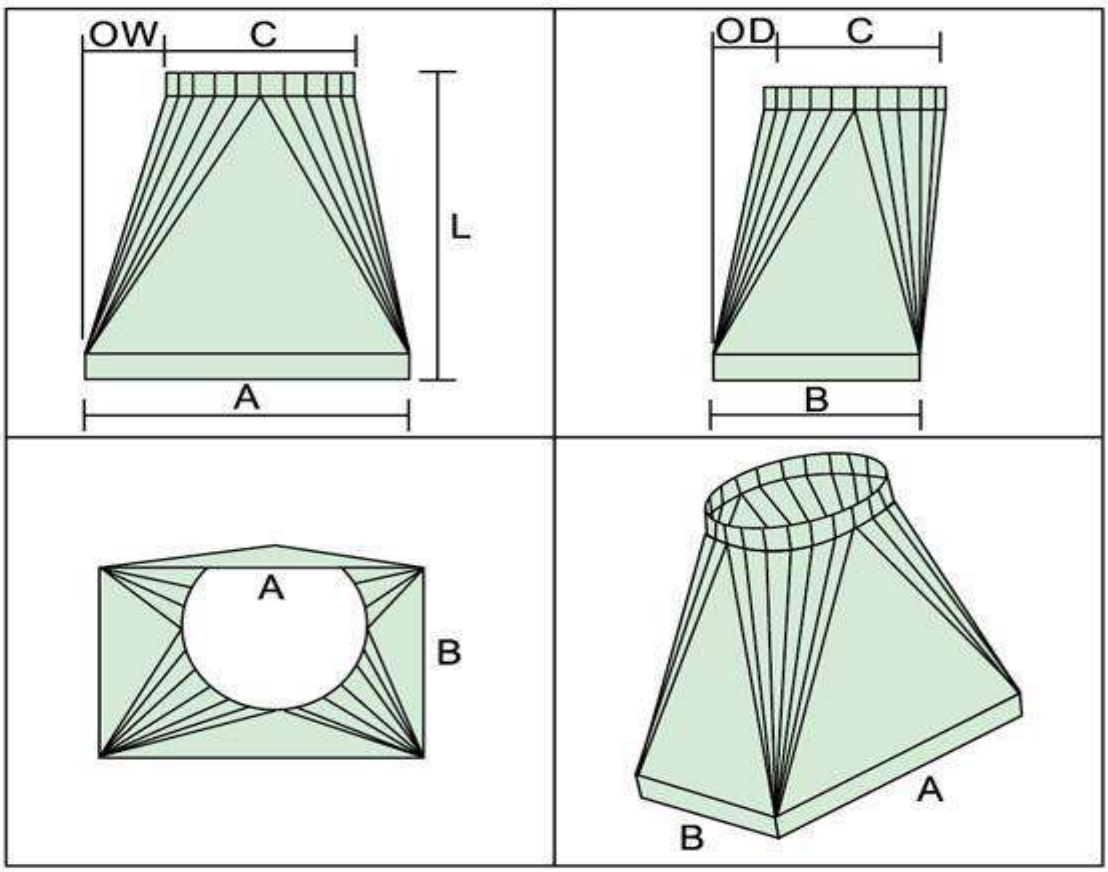


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**8.3 Importance of transition pieces**

1. They connect components of different dimensions.
2. They allow changes in the direction or size of airflow.
3. They help connect different types of pipes.
4. They reduce abrupt changes in duct dimensions.
5. They improve the arrangement of ventilation systems.
6. They are useful in industrial and agricultural processing systems.

**8.4 Development of transition pieces**

Triangulation is commonly used to develop transition pieces with complex geometries.

**General procedure**

1. Draw the plan and elevation of the transition piece.
2. Identify the corresponding corners and edges of the two openings.
3. Divide the surfaces into triangular sections.
4. Determine the true lengths of the required edges.
5. Draw the first triangular section.
6. Construct adjoining triangles using their true lengths.
7. Continue until all surfaces are developed.
8. Join the outer boundary points.
9. Check that the pattern corresponds to the required transition.
10. Add allowances for seams and joints.

**Practical example**

A metal fabrication workshop in Nakuru is required to make a transition piece connecting a rectangular ventilation duct to a smaller rectangular outlet.

The metalworker:

- Measures both openings.
- Draws the two rectangular profiles.
- Identifies corresponding corners.
- Divides the transition surfaces into triangles.
- Determines true lengths.
- Develops the triangular sections.
- Transfers the pattern onto sheet metal.
- Cuts, folds and joins the component.

## 9.0 ALLOWANCES IN SURFACE DEVELOPMENT

### 9.1 Meaning of allowance

An allowance is additional material added to the dimensions of a developed pattern to facilitate joining, folding, wiring or finishing.

Allowances are important because the dimensions of the final product may be smaller than the overall dimensions of the original flat pattern.

### 9.2 Types of allowances

**A. Seam allowance**

This is additional material provided along an edge to enable two sheet-metal edges to be joined.

Examples:

- Lap seams.
- Grooved seams.
- Folded seams.

**B. Hem allowance**

This is extra material provided to fold an edge over itself.

It is used to:

- Remove sharp edges.
- Strengthen sheet-metal edges.
- Improve appearance.
- Prevent injuries from exposed edges.

**C. Wiring allowance**

This is extra material provided when the edge of sheet metal is folded around a wire.

It is commonly used when manufacturing:

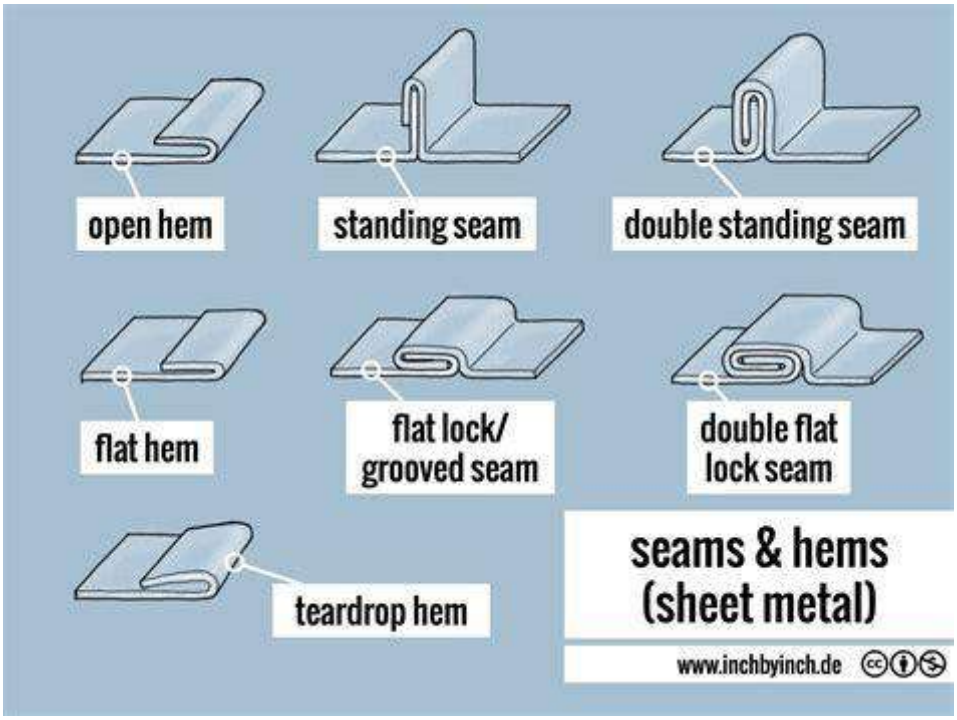
- Metal buckets.
- Circular containers.
- Metal trays.
- Cooking utensils.

**D. Folding allowance**

This is additional material provided to facilitate the folding or bending of sheet metal.

**E. Joining allowance**

This is material provided to enable components to be joined by riveting, soldering, brazing or other joining processes.



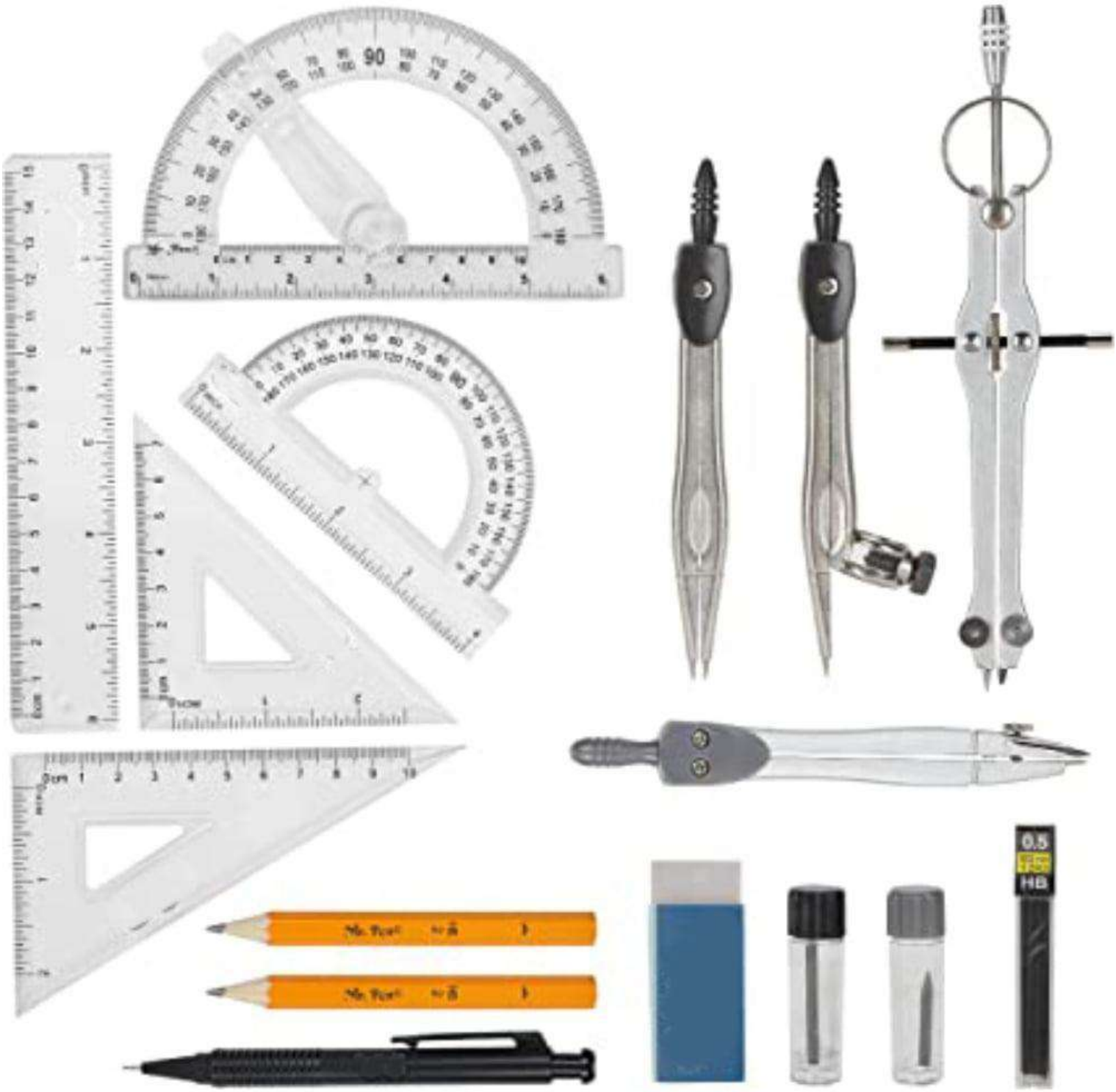

**9.3 Factors affecting allowances**

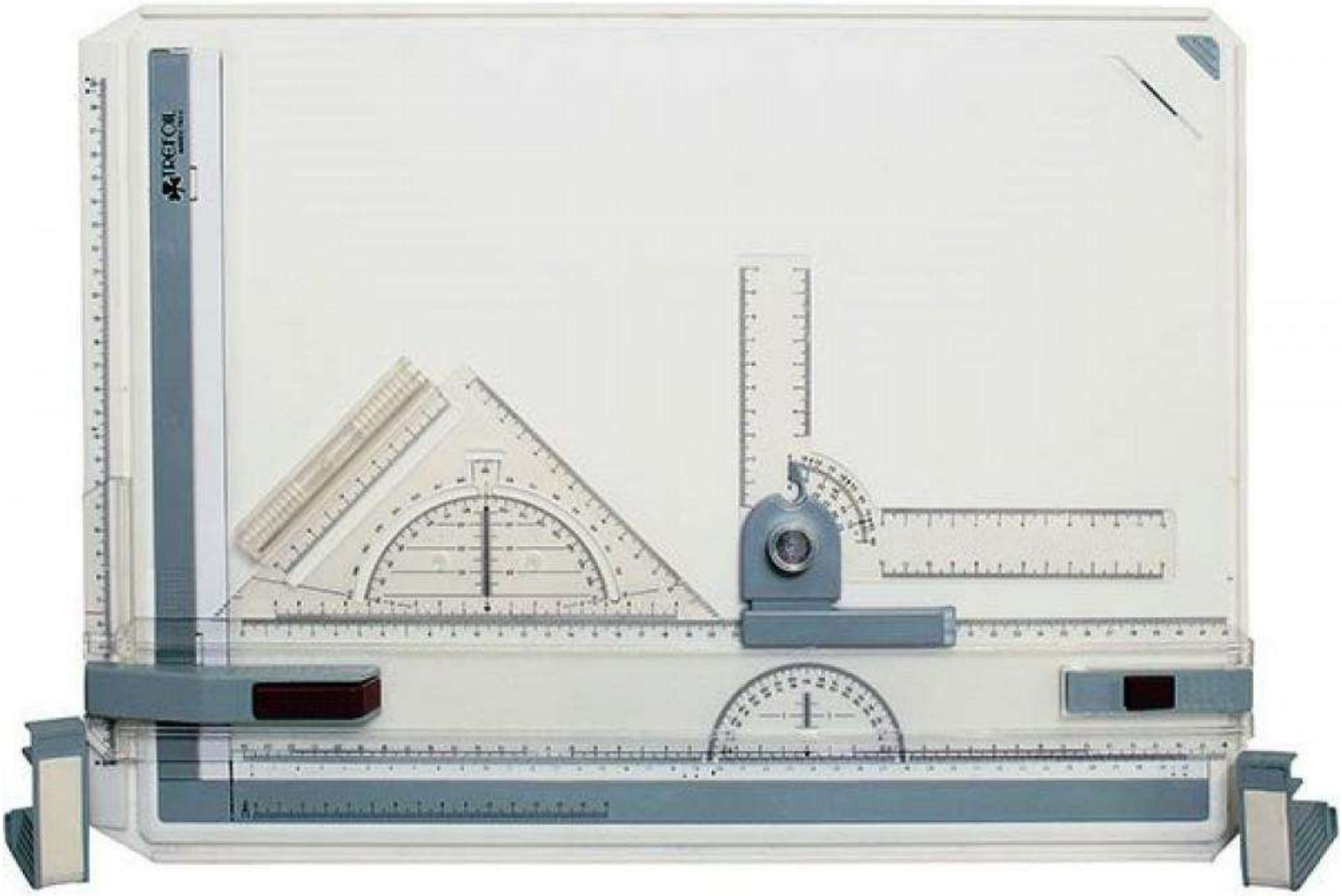
1. Thickness of the sheet metal.
2. Type of joint required.
3. Method of joining.
4. Type of material being used.
5. Radius of the bend.
6. Size of the finished component.
7. Manufacturing requirements.
8. Tools and machines available.

**Important:** Allowances should be determined according to the joint design, sheet thickness and fabrication method. They should not be added arbitrarily.

**10.0 DRAWING INSTRUMENTS AND EQUIPMENT USED IN SURFACE DEVELOPMENT**

Accurate surface development requires appropriate drawing instruments and workshop equipment.


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**10.1 Drawing instruments**

| Instrument | Function |
|---|---|
| Drawing board | Provides a flat working surface |
| T-square | Draws horizontal parallel lines |
| Set squares | Draw vertical and inclined lines |
| Compass | Draws circles and arcs |
| Divider | Transfers and divides distances |
| Protractor | Measures and constructs angles |
| Steel rule | Measures and draws straight lines |
| Pencil | Produces construction lines |
| Eraser | Removes unwanted pencil marks |
| Scale rule | Measures and draws scaled dimensions |

**10.2 Sheet-metal marking and cutting tools**

1. **Scriber:** Used to mark fine lines on sheet metal.
2. **Steel rule:** Used to measure dimensions accurately.
3. **Dividers:** Used to transfer measurements and mark arcs.
4. **Centre punch:** Used to make small locating marks.
5. **Tin snips:** Used to cut thin sheet metal.
6. **Bench shears:** Used to cut sheet metal.
7. **Try square:** Used to check right angles.
8. **Hammer:** Used for shaping and folding metal.

9. **Folding bars:** Used to assist in bending sheet metal.
10. **Bench vice:** Holds work securely during fabrication.

**10.3 Care and maintenance of drawing instruments**

1. Keep instruments clean and dry.
2. Store them in protective cases.
3. Avoid dropping or throwing instruments.
4. Keep pencil points sharp.
5. Wipe metal instruments after use.
6. Protect compass points from damage.
7. Avoid using measuring instruments as striking tools.
8. Return instruments to their proper storage areas.

**11.0 SAFETY PRECAUTIONS DURING SURFACE DEVELOPMENT**

Safety must be observed when drawing, marking, cutting and forming sheet metal.

**11.1 Personal protective equipment (PPE)**

- Safety goggles.
- Protective gloves suitable for handling sheet metal.
- Safety boots.
- Workshop apron or overalls.
- Hearing protection when using noisy machinery.

**11.2 Safety precautions**

1. Keep the working area clean and organised.
2. Handle sheet metal carefully because its edges may be sharp.
3. Wear suitable protective gloves when handling sharp sheets.
4. Wear safety goggles when cutting or working with metal.
5. Secure sheet metal before cutting or marking.
6. Use the correct cutting tools for the material thickness.
7. Do not use damaged tools.
8. Keep fingers away from cutting edges.
9. Avoid loose clothing near rotating machinery.
10. Store sharp offcuts in designated containers.
11. Do not leave sharp metal sheets on the floor.
12. Follow the teacher's or workshop instructor's instructions.
13. Switch off machines after use.
14. Maintain good housekeeping throughout the activity.

### 11.3 Environmental conservation in sheet-metal work

Metalwork learners should practise responsible use of resources by:

- Minimising unnecessary sheet-metal offcuts.
- Reusing suitable leftover materials.
- Separating metal waste for recycling.
- Avoiding unnecessary consumption of materials.
- Maintaining tools to reduce frequent replacement.
- Disposing of sharp scrap safely.

## 12.0 PRACTICAL LEARNING ACTIVITIES

### Activity 1: Development of a cube

**Materials:** Drawing paper, pencil, ruler, set square and eraser.

**Instructions:**

1. Draw a square measuring 40 mm by 40 mm.
2. Construct four equal squares around the central square.
3. Add the sixth square to one of the outer squares.
4. Check all dimensions.
5. Identify the six faces.
6. Display the completed development.

**Expected outcome:** A correctly constructed cube net.

### Activity 2: Development of a cylinder

**Materials:** Drawing paper, compass, ruler, pencil and calculator.

**Instructions:**

1. Use a cylinder with a diameter of 80 mm and height of 120 mm.
2. Calculate its circumference.
3. Draw a rectangle representing the curved surface.
4. Draw two circles representing the ends.
5. Label the dimensions.
6. Display the completed development.

### Activity 3: Development of a cone

**Instructions:**

1. Use a cone with a base radius of 40 mm and slant height of 100 mm.
2. Calculate the sector angle.
3. Draw the circular sector.
4. Draw the circular base.
5. Label the developed surfaces.

6. Display the completed work.

**Activity 4: Development of intersecting surfaces**

**Instructions:**

1. Observe two intersecting cylindrical pipes.
2. Draw their elevation and plan.
3. Divide the circular surface into equal parts.
4. Construct the intersection curve.
5. Develop the branch pipe.
6. Mark the shape of the opening.
7. Present the drawing to classmates.

**Activity 5: Development of truncated surfaces**

**Instructions:**

1. Draw a cylinder.
2. Draw an inclined cutting plane.
3. Divide its circular base into equal sections.
4. Project the points onto the cutting plane.
5. Transfer the points to the development.
6. Join the points smoothly.
7. Present the completed drawing.

**STRAND 3.0: RELATED DRAWING IN METALWORK**

**SUB-STRAND 3.2: ORTHOGRAPHIC PROJECTION**

**1.0 Introduction to Orthographic Projection**

Technical drawing is an important aspect of Metal Technology. It provides a universal means of communicating information about the shape, size, features and construction of metal components.

In metalwork, learners and artisans use technical drawings to understand how a metal product should be manufactured, assembled and inspected.

Metal objects have three dimensions:

- Length – the distance from one end of an object to the other.
- Width – the distance from the front to the back.
- Height – the vertical distance from the bottom to the top.

A single pictorial drawing may not clearly communicate all the details of a complicated metal component. Therefore, different views are used to represent an object accurately.

One of the most widely used methods of representing three-dimensional objects on a two-dimensional drawing sheet is orthographic projection.

**1.1 Definition of Orthographic Projection**

**Orthographic projection** is a method of representing a three-dimensional object on a two-dimensional drawing surface using two or more views projected at right angles to one another.

The views are produced by projecting the features of an object onto imaginary vertical or horizontal planes using parallel projectors.

The resulting drawings show the actual shapes and dimensions of the object's visible faces without the distortion associated with pictorial drawings.

**1.2 Importance of Orthographic Projection in Metalwork**

Orthographic projection is important because it:

1. Communicates design information accurately – it enables a metalworker to understand the exact shape and features of a component.
2. Shows different sides of an object – it presents the front, top and side views.
3. Assists in manufacturing – metalworkers use drawings to produce components according to specified dimensions.
4. Reduces manufacturing errors – accurate drawings minimise mistakes during cutting, drilling, bending and machining.
5. Facilitates inspection – manufactured components can be compared with the original drawing.
6. Promotes standardisation – technical drawings follow recognised drawing conventions.
7. Saves materials – accurate measurements reduce unnecessary wastage of metal.
8. Supports teamwork – designers, engineers, technicians and metalworkers can communicate using the same drawing.
9. Helps in assembling components – the different views show the positions and relationships of features.
10. Provides a permanent record – drawings can be stored and referred to during repairs and future production.

### 1.3 Applications of Orthographic Projection in Real Life

Orthographic projection is used in many industries and everyday activities.

- **Automotive industry:** Used when designing engine blocks, brackets, shafts, gear housings and vehicle body components.
- **Building construction:** Used to show metal doors, window frames, steel trusses and staircase components.
- **Agricultural machinery:** Used when designing plough parts, tractor components, wheelbarrows and irrigation equipment.
- **Manufacturing industries:** Used in the production of machine parts, tools, equipment and metal furniture.
- **Welding workshops:** Used to communicate the dimensions and positions of metal parts before welding.
- **Mechanical engineering:** Used in designing gears, pulleys, bearings and machine frames.
- **Electrical installations:** Used in designing metal enclosures, mounting brackets and equipment cabinets.
- **Shipbuilding:** Used in representing metal plates, structural supports and ship components.

**Kenyan context:** Metal fabrication workshops in Nairobi's Industrial Area, Nakuru, Kisumu, Eldoret and other towns use engineering drawings to manufacture gates, tanks, trailers, agricultural implements, metal furniture and structural components.

### 2.0 Principles of Orthographic Projection

Orthographic projection is based on the use of imaginary projection lines to transfer the features of a three-dimensional object onto a flat drawing plane.

### 2.1 Main Principles

1. The object is viewed from a particular direction.
2. Projectors are drawn perpendicular to the plane of projection.
3. The projectors are parallel to one another.
4. Each view represents the shape of the object as seen from that direction.
5. Corresponding features must align correctly between the different views.
6. Dimensions are represented using appropriate dimensioning conventions.
7. Hidden features are represented using dashed lines where necessary.

### 2.2 Planes of Projection

A plane of projection is an imaginary flat surface onto which the image of an object is projected.

The three principal planes are:

**a) Vertical Plane (VP)**

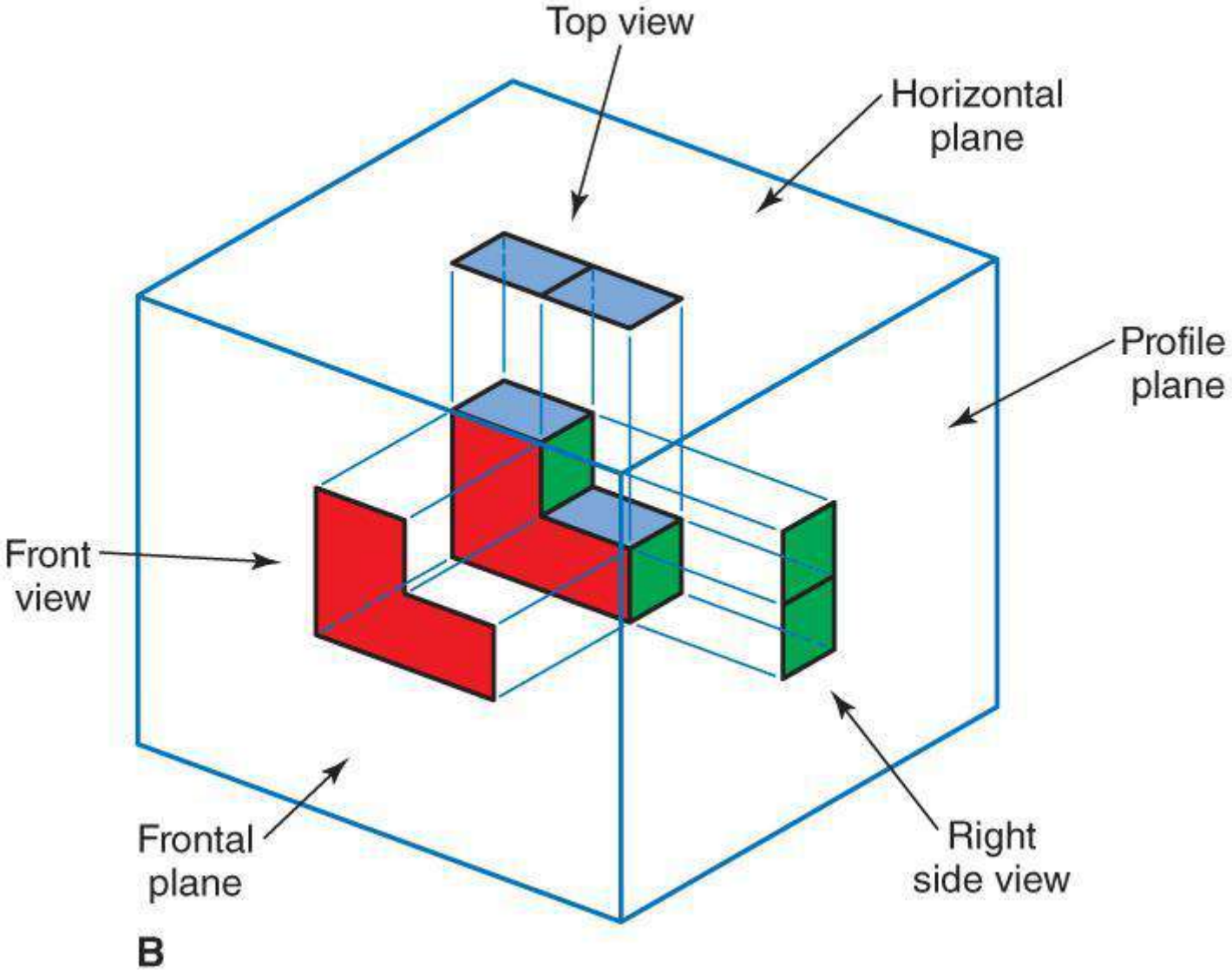
- It is the vertical surface onto which the front view is projected.
- It shows the height and length of an object.
- The front view is also called the elevation.

**b) Horizontal Plane (HP)**

- It is the horizontal surface onto which the top view is projected.
- It shows the length and width of an object.
- The top view is also called the plan.

**c) Profile Plane (PP)**

- It is the vertical plane positioned at the side of the object.
- It is used to obtain the side view.
- It shows the height and width of the object.




**2.3 Main Orthographic Views**

An object can be represented using several views depending on its complexity.

The three principal views are:

**1. Front View (Elevation)**

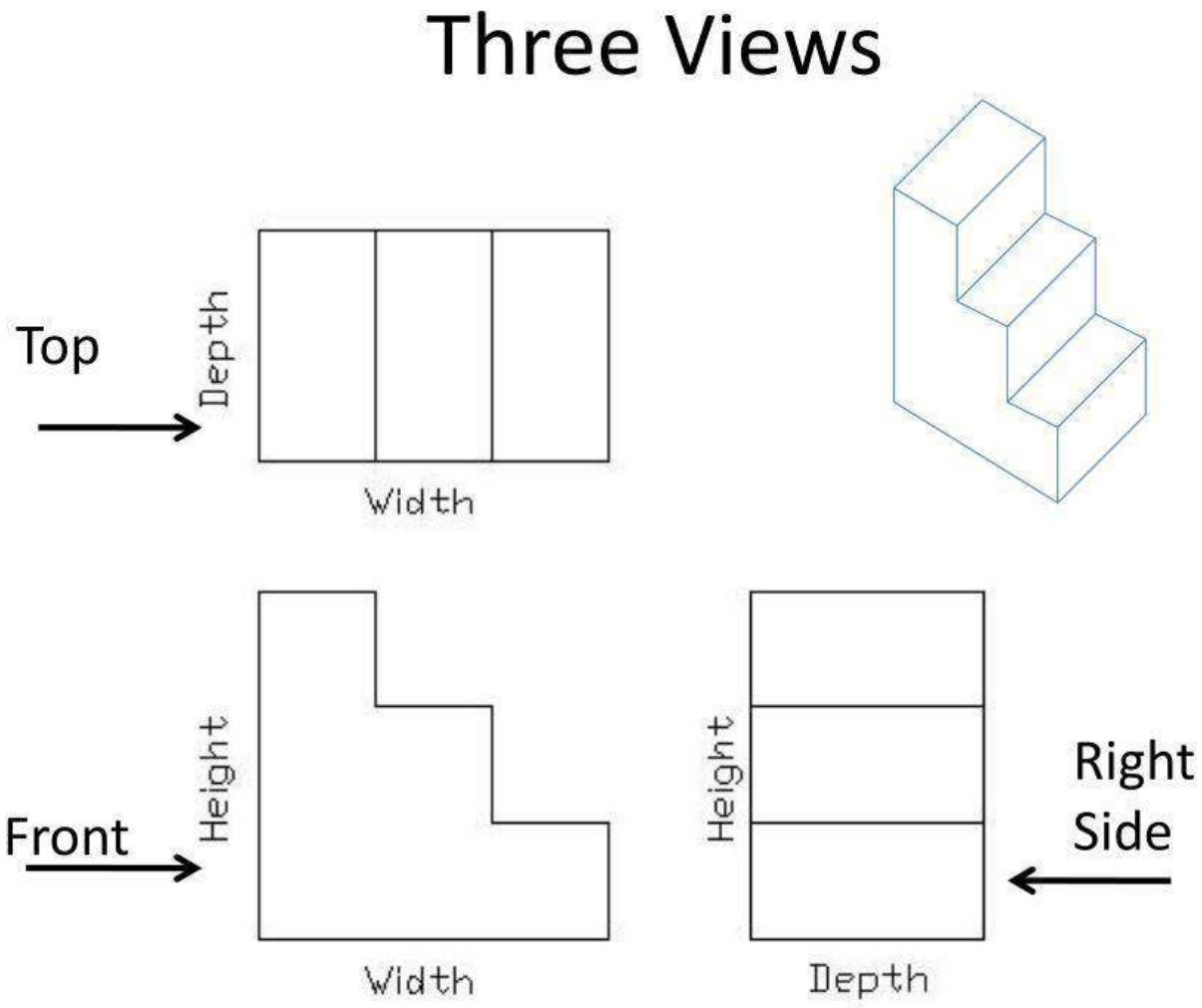
- This is the view obtained when an object is observed directly from the front.
- It shows the height and length of the object.
- It is normally selected to reveal the most important features.
- It is usually the principal view on a technical drawing.

**2. Top View (Plan)**

- This is the view obtained when an object is observed directly from above.
- It shows the length and width of the object.
- It is projected onto the horizontal plane.

**3. Side View (End Elevation)**

- This is the view obtained when an object is observed from either the left or right side.
- It shows the height and width of the object.
- It helps to reveal features that may not be visible in the front or top views.




**2.4 Relationship Between the Three Principal Views**

The three principal views must correspond accurately.

- The front view and top view share the same length.
- The front view and side view share the same height.
- The top view and side view share the same width.
- Corresponding edges and features must be aligned using projection lines.

| View | Dimensions represented |
|---|---|
| Front view | Length and height |
| Top view | Length and width |
| Side view | Width and height |

**Example:**

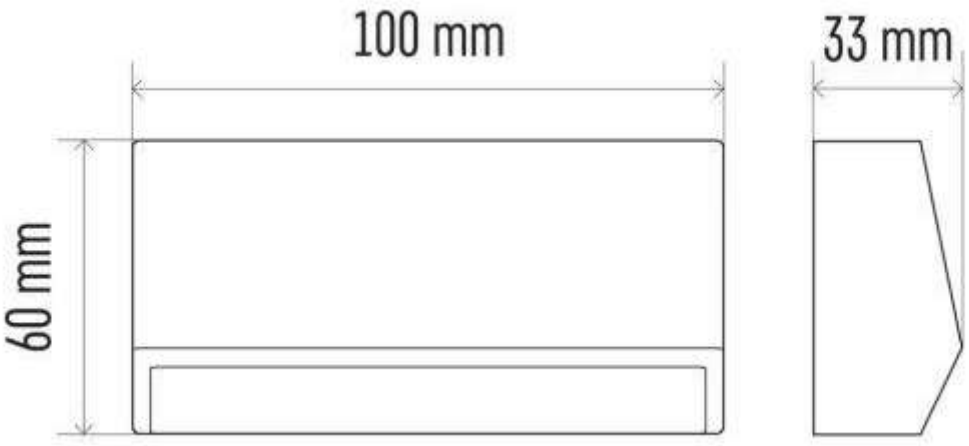
A rectangular metal block measuring:

- Length = 100 mm
- Width = 60 mm

- Height = 40 mm

Its three orthographic views will be:

- Front view: 100 mm × 40 mm.
- Top view: 100 mm × 60 mm.
- Side view: 60 mm × 40 mm.




**3.0 Types of Orthographic Projection**

There are two commonly used methods of orthographic projection in technical drawing:

1. First angle projection.
2. Third angle projection.

Both methods represent the same object but differ in the arrangement of the views on the drawing sheet.

**3.1 First Angle Projection**

**Definition:** First angle projection is a method of orthographic projection in which the object is positioned between the observer and the plane of projection.

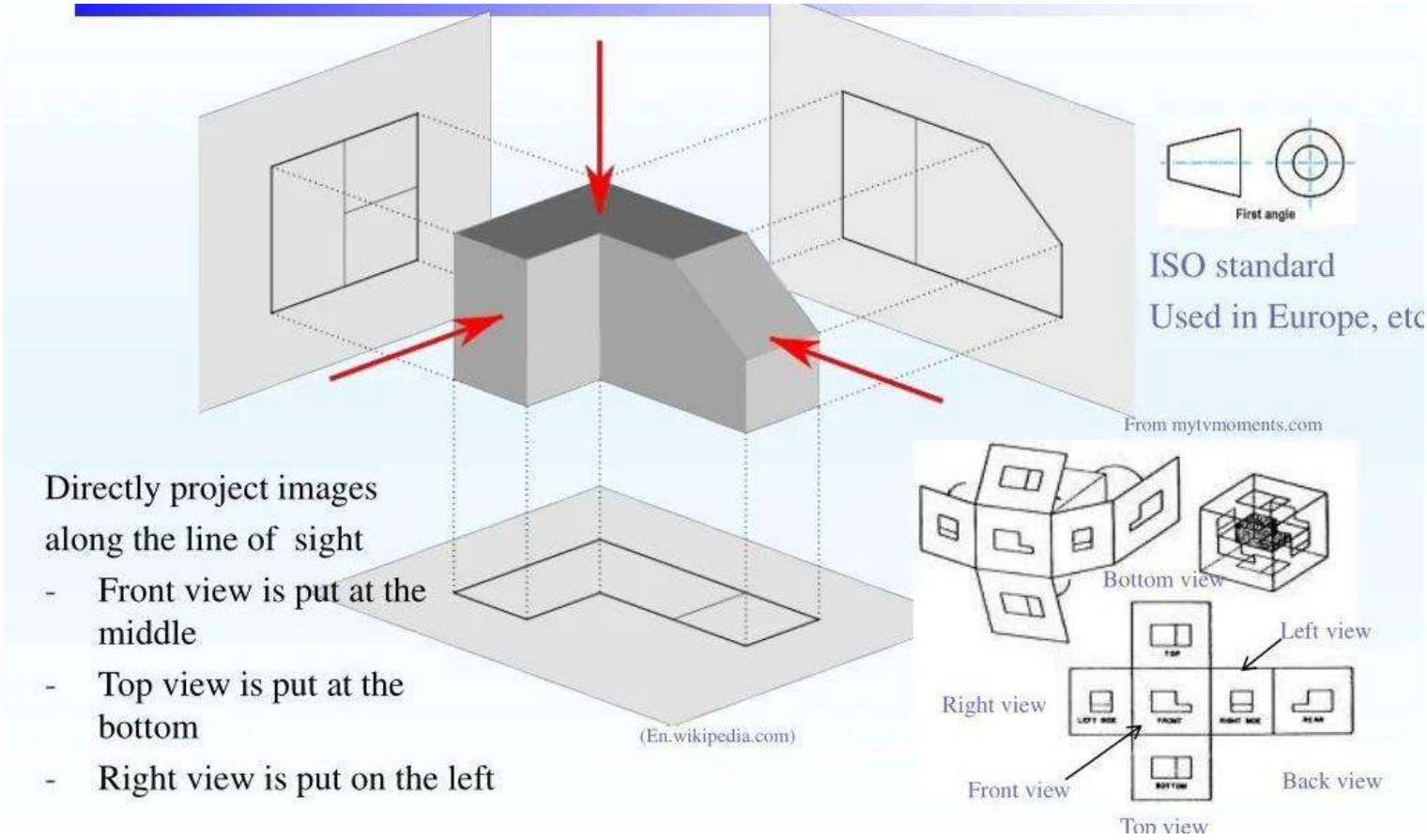
The object is assumed to be in the first quadrant, above the horizontal plane and in front of the vertical plane.

In this system, the views are arranged opposite to the direction from which they are observed.

**3.1.1 Arrangement of Views in First Angle Projection**

The views are arranged as follows:

- Front view: occupies the central position.
- Top view: placed below the front view.
- Bottom view: placed above the front view.
- Right-side view: placed on the left of the front view.
- Left-side view: placed on the right of the front view.




### 3.1.2 Characteristics of First Angle Projection

1. The object is between the observer and the projection plane.
2. The object is located in the first quadrant.
3. The top view is placed below the front view.
4. The right-side view is placed to the left of the front view.
5. The left-side view is placed to the right of the front view.
6. It is commonly used in many engineering drawing systems, including those following ISO conventions.

### 3.1.3 Steps in Constructing First Angle Projection

1. Study the given three-dimensional object carefully.
2. Identify the most suitable front face.
3. Determine the length, width and height of the object.
4. Select an appropriate drawing scale.
5. Draw the front view using thin construction lines.
6. Project vertical lines downwards to construct the top view below the front view.
7. Project horizontal lines from the front view to construct the side view on the appropriate side.
8. Transfer widths using a 45-degree mitre line where required.
9. Add hidden details using dashed lines.
10. Darken the visible outlines.
11. Add centre lines, dimensions and the first angle projection symbol where necessary.
12. Check that all views correspond correctly.

### 3.2 Third Angle Projection

**Definition:** Third angle projection is a method of orthographic projection in which the plane of projection is positioned between the observer and the object.

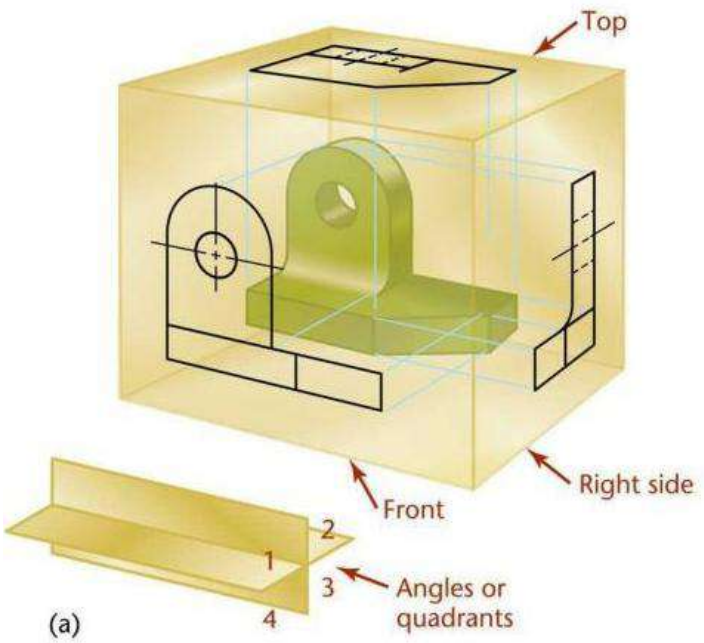
The object is assumed to be in the third quadrant, below the horizontal plane and behind the vertical plane.

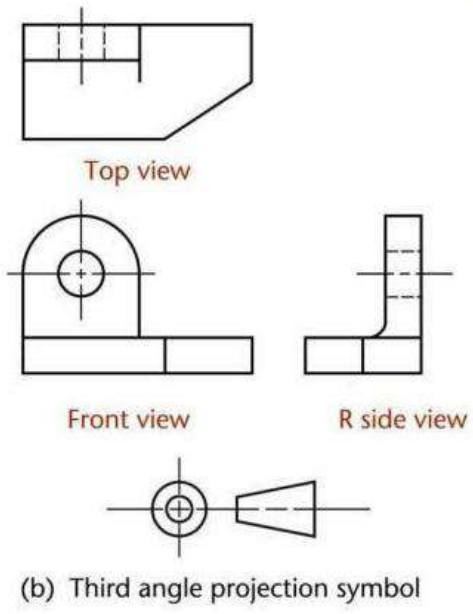
In this system, views are placed on the same side of the front view as the direction from which they are observed.

#### 3.2.1 Arrangement of Views in Third Angle Projection

The views are arranged as follows:

- Front view: occupies the central position.
- Top view: placed above the front view.
- Bottom view: placed below the front view.
- Right-side view: placed on the right of the front view.
- Left-side view: placed on the left of the front view.




#### 3.2.2 Characteristics of Third Angle Projection

1. The projection plane is between the observer and the object.
2. The object is located in the third quadrant.
3. The top view is placed above the front view.
4. The right-side view is placed to the right of the front view.
5. The left-side view is placed to the left of the front view.
6. It is widely used in engineering drawings in countries such as the United States and Canada.

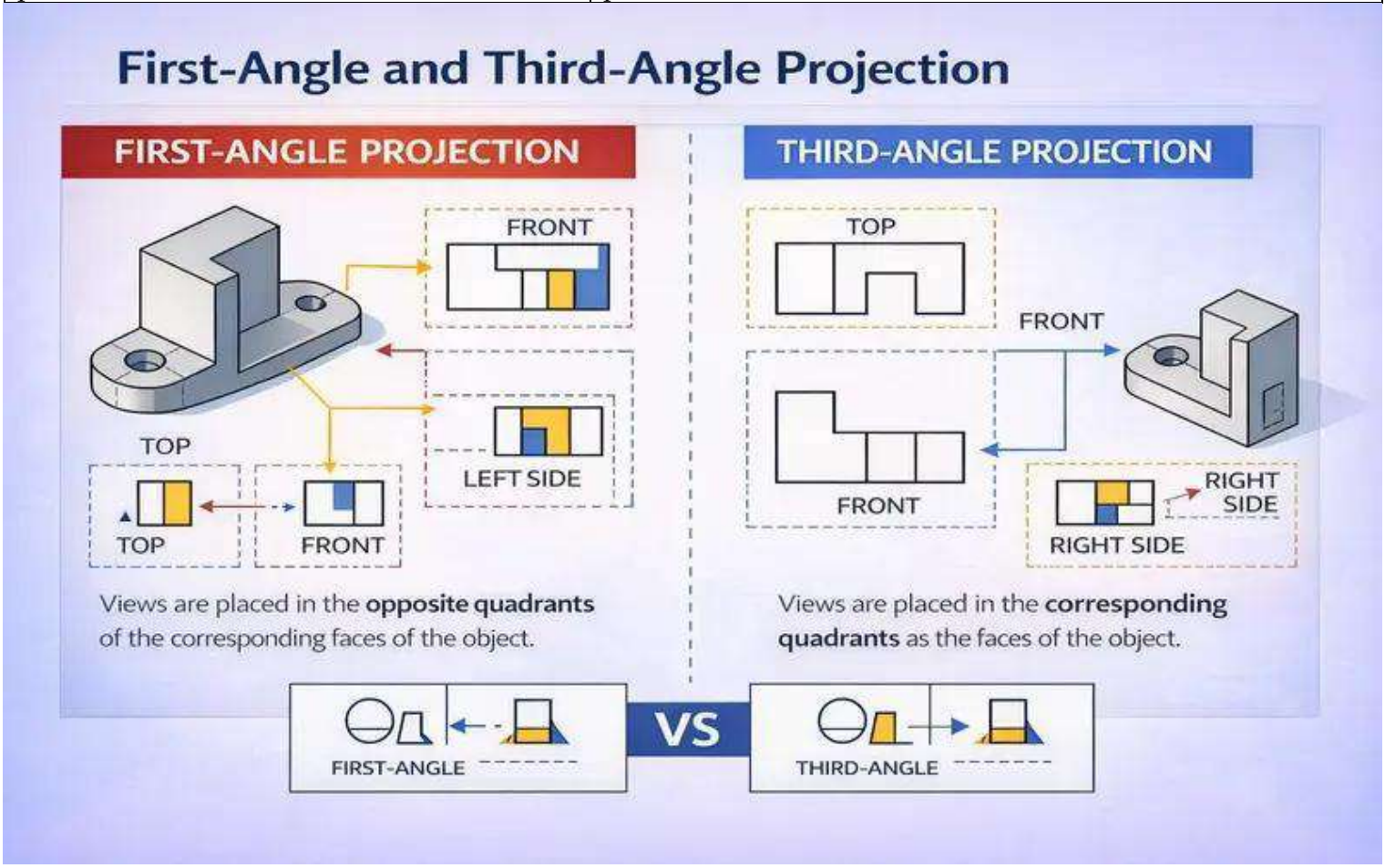
#### 3.2.3 Steps in Constructing Third Angle Projection

1. Study the given object.
2. Identify the front face.
3. Establish the length, width and height.

4. Choose an appropriate drawing scale.
5. Draw the front view using construction lines.
6. Project lines upwards to obtain the top view above the front view.
7. Project lines sideways to obtain the appropriate side view.
8. Use a 45-degree mitre line to transfer measurements where necessary.
9. Draw hidden details using dashed lines.
10. Darken visible outlines.
11. Add dimensions and centre lines.
12. Check the alignment of the views.

### 3.3 Differences Between First Angle and Third Angle Projection

| First angle projection | Third angle projection |
|---|---|
| Object is between observer and plane. | Plane is between observer and object. |
| Top view is below front view. | Top view is above front view. |
| Right-side view is on the left. | Right-side view is on the right. |
| Left-side view is on the right. | Left-side view is on the left. |
| Object is in the first quadrant. | Object is in the third quadrant. |
| Commonly associated with ISO drawing practice. | Commonly associated with American engineering drawing practice. |




### 3.4 Symbols of First and Third Angle Projection

Engineering drawings use standard symbols to indicate the projection system used. This prevents confusion when interpreting the arrangement of views.

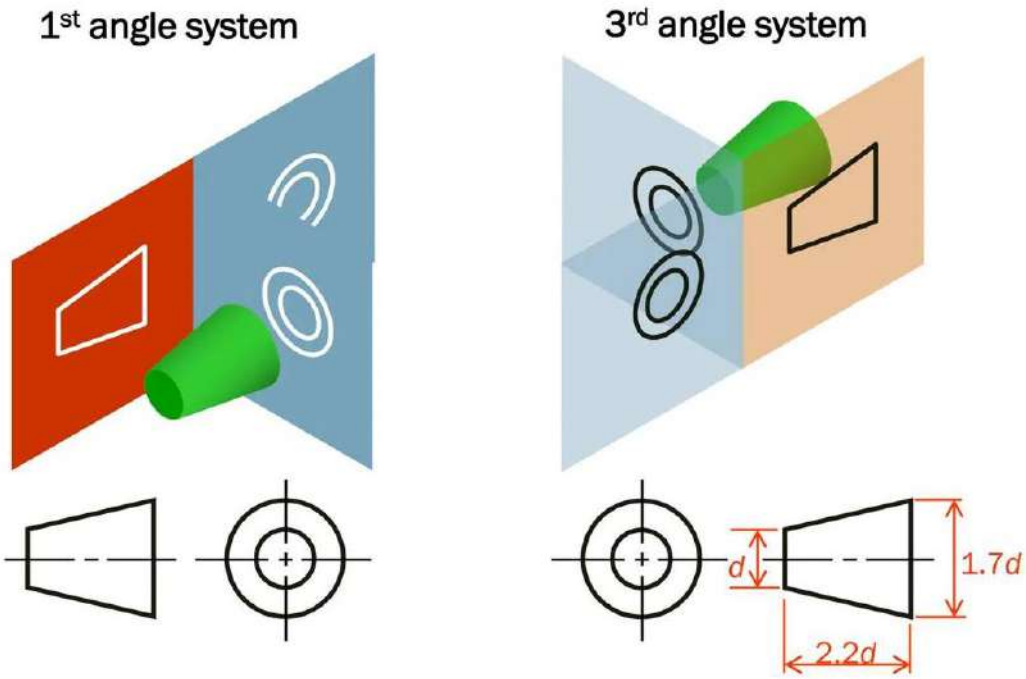
The symbols are based on the side view and end view of a truncated cone.

**First angle projection symbol**

- The circular end view is positioned on the left.
- The truncated cone side view is positioned on the right.

**Third angle projection symbol**

- The circular end view is positioned on the right.
- The truncated cone side view is positioned on the left.




**Importance of projection symbols**

1. They identify the projection method used.
2. They prevent incorrect interpretation of drawings.
3. They help technicians arrange views correctly.
4. They promote consistency in technical communication.
5. They make engineering drawings understandable across different workplaces and countries.

**4.0 Constructing Orthographic Views of Shaped Blocks**

A shaped block is a solid object whose surfaces may include flat faces, steps, slots, grooves, holes and projections.

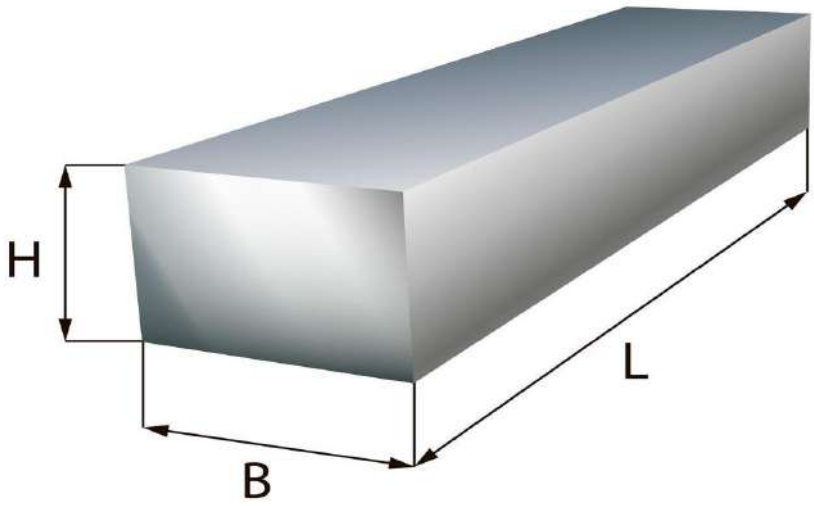
In metalwork, shaped blocks are used as models for understanding the construction of machine components, brackets, supports and fabricated parts.

**4.1 Types of Shaped Blocks**

Common shaped blocks used in orthographic drawing include:

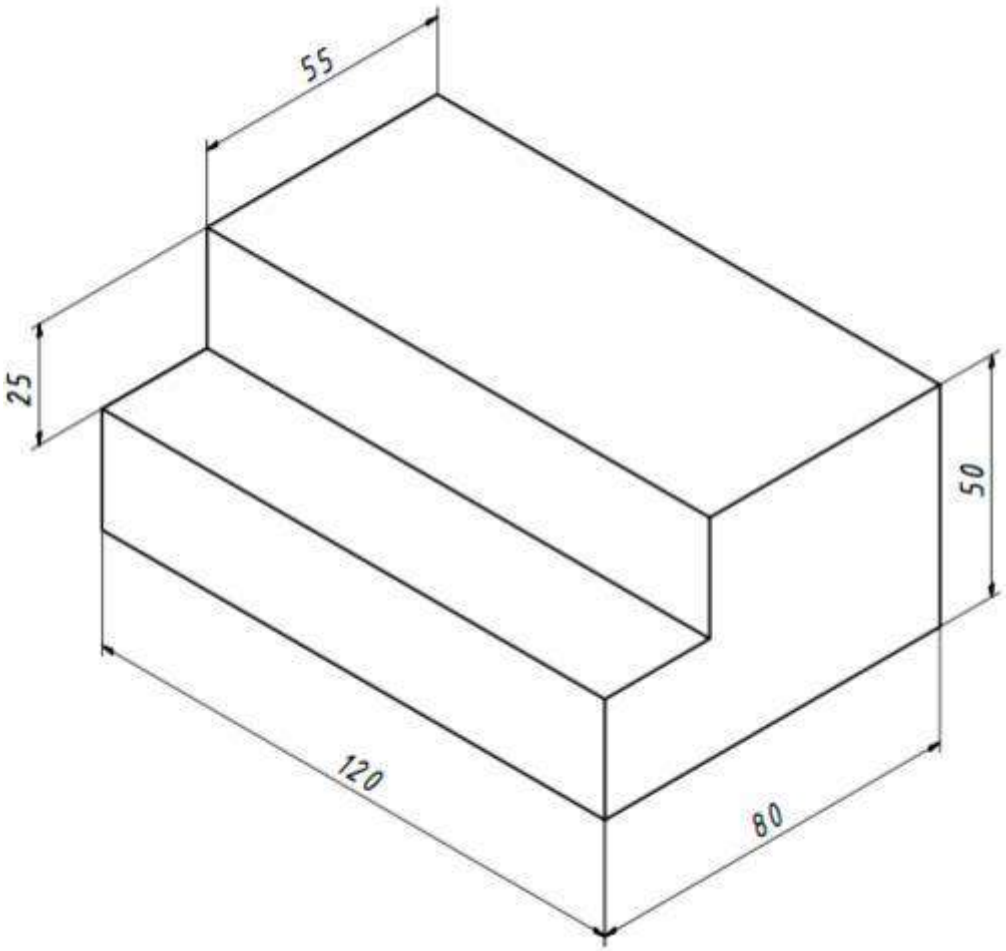
**a) Rectangular block**

- Has six rectangular faces.
- Has length, width and height.
- It is one of the simplest objects used in technical drawing.




**b) Stepped block**

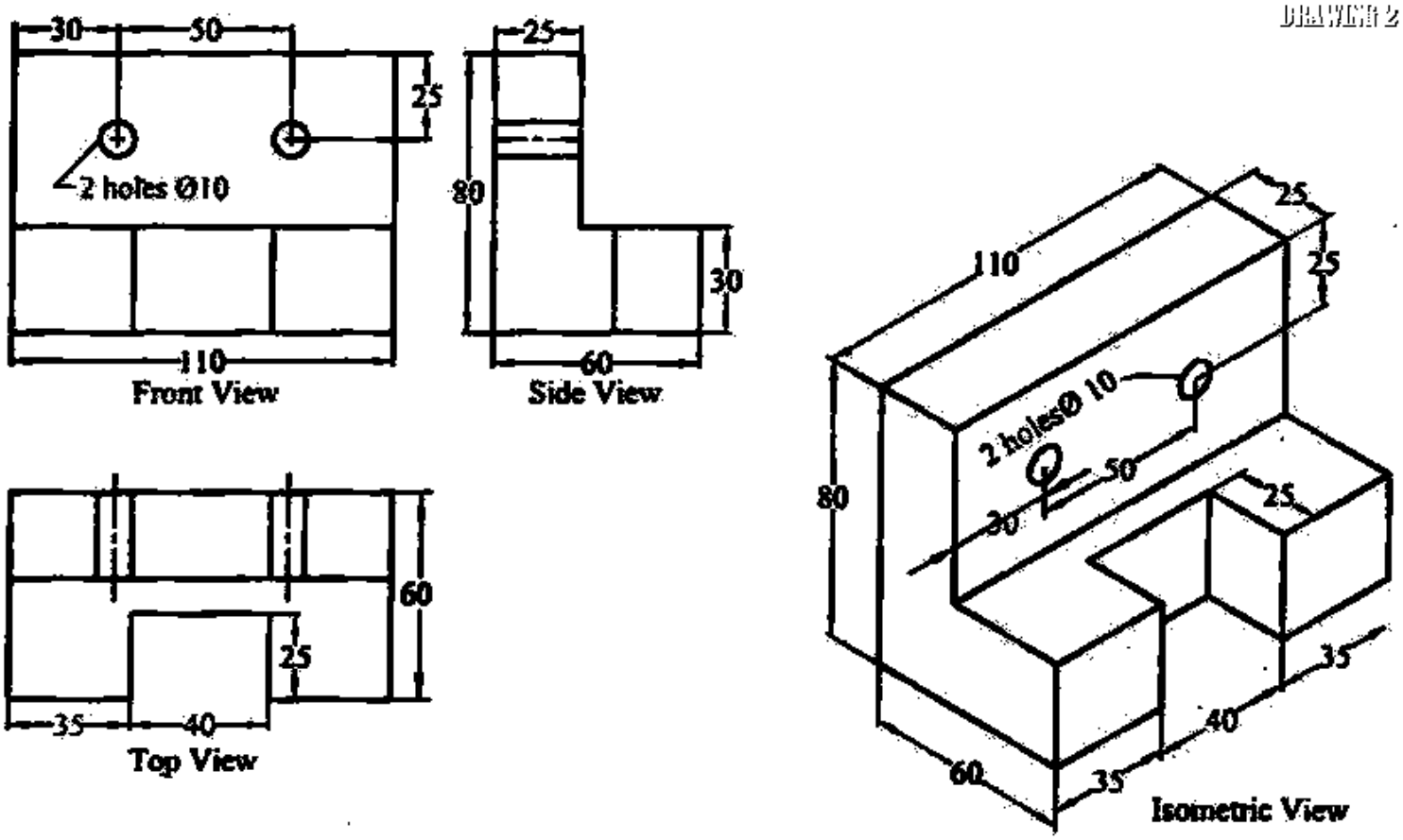
- Has two or more levels of different heights.
- It may have a raised or lowered section.
- It is commonly used to practise drawing different elevations.




**c) L-shaped block**

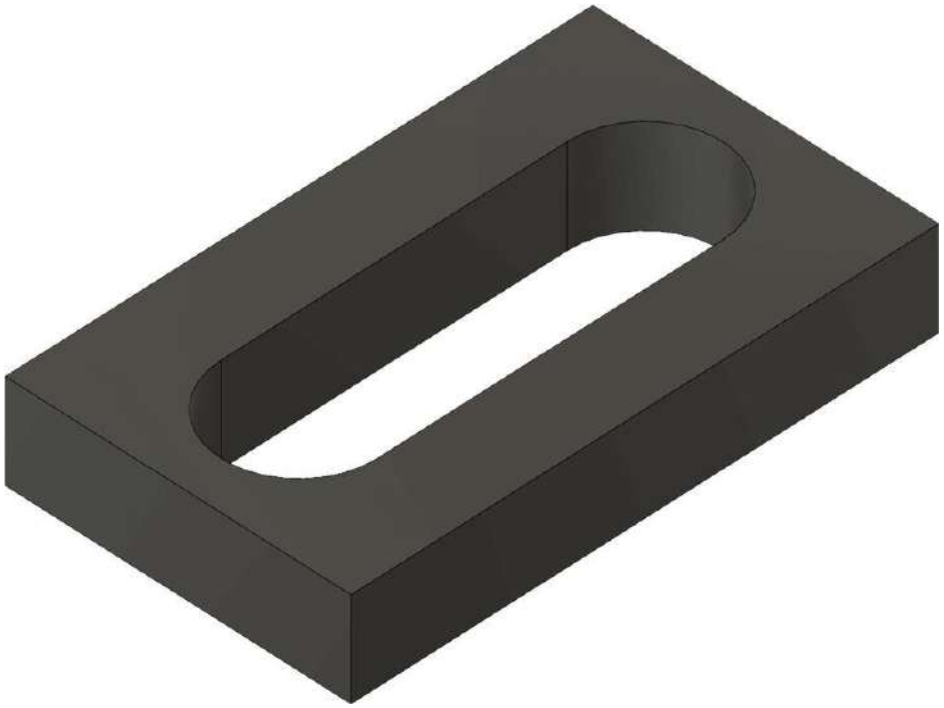
- Has an outline resembling the letter L when viewed from a particular direction.
- It can be used to represent brackets and support components.

- It requires careful projection of the internal corner.




**d) Block with a slot**

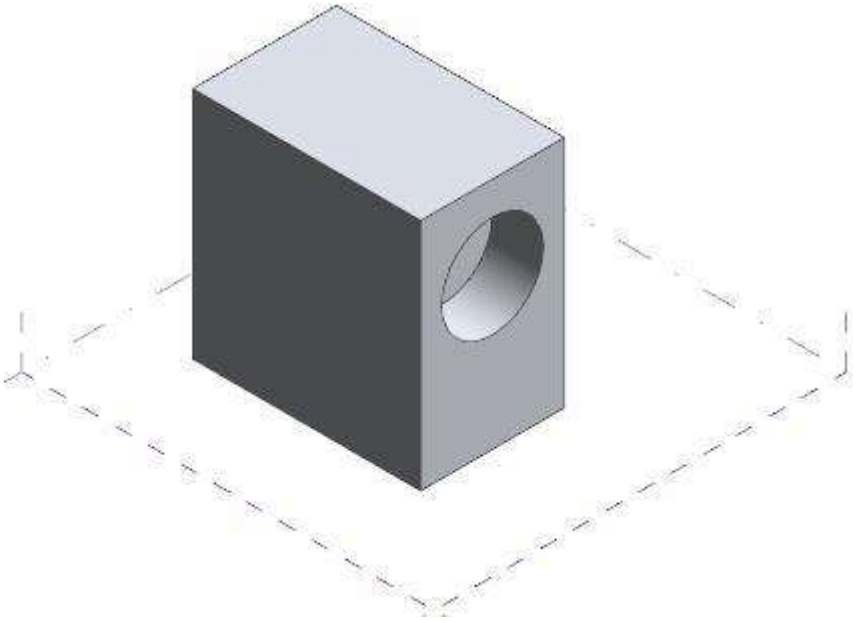
- Contains a narrow opening or groove.
- The slot may extend partially or completely through the component.
- It is used in designing sliding and adjustable metal components.



**e) Block with a hole**

- Contains one or more circular or cylindrical openings.

- Holes may be drilled, bored or punched.
- It is common in machine brackets, mounting plates and connecting components.



**4.2 Procedure for Drawing Orthographic Views of a Shaped Block**

The following procedure can be used when constructing orthographic views using either first angle or third angle projection.

**Step 1: Study the given object**

- Observe the object carefully.
- Identify all its surfaces, corners and edges.
- Identify any holes, slots, grooves and projections.
- Determine which face gives the clearest representation of the object.

**Step 2: Determine the dimensions**

Establish the:

- Overall length.
- Overall width.
- Overall height.
- Length, width and depth of any steps.
- Diameter and position of holes.
- Width and depth of slots.

**Step 3: Select the front view**

- Choose the face that reveals the most important features.
- Avoid selecting a face that hides important details unnecessarily.
- The selected front view should make interpretation easy.

**Step 4: Select the drawing scale**

A scale is the ratio between the size of an object on a drawing and its actual size.

Examples include:

- Full scale: 1:1.
- Half scale: 1:2.
- Double scale: 2:1.

**Step 5: Draw the front view**

- Begin with thin construction lines.
- Draw the overall height and length.
- Add all steps, projections and visible details.
- Ensure the dimensions are accurate.

**Step 6: Project the top view**

- Draw projectors from the front view.
- Transfer the width measurements.
- Position the top view according to the projection system being used.
- Complete all visible features.

**Step 7: Project the side view**

- Transfer the height and width measurements.
- Use horizontal and vertical projection lines.
- Use a 45-degree mitre line to transfer measurements between the top and side views when necessary.

**Step 8: Add details**

- Draw visible edges using continuous thick lines.
- Draw hidden edges using dashed lines.
- Use centre lines for circular and symmetrical features.

**Step 9: Complete the drawing**

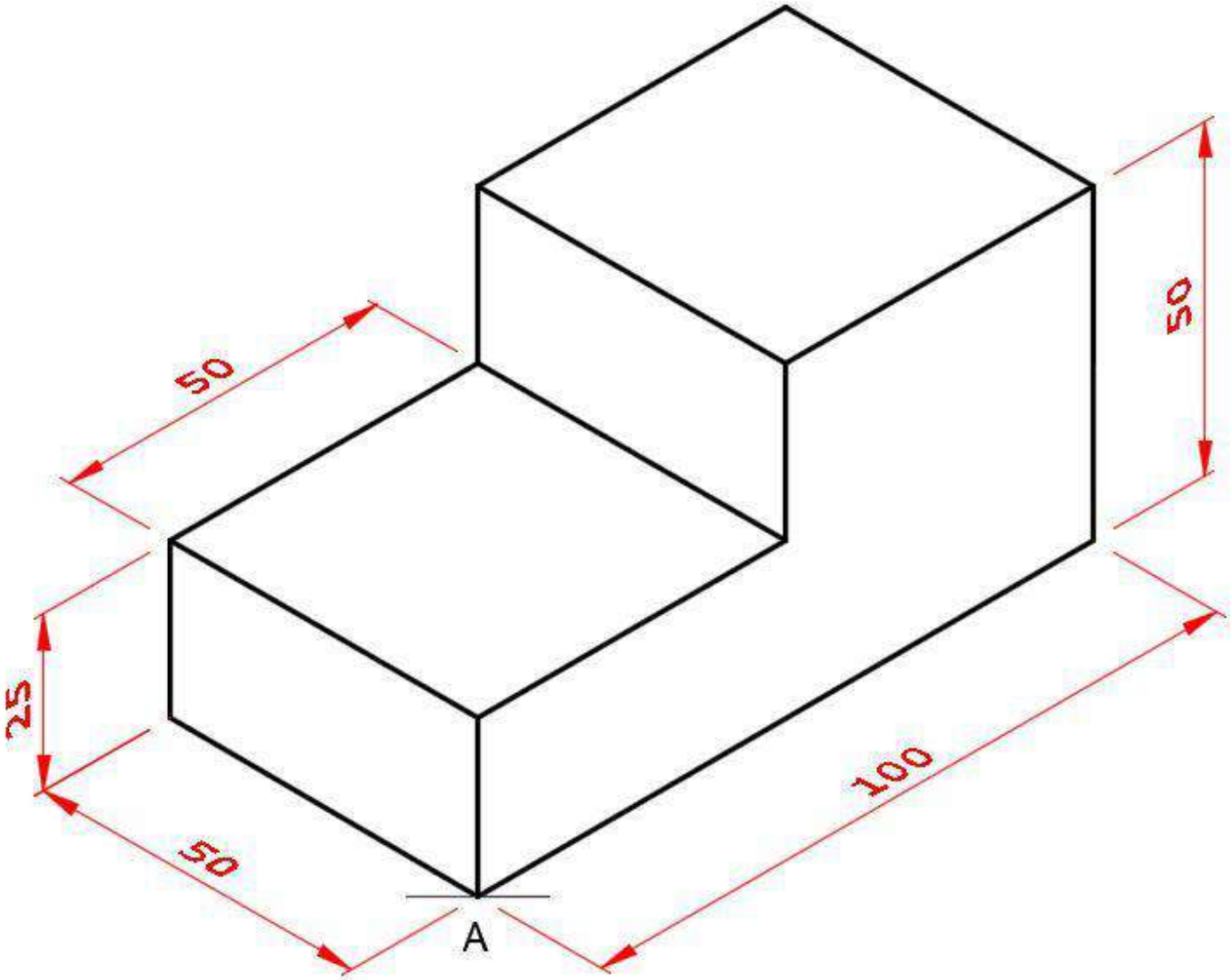
- Darken the final outlines.
- Remove unnecessary construction lines.
- Add dimensions and labels.
- Indicate the projection method.
- Check that all the views are properly aligned.

**4.3 Worked Example 1: Orthographic Projection of a Stepped Block**

A metal block has the following dimensions:

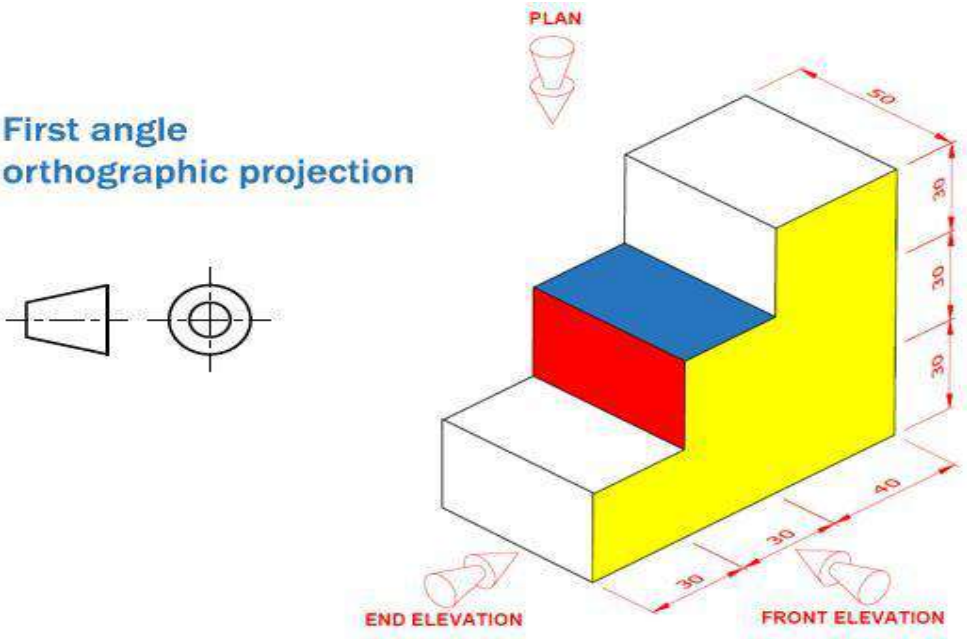
- Overall length: 100 mm.
- Overall width: 60 mm.
- Overall height: 50 mm.
- Lower section height: 25 mm.
- Raised section length: 40 mm.

The learner is required to draw the front, top and right-side views using first angle projection.




**Solution and interpretation**

1. Draw the front view showing the total length of 100 mm and maximum height of 50 mm.
2. Show the raised section according to its specified length.
3. Project the top view below the front view because first angle projection is being used.
4. The top view must show the overall length of 100 mm and width of 60 mm.
5. Draw the right-side view to the left of the front view.
6. The side view must show the width of 60 mm and height of 50 mm.
7. Complete all visible edges and dimensions.



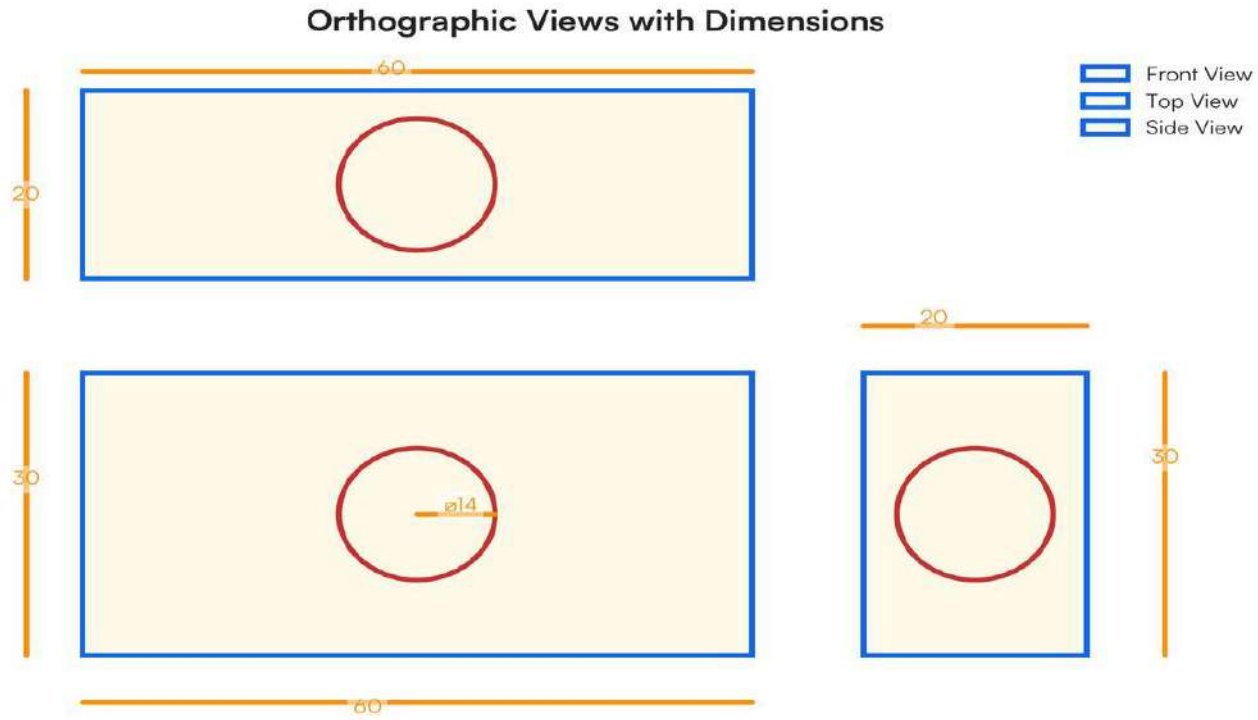

**4.4 Worked Example 2: Orthographic Projection of a Block with a Through Hole**

A rectangular metal block has the following dimensions:

- Length: 80 mm.
- Width: 50 mm.
- Height: 30 mm.
- A vertical through hole of diameter 20 mm at the centre.

**Interpretation of the views**

1. Front view: shows the rectangular outline and the hidden edges of the vertical hole where applicable.
2. Top view: shows the rectangular outline and a circular hole of diameter 20 mm.
3. Side view: shows the rectangular outline and the hidden edges of the hole where applicable.

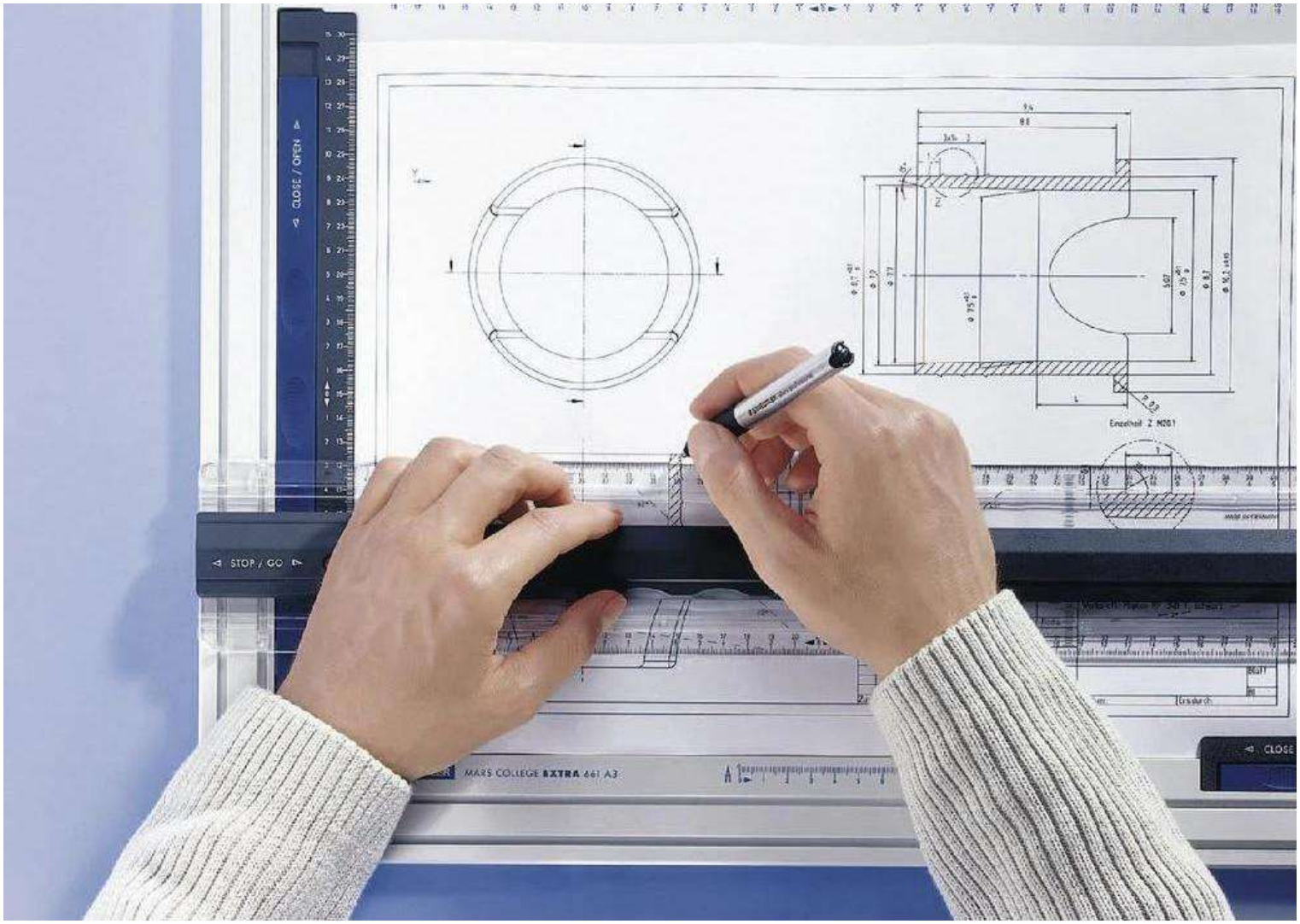


**Important drawing consideration:** The appearance of a hole depends on the direction of viewing. A vertical cylindrical through hole appears circular in the top view, while its hidden edges are represented appropriately in the front and side views.

**5.0 Drawing Instruments and Materials Used in Orthographic Projection**

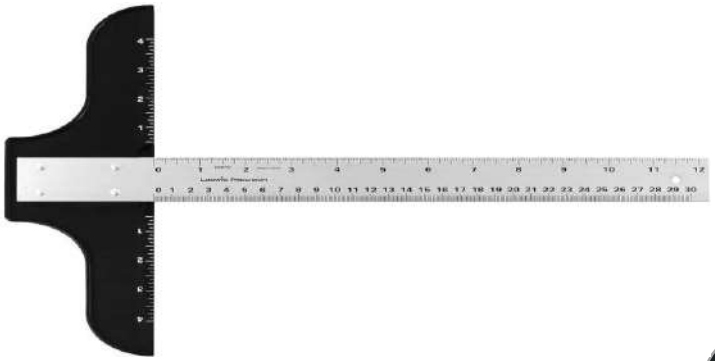
Accurate orthographic drawings require suitable drawing instruments and materials.

**5.1 Drawing Board**



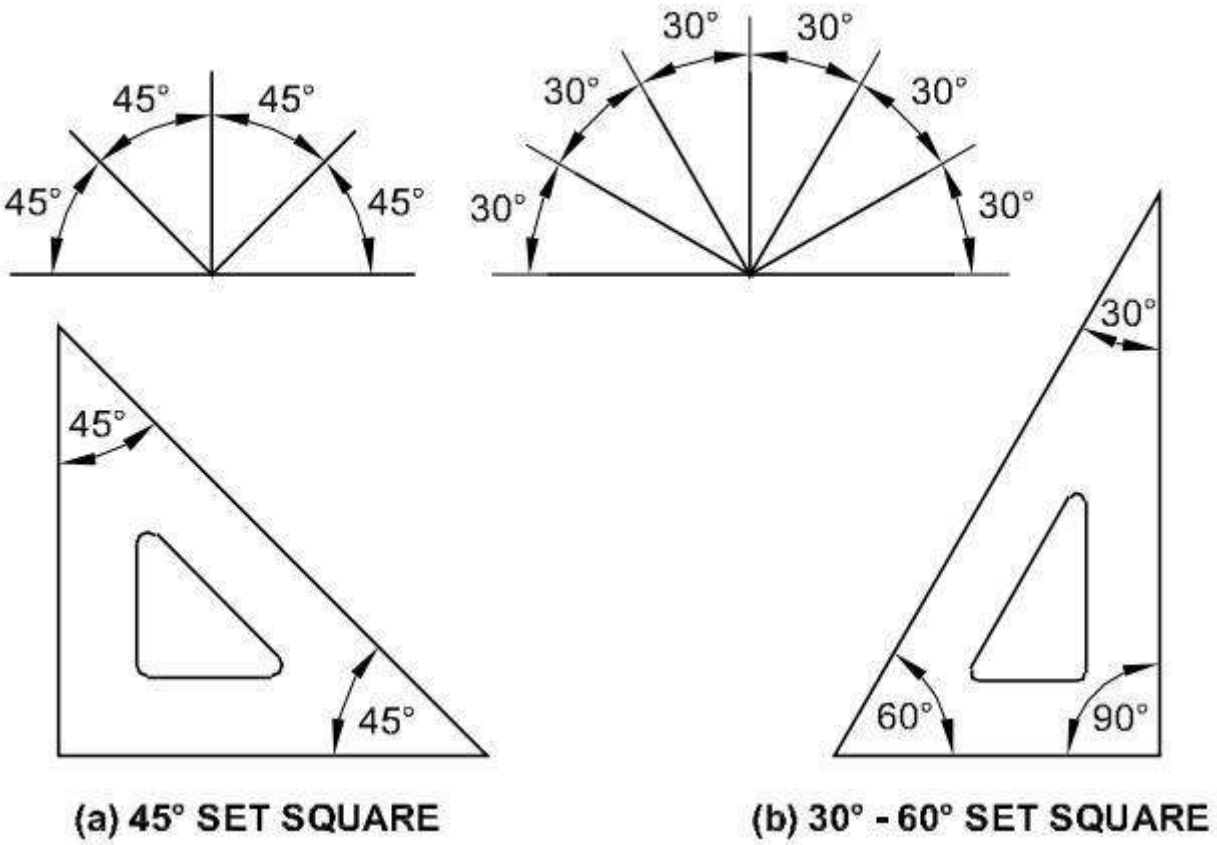

- It provides a flat surface for drawing.
- It supports the drawing paper.
- It enables accurate construction of horizontal and vertical lines.
- It should be clean, smooth and stable.

**5.2 T-Square**



- It is used to draw horizontal lines.
- It guides set squares when constructing vertical and inclined lines.
- It should be held firmly against the working edge of the drawing board.

**5.3 Set Squares**




(a) 45° SET SQUARE (b) 30° - 60° SET SQUARE

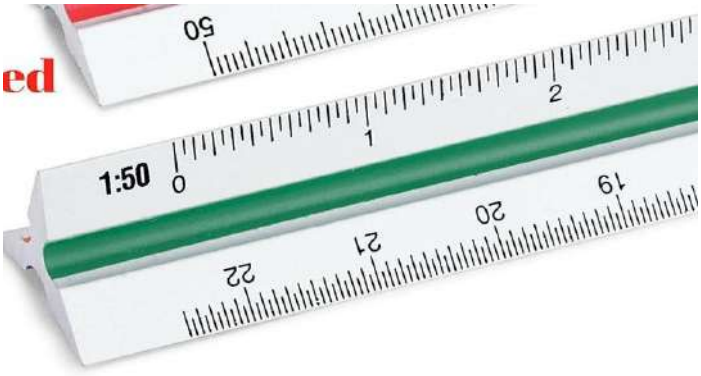
- They are used to draw vertical and inclined lines.
- A 45-degree set square is useful for constructing mitre lines.
- A 30°–60° set square helps construct lines at specific angles.

**5.4 Drawing Pencils**




- They are used for drawing construction lines and final outlines.
- Hard pencils such as 2H are suitable for thin construction lines.
- HB pencils can be used for general drawing and visible outlines, depending on the required line weight.

**5.5 Scale Rule**



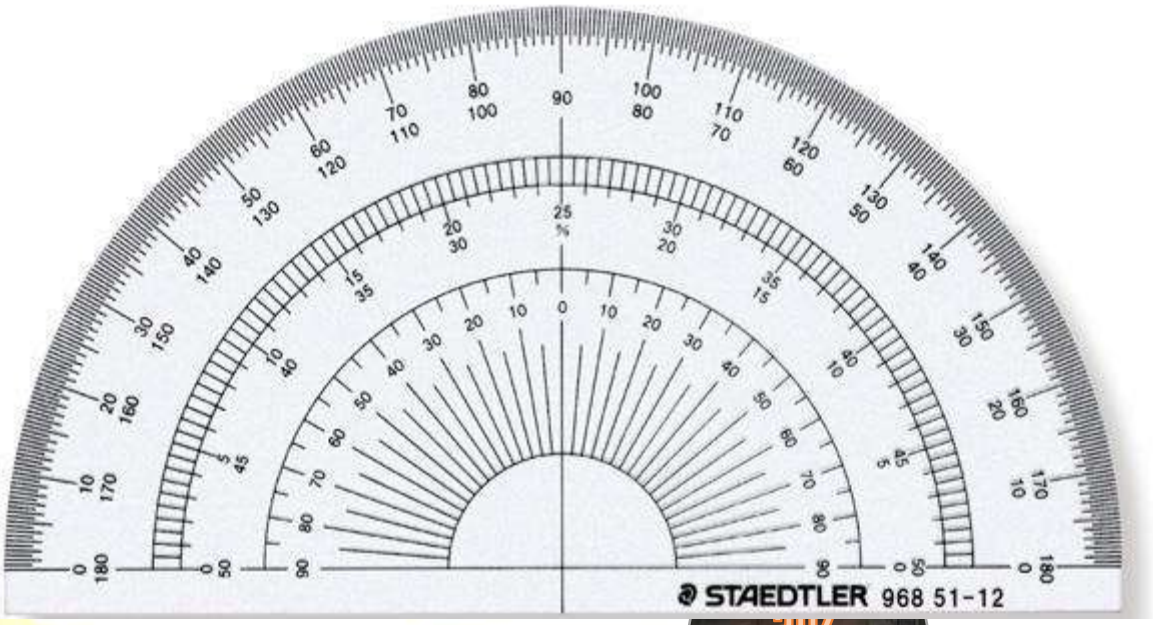

- It is used to measure and transfer dimensions.
- It assists in drawing objects using different scales.
- Metric measurements are commonly expressed in millimetres.

**5.6 Drawing Compass**



- It is used to draw circles and arcs.
- It is useful when representing drilled holes and rounded features.
- It helps maintain consistent radii.

**5.7 Protractor**



- It is used to measure and construct angles.
- It assists in drawing inclined features.
- It can be used when interpreting angled components.

**5.8 Eraser**

- It removes unwanted construction lines.
- It corrects drawing mistakes.
- It should be used carefully to avoid damaging the drawing paper.

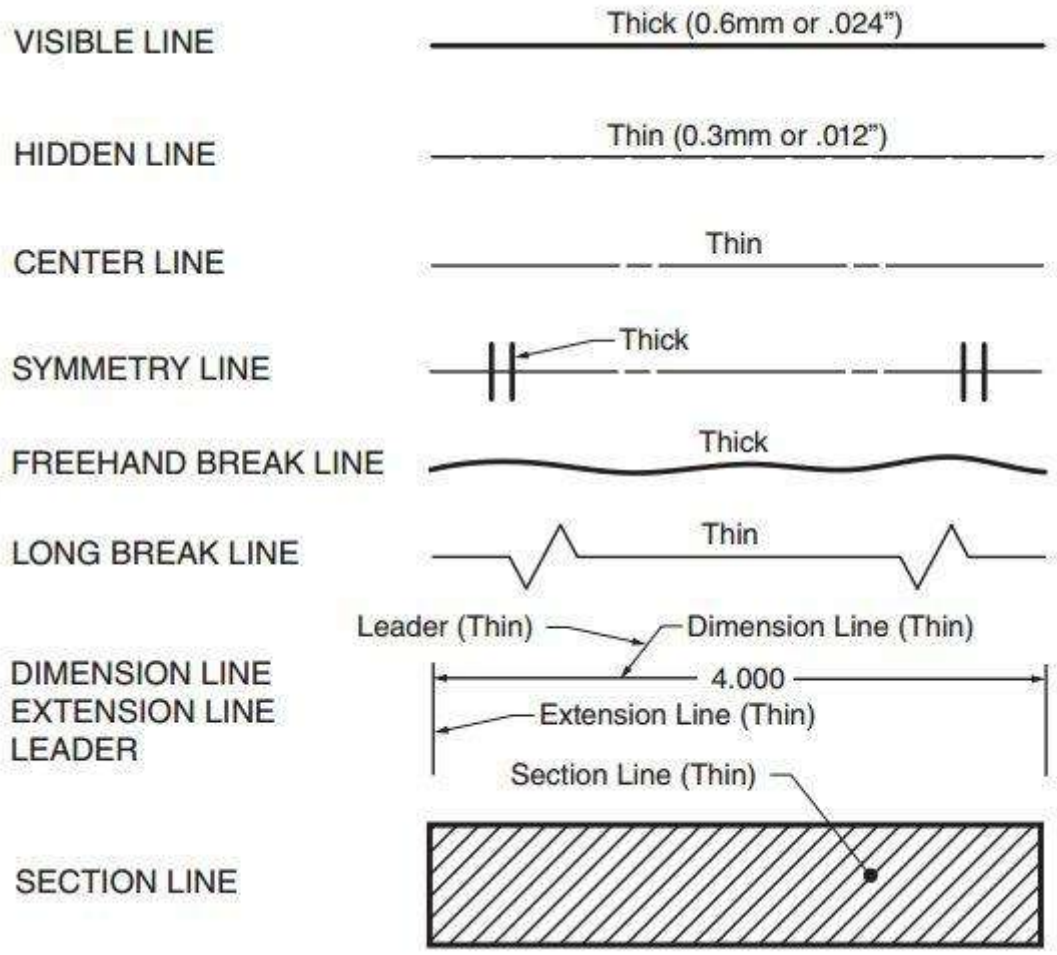
**5.9 Drawing Paper**

- It provides the surface on which drawings are produced.
- It should be clean and free from folds.
- Its size should be suitable for the drawing.

**6.0 Types of Lines Used in Orthographic Projection**

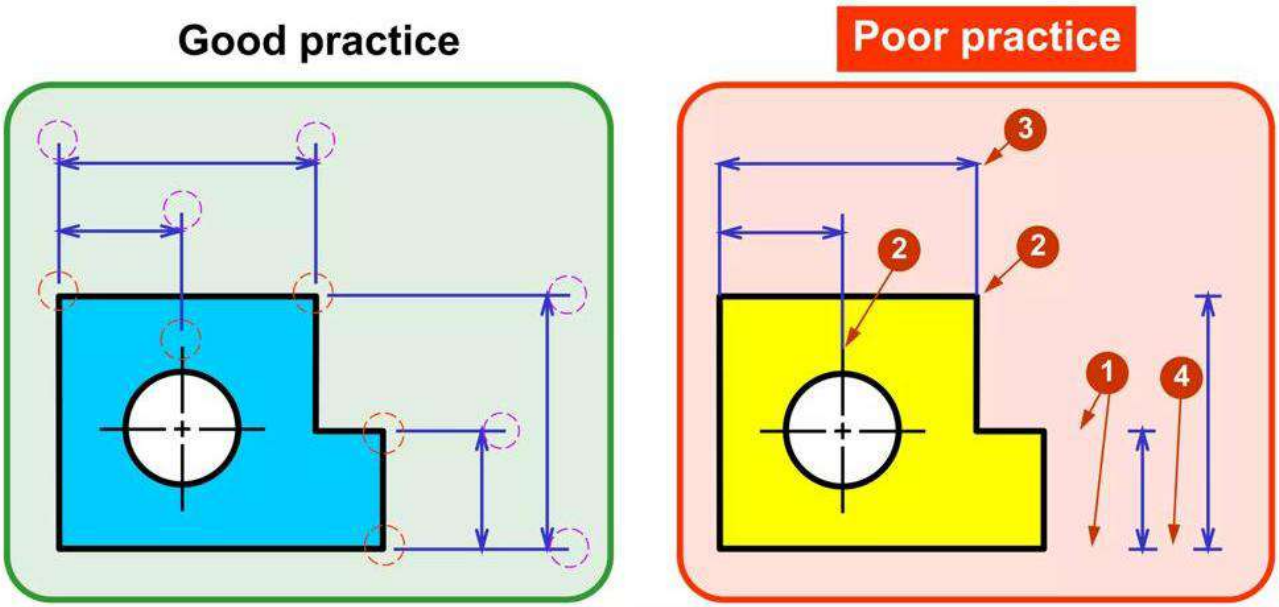
Different lines are used in technical drawing to communicate different types of information.

**6.1 Continuous Thick Line**



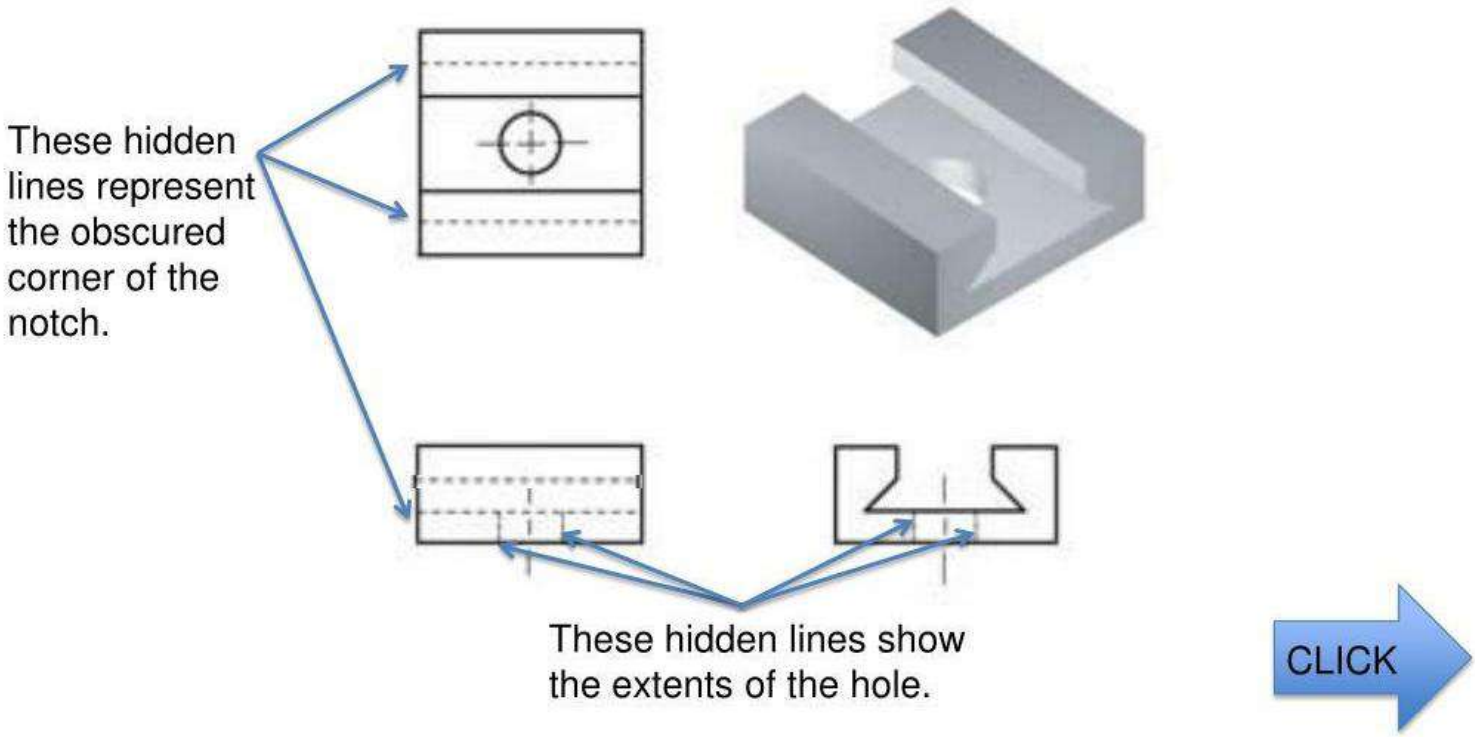

- It represents visible outlines and edges.
- It is used to define the external shape of an object.
- It is usually darker than construction lines.

**6.2 Continuous Thin Line**



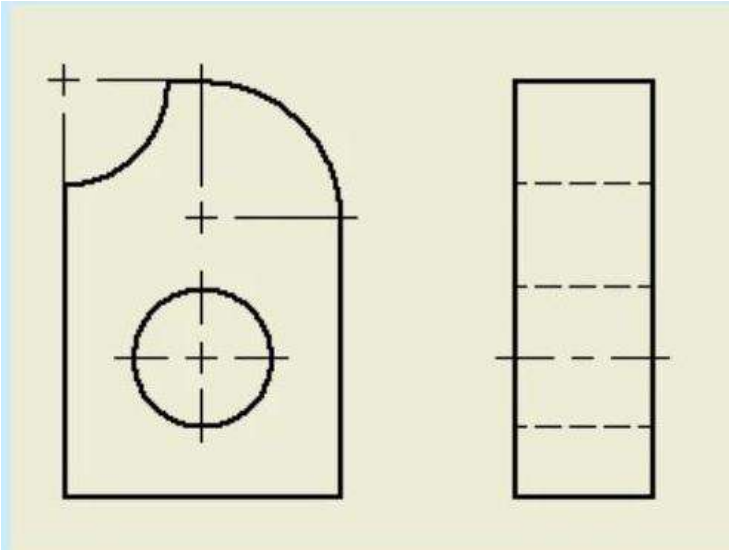

- It is used for dimension lines.
- It is used for extension lines.
- It is used for projection and construction lines.
- It is also used for hatching in sectional drawings.

**6.3 Dashed Thin Line**



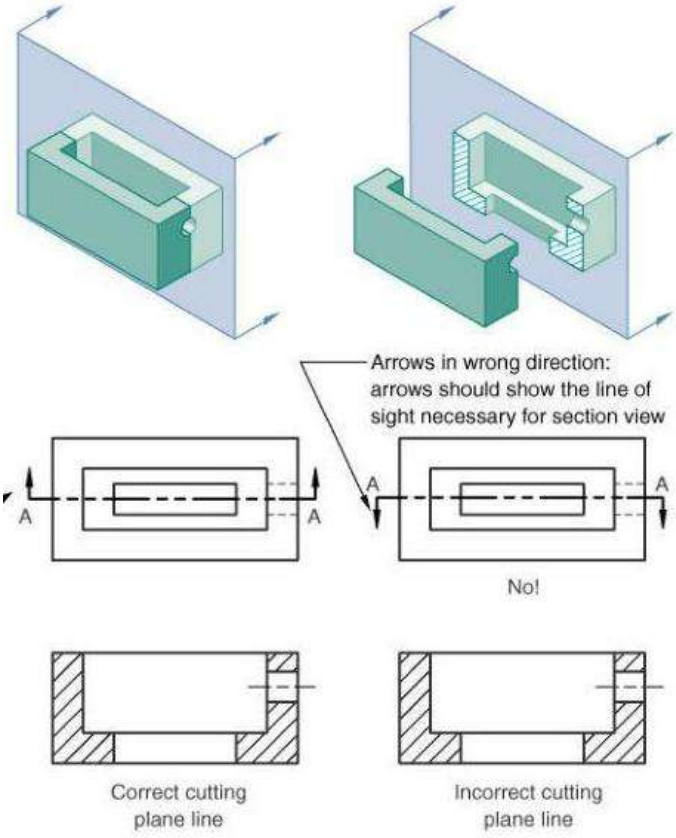

- It represents hidden edges and surfaces.
- It shows features that cannot be seen directly from the viewing direction.
- It is useful when representing holes, slots and internal details.

### 6.4 Chain Thin Line



- It represents centre lines.
- It indicates axes of circular or cylindrical components.
- It shows lines of symmetry.

### 6.5 Cutting Plane Line




- It indicates the position where an object is imagined to be cut.
- It shows the direction of viewing for a sectional drawing.
- It is used when internal features need to be revealed.

## 7.0 Dimensioning in Orthographic Projection

### 7.1 Meaning of Dimensioning

Dimensioning is the process of indicating the measurements of an object on a technical drawing using figures, dimension lines, extension lines and symbols.

Dimensioning communicates the actual size of a component to the person manufacturing it.

### 7.2 Elements of Dimensioning

**a) Dimension line**

- It is a thin continuous line.
- It indicates the direction and extent of a measurement.
- It normally has arrowheads at both ends.

**b) Extension line**

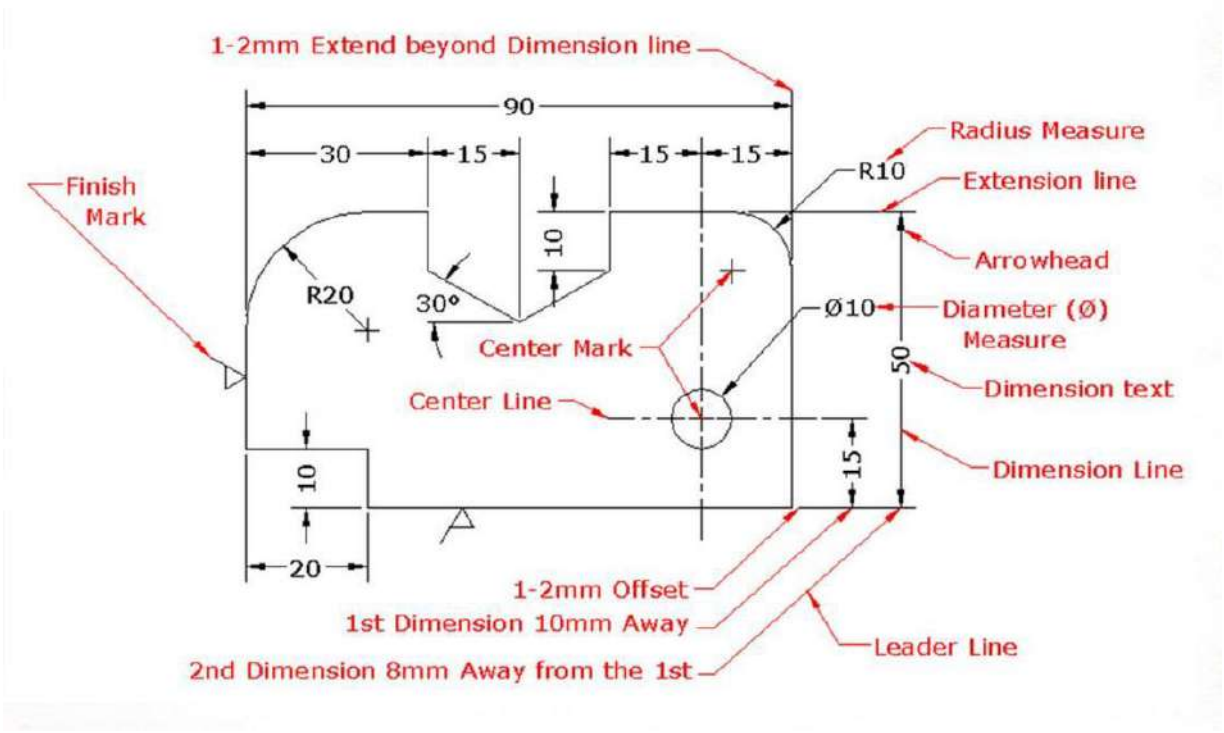
- It extends from the feature being measured.
- It indicates the limits of the dimension.
- It is drawn slightly beyond the dimension line.

**c) Dimension figures**

- They indicate the actual measurement.
- They are placed clearly to avoid confusion.
- In metalwork, dimensions are commonly expressed in millimetres.

**d) Arrowheads**

- They indicate the endpoints of a dimension.
- They should be clear and consistent.




### 7.3 Rules of Dimensioning

1. Dimensions should be clear and easy to read.

2. All necessary dimensions should be provided.
3. Unnecessary repetition of dimensions should be avoided.
4. Dimensions should preferably be placed outside the object outline.
5. Dimension lines should not cross one another unnecessarily.
6. Dimensions should not be taken by measuring the drawing where actual figures are provided.
7. Dimension figures should be placed in positions where they can be read easily.
8. The unit of measurement should be clearly understood.
9. The drawing should not contain conflicting dimensions.
10. Dimensioning should follow recognised technical drawing standards.

**7.4 Common Dimensioning Symbols**

| Symbol | Meaning |
|---|---|
| Ø | Diameter |
| R | Radius |
| □ | Square |
| ° | Degrees |
| ± | Plus or minus tolerance |
| M | Metric screw thread designation when used with a thread size |

Examples:

- Ø20 = Diameter of 20 mm.
- R10 = Radius of 10 mm.
- 45° = An angle of 45 degrees.
- M12 = Metric thread designation of nominal size 12 mm.

**8.0 Scales Used in Orthographic Projection**

**8.1 Definition of Scale**

A scale is the ratio between the dimensions of a drawing and the corresponding actual dimensions of the object.

Scales are used when objects are too large or too small to be represented conveniently on a drawing sheet.

**8.2 Types of Scales**

**a) Full-size scale (1:1)**

- The drawing has the same dimensions as the actual object.
- It is suitable for components that can fit on the drawing sheet.
- Example: A 50 mm metal plate is drawn as 50 mm.

**b) Reducing scale**

- The drawing is smaller than the actual object.
- It is used when representing large objects.
- Examples: 1:2, 1:5, 1:10 and 1:100.
- Example: A 100 mm component drawn at 1:2 will measure 50 mm on paper.

**c) Enlarging scale**

- The drawing is larger than the actual object.

- It is used when showing small details clearly.
- Examples: 2:1, 5:1 and 10:1.
- Example: A 5 mm feature drawn at 2:1 will measure 10 mm on paper.

**8.3 Scale Calculation**

Scale=Drawing size/Actual size

**Example 1**

A metal component is 120 mm long. It is represented using a scale of 1:2. Find the drawing length.

Drawing length=120/2=60 mm

**Example 2**

A small metal feature measures 8 mm. It is drawn at a scale of 5:1. Find its drawing size.

8×5=40 mm

**9.0 Quality and Accuracy in Orthographic Drawing**

A good orthographic drawing should meet specific quality requirements.

**9.1 Characteristics of a Good Orthographic Drawing**

1. **Accuracy:** All measurements and proportions should be correct.
2. **Clarity:** The drawing should be easy to understand.
3. **Correct alignment:** Corresponding features should align between views.
4. **Proper line work:** Different line types should be used appropriately.
5. **Correct projection system:** The views should be arranged according to the selected method.
6. **Completeness:** All necessary features and dimensions should be included.
7. **Neatness:** The drawing should be clean and well presented.
8. **Standardisation:** Recognised technical drawing conventions should be followed.

**9.2 Common Errors in Orthographic Projection**

| Error | Explanation |
|---|---|
| Incorrect view arrangement | Placing views in the wrong positions. |
| Poor alignment | Corresponding features do not match. |
| Incorrect dimensions | Measurements do not represent the actual object. |
| Wrong line types | Hidden edges are shown as visible edges. |
| Missing features | Important slots, holes or steps are omitted. |
| Poor scale selection | The drawing does not fit properly on the sheet. |
| Excessive construction lines | The final drawing appears untidy. |
| Incorrect front view | The selected view hides important features. |

**9.3 Ways of Improving Drawing Accuracy**

- Use appropriate drawing instruments.
- Study the object before beginning the drawing.
- Select the correct projection method.
- Use thin construction lines initially.
- Check measurements before darkening outlines.
- Keep the drawing board and paper clean.

- Practise regularly using different shaped blocks.
- Ask peers and teachers to assess completed drawings.

**10.0 Safety and Care When Using Drawing Instruments**

Although technical drawing is generally a low-risk activity, proper care and safety practices are necessary.

1. Handle compasses carefully because their sharp points can cause injuries.
2. Do not throw drawing instruments around.
3. Keep pencils sharpened using suitable sharpeners.
4. Avoid leaving instruments on the edge of the drawing board.
5. Store instruments in appropriate cases after use.
6. Keep the working area clean and organised.
7. Avoid using damaged drawing instruments.
8. Do not use drawing instruments for purposes for which they were not designed.
9. Keep food and liquids away from drawing sheets.
10. Ensure adequate lighting to prevent eye strain.

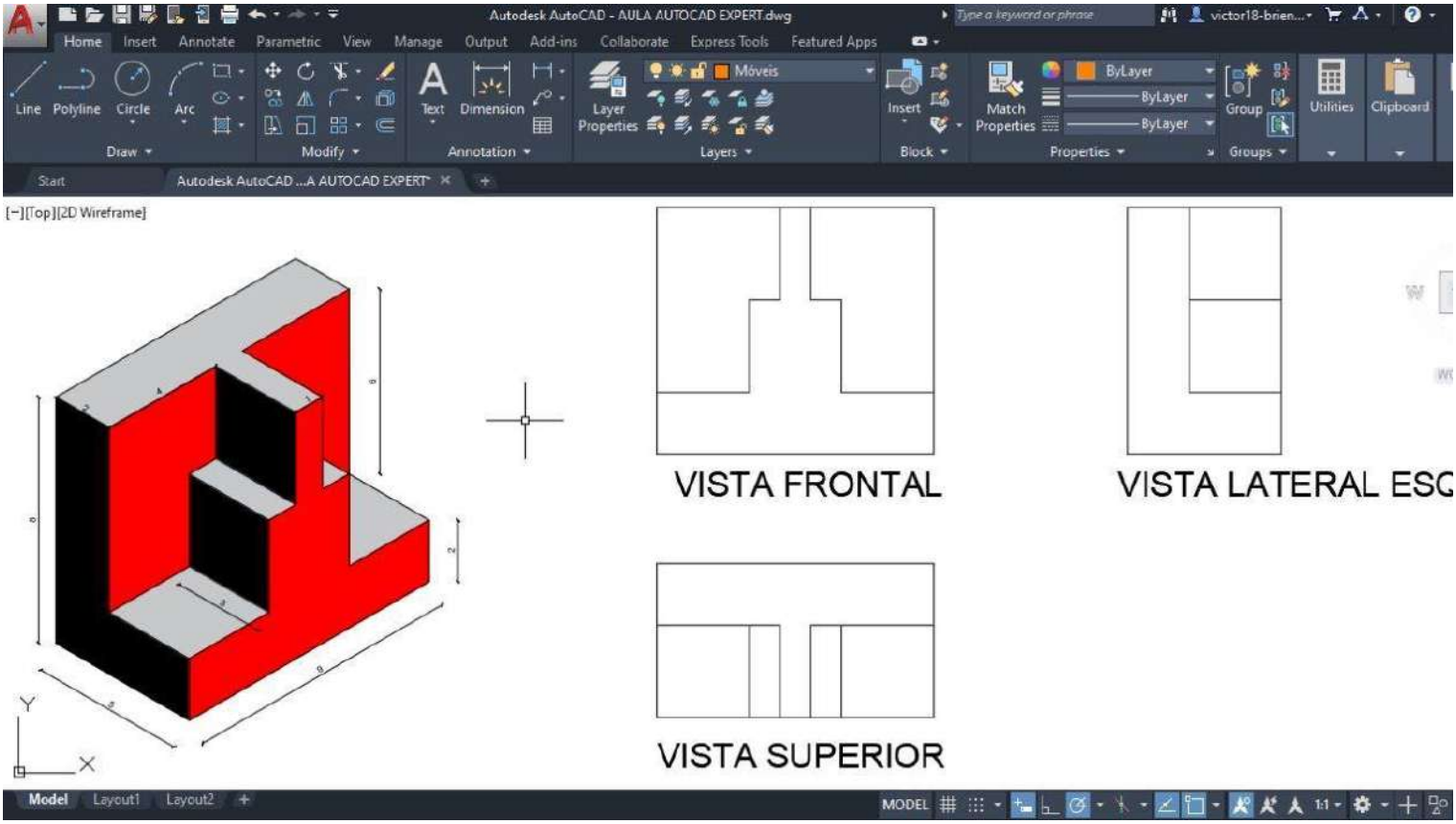
**11.0 Digital Orthographic Drawing**

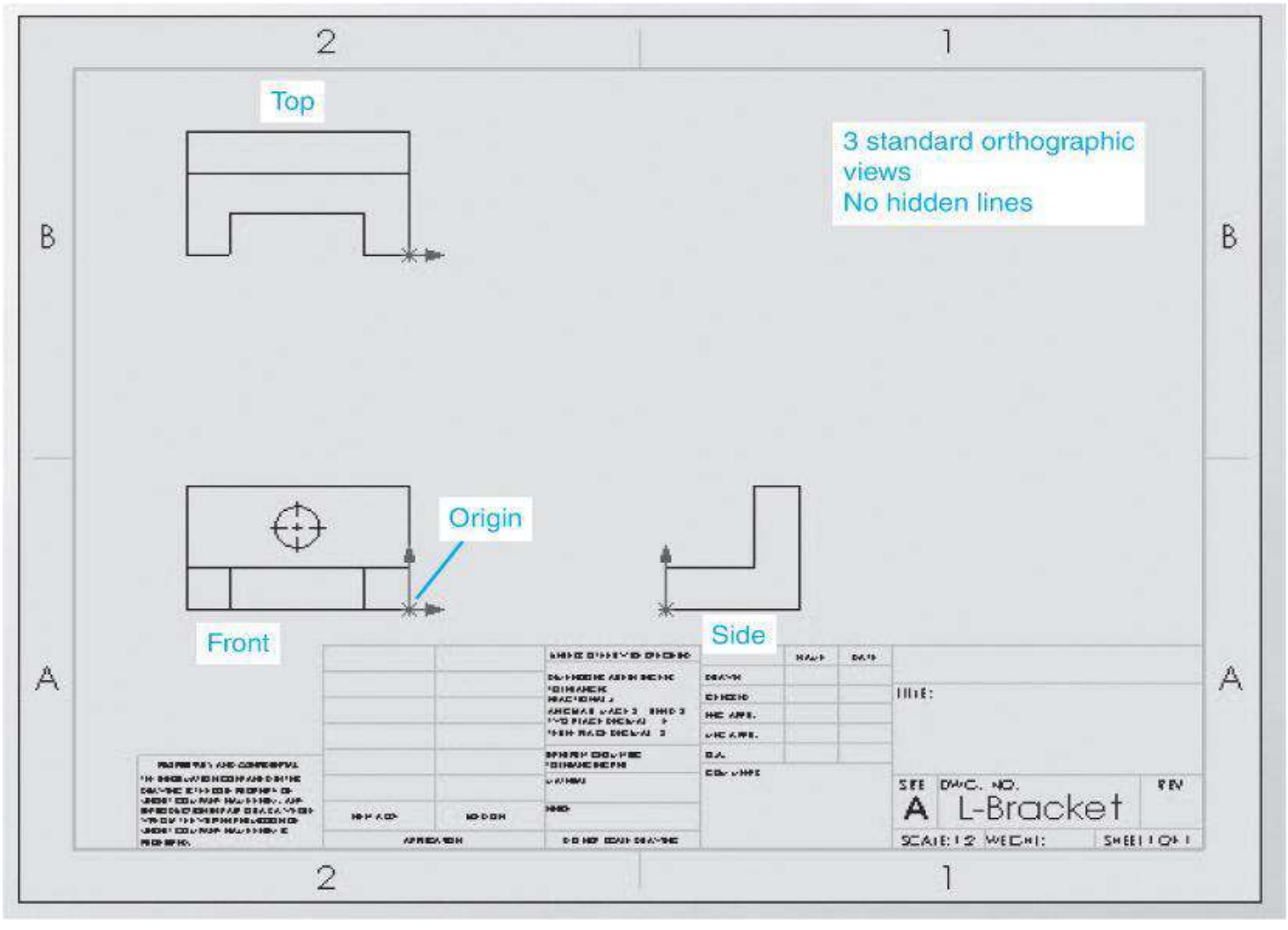
Modern metalwork uses computer-based drawing tools to produce accurate engineering drawings.

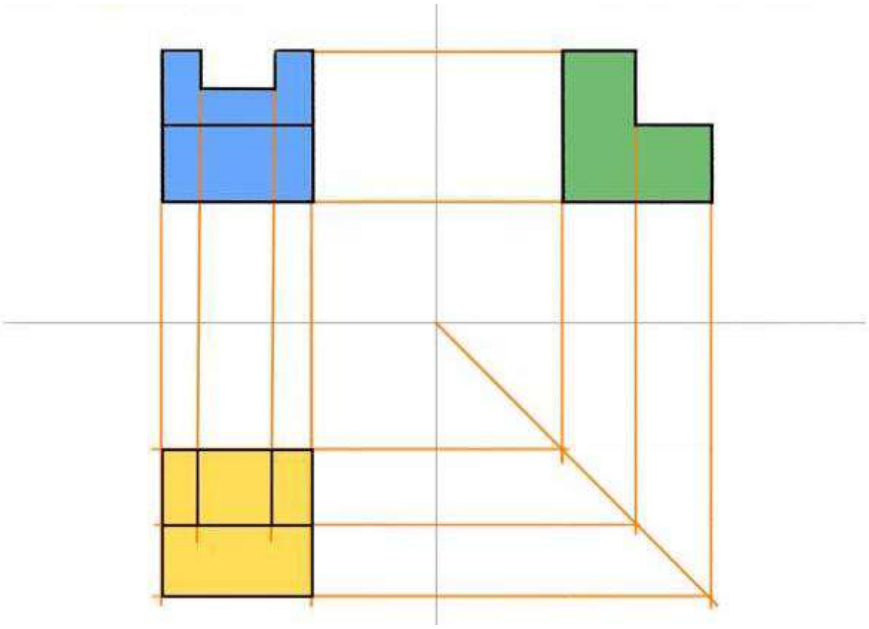
Computer-Aided Design (CAD) refers to the use of computer software to create, modify and present technical drawings and designs.

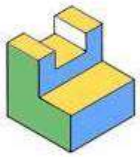
**11.1 Examples of CAD Software**

- AutoCAD.
- SolidWorks.
- FreeCAD.
- Fusion.


Autodesk AutoCAD - AULA AUTOCAD EXPERT.dwg
Home
Insert
Annotate
Parametric
View
Manage
Output
Add-ins
Collaborate
Express Tools
Featured Apps
Line
Polyline
Circle
Arc
Text
Dimension
Layer Properties
Insert
Match Properties
Group
Utilities
Clipboard
Draw
Modify
Annotation
Layers
Block
Properties
Groups
[−][Top][2D Wireframe]
VISTA FRONTAL
VISTA LATERAL ESQ
VISTA SUPERIOR
Model
Layout1
Layout2


Top
3 standard orthographic views
No hidden lines
Origin
Front
Side
L-Bracket





**11.2 Advantages of Digital Orthographic Drawing**

1. It improves drawing accuracy.
2. It allows easy correction of mistakes.
3. It enables drawings to be stored electronically.
4. It facilitates sharing of drawings.
5. It allows easy production of multiple views.
6. It supports accurate dimensioning.
7. It saves time when modifying designs.
8. It facilitates three-dimensional modelling.

**11.3 Limitations of Digital Drawing**

- It requires access to computers.
- Some CAD programmes require paid licences.
- Learners need adequate computer skills.
- Power interruptions may disrupt work.
- Some software requires powerful computers.
- Technical support and training may be necessary.

**12.0 Practical Learning Activities**

The following activities can be undertaken in a Kenyan Senior School Metal Technology workshop or drawing room.

**Activity 1: Identifying Orthographic Views**

**Materials:** Rectangular metal blocks, shaped wooden blocks, charts and drawing sheets.

**Procedure:**

1. Obtain a rectangular block.
2. Observe it from the front, top and right side.
3. Identify the features visible from each direction.

4. Sketch the three views.
5. Label each view correctly.
6. Discuss the importance of the views in metalwork.

**Expected outcome:** The learner identifies and distinguishes the principal orthographic views.

**Activity 2: Constructing First Angle Projection**

**Materials:** Drawing board, T-square, set squares, pencils, ruler, eraser and drawing paper.

**Procedure:**

1. Obtain a stepped block.
2. Measure its length, width and height.
3. Select the front view.
4. Draw the front view.
5. Construct the top view below the front view.
6. Construct the right-side view to the left of the front view.
7. Add dimensions.
8. Display the completed drawing.

**Expected outcome:** The learner constructs accurate first angle orthographic views.

**Activity 3: Constructing Third Angle Projection**

**Procedure:**

1. Obtain a shaped block with a slot.
2. Identify the front, top and right-side faces.
3. Draw the front view.
4. Draw the top view above the front view.
5. Draw the right-side view to the right of the front view.
6. Add hidden details.
7. Label and display the drawing.

**Expected outcome:** The learner constructs third angle orthographic views correctly.

**Activity 4: Comparing Projection Systems**

1. Work in small groups.
2. Select a shaped metal component.
3. Draw its orthographic views using first angle projection.
4. Draw the same component using third angle projection.
5. Compare the arrangement of the views.
6. Identify the similarities and differences.
7. Present the findings to the class.

**Expected outcome:** The learner explains the differences between first and third angle projection.

**Key Terms and Definitions**

| Term | Meaning |
|---|---|
| Orthographic projection | Representing a 3D object using 2D views projected at right angles. |
| Projection plane | An imaginary surface onto which an object is projected. |
| Projector | An imaginary straight line used to transfer features onto a plane. |
| Elevation | A view of an object from the front or side. |
| Plan | The view of an object from above. |
| First angle projection | Projection method where the object lies between the observer and the plane. |
| Third angle projection | Projection method where the plane lies between the observer and the object. |
| Profile plane | A vertical plane used to obtain a side view. |
| Hidden detail | An edge or feature not directly visible from the viewing direction. |
| Centre line | A line indicating the centre or axis of a feature. |
| Scale | The ratio of drawing size to actual size. |
| Dimensioning | Indicating measurements on a technical drawing. |
| CAD | Computer-Aided Design. |
| Mitre line | A line, commonly at 45°, used to transfer measurements between orthographic views. |

**16.0 Summary of the Sub-Strand**

Orthographic projection is an essential drawing technique in Metal Technology. It enables three-dimensional metal components to be represented accurately using two-dimensional views.

The three principal views are:

- Front view.
- Top view.
- Side view.

The two main systems are:

- First angle projection.
- Third angle projection.

In first angle projection, the top view is below the front view, while in third angle projection, the top view is above the front view.

Orthographic projection is widely used in engineering, construction, automotive production, agriculture, welding and metal fabrication.

Learners should practise constructing the views of rectangular blocks, stepped blocks, L-shaped blocks and blocks with holes and slots.

**Revision Questions**

SECTION A: MULTIPLE-CHOICE QUESTIONS

**Instructions:** Answer all questions. Choose the correct answer from the alternatives A, B, C and D.

1. What is orthographic projection?

A. A method of representing objects using freehand sketches.

B. A method of representing three-dimensional objects using two-dimensional views.

C. A method of producing pictorial drawings only.

D. A method of shading engineering drawings.

2. Which of the following is the main purpose of orthographic projection in metalwork?

A. To decorate metal surfaces.

B. To show the colour of metal components.

C. To communicate the shape and dimensions of components accurately.

D. To identify different types of metals.

3. Which plane is used to obtain the front view of an object?

A. Horizontal plane.

B. Vertical plane.

C. Profile plane.

D. Inclined plane.

4. The top view of an object is also known as the:

A. Elevation.

B. Section.

C. Plan.

D. Profile.

5. Which dimensions are represented in the front view?

A. Length and height.

B. Length and width.

C. Width and height.

D. Width and depth only.

6. Which of the following views shows the width and height of an object?

A. Top view.

B. Front view.

C. Side view.

D. Plan view.

7. In first angle projection, the object is positioned:

A. Behind the observer.

B. Between the observer and the projection plane.

C. Below the drawing board.

D. Outside the projection system.

8. In first angle projection, where is the top view placed?

A. Above the front view.

B. Below the front view.

C. To the right of the front view.

D. To the left of the front view.

9. In first angle projection, the right-side view is placed:

A. To the right of the front view.

B. Above the front view.

C. To the left of the front view.

D. Below the front view.

10. In third angle projection, the top view is placed:

A. Below the front view.

B. Above the front view.

C. To the left of the front view.

D. To the right of the front view.

11. In third angle projection, the right-side view is positioned:

A. To the left of the front view.

B. Below the front view.

C. To the right of the front view.

D. Above the front view.

12. Which of the following projection systems places the object between the observer and the projection plane?

A. Third angle projection.

B. First angle projection.

C. Oblique projection.

D. Isometric projection.

13. Which instrument is mainly used for drawing horizontal lines?

A. Compass.

B. Protractor.

C. T-square.

D. Divider.

14. Which instrument is used to construct a 45-degree mitre line?

A. Set square.

B. Compass.

C. Eraser.

D. Scale rule.

15. Which drawing line is used to represent visible outlines?

A. Dashed thin line.

B. Continuous thick line.

C. Chain thin line.

D. Construction line.

16. Hidden edges in orthographic projection are represented using:

A. Continuous thick lines.

B. Continuous thin lines.

C. Dashed thin lines.

D. Chain thick lines.

17. Which line is commonly used to represent the axis of a circular hole?

A. Centre line.

B. Dimension line.

C. Extension line.

D. Cutting plane line.

18. What is the function of a dimension line?

A. To indicate hidden features.

B. To indicate the measurement of an object.

C. To represent the centre of a hole.

D. To show the colour of a component.

19. What does the symbol Ø represent in technical drawing?

A. Radius.

B. Angle.

C. Diameter.

D. Length.

20. What does a scale of 1:2 represent?

A. An enlargement.

B. A reduction to half the actual size.

C. A full-size drawing.

D. A drawing twice the actual size.

21. A metal component measuring 100 mm is drawn at a scale of 1:2. What is its drawing length?

A. 25 mm.

B. 50 mm.

C. 100 mm.

D. 200 mm.

22. A component measuring 10 mm is drawn at a scale of 5:1. What is its drawing length?

A. 2 mm.

B. 10 mm.

C. 25 mm.

D. 50 mm.

23. Which instrument is used to draw circles and arcs?

A. T-square.

B. Compass.

C. Set square.

D. Protractor.

24. Which of the following is an example of a shaped block?

A. A stepped block.

B. A drawing pencil.

C. A T-square.

D. A protractor.

25. Which of the following is an important consideration when selecting the front view?

A. It should hide all the important features.

B. It should reveal the most important features of the object.

C. It should always be the smallest face.

D. It should contain no dimensions.

26. What is the function of a profile plane?

A. To obtain the top view.

B. To obtain the side view.

C. To obtain the bottom view only.

D. To construct circles.

27. What is the purpose of CAD in technical drawing?

A. To melt metal components.

B. To join metal surfaces.

C. To create and modify technical drawings using computers.

D. To measure the hardness of metals.

28. Which of the following is an advantage of computer-aided drawing?

A. It makes correction of drawings difficult.

B. It increases drawing errors.

C. It allows accurate modification of drawings.

D. It eliminates the need for measurements.

29. Why should construction lines be drawn lightly?

A. To make them difficult to see.

B. To allow easy removal after completing the drawing.

C. To make them appear as visible outlines.

D. To replace dimension lines.

30. Which of the following industries uses orthographic projection?

A. Automotive manufacturing.

B. Metal fabrication.

C. Agricultural machinery production.

D. All of the above.

**SECTION B: STRUCTURED QUESTIONS**

**50 MARKS**

**Instructions:** Answer all questions. Show all necessary construction procedures where applicable.

**QUESTION 1: INTRODUCTION TO ORTHOGRAPHIC PROJECTION (8 MARKS)**

a) Define orthographic projection as used in Metal Technology. (2 marks)

b) State three reasons why orthographic projection is important in metalwork. (3 marks)

c) Identify three principal views used in orthographic projection. (3 marks)

**QUESTION 2: PLANES AND PRINCIPAL VIEWS (8 MARKS)**

a) Name the three principal planes of projection. (3 marks)

b) State the dimensions represented by each of the following views:

i. Front view. (1 mark)

ii. Top view. (1 mark)

iii. Side view. (1 mark)

c) Explain why corresponding features in different orthographic views must be properly aligned. (2 marks)

**QUESTION 3: FIRST ANGLE AND THIRD ANGLE PROJECTION (8 MARKS)**

a) Explain the meaning of first angle projection. (2 marks)

b) State two characteristics of third angle projection. (2 marks)

c) Give two differences between first angle and third angle projection. (2 marks)

d) State two reasons why projection symbols are included on engineering drawings. (2 marks)

**QUESTION 4: DRAWING INSTRUMENTS AND LINE CONVENTIONS (8 MARKS)**

a) State the functions of the following drawing instruments:

i. T-square. (1 mark)

ii. Compass. (1 mark)

iii. Set square. (1 mark)

iv. Scale rule. (1 mark)

b) Identify the line types used to represent:

i. Visible outlines. (1 mark)

ii. Hidden edges. (1 mark)

c) State two characteristics of a good orthographic drawing. (2 marks)

**QUESTION 5: SCALES AND DIMENSIONING (9 MARKS)**

a) Define the term scale as used in technical drawing. (2 marks)

b) Distinguish between a reducing scale and an enlarging scale. (2 marks)

c) A metal component has an actual length of 160 mm. Calculate its drawing length when represented using a scale of 1:4. (2 marks)

d) Explain the meaning of the following symbols:

i. Ø (1 mark)

ii. R (1 mark)

e) State one importance of dimensioning in metalwork. (1 mark)

**QUESTION 6: PRACTICAL APPLICATION OF ORTHOGRAPHIC PROJECTION (9 MARKS)**

A rectangular metal block has the following dimensions:

- Length = 100 mm.
- Width = 60 mm.
- Height = 40 mm.

a) Calculate the dimensions of the:

i. Front view. (1 mark)

ii. Top view. (1 mark)

iii. Side view. (1 mark)

b) Describe the procedure followed when constructing the three principal views of the block using first angle projection. (4 marks)

c) Explain two applications of orthographic projection in Kenyan metal fabrication workshops. (2 marks)

**Answers and Marking Guide**

**Section A: Multiple-Choice Answer Key**

| Question | Answer | Question | Answer |
|---|---|---|---|
| 1 | B | 16 | C |
| 2 | C | 17 | A |
| 3 | B | 18 | B |
| 4 | C | 19 | C |
| 5 | A | 20 | B |
| 6 | C | 21 | B |
| 7 | B | 22 | D |
| 8 | B | 23 | B |
| 9 | C | 24 | A |
| 10 | B | 25 | B |
| 11 | C | 26 | B |
| 12 | B | 27 | C |
| 13 | C | 28 | C |
| 14 | A | 29 | B |
| 15 | B | 30 | D |

**Section B: Suggested Marking Guide**

**Question 1**

a) Representation of a three-dimensional object using two-dimensional views projected at right angles. (2)

b) Any three:

- Communicates component dimensions.
- Assists manufacturing.
- Reduces production errors.
- Facilitates inspection.

- Supports communication between metalworkers. (3)

c) Front view, top view and side view. (3)

**Question 2**

a) Vertical plane, horizontal plane and profile plane. (3)

b)

- Front: length and height. (1)
- Top: length and width. (1)
- Side: width and height. (1)

c) To ensure corresponding features represent the same physical positions and dimensions, enabling accurate interpretation. (2)

**Question 3**

a) A projection system in which the object is between the observer and the projection plane. (2)

b) Any two:

- Top view is above the front view.
- Right-side view is to the right of the front view.
- Left-side view is to the left of the front view.
- Projection plane is between the observer and object. (2)

c) Any two correct differences. (2)

d) Any two:

- Identify the projection system.
- Prevent incorrect arrangement of views.
- Promote standardisation.
- Improve interpretation. (2)

**Question 4**

a)

- T-square: Drawing horizontal lines. (1)
- Compass: Drawing circles and arcs. (1)
- Set square: Drawing vertical and inclined lines. (1)
- Scale rule: Measuring and transferring dimensions. (1)

b)

- Visible outlines: Continuous thick line. (1)
- Hidden edges: Dashed thin line. (1)

c) Any two:

- Accurate dimensions.
- Proper alignment.
- Correct line conventions.

- Neat presentation. (2)

**Question 5**

a) Ratio between the drawing dimensions and actual dimensions of an object. (2)

b)

- Reducing scale produces a drawing smaller than the actual object.
- Enlarging scale produces a drawing larger than the actual object. (2)

c)

Drawing length=1604Drawing length=4160

40 mm40 mm

(2)

d)

- Ø = Diameter. (1)
- R = Radius. (1)

e) It communicates the actual measurements required during manufacturing. (1)

**Question 6**

a)

- Front view: 100 mm × 40 mm. (1)
- Top view: 100 mm × 60 mm. (1)
- Side view: 60 mm × 40 mm. (1)

b) Any four correctly explained steps:

- Study the block and establish its dimensions.
- Draw the front view.
- Project the top view below the front view.
- Project the right-side view to the left of the front view.
- Ensure corresponding views are aligned.
- Complete visible and hidden details.
- Add dimensions and finish the drawing. (4)

c) Any two:

- Designing metal gates, doors and window frames.
- Manufacturing agricultural machinery and equipment.
- Producing vehicle brackets and components.
- Fabricating metal tanks and trailers.
- Manufacturing metal furniture and machine parts. (2)

**STRAND 4.0: METAL JOINING AND FINISHING PROCESSES**

**SUB-STRAND 4.1: SOFT SOLDERING**

**1.0 Introduction to Soft Soldering**

Metal components are joined together in metalwork to produce useful products and structures. Different joining methods are used depending on the type of metals, the purpose of the product, the strength required and the working conditions.

One method of joining metals is **soft soldering**. It is commonly used when joining thin metal sheets, electrical wires, electronic components and light metalwork products.

Soft soldering is particularly useful where a permanent joint is required without melting the parent metals.

**1.1 Definition of Soft Soldering**

**Soft soldering** is a thermal metal-joining process in which two or more metal surfaces are joined using a low-melting-point filler metal called solder, without melting the parent metals.

- Heat is applied to the surfaces being joined.
- A suitable flux is used to remove or prevent oxide films and improve the flow of solder.
- The solder melts and flows into the joint through capillary action and surface wetting.
- The solder cools and solidifies, forming a joint between the metal components.

**Important:** In soft soldering, the parent metals do not melt. Only the solder melts.

**1.2 Meaning of Important Terms**

1. **Solder:** A low-melting-point metal alloy used as a filler material to join metal surfaces.
2. **Flux:** A chemical cleaning agent that removes or prevents oxide films and helps molten solder spread over metal surfaces.
3. **Parent metal:** The original metal components being joined.
4. **Filler metal:** The metal introduced into a joint to connect the parent materials.
5. **Capillary action:** The movement of molten solder into a narrow gap between closely fitting metal surfaces.
6. **Wetting:** The ability of molten solder to spread over and adhere to a clean metal surface.
7. **Thermal joining:** A joining process that uses heat to assist in forming a joint.
8. **Soldering iron:** A heated hand tool used to transfer heat to the surfaces being soldered.

**1.3 Characteristics of Soft Soldering**

Soft soldering has the following characteristics:

- It uses solder with a melting temperature generally below 450°C.
- It does not melt the parent metals.
- It requires a source of heat.
- It normally uses flux to improve the quality of the joint.
- It is suitable for thin sheets and small metal components.
- It produces joints that are generally weaker than brazed and welded joints.
- It can join certain dissimilar metals.
- It requires clean surfaces for effective bonding.

- It is suitable for delicate components that could be damaged by excessive heat.

**1.4 Difference Between Soft Soldering, Brazing and Welding**

| Feature | Soft soldering | Brazing | Welding |
|---|---|---|---|
| Joining material | Soft solder | Brazing filler metal | Usually parent metal itself or added filler |
| Temperature | Below 450°C | Above 450°C | Depends on process |
| Parent metals melt? | No | No | Usually yes in fusion welding |
| Joint strength | Generally low | Generally higher | Generally high |
| Common applications | Electrical connections, sheet metal | Pipes, fittings, metal components | Frames, gates, structures |







**2.0 Principles of Soft Soldering**

Soft soldering works through the application of heat, surface cleaning, flux action, solder melting and solidification.

**2.1 How Soft Soldering Works**

The process takes place through the following stages:

1. **Surface preparation**

- The surfaces to be joined are cleaned.
- Dirt, grease, paint and oxide layers are removed.
- The surfaces are brought into close contact.

2. **Application of flux**

- Flux is applied to the joint area.
- It removes or prevents oxidation during heating.
- It improves the ability of molten solder to wet the metal surfaces.

3. **Heating**

- A soldering iron or another suitable heat source is used.
- Heat is transferred to the metal surfaces.
- The workpiece is heated to a suitable soldering temperature.

4. **Application of solder**

- Solder is brought into contact with the heated joint.
- It melts due to the heat from the workpiece.
- The molten solder flows over the clean surfaces and into the joint.

5. **Cooling and solidification**

- The heat source is removed.
- The molten solder cools and solidifies.
- A bond is formed between the components.

6. **Inspection**

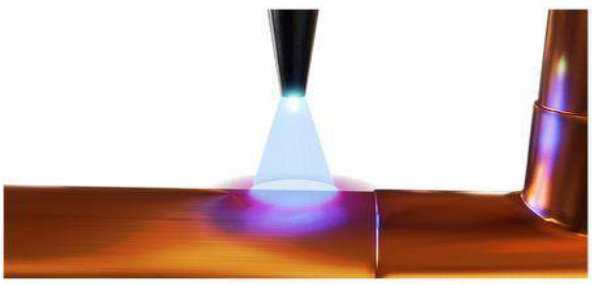
- The completed joint is examined.
- Defects such as cracks, gaps and poor solder flow are identified.



1. Cleaning



2. Fluxing



3. Heating



4. Applying Filler Metal

**2.2 Importance of Temperature Control**

Temperature control is essential in soft soldering because:

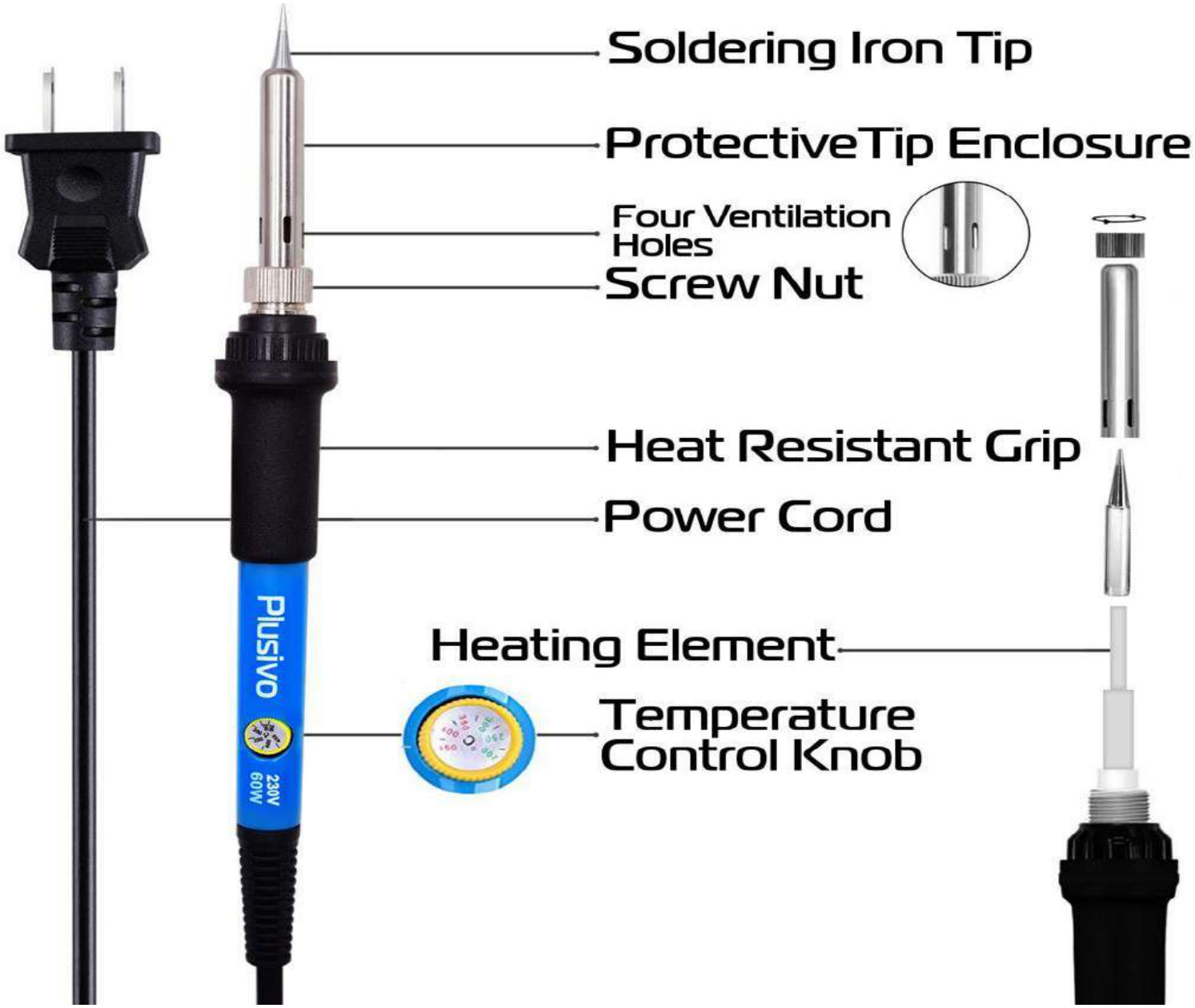
- Excessive heat may damage thin metal sheets.
- Insufficient heat may prevent solder from melting and flowing properly.
- Overheating may burn the flux before it performs its function.
- Correct heating produces good solder flow and bonding.
- Sensitive electrical components may be damaged by prolonged heating.

**Note:** The soldering temperature should be appropriate for the solder alloy, flux and parent metals being used.

**3.0 Tools and Equipment Used in Soft Soldering**

Different tools and equipment are used to prepare, heat, join and inspect metal components during soft soldering.

**3.1 Soldering Iron**




**Definition:** A soldering iron is a hand-held heating tool used to transfer heat to metal surfaces during soldering.

**Main parts:**

- Handle – provides a safe grip.
- Heating element – produces heat.
- Metal barrel – transfers heat towards the tip.
- Soldering tip – contacts the workpiece and transfers heat.
- Electrical cable – supplies electrical power.
- Stand – supports the hot soldering iron when not in use.

**Uses:**

- Heating small metal joints.
- Joining electrical wires.
- Soldering electronic components.
- Joining small sheet-metal components.

**Care and maintenance:**

- Clean the tip regularly.
- Keep the tip properly tinned.
- Place the iron on its stand when not in use.
- Avoid dropping it.
- Inspect the electrical cable for damage.
- Switch off and unplug after use.
- Allow it to cool before storage.

**3.2 Soldering Gun**




A soldering gun is an electrically powered heating tool that produces heat at its tip when activated.

**Uses:**

- Joining electrical connections.
- Soldering relatively larger connections.
- Carrying out repair work.
- Joining metal components requiring concentrated heat.

**Maintenance:**

- Inspect the power cable.
- Check the heating tip.
- Keep the tool clean.
- Store it in a dry place.
- Disconnect it after use.

**3.3 Blow Lamp or Gas Torch**




A blow lamp or gas torch is a heat-producing device used to heat larger metal surfaces during soldering.

**Uses:**

- Heating larger sheet-metal joints.
- Soldering metal containers.
- Joining certain metal pipes and fittings.
- Carrying out workshop repair tasks.

**Precautions:**

- Keep away from flammable materials.
- Check for gas leaks.
- Use in a well-ventilated area.
- Never direct the flame towards people.
- Shut off the gas supply after use.

### 3.4 Soldering Iron Stand



**Uses:**

- Holds the hot soldering iron safely.
- Prevents accidental burns.
- Protects the workbench from heat damage.
- Keeps the working area organised.

### 3.5 Wire Brush



**Uses:**

- Removes loose rust.
- Removes dirt and surface oxides.
- Cleans metal surfaces before soldering.
- Cleans certain soldering tips where the manufacturer's instructions permit.

### 3.6 Files




**Uses:**

- Smoothens rough metal edges.
- Removes burrs.
- Prepares surfaces for close fitting.
- Removes excess solder where appropriate.

### 3.7 Pliers



**Uses:**

- Holding small components.
- Bending metal parts.
- Positioning wires.
- Supporting workpieces during joining.

### 3.8 Clamps and Bench Vice



**Uses:**

- Holding workpieces firmly.
- Preventing movement during soldering.
- Maintaining correct joint alignment.
- Improving accuracy and safety.

**3.9 Snips and Scissors**



**Uses:**

- Cutting thin sheet metal.
- Trimming metal components.
- Preparing metal pieces to the required dimensions.

**3.10 Other Equipment**

Other equipment used includes:

- Heat-resistant working surface.
- Protective goggles.
- Heat-resistant gloves where appropriate.
- Fume extraction equipment.
- Cleaning sponges.
- Measuring tools.
- Scrapers.
- Heat-resistant tweezers.
- Fire extinguisher suitable for the workshop hazards.

**4.0 Materials Used in Soft Soldering**

**4.1 Solder**

**Definition:** Solder is a fusible metal alloy that melts at a relatively low temperature and is used to join metal surfaces.

Solder acts as the filler metal in the joint.

**Types of solder**

1. **Tin-lead solder**

- Contains tin and lead.
- Has been used traditionally in electrical and metalwork applications.
- Requires strict precautions because lead is toxic.
- Should not be used for drinking-water systems or food-contact products.

2. **Lead-free solder**

- Contains tin combined with other metals such as copper or silver.
- Is widely used in modern electrical and electronic work.
- Avoids the use of lead.
- Requires a suitable soldering temperature and compatible flux.

3. **Tin-based solder**

- Uses tin as the main constituent.
- May contain other metals to improve its properties.
- Is available in different compositions for different applications.

**Forms of solder**




Solder wire



solder bars




solder paste

- Solder wire.
- Solder sticks.
- Solder bars.
- Solder paste.

**Properties of a good solder**

- Should have a suitable melting temperature.
- Should flow easily when molten.
- Should wet the parent metals properly.
- Should form a sound joint.
- Should be compatible with the metals being joined.
- Should provide adequate strength for the intended application.

**4.2 Flux**

**Definition:** Flux is a chemical substance applied to metal surfaces during soldering to remove or prevent oxide films and improve the flow of molten solder.

**Functions of flux**

1. Removes or chemically disrupts oxide films.
2. Prevents further oxidation during heating.
3. Improves wetting of the parent metal.
4. Helps solder flow into the joint.
5. Improves the quality and appearance of the joint.
6. Reduces the possibility of poor bonding caused by surface contamination.

**Types of flux**

**a) Rosin-based flux**

- Commonly used in electrical and electronic soldering.
- Is suitable for many copper electrical connections.
- Some formulations leave residues that may require cleaning.

**b) Water-soluble flux**

- Uses water-based cleaning systems.
- Is effective in removing certain oxides.
- Residues must be cleaned according to the manufacturer's instructions.

**c) Inorganic or acid-based flux**

- Used for certain sheet-metal and plumbing applications.
- Can be highly corrosive.
- Must not be used for sensitive electronic work unless specifically approved.
- Residues must be removed thoroughly.










**Qualities of a good flux**

- Should be suitable for the parent metals.
- Should remove or prevent surface oxidation.

- Should remain effective at the soldering temperature.
- Should allow solder to spread easily.
- Should not cause unacceptable corrosion.
- Should be compatible with the solder being used.

**4.3 Difference Between Solder and Flux**

| **Solder** | **Flux** |
|---|---|
| Acts as filler metal | Acts as a chemical cleaning and protective agent |
| Melts during soldering | Usually does not act as the filler metal |
| Forms the joint after solidification | Helps solder wet and flow over the metal |
| Contributes to joint strength | Improves the quality of the joint |

**Remember:** Solder joins the metals, while flux prepares and protects the surfaces to enable proper joining.

**5.0 Preparation of Workpieces Before Soft Soldering**

Proper preparation is essential for producing strong, neat and reliable soldered joints.

**5.1 Cleaning the Metal Surfaces**

The surfaces must be clean before soldering.

**Methods of cleaning include:**

1. **Filing**
   - Removes rough edges and burrs.
   - Produces smooth surfaces.
   - Helps components fit together correctly.
2. **Wire brushing**
   - Removes loose rust and surface dirt.
   - Helps expose clean metal surfaces.
3. **Scraping**
   - Removes paint, oxide layers and unwanted coatings where appropriate.
4. **Abrasive cleaning**
   - Uses abrasive paper or other suitable materials to remove surface contamination.
5. **Degreasing**
   - Removes oil and grease using an appropriate cleaning agent.
   - Prevents contamination that could interfere with solder wetting.

**5.2 Measuring and Cutting**

Before joining:

- Measure the metal pieces accurately.

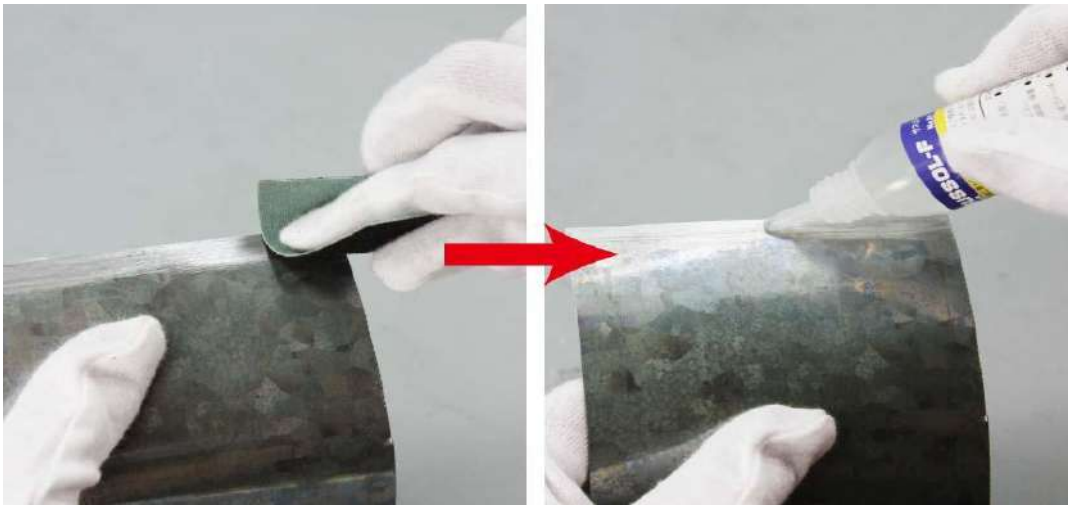
- Mark the required dimensions.
- Cut the materials using appropriate tools.
- Remove sharp edges.
- Check the dimensions against the working drawing.

**5.3 Fitting and Positioning**

- Position the components correctly.
- Ensure the joint surfaces fit closely.
- Avoid unnecessary gaps.
- Use clamps or a vice to hold the work.
- Check alignment before heating.

**5.4 Application of Flux**

- Select the correct flux for the metal and solder.
- Apply a thin, even layer to the joint surfaces.
- Avoid excessive application.
- Follow the manufacturer's safety and cleaning instructions.

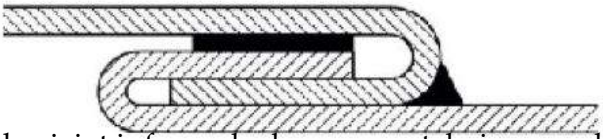


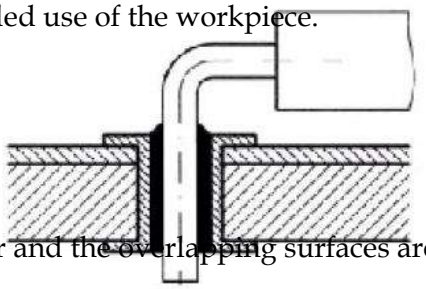
**6.0 Types of Joints Used in Soft Soldering**

A joint is the point at which two or more metal components are connected.

Different joints are selected according to the shape, thickness and intended use of the workpiece.

**6.1 Lap Joint**





**Definition:** A lap joint is formed when one metal piece overlaps another and the overlapping surfaces are soldered together.

**Characteristics:**

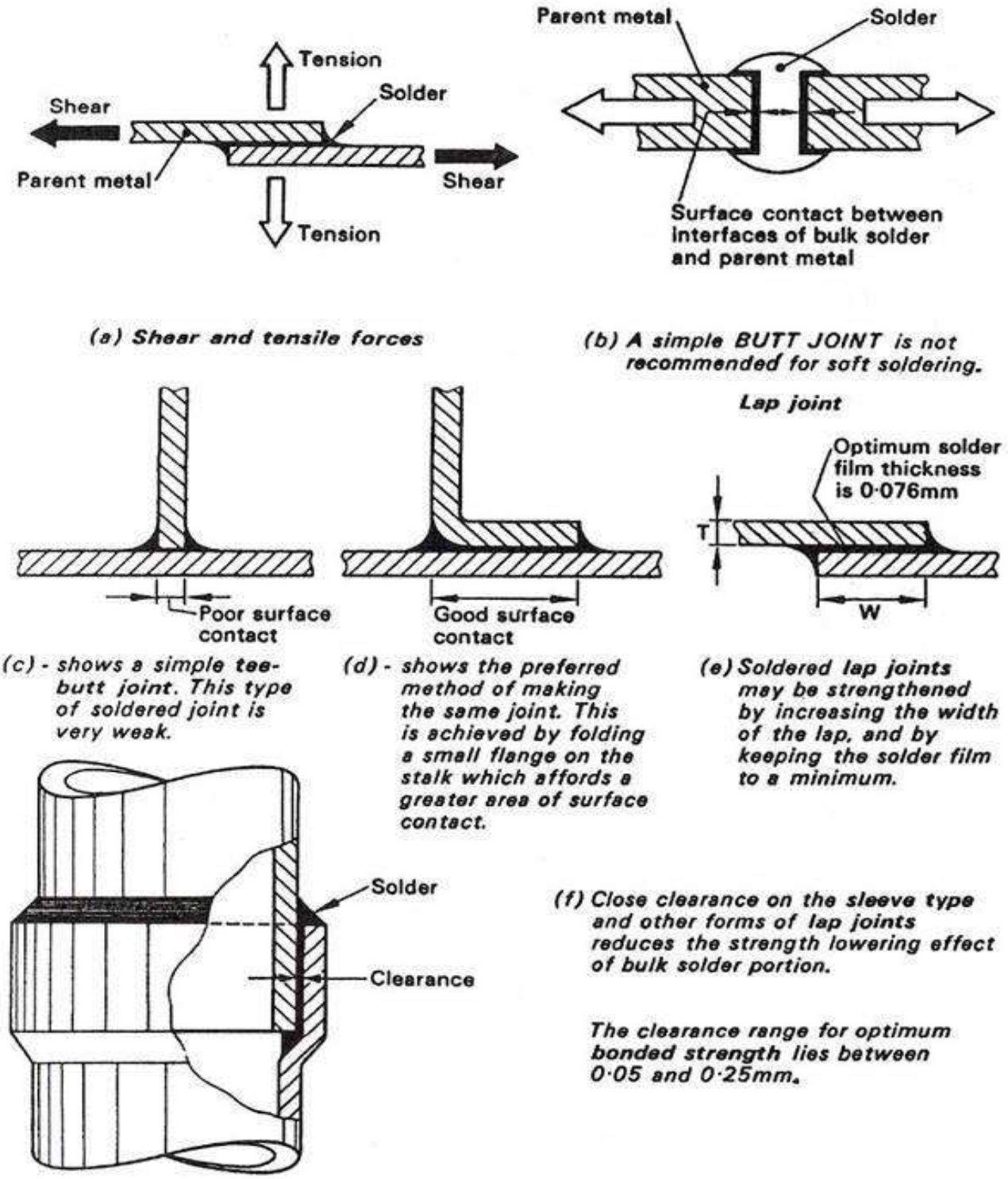
- The components overlap each other.
- Provides a relatively large bonding area.
- Is suitable for thin sheet metals.

- Can be used for joining electrical metal strips.

**Applications:**

- Joining thin metal sheets.
- Repairing metal containers.
- Joining sheet-metal components.
- Making small metal boxes.

**6.2 Butt Joint**




**Definition:** A butt joint is formed when two metal pieces are placed edge to edge and joined using solder.

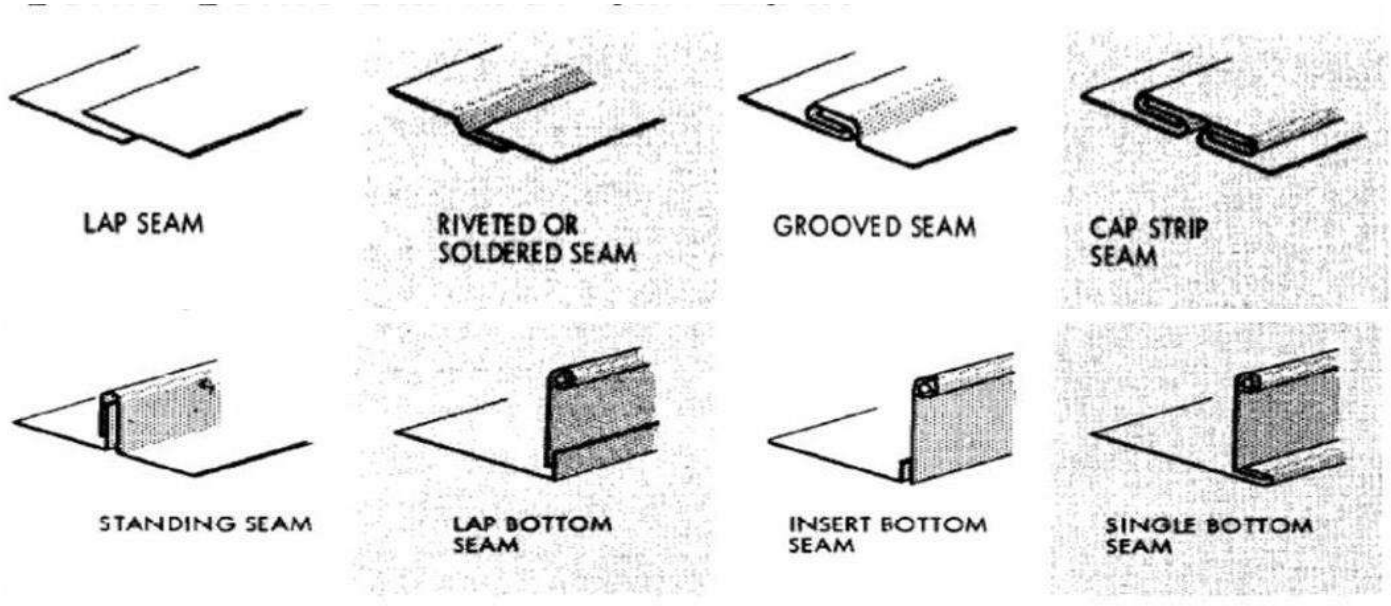
**Characteristics:**

- The edges meet in the same plane.
- Requires accurate alignment.
- Has a relatively small bonding area.
- May require backing or reinforcement depending on the application.

**Applications:**

- Joining thin sheet-metal edges.
- Repairing metal panels.
- Joining certain light metal components.

**6.3 Seam Joint**




**Definition:** A seam joint is formed when the edges of metal sheets are folded, overlapped or interlocked and then joined using solder.

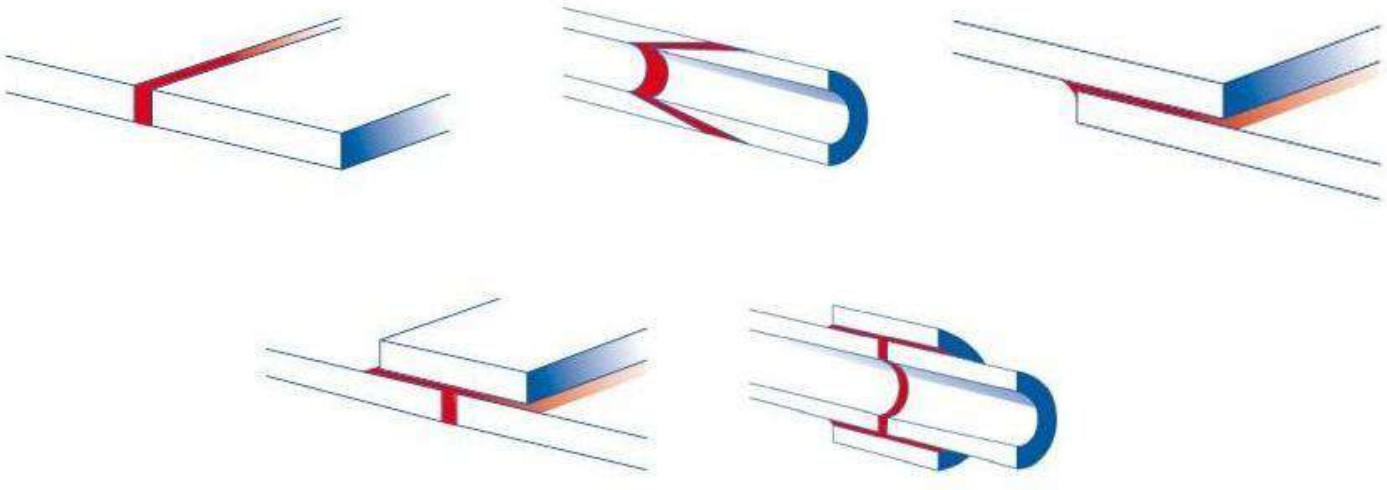
**Characteristics:**

- Often produces a continuous joint.
- Can improve resistance to leakage.
- Requires careful preparation.
- Is suitable for light sheet-metal products.

**Applications:**

- Making metal containers.
- Joining metal trays.
- Manufacturing certain light metal enclosures.
- Repairing sheet-metal products.

### 6.4 Edge Joint



**Definition:** An edge joint is formed when the edges of two metal sheets are brought together and joined by solder.

**Characteristics:**

- The edges are positioned close together.
- It is suitable for certain thin-sheet applications.
- Requires proper alignment and surface preparation.

**Applications:**

- Joining thin sheet-metal components.
- Making light covers and panels.
- Fabricating small metal products.

### 6.5 Comparison of Soldered Joints

| Joint | Arrangement | Common application |
|---|---|---|
| Lap joint | One piece overlaps another | Sheet-metal repairs |
| Butt joint | Edges meet end to end | Thin metal panels |
| Seam joint | Folded or interlocked edges | Metal containers |
| Edge joint | Edges placed together | Light metal fabrication |

## 7.0 Procedure for Performing Soft Soldering

The procedure should be followed systematically to achieve a sound joint.

### 7.1 Step-by-Step Procedure

**Step 1: Study the task**

- Read the workshop instructions.
- Examine the working drawing.
- Identify the materials to be joined.
- Determine the type of joint required.

- Identify the appropriate solder and flux.

**Step 2: Select the tools and equipment**

Collect the required tools, including:

- Soldering iron or suitable heat source.
- Solder wire.
- Suitable flux.
- Wire brush.
- Files.
- Pliers.
- Clamps.
- Cleaning materials.
- Protective equipment.

**Step 3: Observe safety precautions**

- Wear protective goggles.
- Ensure adequate ventilation.
- Remove flammable materials.
- Check electrical equipment.
- Position the soldering iron stand correctly.
- Keep the work area clean and dry.

**Step 4: Measure and mark the materials**

- Measure the required dimensions.
- Mark the cutting lines.
- Check the measurements before cutting.

**Step 5: Cut and prepare the workpieces**

- Cut the metal pieces using suitable tools.
- Remove sharp edges.
- File the surfaces.
- Clean the joint areas.
- Remove grease, dirt and oxide films.

**Step 6: Fit the joint**

- Position the components according to the required joint.
- Ensure proper alignment.
- Hold the pieces using clamps or other suitable holding devices.
- Check that the joint gap is appropriate.

**Step 7: Apply flux**

- Apply a suitable flux to the joining surfaces.
- Spread it evenly.
- Avoid contamination after cleaning.

**Step 8: Heat the joint**

- Heat the soldering iron to the recommended operating temperature.
- Place the heated tip against the joint area.
- Allow sufficient heat to transfer to the workpiece.

**Step 9: Apply solder**

- Bring the solder into contact with the heated joint.
- Allow the solder to melt through the heat transferred from the workpiece.
- Guide it along the joint.
- Ensure proper wetting and flow.
- Avoid applying excessive solder.

**Step 10: Remove the heat source**

- Remove the soldering iron after sufficient solder has flowed.
- Avoid unnecessary movement of the components.

**Step 11: Allow the joint to cool**

- Allow the solder to solidify naturally.
- Do not disturb the joint during solidification.
- Avoid rapid cooling unless specifically required by the process.

**Step 12: Clean and inspect**

- Remove flux residues according to the manufacturer's instructions.
- Examine the soldered joint.
- Check for gaps, cracks, incomplete bonding and excessive solder.
- Correct defects where necessary.

**Step 13: Complete the task**

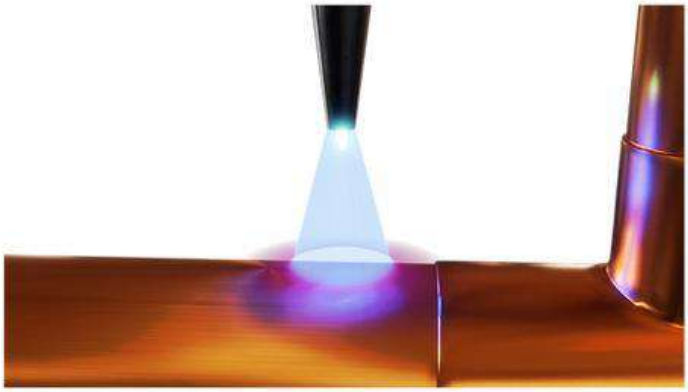
- Clean the workpiece.
- Clean and store tools.
- Switch off and disconnect electrical equipment.
- Leave the workshop clean and orderly.
- Present the completed work for assessment.



1. Cleaning



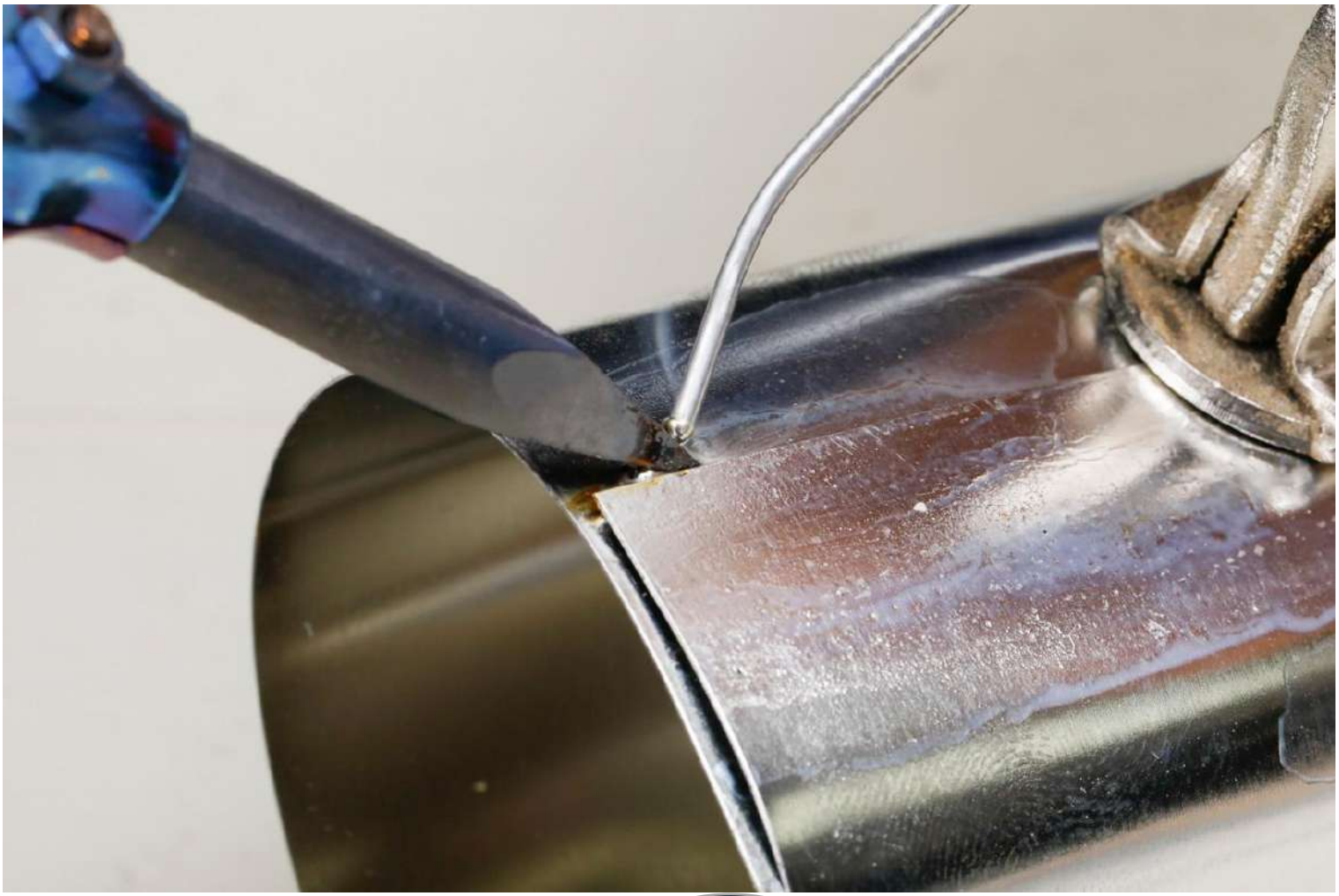
2. Fluxing

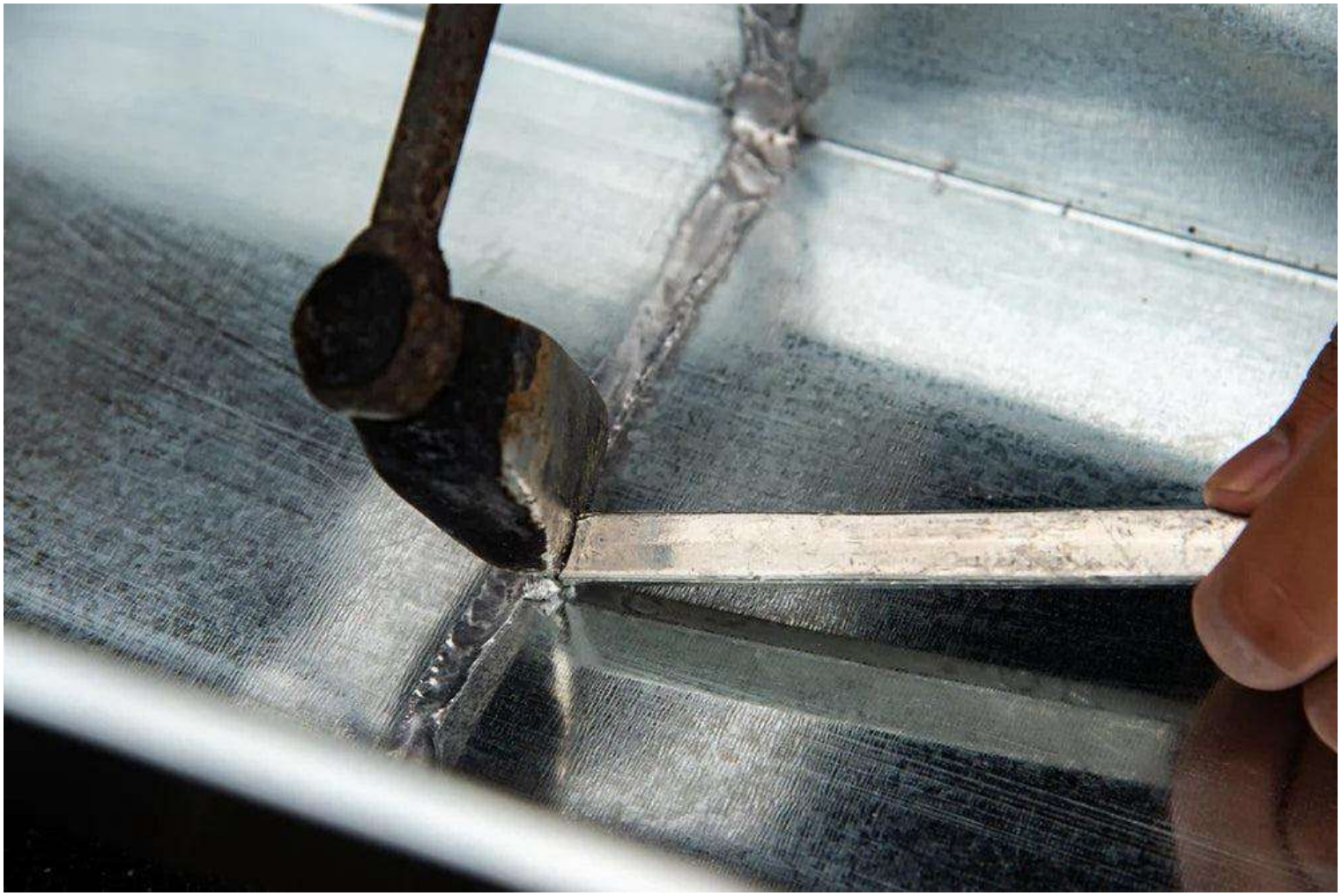


3. Heating



4. Applying Filler Metal





**7.2 Qualities of a Good Soldered Joint**

A good soldered joint should have the following characteristics:

1. **Good wetting:** Solder spreads properly over the metal surfaces.
2. **Uniform appearance:** The solder forms a reasonably even joint.
3. **Proper bonding:** Solder adheres to both parent metal surfaces.
4. **No cracks:** The joint should not have visible cracks.
5. **No excessive solder:** The solder should be sufficient but not excessive.
6. **No major gaps:** The joint should be properly filled.
7. **Clean finish:** The workpiece should be free from unwanted flux residues.
8. **Correct alignment:** The joined components should maintain their intended positions.

**8.0 Safety Precautions During Soft Soldering**

Soft soldering involves heat, electrical equipment, chemicals and potentially harmful fumes. Therefore, safety must be observed throughout the operation.

**8.1 Personal Protective Equipment (PPE)**



The following protective equipment should be used:

1. **Safety goggles**
   - Protect the eyes from solder splashes and flying particles.
2. **Workshop apron**
   - Protects clothing and the body from dirt and accidental splashes.
3. **Safety shoes**
   - Protect the feet from falling tools and sharp metal pieces.
4. **Suitable protective gloves**
   - Protect hands when handling sharp or hot materials.
   - Gloves should not be worn where they could become entangled in machinery or interfere with safe handling.
5. **Respiratory protection**
   - Use suitable respiratory protection where required by a risk assessment.
   - Effective local fume extraction is particularly important.

**8.2 General Safety Rules**

- Never touch a hot soldering iron tip.
- Always place the soldering iron on its stand.
- Do not leave a heated tool unattended.

- Work in a well-ventilated area.
- Use local fume extraction to remove soldering fumes.
- Avoid inhaling fumes from heated flux.
- Wash hands after handling solder and flux.
- Never eat or drink in the metalwork workshop.
- Keep electrical cables away from hot surfaces.
- Do not use damaged electrical equipment.
- Keep water away from electrical connections.
- Handle hot workpieces using suitable tools.
- Keep flammable materials away from the heat source.
- Keep a suitable fire extinguisher accessible.
- Follow the manufacturer's instructions for all materials.

**8.3 Environmental Safety**

- Avoid releasing harmful chemicals into drains.
- Collect solder waste separately.
- Dispose of lead-containing solder as hazardous waste according to applicable requirements.
- Avoid unnecessary wastage of solder and flux.
- Reuse suitable offcuts where possible.
- Keep the workshop free from chemical contamination.

**8.4 First Aid During Soft Soldering**

**In case of burns:**

- Stop the operation.
- Cool the affected area under cool running water for 20 minutes.
- Do not apply ice, oils or toothpaste.
- Do not burst blisters.
- Cover the burn loosely with a sterile non-fluffy dressing.
- Seek medical attention for serious burns.

**In case of eye contact with flux:**

- Rinse immediately with clean running water.
- Follow the product safety instructions.
- Seek medical attention.

**In case of electric shock:**

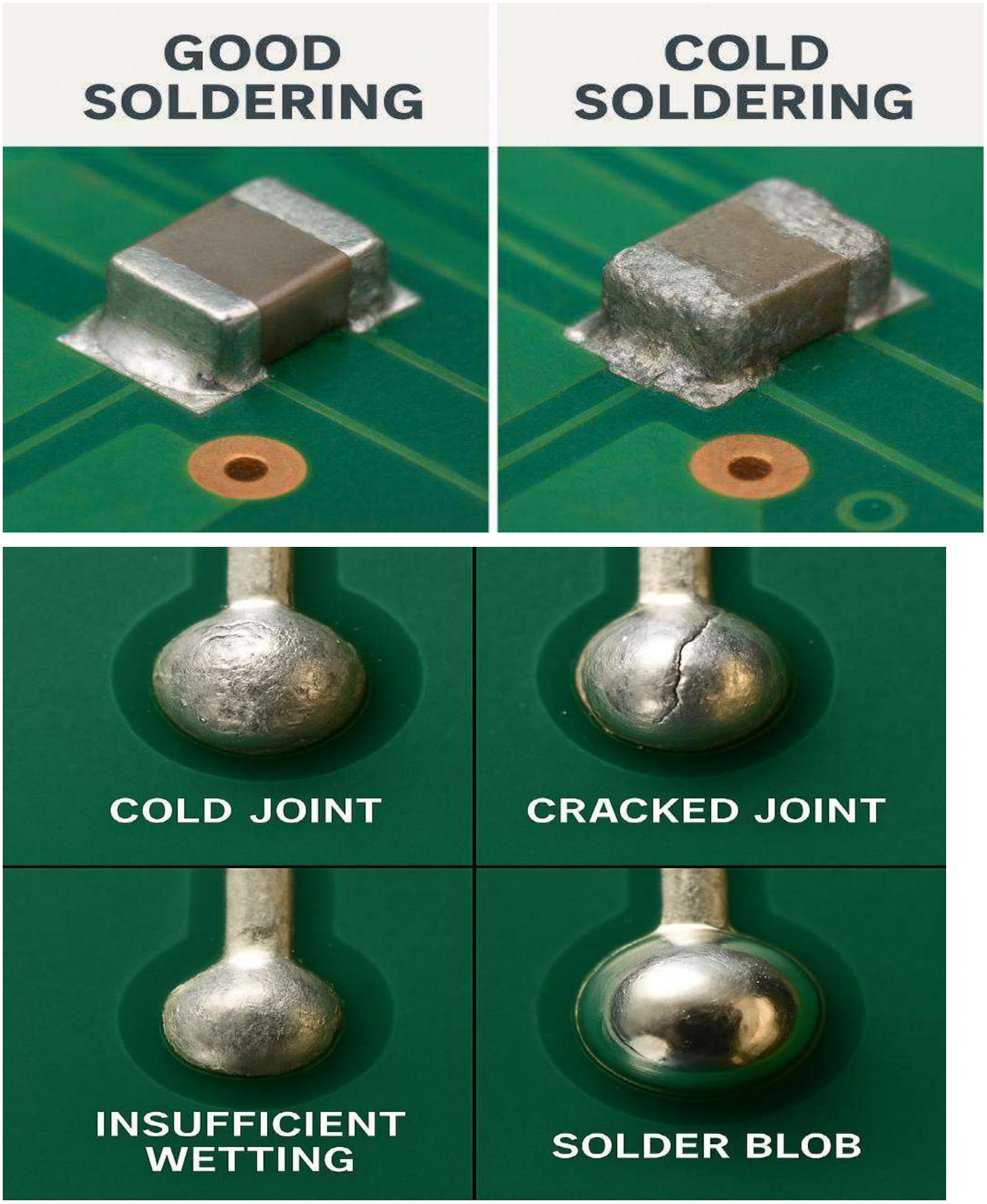
- Do not touch the victim while they remain in contact with the electrical source.
- Switch off the power if safe to do so.
- Seek emergency assistance.

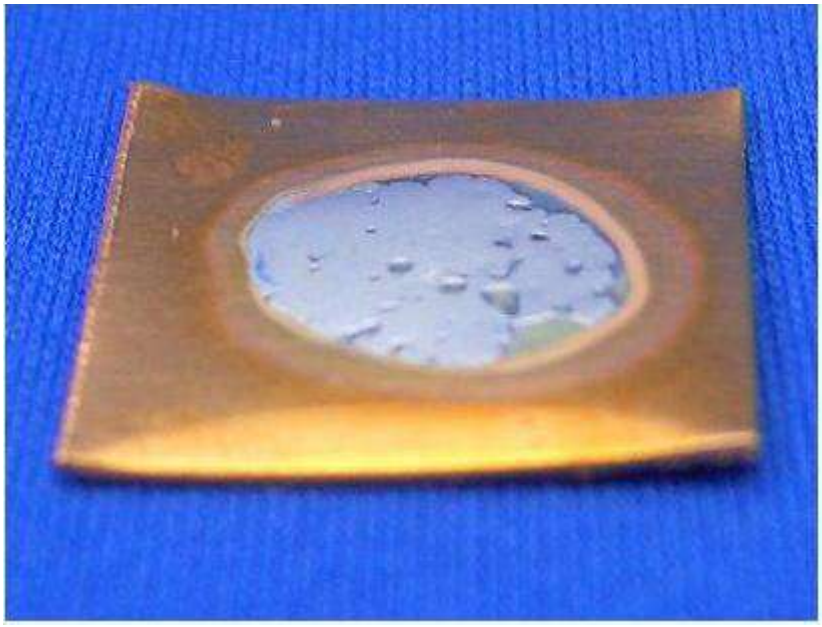
- Begin appropriate first aid and CPR if trained and required.

**9.0 Common Defects in Soft Soldering**

Defects are faults that reduce the appearance, quality or performance of a soldered joint.

**9.1 Common Defects and Their Causes**





**1. Cold solder joint**

A cold solder joint occurs when the solder has not been heated sufficiently to flow and bond properly.

Causes:

- Insufficient heating.
- Movement during solidification.
- Poor heat transfer.

Prevention:

- Heat the joint adequately.
- Ensure correct contact between the soldering tip and workpiece.
- Avoid disturbing the joint during cooling.

**2. Poor wetting**

This occurs when solder does not spread properly over the parent metal.

Causes:

- Dirty surfaces.
- Oxidised metal.
- Incorrect flux.
- Insufficient heat.

Prevention:

- Clean the surfaces thoroughly.
- Use suitable flux.
- Apply the correct amount of heat.

**3. Excessive solder**

This occurs when too much solder is applied to the joint.

Causes:

- Poor control of solder application.
- Excessive solder feeding.
- Incorrect joint preparation.

Prevention:

- Apply solder gradually.
- Use only the required amount.
- Inspect the joint during soldering.

**4. Insufficient solder**

This occurs when too little solder is applied to form an adequate joint.

Causes:

- Insufficient solder supply.
- Poor solder flow.
- Inadequate joint preparation.

Prevention:

- Apply enough solder to fill the joint.
- Ensure proper wetting.
- Check the joint before cooling.

**5. Cracked joint**

A cracked joint contains visible breaks in the solder.

Causes:

- Movement during cooling.
- Mechanical stress.
- Poor joint design.
- Excessive vibration.

Prevention:

- Secure the components.
- Allow natural cooling.
- Avoid loading the joint beyond its intended capacity.

**6. Pinholes and voids**

These are small holes or empty spaces in the soldered joint.

Causes:

- Contaminated surfaces.
- Trapped air or gases.
- Poor solder flow.
- Excessive or unsuitable flux.

Prevention:

- Clean the surfaces.
- Apply flux correctly.
- Ensure proper solder flow.

**7. Corrosion**

Corrosion is the deterioration of the joint due to chemical reactions.

Causes:

- Leaving corrosive flux residues.
- Exposure to moisture.
- Using incompatible materials.

Prevention:

- Use compatible materials.
- Clean residues according to instructions.
- Store finished products in suitable conditions.

**9.2 Inspection of Soldered Joints**

Inspection is carried out to establish whether the joint meets the required standards.

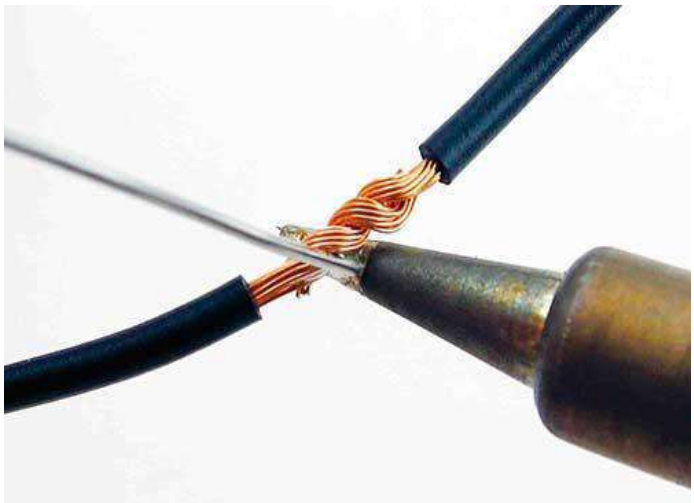
Methods include:

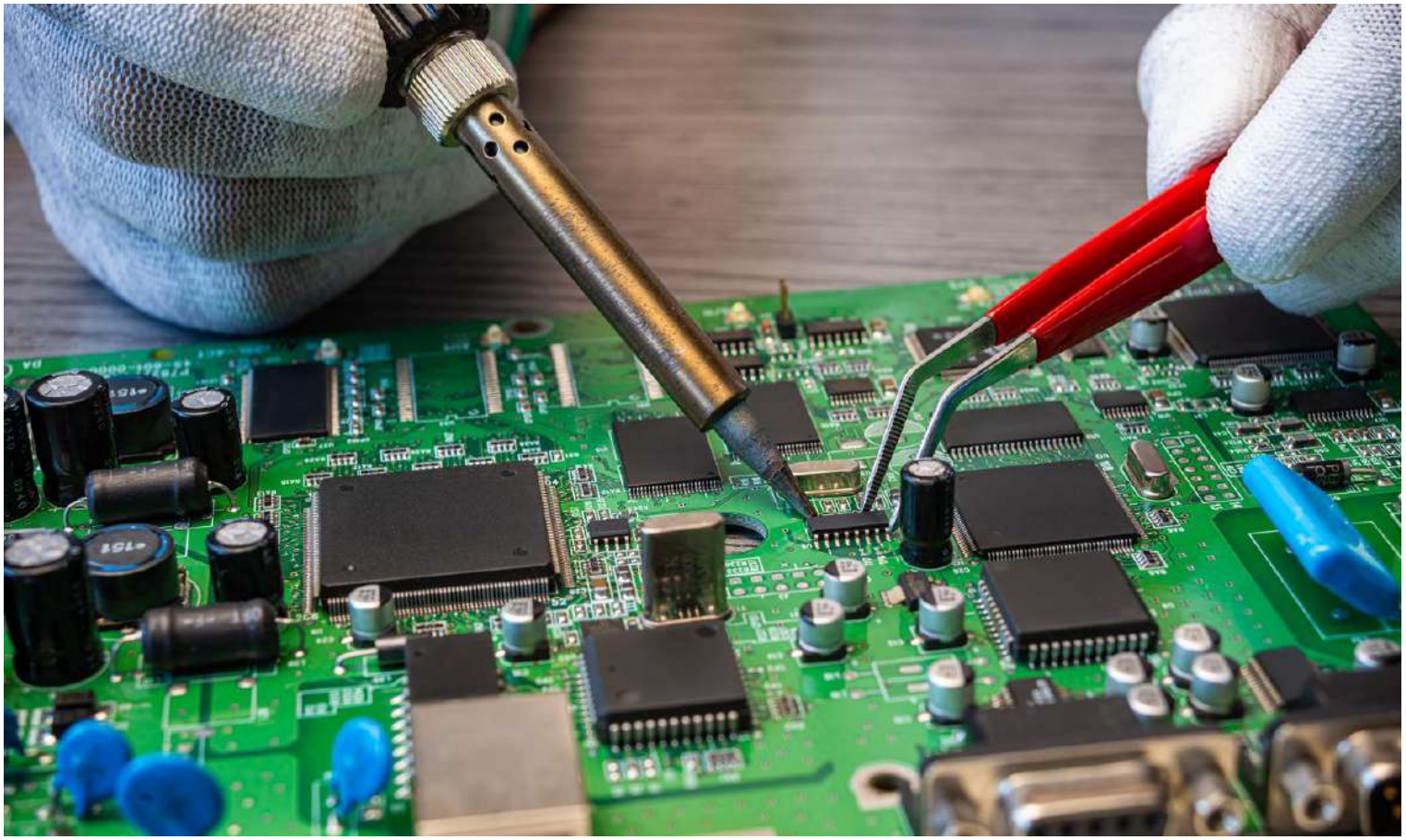
- **Visual inspection:** Checking the appearance of the soldered joint.
- **Dimensional inspection:** Checking the dimensions and alignment.
- **Mechanical inspection:** Checking the joint's performance using an appropriate safe test.
- **Leak testing:** Used for suitable sealed joints where applicable.
- **Electrical testing:** Checking continuity and absence of unintended short circuits in electrical connections.

**Important:** A visually attractive joint is not automatically a reliable joint. The inspection method must be appropriate to the intended use.

**10.0 Applications of Soft Soldering in Day-to-Day Life**

Soft soldering is widely used in homes, schools, industries and repair workshops.







**10.1 Electrical and Electronic Work**

- Joining electrical wires.

- Connecting electronic components to printed circuit boards.
- Repairing radio and television circuits.
- Joining terminals in suitable electrical devices.
- Repairing certain low-voltage electronic equipment.

**10.2 Sheet-Metal Fabrication**

- Making light metal containers.
- Joining thin metal sheets.
- Repairing certain metal trays.
- Making light metal enclosures.
- Joining decorative metal components.

**10.3 Plumbing Applications**

- Joining compatible copper pipes and fittings in suitable non-potable water applications.
- Repairing certain copper pipe connections.
- Making selected low-pressure pipe joints.

**Note:** Drinking-water systems require approved lead-free materials and compliance with applicable plumbing standards. Soft soldering is not suitable for every plumbing application.

**10.4 Automotive and Electrical Repairs**

- Repairing suitable vehicle electrical connections.
- Joining certain wiring terminals.
- Repairing electronic control components where the manufacturer permits soldering.
- Repairing certain light electrical connections.

**10.5 Domestic Applications**

- Repairing selected metal household items.
- Joining suitable decorative metal components.
- Repairing certain small metal enclosures.
- Joining certain thin metal parts.

**10.6 Educational and Training Applications**

In Kenyan technical institutions and schools, soft soldering can be used for:

- Metal Technology practical lessons.
- Basic electronics projects.
- Fabrication of simple sheet-metal products.
- Repair and maintenance training.
- Development of learners' practical joining skills.

**11.0 Advantages and Disadvantages of Soft Soldering**

**11.1 Advantages**

1. **Low operating temperature**

- Reduces the risk of melting or severely distorting the parent metals.

2. **Simple equipment**

- Requires relatively simple and affordable tools.

3. **Suitable for delicate components**

- Can join small electrical and electronic components.

4. **Joins dissimilar metals**

- Can join certain different metals when compatible solder and flux are selected.

5. **Good electrical conductivity**

- Produces suitable electrical connections when correctly performed.

6. **Neat joints**

- Can produce clean and attractive joints.

7. **Easy repair**

- Some soldered joints can be reheated and separated.

8. **Low heat damage**

- Helps protect heat-sensitive components when appropriate procedures are used.

**11.2 Disadvantages**

1. **Low joint strength**

- Generally unsuitable for heavily loaded structures.

2. **Limited temperature resistance**

- Soldered joints may weaken when exposed to high temperatures.

3. **Surface preparation required**

- Dirty or oxidised surfaces can cause poor bonding.

4. **Corrosion risk**

- Certain flux residues may cause corrosion if not properly removed.

5. **Limited applications**

- Not suitable for all metals and engineering components.

6. **Health hazards**

- Some solder and flux materials may contain harmful substances.

7. **Careful temperature control**

- Requires proper heating to avoid defects.

**11.3 Comparison of Advantages and Disadvantages**

| Advantages | Disadvantages |
|---|---|
| Simple equipment | Low joint strength |
| Low joining temperature | Limited heat resistance |
| Suitable for delicate parts | Requires clean surfaces |
| Can join compatible dissimilar metals | Some fluxes are corrosive |
| Easy to repair | Not suitable for heavy structures |

**12.0 Maintenance of Soft Soldering Tools and Equipment**

Maintenance refers to the activities carried out to keep tools and equipment in good working condition.

Proper maintenance improves safety, accuracy, durability and efficiency.

**12.1 Maintenance of Soldering Iron**

- Clean the soldering tip regularly.
- Keep the tip properly tinned according to the manufacturer's instructions.
- Replace damaged or worn tips.
- Inspect the heating element.
- Check electrical cables and plugs.
- Keep the handle free from oil and grease.
- Use the correct stand.
- Switch off and unplug after use.
- Store in a dry and secure place.

**12.2 Maintenance of Soldering Gun**

- Inspect the electrical cable.
- Clean the gun after cooling.
- Check the soldering tip for wear.
- Replace damaged components.
- Avoid excessive heating.
- Store in a dry place.

**12.3 Maintenance of Blow Lamp or Gas Torch**

- Check the gas hose for damage.
- Inspect connections for leaks using an approved leak-testing method.
- Keep the nozzle clean.
- Check the valve.
- Store fuel containers safely.
- Close the fuel supply after use.
- Keep away from heat and direct sunlight where required by the manufacturer's instructions.

**12.4 Maintenance of Hand Tools**

| Tool | Maintenance practice |
|---|---|
| Files | Clean teeth using a file card and store dry |
| Wire brushes | Remove accumulated dirt and replace worn brushes |
| Pliers | Clean, lubricate moving joints and inspect handles |
| Snips | Clean, sharpen or service according to the manufacturer's instructions |
| Clamps | Clean threads and lubricate where necessary |
| Bench vice | Clean, lubricate the screw and inspect jaws |
| Soldering iron stand | Clean and check stability |

**12.5 Importance of Tool Maintenance**

- Extends the working life of equipment.
- Reduces accidents.
- Improves quality of soldered joints.
- Reduces repair and replacement costs.
- Promotes efficient workshop operations.
- Maintains accuracy.
- Reduces wastage of materials.

**13.0 Environmental Conservation During Soft Soldering**

Environmental conservation involves using materials and equipment responsibly to reduce pollution and wastage.

**13.1 Environmental Practices**

1. Use solder economically.
2. Avoid unnecessary release of flux chemicals.
3. Collect solder offcuts for appropriate recovery or disposal.
4. Separate lead-containing waste from ordinary workshop waste.
5. Use local fume extraction systems.
6. Dispose of chemicals according to their safety data sheets.
7. Avoid pouring flux or chemical cleaning agents into drains.
8. Switch off electrical equipment when not in use.
9. Reuse suitable metal offcuts.
10. Maintain a clean working environment.

**13.2 Sustainable Workshop Practices in Kenya**

In Kenyan technical workshops, learners can promote sustainability by:

- Reusing suitable sheet-metal offcuts for practical exercises.
- Purchasing durable and repairable soldering equipment.
- Using lead-free solder where suitable.
- Separating hazardous waste.
- Minimising unnecessary consumption of electricity.
- Maintaining proper ventilation and waste management.

**14.0 Entrepreneurial Opportunities in Soft Soldering**

Soft soldering provides opportunities for self-employment and income generation.

**14.1 Possible Business Activities**

- Repair of electrical and electronic equipment.
- Manufacture of small sheet-metal products.
- Fabrication of light metal containers.

- Repair of suitable metal household items.
- Electronic component assembly.
- Production of decorative metal products.

**14.2 Skills Required for Successful Entrepreneurship**

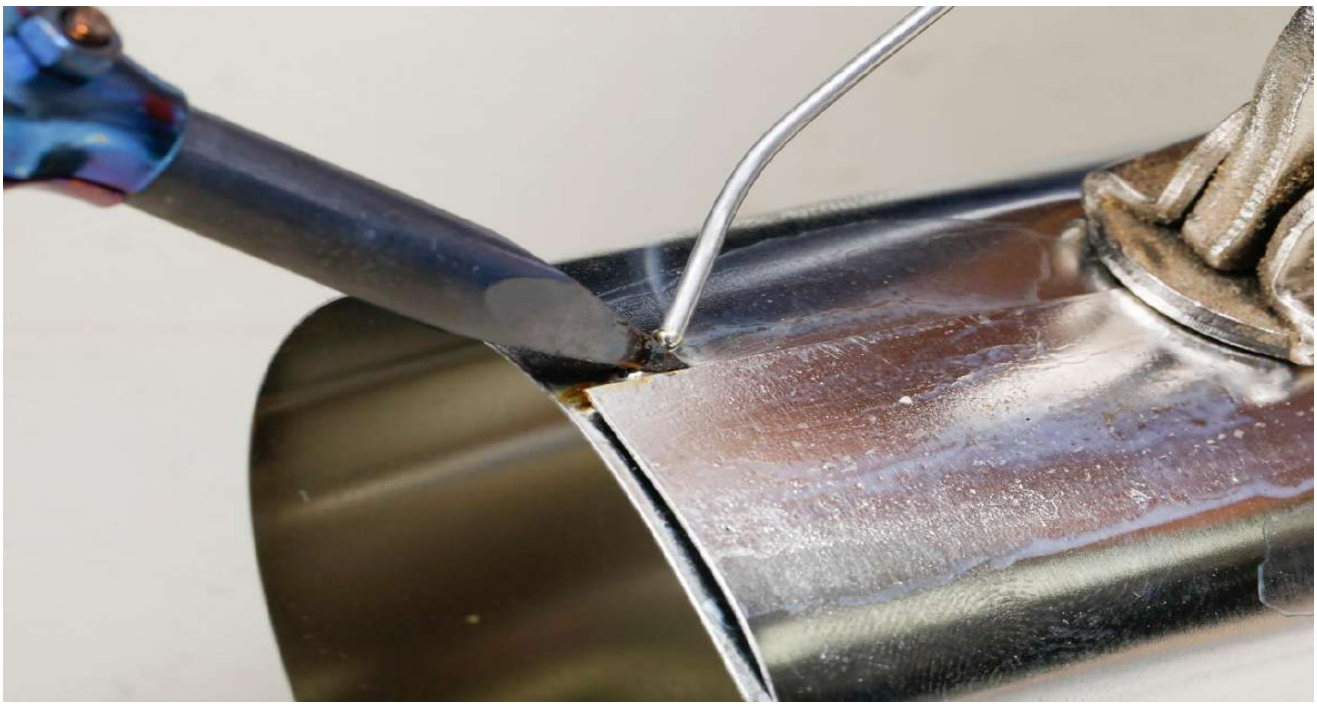
A person intending to establish a soldering business should develop:

- Technical competence.
- Accuracy and attention to detail.
- Communication skills.
- Customer-care skills.
- Financial management skills.
- Record-keeping skills.
- Problem-solving skills.
- Safety awareness.

**14.3 Importance of Soft Soldering in Kenya's Economy**

- Promotes small-scale manufacturing.
- Supports electrical and electronic repair industries.
- Creates employment opportunities.
- Encourages innovation.
- Promotes technical and vocational skills.
- Reduces the cost of replacing repairable products.
- Supports the development of local enterprises.

**15.0 Practical Activity: Joining Two Thin Metal Sheets Using a Lap Joint**



**Activity:** Prepare and soft-solder two suitable thin metal sheets using a lap joint.

**Materials required:**

- Two thin, solderable metal sheets.
- Suitable solder.
- Compatible flux.
- Abrasive paper.
- Cleaning material.

**Tools and equipment:**

- Soldering iron.
- Soldering iron stand.
- Wire brush.
- Flat file.
- Pliers.
- Clamps.
- Measuring rule.
- Marking tools.
- Protective equipment.

**Procedure:**

1. Collect all required materials and tools.
2. Wear the appropriate protective equipment.
3. Measure and mark the metal sheets.
4. Cut the sheets to the required dimensions.
5. Remove burrs and sharp edges.
6. Clean the joining surfaces.
7. Overlap the two sheets by the specified amount.
8. Secure the sheets using suitable clamps.
9. Apply the appropriate flux.
10. Heat the joint using the soldering iron.
11. Apply solder gradually.
12. Allow the solder to flow along the joint.
13. Remove the heat source.
14. Allow the joint to cool without disturbance.
15. Clean flux residues as required.
16. Inspect the completed joint.
17. Correct any identified defects.
18. Clean and store the tools.

19. Display the completed workpiece for peer assessment.

**Expected outcome:**

The learner should produce a neat, properly aligned lap joint with good solder wetting and no visible major defects.

**15.1 Assessment Checklist**

| Assessment area | Expected performance |
|---|---|
| Preparation | Materials and tools selected correctly |
| Safety | Appropriate safety procedures observed |
| Measurement | Workpieces measured accurately |
| Cleaning | Joining surfaces cleaned properly |
| Joint preparation | Correct overlap achieved |
| Flux application | Suitable flux applied correctly |
| Heating | Appropriate heat applied |
| Solder application | Solder flows properly |
| Cooling | Joint allowed to solidify undisturbed |
| Inspection | Defects identified |
| Maintenance | Tools cleaned and stored properly |

**SOFT SOLDERING**

**TOPICAL REVISION QUESTIONS AND MARKING SCHEME**

TOTAL: 80 MARKS

- Section A: Multiple-Choice Questions – 30 Marks
- Section B: Structured Questions – 50 Marks

**PART I: REVISION QUESTIONS**

**SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)**

Instructions: Answer all questions. Choose the correct answer from the four alternatives A, B, C and D.

1. What is soft soldering?

A. A process of joining metals by melting the parent metals.
B. A thermal joining process that uses a low-melting-point filler metal.
C. A process of joining metals using mechanical fasteners.
D. A process of shaping metals using heat.

2. Which material acts as the filler metal during soft soldering?

A. Flux
B. Abrasive paper
C. Solder
D. Carbon

3. What is the main function of flux during soft soldering?

A. To increase the thickness of the parent metals.
B. To remove or prevent oxide films and improve solder wetting.
C. To cool the soldered joint.
D. To harden the parent metals.

4. Which tool is primarily used to transfer heat to a soldered joint?

A. Bench vice
B. Flat file
C. Soldering iron
D. Hacksaw

5. Which statement correctly describes soft soldering?

A. The parent metals must melt completely.
B. The parent metals remain solid during joining.
C. The process requires no heat.
D. It is only suitable for thick steel plates.

6. Which of the following is commonly used as soldering material?

A. Tin-based alloy
B. Cast iron
C. Cement
D. Aluminium oxide

7. Which type of flux is commonly used in electrical and electronic soldering?

A. Cement flux
B. Rosin-based flux
C. Sand flux
D. Water paint

8. What is the main function of a soldering iron stand?

A. To sharpen the soldering iron.
B. To support the hot soldering iron safely.
C. To measure solder temperature.
D. To hold parent metals permanently.

9. Which type of joint is formed when one metal sheet overlaps another?

A. Butt joint
B. Edge joint
C. Lap joint
D. Corner joint

10. Which joint involves joining two metal pieces edge to edge in the same plane?

A. Lap joint
B. Butt joint
C. Seam joint
D. Folded joint

11. What should be done before applying flux to a metal surface?

A. Paint the surface.
B. Cool the surface using water.
C. Clean the joining surfaces.
D. Apply oil to the surface.

12. Which of the following is a characteristic of a good soldered joint?

A. It contains visible cracks.
B. It has excessive solder.
C. It has good wetting and bonding.
D. It has large unfilled gaps.

13. What is a major cause of a cold solder joint?

A. Excessive cleaning.
B. Insufficient heating during soldering.
C. Correct application of flux.
D. Proper joint alignment.

14. Which equipment is suitable for holding a small workpiece during soldering?

A. Clamp
B. Hacksaw
C. Scriber
D. Steel rule

15. Why should soldering surfaces be cleaned before joining?

A. To increase the weight of the workpiece.
B. To improve solder wetting and bonding.
C. To change the colour of the metal.
D. To increase the thickness of the solder.

16. Which of the following is an application of soft soldering?

A. Construction of heavy railway bridges.
B. Joining electronic components.
C. Forging large steel shafts.
D. Manufacturing reinforced concrete beams.

17. Which safety equipment protects the eyes during soft soldering?

A. Safety goggles
B. Safety boots
C. Workshop apron
D. Ear defenders

18. Why is ventilation important during soft soldering?

A. To increase the weight of the solder.
B. To remove harmful fumes from the working area.
C. To cool the parent metals rapidly.
D. To increase the melting point of solder.

19. Which of the following is a disadvantage of soft soldering?

A. It requires no equipment.
B. It produces joints with generally low strength.
C. It cannot join any dissimilar metals.
D. It always melts the parent metals.

20. What should be done immediately after soldering a joint?

A. Disturb the joint.
B. Allow the joint to cool and solidify naturally.
C. Pour water onto the hot solder.
D. Bend the joint while the solder is molten.

21. Which of the following can cause poor solder wetting?

A. Clean metal surfaces.
B. Appropriate flux.
C. Oxidised metal surfaces.
D. Correct heating.

22. What is the main purpose of a wire brush during soft soldering?

A. To measure the thickness of solder.
B. To remove dirt and loose surface oxides.
C. To melt solder.
D. To hold hot workpieces.

23. Which type of solder should be preferred where lead exposure must be avoided?

A. Lead-free solder
B. Lead-based solder
C. Iron filings
D. Carbon powder

24. Which of the following demonstrates environmental conservation during soft soldering?

A. Pouring flux into drainage systems.
B. Burning solder waste in the open.
C. Collecting solder waste for appropriate disposal or recovery.
D. Leaving chemicals on the workshop floor.

25. What is the purpose of a clamp during soldering?

A. To melt solder.
B. To hold workpieces in position.
C. To clean metal surfaces.
D. To remove flux.

26. Which defect occurs when too much solder is applied to a joint?

A. Insufficient solder
B. Excessive solder
C. Correct wetting
D. Proper bonding

27. Which of the following is a suitable method of inspecting a soldered joint?

A. Visual inspection
B. Guessing the joint strength
C. Painting the joint immediately
D. Heating the joint unnecessarily

28. Why should corrosive flux residues be removed after soldering?

A. To increase the weight of the workpiece.
B. To prevent corrosion of the joint.
C. To make the solder melt again.
D. To increase the thickness of the parent metals.

29. Which of the following is an entrepreneurial opportunity associated with soft soldering?

A. Repairing suitable electronic equipment.
B. Mining gemstones.
C. Growing maize.
D. Constructing concrete roads.

30. Which action demonstrates proper maintenance of a soldering iron?

A. Leaving it switched on after work.
B. Storing it while still hot in a toolbox.
C. Cleaning its tip and storing it safely after use.
D. Immersing the hot tip in water.

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

Instructions: Answer all questions. Give clear explanations and relevant examples where necessary.

**QUESTION 1: INTRODUCTION TO SOFT SOLDERING (8 MARKS)**

a) Define the term soft soldering. (2 marks)

b) State four characteristics of soft soldering. (4 marks)

c) State two differences between soft soldering and welding. (2 marks)

**QUESTION 2: TOOLS AND MATERIALS USED IN SOFT SOLDERING (8 MARKS)**

a) Name four tools or equipment used in soft soldering. (2 marks)

b) Explain the function of each of the following materials:

i. Solder. (2 marks)

ii. Flux. (2 marks)

c) State two maintenance practices for a soldering iron. (2 marks)

**QUESTION 3: TYPES OF JOINTS AND JOINT PREPARATION (8 MARKS)**

a) Identify four types of joints that may be used in soft soldering. (4 marks)

b) Explain two procedures followed when preparing metal surfaces before soft soldering. (2 marks)

c) State two reasons why workpieces should be held firmly during soldering. (2 marks)

**QUESTION 4: PROCEDURE FOR SOFT SOLDERING (8 MARKS)**

a) Outline six steps followed when performing soft soldering. (6 marks)

b) State two qualities of a good soldered joint. (2 marks)

**QUESTION 5: SAFETY AND DEFECTS IN SOFT SOLDERING (9 MARKS)**

a) State three safety precautions observed when performing soft soldering. (3 marks)

b) Identify three defects that may occur during soft soldering. (3 marks)

c) Explain three possible causes of poor soldered joints. (3 marks)

**QUESTION 6: APPLICATIONS, MAINTENANCE AND ENVIRONMENTAL CONSERVATION (9 MARKS)**

a) State three applications of soft soldering in day-to-day life. (3 marks)

b) Explain three benefits of maintaining soft soldering tools and equipment. (3 marks)

c) State three environmental conservation practices observed during soft soldering. (3 marks)

**PART II: MARKING SCHEME**

**SECTION A: MULTIPLE-CHOICE ANSWERS (30 MARKS)**

Instructions to the teacher: Award 1 mark for each correct answer. No mark should be awarded for an incorrect answer.

| Question | Answer |
|---|---|
| 1 | B |
| 2 | C |
| 3 | B |
| 4 | C |
| 5 | B |
| 6 | A |
| 7 | B |
| 8 | B |
| 9 | C |
| 10 | B |
| 11 | C |
| 12 | C |
| 13 | B |
| 14 | A |
| 15 | B |
| 16 | B |
| 17 | A |
| 18 | B |
| 19 | B |
| 20 | B |
| 21 | C |
| 22 | B |
| 23 | A |
| 24 | C |
| 25 | B |
| 26 | B |
| 27 | A |
| 28 | B |
| 29 | A |
| 30 | C |

TOTAL: 30 MARKS

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

**QUESTION 1: INTRODUCTION TO SOFT SOLDERING (8 MARKS)**

a) Define the term soft soldering. (2 marks)

Soft soldering is a thermal joining process in which two or more metal pieces are joined using a low-melting-point filler metal called solder without melting the parent metals.

- Joining process involving heat – 1 mark.
- Uses low-melting-point solder while parent metals remain solid – 1 mark.

b) State four characteristics of soft soldering. (4 marks)

Award 1 mark for each correct characteristic.

1. Uses a low-melting-point filler metal.
2. The parent metals remain solid during joining.
3. Requires heat to melt the solder.
4. Uses flux to remove or prevent oxide formation.
5. Produces joints with relatively low mechanical strength.
6. Can join thin metal sheets and electrical components.
7. Can be used to join certain dissimilar metals.

Any four – 4 marks.

c) State two differences between soft soldering and welding. (2 marks)

| **Soft soldering** | **Welding** |
|---|---|
| Parent metals remain solid during joining. | Parent metals are melted or fused during conventional fusion welding. |
| Uses a low-melting-point filler metal. | May use a filler metal or no filler metal. |
| Produces relatively low-strength joints. | Generally produces stronger joints. |

Award 1 mark for each correctly explained difference.

**QUESTION 2: TOOLS AND MATERIALS USED IN SOFT SOLDERING (8 MARKS)**

a) Name four tools or equipment used in soft soldering. (2 marks)

Award ½ mark for each correct answer.

1. Soldering iron.
2. Soldering iron stand.
3. Wire brush.
4. Clamp.
5. Pliers.
6. Tweezers.
7. Wire cutters.
8. Safety goggles.

9. Fume extractor.

Any four – 2 marks.

b) Explain the function of each of the following materials.

i. Solder. (2 marks)

- Acts as the filler metal used to join the parent metals – 1 mark.
- Melts and flows into the joint, forming a bond when it solidifies – 1 mark.

ii. Flux. (2 marks)

- Removes existing oxide films from the metal surfaces – 1 mark.
- Prevents further oxidation and improves the flow and wetting of solder – 1 mark.

c) State two maintenance practices for a soldering iron. (2 marks)

Award 1 mark for each correct answer.

1. Clean the soldering iron tip regularly.
2. Remove excess solder and dirt from the tip.
3. Switch off and unplug the soldering iron after use.
4. Store the soldering iron in a safe, dry place.
5. Replace damaged tips or electrical cables.
6. Check the heating element and electrical connections regularly.

Any two – 2 marks.

**QUESTION 3: TYPES OF JOINTS AND JOINT PREPARATION (8 MARKS)**

a) Identify four types of joints that may be used in soft soldering. (4 marks)

Award 1 mark for each correct answer.

1. Lap joint.
2. Butt joint.
3. Edge joint.
4. Seam joint.
5. Corner joint.

Any four – 4 marks.

b) Explain two procedures followed when preparing metal surfaces before soft soldering. (2 marks)

Award 1 mark for each well-explained procedure.

1. Cleaning: Remove dirt, grease, oil and other contaminants using a suitable cleaning agent.
2. Abrasive cleaning: Use abrasive paper or a wire brush to remove oxide films and improve the surface condition.
3. Drying: Ensure that the surfaces are dry before soldering.

Any two – 2 marks.

c) State two reasons why workpieces should be held firmly during soldering. (2 marks)

1. To maintain correct alignment of the metal pieces during joining. (1 mark)

2. To prevent movement that may result in weak or defective joints. (1 mark)

**QUESTION 4: PROCEDURE FOR SOFT SOLDERING (8 MARKS)**

a) Outline six steps followed when performing soft soldering. (6 marks)

Award 1 mark for each correctly stated step.

1. Prepare the workpieces: Clean the metal surfaces to remove dirt, grease and oxide films.
2. Position the workpieces: Arrange the metal pieces in the required joint position.
3. Secure the workpieces: Hold the pieces firmly using clamps or other suitable holding devices.
4. Apply flux: Apply a suitable flux to the joining surfaces.
5. Heat the soldering iron: Switch on the soldering iron and allow its tip to reach the required working temperature.
6. Heat the joint: Place the heated soldering iron tip against the joint to transfer heat.
7. Apply solder: Feed solder into the heated joint so that it melts and flows over the surfaces.
8. Remove the soldering iron: Remove the iron after sufficient solder has flowed into the joint.
9. Allow cooling: Leave the joint undisturbed until the solder solidifies.
10. Inspect and clean: Examine the joint and remove any harmful flux residues using an appropriate method.

Any six correct steps in a logical sequence – 6 marks.

b) State two qualities of a good soldered joint. (2 marks)

1. It has a smooth, neat and continuous appearance. (1 mark)
2. It has good wetting and bonding with no cracks or gaps. (1 mark)

Other acceptable answers:

- Has sufficient solder without excessive buildup.
- Is mechanically secure.
- Has no visible signs of poor bonding.

**QUESTION 5: SAFETY AND DEFECTS IN SOFT SOLDERING (9 MARKS)**

a) State three safety precautions observed when performing soft soldering. (3 marks)

Award 1 mark for each correct answer.

1. Wear safety goggles to protect the eyes from splashes.
2. Work in a well-ventilated area to remove harmful fumes.
3. Use a soldering iron stand to support the hot iron.
4. Avoid touching the hot soldering iron tip.
5. Switch off and unplug the soldering iron after use.
6. Avoid eating or drinking in the soldering area.
7. Wash hands after handling solder, particularly lead-containing solder.
8. Use suitable protective equipment.

Any three – 3 marks.

b) Identify three defects that may occur during soft soldering. (3 marks)

Award 1 mark for each correct answer.

1. Cold solder joint.
2. Excessive solder.
3. Insufficient solder.
4. Poor wetting.
5. Incomplete bonding.
6. Cracked solder joint.
7. Porous solder joint.
8. Formation of solder bridges between electrical connections.

Any three – 3 marks.

c) Explain three possible causes of poor soldered joints. (3 marks)

Award 1 mark for each correctly explained cause.

1. Dirty surfaces: Dirt, grease and oxide films prevent proper solder wetting and bonding.
2. Insufficient heating: Prevents solder from melting and flowing properly into the joint.
3. Inadequate flux: Allows oxide films to remain on the metal surfaces.
4. Excessive heating: May damage components or cause flux to deteriorate.
5. Movement during cooling: Disturbs the joint before the solder solidifies.
6. Incorrect solder application: Too much or too little solder may produce a defective joint.

Any three – 3 marks.

**QUESTION 6: APPLICATIONS, MAINTENANCE AND ENVIRONMENTAL CONSERVATION (9 MARKS)**

a) State three applications of soft soldering in day-to-day life. (3 marks)

Award 1 mark for each correct answer.

1. Joining electrical wires and terminals.
2. Joining electronic components on printed circuit boards.
3. Repairing electrical and electronic appliances.
4. Joining thin metal sheets.
5. Repairing metal containers and utensils.
6. Joining components in plumbing systems where soft soldering is appropriate.

Any three – 3 marks.

b) Explain three benefits of maintaining soft soldering tools and equipment. (3 marks)

Award 1 mark for each well-explained benefit.

1. Improves efficiency: Properly maintained tools transfer heat effectively and make soldering easier.
2. Increases durability: Regular cleaning and proper storage reduce wear and damage.
3. Promotes safety: Checking electrical cables and connections helps prevent electric shocks and accidents.
4. Improves quality: A clean soldering iron tip helps produce neat and reliable joints.

5. Reduces costs: Proper maintenance reduces frequent replacement and repair expenses.

Any three – 3 marks.

c) State three environmental conservation practices observed during soft soldering. (3 marks)

Award 1 mark for each correct answer.

1. Collect and dispose of solder waste appropriately.
2. Recycle or recover reusable solder materials.
3. Avoid releasing flux chemicals into drainage systems.
4. Use lead-free solder where appropriate.
5. Ensure proper ventilation or use fume extraction equipment.
6. Store chemicals in properly labelled containers.
7. Avoid burning soldering waste in the open.
8. Keep the workshop clean and free from chemical spills.

Any three – 3 marks.

# Strand 4: Metal Joining and Finishing Processes

## Sub-strand 4.2: Brazing

### 4.2.1 Introduction

**Brazing** is a thermal joining process in which a **filler metal** having a lower melting point than the base metals is melted and flows into the joint by capillary action, without melting the base metals.

### Definition

**Brazing** is the process of joining metals by melting a filler metal (brazing rod) above 450°C but below the melting point of the base metals.

### Why Brazing?

- ✅ It joins different metals.
- ✅ It produces strong and neat joints.
- ✅ It is useful for thin sheets and pipes.

### 4.2.2 Brazing as a Thermal Joining Process

**Brazing** is a type of thermal joining where the base metals are not melted. The filler metal fills the joint by capillary action and on cooling, forms a strong bond.



**Figure 1:** Brazing a copper pipe

### 4.2.3 Tools and Equipment for Brazing

1. **Oxyacetylene torch** – provides a hot flame (≈ 950–1200°C).
2. **Brazing rods** – filler metal.
3. **Flux** – prevents oxidation.
4. **Cleaning tools** – wire brush, sandpaper, emery cloth.
5. **Clamps and jigs** – hold parts in position.
6. **Heat resistant gloves and goggles** – for safety.




**Figure 2:** Tools and equipment for brazing

### Brazing with Oxyacetylene Equipment

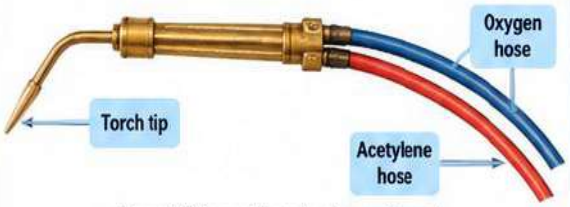



**Figure 3:** Oxyacetylene brazing equipment

### Types of Filler Rods and Fluxes

#### A. Brazing Rods

- Brass rods (copper-zinc) – for copper and its alloys.
3. **Silver brazing rods** – for high strength joints.
4. **Aluminium brazing rods** – for aluminium alloys.

#### B. Fluxes

- **Boric acid flux** – for copper and brass.
- **Non-corrosive flux** – for aluminium.
- **Paste flux** – easy to apply on sheets.

### 4.2.4 Brazing Procedure

1. **Prepare the joint** – clean the surfaces (removing rust, grease and dirt).
2. **Apply flux** – to prevent oxidation.
3. **Heat the joint** – using an oxyacetylene flame until the base metal is hot.
4. **Apply brazing rod** – touch the rod to the hot joint, it should melt and flow.
5. **Allow to cool** – do not quench.

### 4.2.5 Procedure and Process in Detail

- Clean the metal surface using a wire brush and degreaser.
- Apply flux evenly.
- Heat the joint area with a neutral flame (blue flame).
- Feed the brazing rod into the hot joint.
- Let the filler metal flow and fill the gap.
- Remove excess flux and clean the joint.

### 4.2.6 Brazing on Different Joints

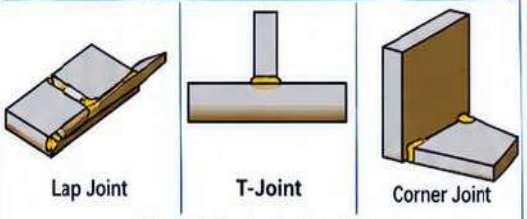



**Figure 4:** Types of brazed joints

### Common Defects on Brazed Sheets

- **Poor flow** – due to insufficient heat.
- **Porosity** – due to trapped gas.
- **Cracks** – due to excessive heat or poor technique.
- **Weak joint** – due to poor cleaning or wrong flux.



**Figure 5:** A good brazed joint

### Brazing Project Work and Activities

- ✅ Make a brazed copper pipe joint.
- ✅ Braze a T-joint on sheet metal.
- ✅ Construct a small brazed frame.

### 4.2.7 Uses of Brazing

- ✅ Plumbing and pipe work.
- ✅ Electrical and electronics.
- ✅ Aerospace and automotive industries.
- ✅ Sheet metal fabrication.

### 4.2.8 Maintenance of Brazing Tools

- ✅ Clean torch tips after use.
- ✅ Check for gas leaks regularly.
- ✅ Store rods and flux in a dry place.
- ✅ Replace worn out parts.

### Safety Precautions

- Wear goggles and gloves.
- Ensure good ventilation.
- Check for gas leaks.
- Keep away from flammable materials.
- Use a fire extinguisher.

### REVISION QUESTIONS

**SECTION A: Multiple Choice (30 Marks)**

**Choose the correct answer.**

1. Brazing is a thermal joining process where the filler metal melts at:
   A. below 450°C B. above 1200°C
   **C. between 450–950°C** D. above 2000°C
2. Which tool provides a hot flame for brazing?
   A. Screwdriver **B. Oxyacetylene torch**
   C. Hammer D. Pliers

(...questions continue up to 30)

**SECTION B: Structured Questions (50 Marks)**

1. Explain the meaning of brazing. (5 marks)
2. State five advantages of brazing. (5 marks)
3. Describe the procedure of brazing. (10 marks)
4. With the aid of a diagram, show the different types of brazed joints. (10 marks)
5. Explain three defects on brazed sheet metal joints and how to prevent them. (10 marks)
6. Describe the maintenance of brazing tools. (10 marks)

**STRAND 4.0: METAL JOINING AND FINISHING PROCESSES**

**SUB-STRAND 4.2: BRAZING**

## 1.0 INTRODUCTION TO BRAZING

### 1.1 Meaning of brazing

Brazing is a metal-joining process in which two or more metal components are permanently joined by heating them and melting a filler metal into the joint without melting the parent metals.

The molten filler metal flows into the narrow space between the surfaces being joined through a process known as **capillary action**. On cooling, the filler metal solidifies and forms a strong metallic bond.

Brazing is classified as a thermal joining process because heat is used to melt the filler metal and produce the joint.

**Important characteristics of brazing:**

1. The parent metals are not melted during the process.
2. A separate filler metal is used to form the joint.
3. The filler metal has a melting temperature above 450°C.
4. The filler metal melts at a lower temperature than the parent metals being joined.
5. The molten filler metal flows into the joint through capillary action.
6. Flux may be used to prevent oxidation and improve the flow of the filler metal.
7. The joint becomes strong when the filler metal cools and solidifies.

### 1.2 Definition of important terms

**a) Brazing**

A thermal metal-joining process that uses a molten filler metal with a liquidus temperature above 450°C to join parent metals without melting them.

**b) Parent metal (base metal)**

The original metal components that are being joined together during brazing.

Examples include:

- Copper sheets.
- Brass pipes.
- Steel components.
- Stainless steel components.
- Copper pipes.

**c) Filler metal**

A special metal or alloy that melts during brazing and flows into the joint to connect the parent metals.

Examples:

- Brass brazing rods.
- Silver brazing alloys.
- Copper-phosphorus rods.
- Aluminium brazing filler alloys.

**d) Flux**

A chemical substance applied to the surfaces being joined to remove or prevent oxide formation and improve the flow of molten filler metal.

**e) Capillary action**

The movement of molten filler metal into a narrow gap between closely fitting metal surfaces due to surface tension and wetting forces.

**f) Brazed joint**

A permanent connection formed when the molten filler metal solidifies between two or more parent metal surfaces.

**g) Oxidation**

A chemical reaction in which a metal combines with oxygen, usually forming a layer of metal oxide on its surface.

**1.3 Brazing as a thermal joining process**

Brazing belongs to the group of thermal metal-joining processes because heat is applied to produce a joint.

During brazing:

1. The metal surfaces are cleaned to remove dirt, grease, rust and oxides.
2. The components are positioned and held together.
3. Flux is applied where required.
4. Heat is applied to the joint using a suitable heating source.
5. The filler metal is brought into contact with the heated joint.
6. The filler metal melts and flows into the joint.
7. The heat source is removed.
8. The joint is allowed to cool.
9. The finished joint is inspected for quality.

**Why the parent metals do not melt**

The filler metal is selected to melt at a lower temperature than the parent metals. This enables the filler to flow between the parent metals while the original components retain their shapes.

**1.4 Difference between brazing and soldering**

Brazing and soldering are both thermal joining processes, but they differ mainly in the melting temperature of their filler metals.

| **Aspect** | **Brazing** | **Soldering** |
|---|---|---|
| Filler metal melting temperature | Above 450°C | At or below 450°C |
| Joint strength | Generally higher | Generally lower |
| Heat required | Higher | Lower |

| | | |
|---|---|---|
| Applications | Pipes, metal frames, engineering components | Electronics, light electrical connections |
| Parent metals | Not melted | Not melted |
| Filler flow | Capillary action | Wetting and capillary action |

**1.5 Advantages of brazing**

1. **Joining different metals:** Brazing can join dissimilar metals such as copper and brass when compatible filler metals and fluxes are selected.
2. **Good joint strength:** Properly produced brazed joints can withstand considerable mechanical loads.
3. **Less distortion:** Since the parent metals are not melted, distortion is often lower than in fusion welding.
4. **Neat appearance:** Brazing can produce clean and attractive joints with controlled filler-metal application.
5. **Joining thin materials:** It is suitable for joining thin metal sheets that could easily burn through during welding.
6. **Joining complex components:** It can be used to join components with complicated shapes and inaccessible joint areas.
7. **Reduced finishing work:** Well-controlled brazing produces joints that may require minimal finishing.
8. **Joining dissimilar thicknesses:** It can join components of different thicknesses when the joint is properly designed.

**1.6 Limitations of brazing**

1. Brazing requires careful surface preparation.
2. The joint may have lower high-temperature service capability than a suitable welded joint.
3. Some brazing fillers and fluxes are expensive.
4. Excessive heat may distort thin metal sheets.
5. Some flux residues are corrosive and must be removed.
6. The quality of the joint depends on correct joint clearance.
7. Brazing may not be suitable for every heavily loaded structural application.
8. Certain combinations of metals may form brittle compounds if unsuitable fillers or procedures are used.

**2.0 PRINCIPLE AND PROCESS OF BRAZING**

**2.1 Principle of brazing**

Brazing works on the principle of wetting and capillary action.

When a suitable filler metal is heated until molten, it wets the clean surfaces of the parent metals and flows into the narrow gap between them.

As the filler metal cools, it solidifies and bonds the components together.

**The main conditions required for successful brazing are:**

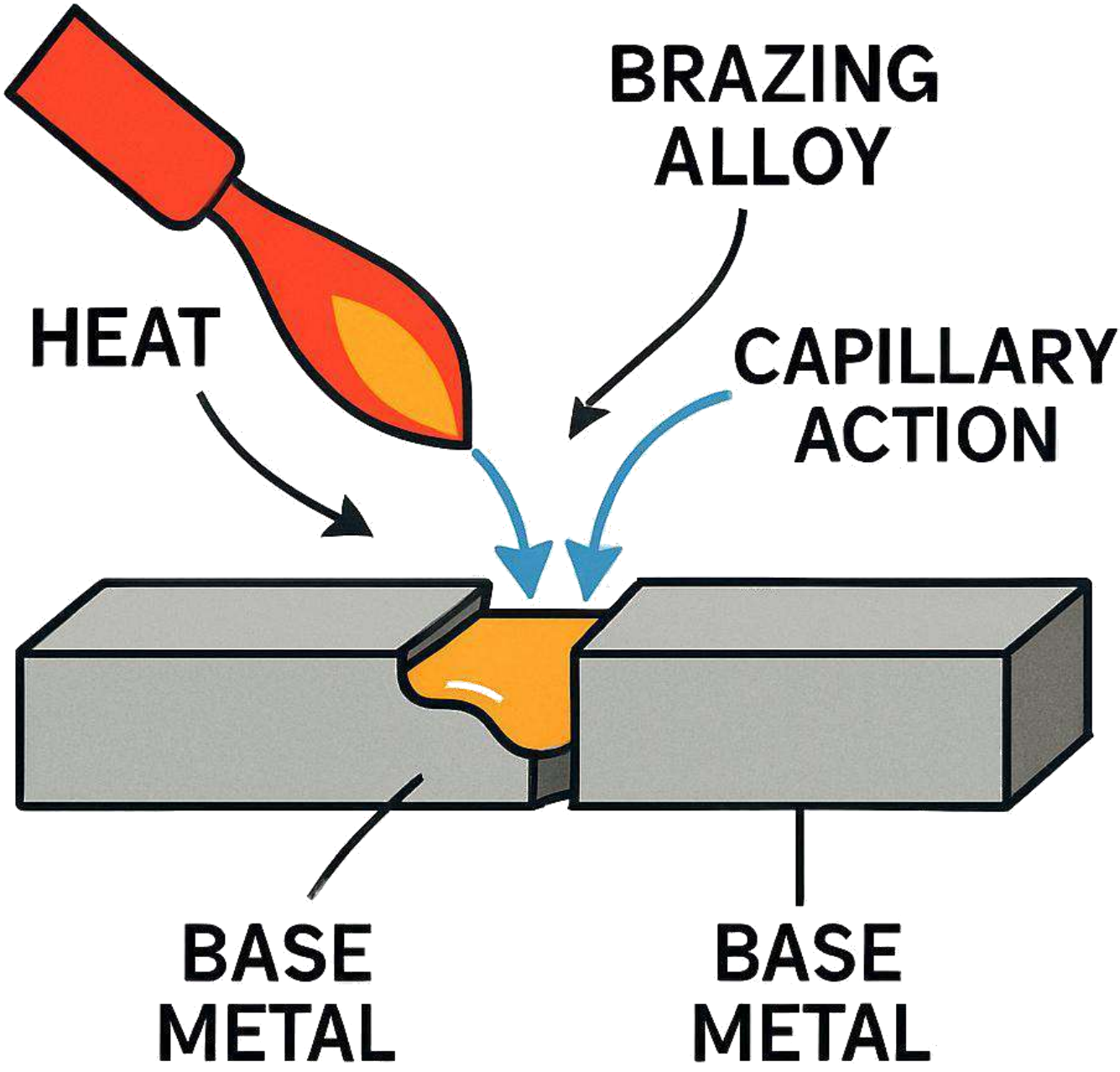
1. Clean metal surfaces.
2. Correct joint clearance.
3. Appropriate filler metal.

4. Suitable flux where required.
5. Correct heating temperature.
6. Uniform heating of the joint.
7. Proper positioning of the components.
8. Controlled cooling.

**2.2 Capillary action in brazing**

Capillary action is an important principle in brazing.

It allows molten filler metal to move into the narrow space between two closely fitting metal surfaces.



**Explanation of capillary action:**

1. Two metal surfaces are positioned close to each other.
2. A small clearance is maintained between the surfaces.
3. The surfaces are cleaned and prepared.
4. The filler metal is heated until molten.
5. The molten filler metal wets the surfaces.
6. Surface tension and capillary forces draw the filler metal into the gap.
7. The filler metal fills the joint.
8. On cooling, a permanent joint is formed.

**Importance of capillary action:**

- It enables the filler metal to penetrate the joint.
- It improves contact between the filler and parent metals.
- It helps produce a continuous joint.
- It reduces the likelihood of unfilled spaces when the joint is properly designed.

**2.3 Factors affecting successful brazing**

**a) Surface cleanliness**

Clean surfaces allow the molten filler metal to wet the parent metals properly.

**b) Joint clearance**

The gap between the components must be suitable for the filler metal being used. A gap that is too wide or too narrow may interfere with capillary flow.

**c) Heating temperature**

The joint must reach the correct temperature for the filler metal to melt and flow.

**d) Heating method**

The heat source should distribute heat evenly around the joint.

**e) Type of filler metal**

The filler must be compatible with the parent metals and the intended service conditions.

**f) Flux selection**

The flux must be suitable for the metals and brazing temperature.

**g) Heating duration**

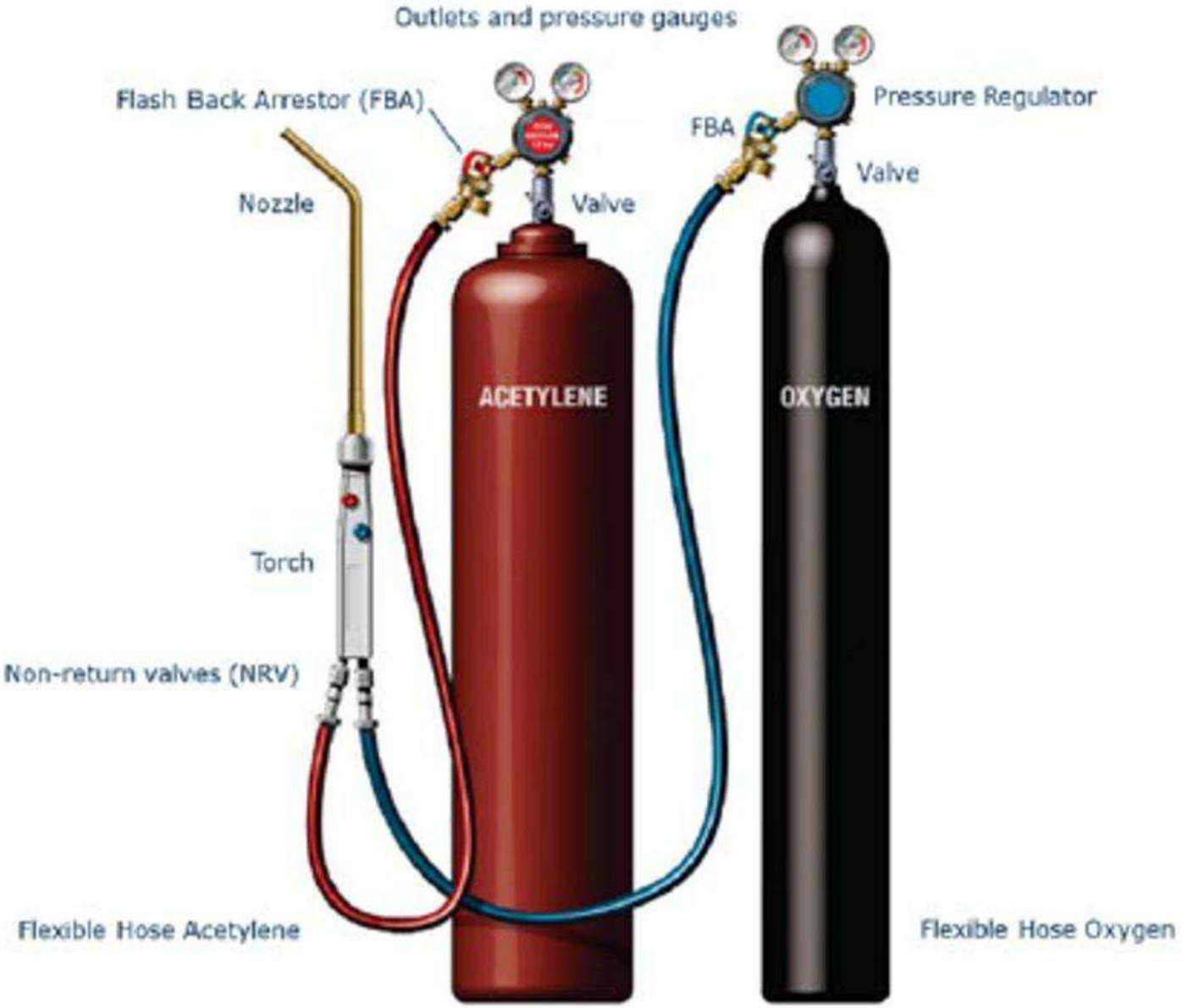
Insufficient heating prevents proper flow, while excessive heating may damage the parent metal or filler.

**3.0 TOOLS AND EQUIPMENT USED IN BRAZING**

Brazing requires tools and equipment for heating, cleaning, positioning, applying filler metal, protecting the operator and inspecting the finished work.

**3.1 Oxyacetylene brazing equipment**

Oxyacetylene equipment is commonly used in workshop brazing because it produces a high-temperature flame through the combustion of oxygen and acetylene.




Typical oxy-acetylene equipment configuration

**Main components of oxyacetylene equipment**

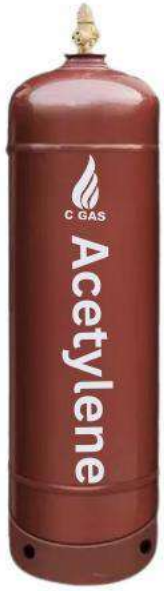
**1. Oxygen cylinder**



- Stores oxygen under high pressure.

- Supplies oxygen required for combustion.
- Is fitted with a suitable cylinder valve.
- Must be secured upright during use and storage.
- Must be kept away from oil and grease.

**2. Acetylene cylinder**




- Stores acetylene gas.
- Supplies fuel for the oxyacetylene flame.
- Contains acetylene in a specially designed porous material and solvent system.
- Must be kept upright and handled carefully.
- Must be protected from heat and physical damage.

**3. Pressure regulators**



Pressure regulators control the pressure of gases supplied from the cylinders.

Functions:

- Reduce high cylinder pressure to a usable working pressure.
- Maintain a controlled gas supply.
- Indicate pressure through gauges.
- Help the operator monitor gas supply conditions.

**4. Gas hoses**



Gas hoses transport oxygen and acetylene from the regulators to the torch.

Functions:

- Supply oxygen and fuel gas to the torch.
- Provide flexibility during workshop operations.
- Connect the cylinders to the torch.

The hoses must be inspected for cracks, leaks, damage and loose connections.

**5. Brazing torch**



The torch mixes oxygen and acetylene in controlled proportions and produces a flame.

Functions:

- Produces heat for brazing.
- Directs the flame towards the joint.

- Controls the heating process.
- Allows the operator to regulate the flame using the appropriate controls.

**6. Torch nozzle or tip**

The nozzle directs the flame onto the workpiece.

Functions:

- Determines flame characteristics.
- Directs heat towards the joint.
- Helps control the heating area.

**7. Flashback arrestors**

These are safety devices fitted in gas systems to help prevent a flame from travelling backwards into hoses or gas supplies.

Functions:

- Help prevent flashback.
- Reduce the risk of fires and explosions.
- Improve the safety of gas equipment.

**3.2 Other tools and equipment used in brazing**








**1. Brazing filler rods**

These are rods or wires made from suitable filler-metal alloys.

Uses:

- Supply filler metal for the joint.
- Fill the clearance between components.
- Produce the metallic bond.

**2. Wire brush**

A wire brush is used to remove loose oxide, dirt, scale and other contaminants from metal surfaces.

Uses:

- Cleaning joint surfaces.
- Removing loose flux residues.

- Preparing metal surfaces before brazing.

**3. Files**

Files are used to remove burrs and irregularities from the edges of metal components.

Uses:

- Smoothing joint edges.
- Removing sharp projections.
- Preparing surfaces for close fitting.

**4. Emery cloth or abrasive paper**

This is used to clean and smooth metal surfaces.

Uses:

- Removing surface oxidation.
- Removing light rust.
- Improving surface preparation.

**5. Metal vice**

A vice holds metal components firmly during preparation and brazing where appropriate.

Uses:

- Holding workpieces.
- Maintaining alignment.
- Preventing unwanted movement.

**6. Clamps**

Clamps hold components in their required positions during brazing.

Uses:

- Securing sheet metal.
- Maintaining joint alignment.
- Preventing movement during heating.

**7. Tongs**

Tongs are used to handle hot metal components safely.

**8. Heat-resistant work surface**

A suitable fire-resistant work surface supports the workpiece and protects the workshop environment.

**9. Pickling or cleaning solution**

Where appropriate, an approved cleaning solution may be used to remove oxidation or flux residues after brazing.

The solution must be compatible with the metal and flux, and the manufacturer's handling instructions must be followed.

**10. Measuring tools**

Examples include:

- Steel rule.

- Vernier callipers.
- Try square.
- Feeler gauges.

These are used to measure component dimensions, check alignment and assess joint clearance.

**3.3 Personal protective equipment used in brazing**



1. **Safety goggles:** Protect the eyes from intense light, sparks and flying particles.
2. **Leather gloves:** Protect the hands from heat and hot metal.
3. **Protective apron:** Protects the body and clothing from sparks and heat.
4. **Safety boots:** Protect the feet from falling objects and hot metal.
5. **Protective clothing:** Reduces exposure of the skin to heat and sparks.
6. **Suitable respiratory protection:** Used where required by the risk assessment and workshop conditions.

**4.0 TYPES OF FILLER RODS USED IN BRAZING**

**4.1 Meaning of brazing filler rods**

Brazing filler rods are metallic materials supplied in rod, wire or other suitable forms. They melt during the brazing process and flow into the joint to connect the parent metals.

The filler metal must be selected according to:

- Type of parent metal.
- Required joint strength.
- Service temperature.
- Operating environment.
- Corrosion resistance.

- Brazing method.
- Joint design.

**4.2 Types of brazing filler rods**







**1. Brass brazing rods**

Brass rods are copper-zinc alloys.

Characteristics:

- Have good flow properties when correctly heated.
- Are commonly used for joining suitable copper alloys and steels.
- Are available in different compositions.
- Often require an appropriate flux.

Uses:

- Joining steel components.
- Repairing metal parts.
- Joining suitable copper and brass components.
- General workshop brazing.

**2. Silver brazing rods**

These are filler metals containing silver and other alloying elements.

Characteristics:

- Have good fluidity.
- Produce strong joints when correctly selected and applied.
- Can operate at relatively lower brazing temperatures than many brass fillers.
- Are available in different silver contents.

Uses:

- Joining copper pipes.
- Joining stainless steel components.
- Joining dissimilar metals.

- Refrigeration and air-conditioning pipework.

**3. Copper-phosphorus brazing rods**

These are filler metals made mainly from copper and phosphorus, sometimes with silver.

Characteristics:

- Have good flow characteristics on suitable copper joints.
- Some compositions are self-fluxing on copper-to-copper joints.
- Are not suitable for every metal combination.

Uses:

- Joining copper pipes.
- Plumbing applications.
- Refrigeration pipework.
- Air-conditioning systems.

**4. Aluminium brazing filler rods**

These are special filler alloys formulated for aluminium and suitable aluminium alloys.

Characteristics:

- Are designed to work with aluminium.
- Require careful control of heat because aluminium conducts heat rapidly.
- Require suitable flux or a specifically designed fluxless process.

Uses:

- Aluminium heat exchangers.
- Radiators.
- Aluminium fabrication.
- Suitable aluminium sheet assemblies.

**5. Nickel-based brazing filler metals**

These are filler alloys containing nickel and other elements.

Characteristics:

- Can withstand demanding service environments.
- Offer useful oxidation and corrosion resistance depending on composition.
- Are often used in controlled-atmosphere or furnace brazing.

Uses:

- Turbine components.
- Heat exchangers.
- Engineering assemblies.
- High-temperature applications.

**4.3 Factors to consider when selecting brazing rods**

1. The type of metal being joined.
2. The melting temperature of the parent metals.
3. The required strength of the joint.
4. The operating temperature of the finished component.
5. The service environment.
6. The possibility of corrosion.
7. The joint clearance.
8. The brazing method being used.
9. The cost and availability of the filler metal.
10. Manufacturer's specifications.

**5.0 TYPES OF FLUXES USED IN BRAZING**

**5.1 Meaning of brazing flux**

Brazing flux is a chemical cleaning agent applied to metal surfaces during brazing to remove or dissolve oxides and prevent further oxidation.

It promotes proper wetting of the parent metal by the molten filler metal.

**5.2 Functions of brazing flux**

1. Removes existing oxide films.
2. Prevents further oxidation during heating.
3. Improves the wetting of the parent metals.
4. Helps molten filler metal flow into the joint.
5. Improves the quality and appearance of the joint.
6. Reduces defects caused by surface contamination.

**5.3 Types of brazing fluxes**










**1. Borax-based flux**

Description:

- Contains borax-based compounds.

- Commonly used with suitable brass and copper brazing filler metals.
- Helps remove oxide films during heating.

Applications:

- General workshop brazing.
- Suitable steel brazing applications.
- Certain copper-alloy brazing operations.

**2. Boric acid-based flux**

Description:

- Contains boric acid or related borate compounds.
- Helps control oxidation during heating.
- Often used in combination with other flux ingredients.

Applications:

- Suitable copper and brass brazing.
- Certain silver brazing operations.

**3. Silver brazing flux**

Description:

- Specially formulated for silver brazing alloys.
- Often supplied as powder or paste.
- Works within a specified temperature range.

Applications:

- Copper pipe joints.
- Stainless steel components.
- Dissimilar metal joints.

**4. Aluminium brazing flux**

Description:

- Specially formulated to deal with the stable oxide layer on aluminium.
- Must be selected according to the aluminium alloy and brazing method.

Applications:

- Aluminium sheet assemblies.
- Radiators.
- Heat exchangers.

**5. Paste flux**

Description:

- A ready-to-use flux supplied in paste form.
- Can be applied directly to the joint.

Advantages:

- Easy to apply.
- Adheres to vertical surfaces.
- Reduces the scattering of powder.
- Allows controlled application.

**5.4 Types of flux according to application**

| **Flux type** | **Typical application** |
|---|---|
| Borax-based flux | Suitable copper, brass and steel brazing |
| Silver brazing flux | Silver-alloy brazing |
| Aluminium brazing flux | Aluminium brazing |
| Paste flux | Controlled application on joints |
| Powder flux | Suitable operations requiring dry flux application |

**5.5 Precautions when using flux**

1. Use flux that is compatible with the filler metal.
2. Read the manufacturer's instructions before application.
3. Avoid inhaling flux dust or fumes.
4. Use gloves and suitable eye protection.
5. Apply only the required quantity.
6. Remove harmful or corrosive residues after brazing.
7. Store flux in properly labelled containers.
8. Keep flux away from food and drinking water.

**6.0 OXYACETYLENE EQUIPMENT AND ITS USE IN BRAZING**

**6.1 Meaning of oxyacetylene brazing**

Oxyacetylene brazing is a method of joining metals by heating the joint using a flame produced by burning acetylene gas in oxygen and introducing a suitable filler metal into the heated joint.

The parent metals are heated but are not melted.

**6.2 How oxyacetylene brazing works**

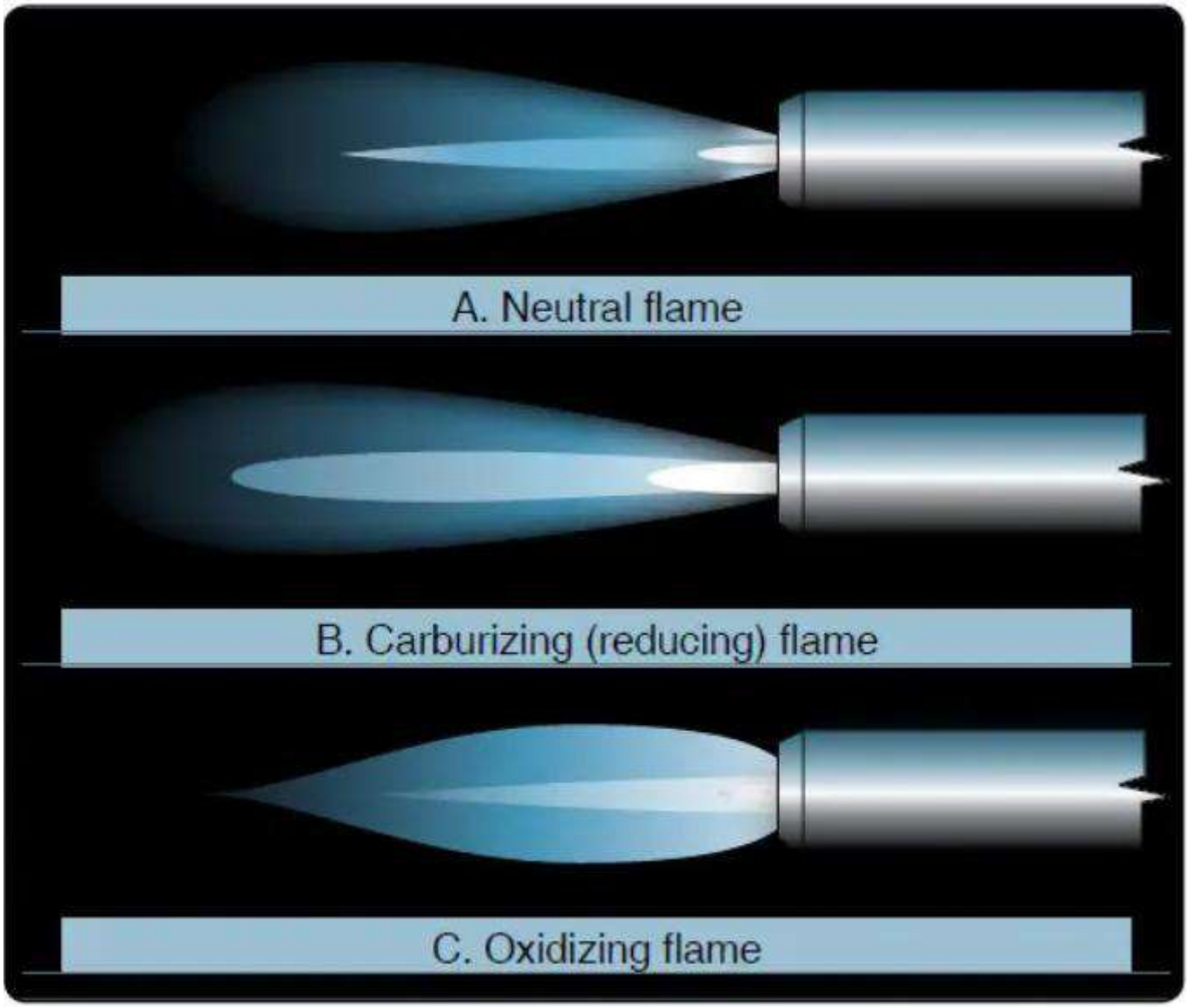


The process takes place as follows:

1. Oxygen is supplied from an oxygen cylinder.
2. Acetylene is supplied from an acetylene cylinder.
3. The gases pass through pressure regulators.
4. The gases travel through separate hoses.
5. They enter the brazing torch.
6. The gases mix in the torch and burn at the nozzle.
7. The resulting flame supplies heat to the parent metals.
8. The filler metal is introduced into the heated joint.
9. The filler melts and flows into the joint.
10. The joint is allowed to cool and solidify.

**6.3 Types of oxyacetylene flames**

There are three main types of oxyacetylene flames.




**1. Neutral flame**

A neutral flame is produced when oxygen and acetylene are mixed in approximately balanced proportions.

Characteristics:

- Has a well-defined inner cone.
- Does not produce a noticeable excess of oxygen or acetylene.
- Produces relatively stable heating conditions.
- Is commonly used for heating many copper and steel components.

Applications:

- General metal heating.
- Suitable brazing operations.
- Oxyacetylene welding of appropriate metals.

**2. Carburising or reducing flame**

A carburising flame is produced when there is excess acetylene compared with oxygen.

Characteristics:

- Has an acetylene-rich flame.
- May show an additional feather beyond the inner cone.
- Produces a reducing atmosphere.
- Can introduce carbon into some metals under unsuitable conditions.

Applications:

- Certain specialised metalworking operations.
- Processes requiring a reducing flame where specified.

**3. Oxidising flame**

An oxidising flame is produced when there is excess oxygen compared with acetylene.

Characteristics:

- Has a shorter, sharper inner cone.
- Produces an oxidising atmosphere.
- Can cause undesirable oxidation of some metals.

Applications:

- Certain specialised oxyacetylene operations, depending on the metal and process.

**Important note:** The correct flame for brazing depends on the parent metal, filler metal and manufacturer's recommendations. A neutral flame is commonly suitable for general copper brazing.

**6.4 Starting and operating oxyacetylene equipment safely**

Only a trained and authorised person should set up, light, adjust and shut down oxyacetylene equipment.

The correct procedure is:

1. Inspect cylinders, regulators, hoses and torch connections.
2. Confirm that cylinders are secured upright.
3. Check that the equipment is suitable for the gases being used.
4. Ensure flashback arrestors and required safety devices are fitted.

5. Check connections for leaks using an approved leak-detection solution.
6. Ensure adequate workshop ventilation.
7. Set the regulators according to the equipment manufacturer's instructions and the approved procedure.
8. Purge each gas line separately according to the manufacturer's instructions.
9. Use an approved spark lighter to ignite the torch.
10. Adjust the flame to the required condition.
11. Direct the flame towards the workpiece without overheating it.
12. Shut down the equipment using the approved torch and cylinder sequence.

**Important safety warning:** Never use oil or grease on oxygen fittings. Never use a match or cigarette lighter to ignite the torch. Never operate equipment with leaking hoses or damaged regulators.

## 7.0 CLEANING AND PREPARATION OF METAL SURFACES BEFORE BRAZING

### 7.1 Meaning of surface preparation

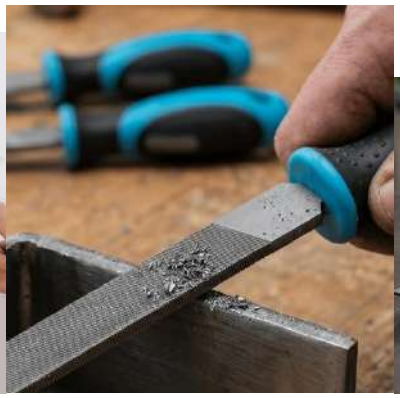
Surface preparation is the process of cleaning, smoothing and arranging metal components before brazing to ensure proper bonding.

It is an important stage because molten filler metal cannot wet contaminated surfaces effectively.

### 7.2 Reasons for cleaning metal surfaces

1. To remove rust and oxide films.
2. To remove grease and oil.
3. To remove paint and dirt.
4. To improve wetting by the filler metal.
5. To allow proper capillary flow.
6. To reduce porosity and other defects.
7. To produce strong and reliable joints.
8. To improve the appearance of the finished work.

### 7.3 Tools used for cleaning metal surfaces


**1. Wire brush**

- Removes loose oxide and dirt.
- Cleans metal surfaces.
- Prepares the joint before applying flux.

**2. Emery cloth**

- Removes light surface oxidation.
- Smoothens rough areas.
- Improves surface cleanliness.

**3. File**

- Removes burrs.
- Smoothens uneven edges.
- Helps components fit together correctly.

**4. Degreasing cloth**

- Removes oil and grease.
- Prevents contamination of the joint.

**5. Suitable cleaning solution**

- Removes certain contaminants.
- Helps prepare surfaces for brazing.
- Must be compatible with the parent metal.

**7.4 Procedure for preparing a metal joint**

1. Measure the components according to the drawing.
2. Mark out the required dimensions.
3. Cut the components using suitable cutting tools.
4. Remove sharp edges and burrs.
5. Clean the joint surfaces using an appropriate abrasive tool.
6. Degrease the surfaces using a suitable cleaning agent.
7. Allow the surfaces to dry completely.
8. Check the joint clearance.
9. Align the components correctly.
10. Apply the recommended flux where required.

**7.5 Importance of joint clearance**

Joint clearance is the small space left between the components being brazed.

It is important because molten filler metal needs an appropriate gap to flow through.

- If the clearance is too wide, capillary action may be poor.
- If the clearance is too narrow, filler metal may fail to penetrate.
- If the clearance is correct, the filler metal flows properly and forms a continuous joint.

The correct clearance depends on the filler metal, parent materials, joint design and brazing temperature. Manufacturer specifications should be followed.

## 8.0 BRAZING PROCEDURE AND PROCESS

### 8.1 General procedure for brazing



The following steps explain the general procedure used in brazing.

**Step 1: Study the job requirements**

- Examine the working drawing.
- Identify the materials to be joined.
- Determine the joint type.
- Select suitable filler metal and flux.
- Identify the heating equipment required.

**Step 2: Measure and mark out the components**

- Measure the metal components.
- Mark the cutting dimensions.
- Identify the positions of the joints.
- Check the dimensions against the drawing.

**Step 3: Cut the components**

- Cut the metal to the required dimensions.
- Use suitable cutting tools.
- Avoid excessive distortion.
- Ensure the edges are properly formed.

**Step 4: Clean the joint surfaces**

- Remove rust and scale.

- Remove grease and oil.
- Use a wire brush or abrasive paper.
- Ensure that the surfaces are clean and dry.

**Step 5: Fit the components together**

- Position the components correctly.
- Maintain the recommended joint clearance.
- Check alignment.
- Use clamps or suitable jigs to hold the components.

**Step 6: Apply flux**

- Select the correct flux.
- Apply it evenly to the joint surfaces where required.
- Avoid excessive application.
- Follow the manufacturer's instructions.

**Step 7: Prepare the heating equipment**

- Inspect the torch and gas equipment.
- Check the gas connections.
- Ensure the correct safety devices are fitted.
- Establish the correct flame using the approved procedure.

**Step 8: Heat the joint**

- Direct the flame towards the parent metals.
- Heat the joint uniformly.
- Avoid concentrating excessive heat on one point.
- Allow the joint to reach the correct brazing temperature.

**Step 9: Apply the filler metal**

- Introduce the brazing rod at the joint.
- Allow the heat from the parent metals to melt the filler.
- Guide the molten filler into the joint.
- Ensure that the filler flows along the required joint area.

**Step 10: Complete the joint**

- Stop feeding the filler when the joint is properly filled.
- Remove the flame carefully.
- Avoid disturbing the joint while the filler is solidifying.

**Step 11: Allow controlled cooling**

- Allow the workpiece to cool naturally or according to the process specification.
- Do not quench the joint unless the specific procedure permits it.

- Avoid unnecessary movement during cooling.

**Step 12: Clean the finished joint**

- Remove flux residues using the recommended method.
- Brush the surface where appropriate.
- Use a suitable cleaning process.
- Dry the workpiece.

**Step 13: Inspect the finished joint**

- Check the appearance.
- Check whether the filler has flowed properly.
- Look for cracks and porosity.
- Check the joint alignment.
- Carry out appropriate tests where necessary.

**8.2 Precautions during brazing**

1. Avoid overheating the parent metals.
2. Use the correct filler metal.
3. Use compatible flux.
4. Ensure proper joint clearance.
5. Maintain uniform heating.
6. Avoid disturbing the joint during solidification.
7. Ensure adequate ventilation.
8. Wear appropriate protective equipment.
9. Keep flammable materials away from the brazing area.
10. Follow the approved oxyacetylene operating procedure.

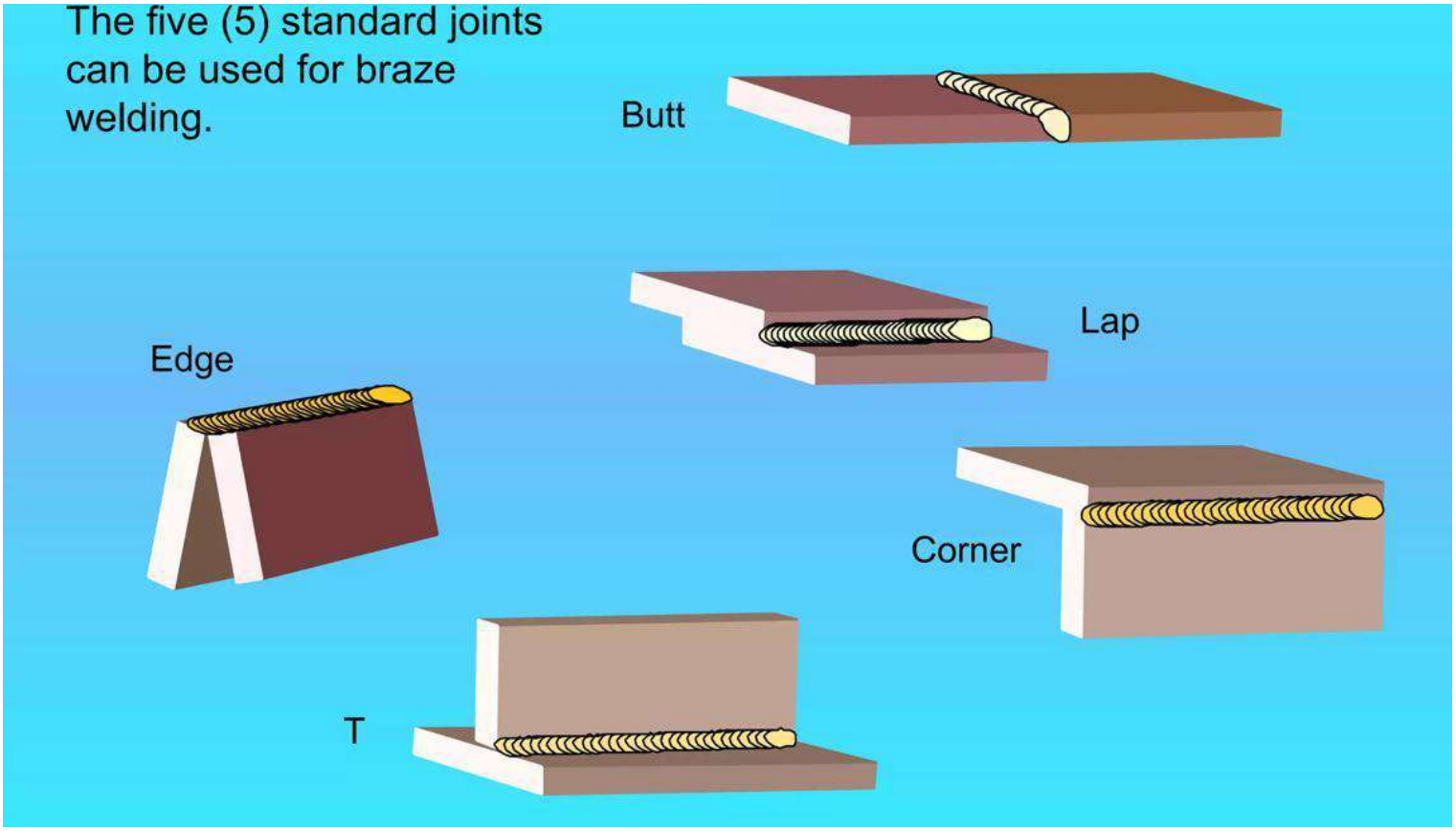
**9.0 BRAZING DIFFERENT TYPES OF JOINTS ON SHEET METALS**

**9.1 Meaning of a sheet metal brazed joint**

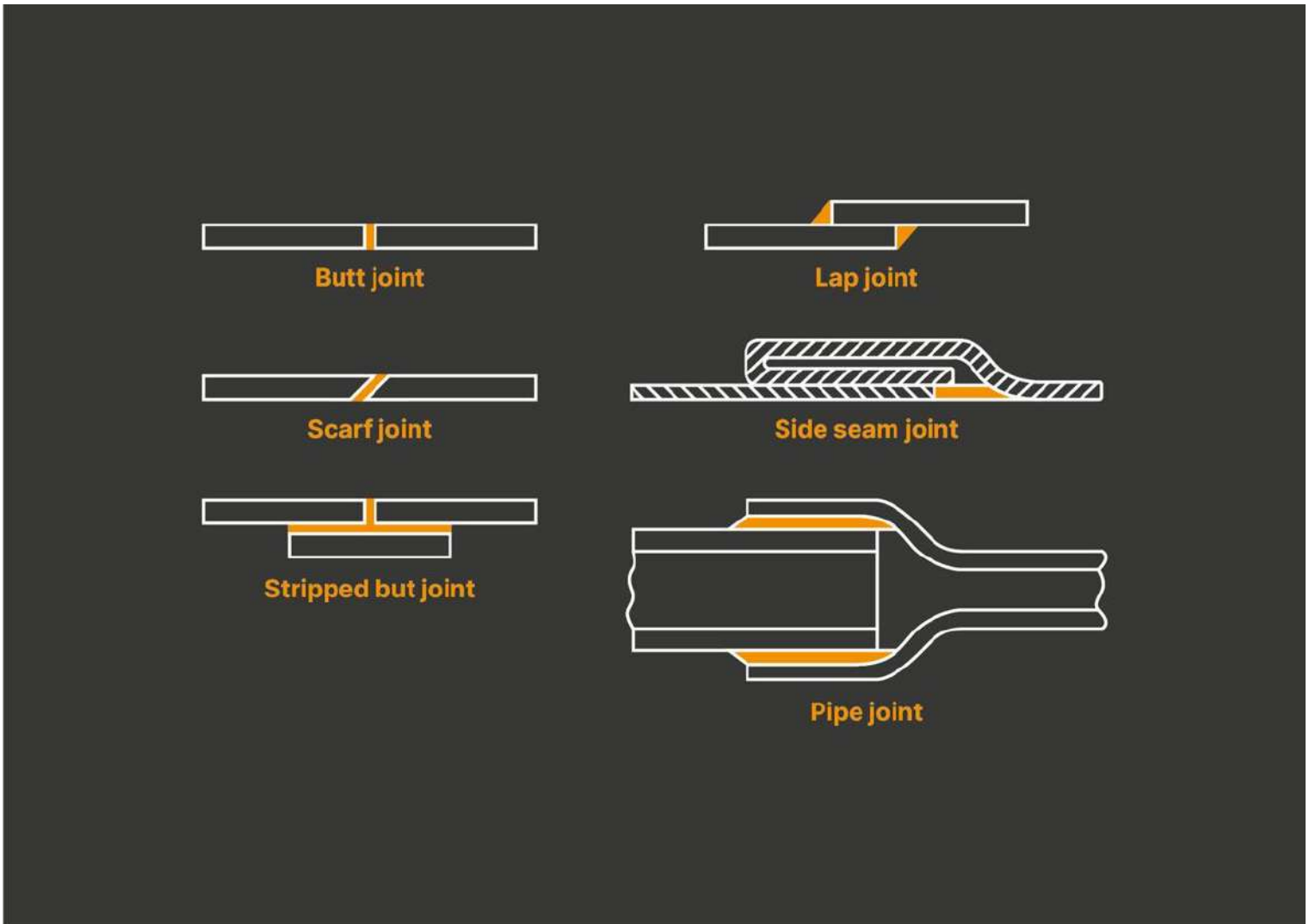
A sheet metal brazed joint is a permanent connection between two or more sheet metal components formed by melting a suitable filler metal into the joint without melting the parent sheets.

Brazing is particularly useful for thin metal sheets because it can join them without the need to melt their edges.

**9.2 Types of brazed joints**


The five (5) standard joints can be used for braze welding.
Butt
Lap
Edge
Corner
T

**1. Lap joint**


Butt joint
Lap joint
Scarf joint
Side seam joint
Stripped but joint
Pipe joint

A lap joint is formed when one metal sheet overlaps another and the overlapping surfaces are joined using filler metal.

**Procedure:**

1. Measure and cut the two sheets.
2. Remove burrs from the edges.
3. Clean the overlapping surfaces.
4. Arrange the sheets with the required overlap.
5. Maintain the recommended joint clearance.
6. Apply suitable flux where required.
7. Heat the joint evenly.
8. Introduce the filler metal.
9. Allow the filler to flow through the overlap.
10. Remove the flame and allow cooling.
11. Clean and inspect the joint.

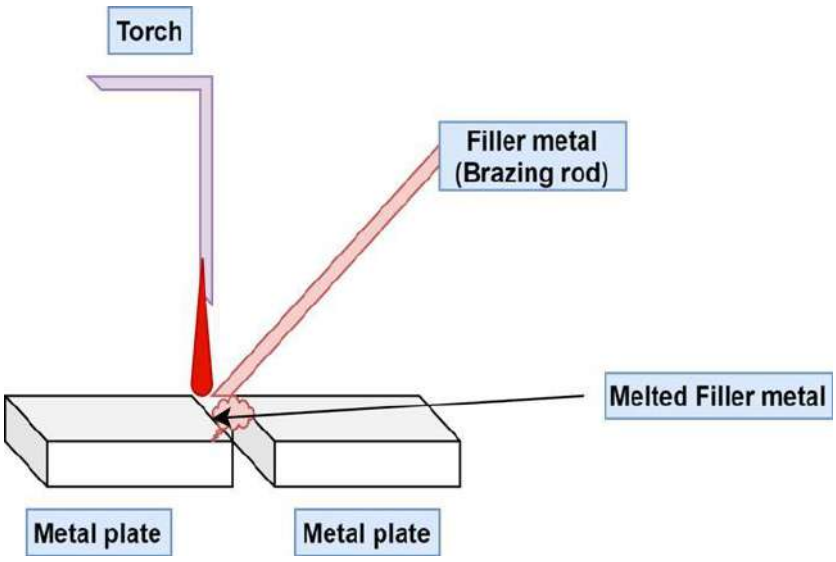
**Applications:**

- Sheet metal containers.
- Light metal fabrications.
- Metal covers.
- Suitable ducting components.

**Advantages:**

- Provides a relatively large bonding area.
- Is easy to prepare.
- Can produce a strong joint when properly designed.

**2. Butt joint**




A butt joint is formed when two sheet metal edges are placed together in the same plane and joined using filler metal.

**Procedure:**

1. Cut the sheets to the required dimensions.
2. Prepare straight and clean edges.
3. Arrange the sheets edge to edge.
4. Maintain the correct clearance.
5. Apply suitable flux.
6. Heat the joint evenly.
7. Introduce the filler metal.
8. Allow the molten filler to enter the joint.
9. Remove the heat source.
10. Allow the joint to cool.
11. Clean and inspect the joint.

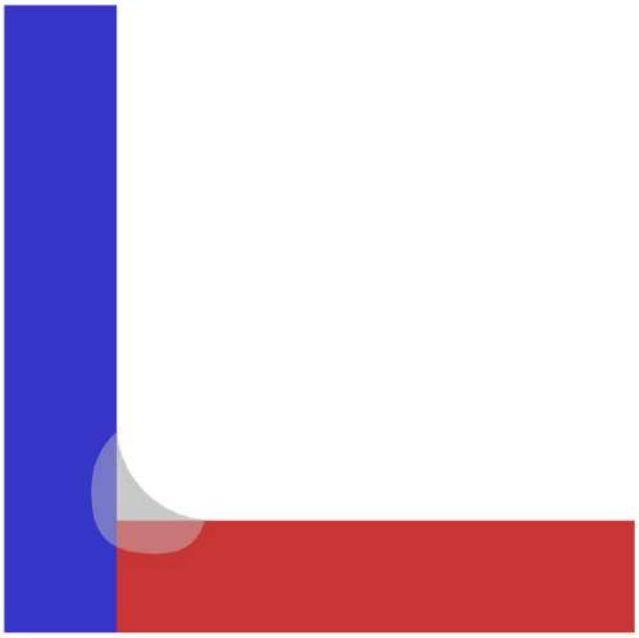
**Applications:**

- Sheet metal fabrication.
- Metal panels.
- Suitable tanks and enclosures.

**Advantages:**

- Produces a relatively flat surface.
- Requires little overlap.
- Can be useful where a flush surface is needed.

**3. T-joint**



A T-joint is formed when one metal component is positioned at approximately 90 degrees to another, forming the shape of the letter T.

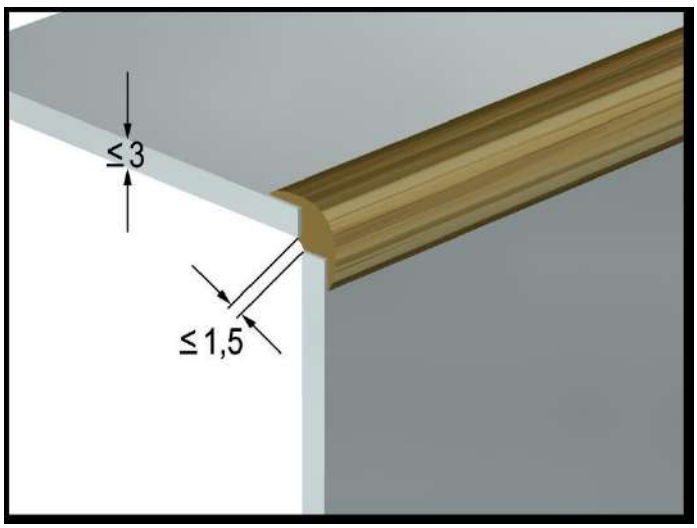
**Procedure:**

1. Measure and prepare the sheets.
2. Clean the contact surfaces.
3. Position one sheet at right angles to the other.
4. Hold the sheets firmly using a suitable jig.
5. Apply suitable flux.
6. Heat the joint uniformly.
7. Introduce the filler metal along the joint.
8. Allow the filler to flow into the joint.
9. Remove the heat source.
10. Allow cooling.
11. Remove flux residues and inspect the joint.

**Applications:**

- Sheet metal frames.
- Brackets.
- Metal supports.
- Fabricated enclosures.

**4. Corner joint**




A corner joint is formed when two metal sheets meet at an angle, commonly 90 degrees, to form a corner.

**Procedure:**

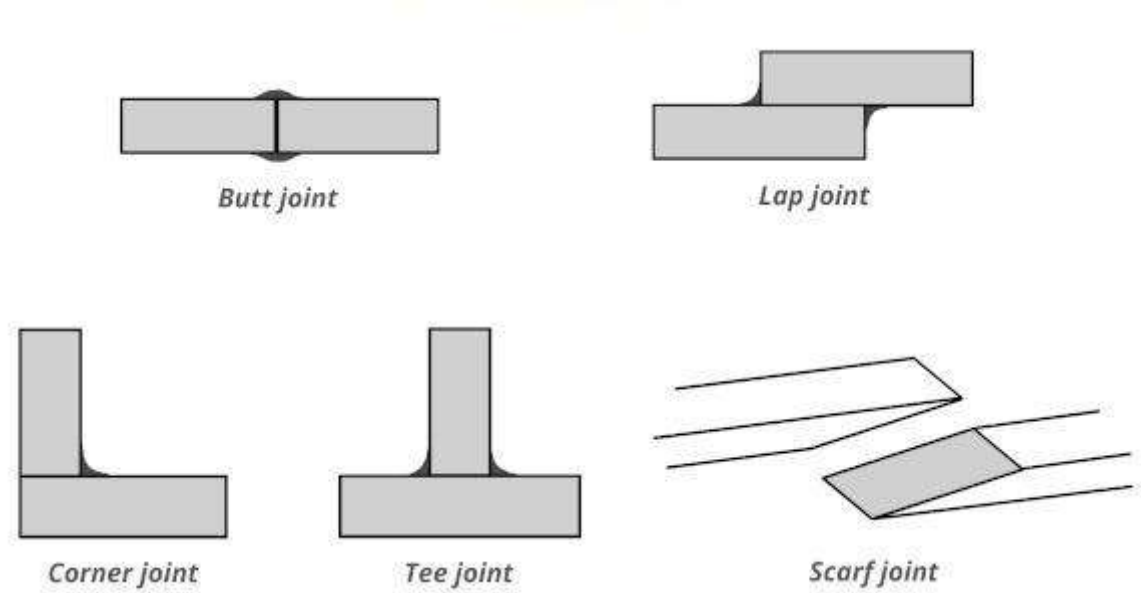
1. Cut the sheets to the required dimensions.
2. Prepare and clean the edges.
3. Arrange the sheets to form the required angle.
4. Secure the components using clamps.

5. Apply suitable flux.
6. Heat the joint evenly.
7. Apply the brazing filler metal.
8. Allow the filler to flow into the joint.
9. Remove the flame.
10. Allow the joint to cool.
11. Clean and inspect the finished joint.

**Applications:**

- Metal boxes.
- Sheet metal cabinets.
- Containers.
- Metal enclosures.

**5. Edge joint**




An edge joint is formed when the edges of two metal sheets are placed together or arranged in a suitable edge configuration and joined by filler metal.

**Applications:**

- Light sheet metal fabrication.
- Metal covers.
- Certain enclosure assemblies.

**9.3 Comparison of sheet metal brazed joints**

| Joint | Arrangement | Common application |
|---|---|---|
| Lap joint | One sheet overlaps another | Containers and sheet fabrication |
| Butt joint | Edges meet in the same plane | Panels and metal sheets |
| T-joint | One component meets another at 90° | Frames and brackets |
| Corner joint | Two sheets form a corner | Box and enclosures |

| | | |
|---|---|---|
| Edge joint | Sheet edges are joined | Light sheet fabrication |

**9.4 Factors affecting the choice of a sheet metal joint**

1. Thickness of the sheet metal.
2. Strength required.
3. Appearance of the finished component.
4. Type of parent metal.
5. Shape of the component.
6. Availability of working space.
7. Type of filler metal.
8. Type of service expected from the component.
9. Accessibility of the joint.
10. Cost of fabrication.

**10.0 DEFECTS IN BRAZED SHEET METAL JOINTS**

**10.1 Meaning of brazing defects**

Brazing defects are faults or imperfections that occur during or after brazing and reduce the strength, appearance, reliability or service performance of a joint.

Defects may result from poor surface preparation, unsuitable filler metals, incorrect heating, wrong joint clearance or improper cooling.

**10.2 Common defects in brazed joints**

**1. Porosity**

Porosity is the presence of small holes or cavities in the brazed joint.

Causes:

- Trapped gas.
- Contaminated metal surfaces.
- Excessive flux.
- Improper heating.
- Poor joint preparation.

Prevention:

- Clean the metal surfaces thoroughly.
- Use the correct flux.
- Control the heating process.
- Avoid contamination.
- Follow the correct brazing procedure.

**2. Incomplete filling**

This occurs when the filler metal does not completely fill the joint clearance.

Causes:

- Insufficient heating.
- Incorrect joint clearance.
- Poor wetting.
- Insufficient filler metal.
- Inappropriate filler selection.

Prevention:

- Use the correct heating temperature.
- Maintain proper joint clearance.
- Select a compatible filler metal.
- Apply suitable flux.
- Ensure uniform heating.

**3. Cracking**

Cracking refers to the formation of fractures in the filler metal or affected joint region.

Causes:

- Excessive heating.
- Rapid or inappropriate cooling.
- Excessive stresses.
- Poor joint design.
- Unsuitable filler metal.

Prevention:

- Select the correct filler metal.
- Avoid overheating.
- Use appropriate joint design.
- Control cooling.
- Avoid unnecessary mechanical stress.

**4. Oxidation**

Oxidation occurs when the metal reacts with oxygen during heating and forms an oxide layer.

Causes:

- Insufficient or unsuitable flux.
- Excessive heating.
- Poor surface preparation.
- Inadequate protection from oxidation.

Prevention:

- Use appropriate flux.
- Clean the metal surfaces.

- Control the heating process.
- Follow the correct brazing procedure.

**5. Poor wetting**

Poor wetting occurs when molten filler metal fails to spread properly over the parent metal surface.

Causes:

- Oil and grease contamination.
- Oxide films.
- Incorrect heating.
- Incompatible filler metal.
- Unsuitable flux.

Prevention:

- Clean the surfaces.
- Select the appropriate flux.
- Use compatible filler metal.
- Heat the joint correctly.

**6. Excessive filler metal**

This occurs when too much filler metal is applied to the joint, resulting in an unattractive or irregular appearance.

Causes:

- Poor control of filler feeding.
- Excessive application.
- Incorrect joint clearance.

Prevention:

- Feed the correct quantity of filler metal.
- Maintain the correct joint clearance.
- Use controlled heating.

**7. Distortion**

Distortion is the unwanted change in the shape or dimensions of the metal components due to heat.

Causes:

- Excessive heat.
- Uneven heating.
- Inadequate support.
- Poor clamping.

Prevention:

- Apply heat uniformly.
- Use appropriate fixtures.

- Avoid excessive heating.
- Support thin sheets properly.

**8. Flux inclusions or residues**

These occur when flux becomes trapped in the joint or remains on the workpiece after brazing.

Causes:

- Excessive flux application.
- Poor joint design.
- Inadequate post-brazing cleaning.

Prevention:

- Apply the correct amount of flux.
- Design the joint to allow proper flow.
- Remove residues using the recommended cleaning procedure.

**10.3 Inspection of brazed joints**

A brazed joint should be inspected to determine whether it meets the required standards.

**Methods of inspection include:**

1. **Visual inspection:** Examining the joint for cracks, poor filler flow, porosity and irregularities.
2. **Dimensional inspection:** Checking the dimensions and alignment of the components.
3. **Leak testing:** Checking pipe joints and containers for leakage using an appropriate approved test.
4. **Mechanical testing:** Testing suitable sample joints for strength using an approved method.
5. **Non-destructive testing:** Using appropriate techniques such as penetrant testing where suitable and performed by trained personnel.

## 11.0 USES AND APPLICATIONS OF BRAZING

Brazing is used in many engineering, manufacturing, construction and repair activities.







**11.1 Plumbing installations**

Brazing is used to join suitable copper pipes and fittings in plumbing installations.

Examples:

- Copper pipe joints.
- Pipe elbows.
- Pipe connectors.
- Plumbing fittings.

**11.2 Refrigeration and air-conditioning**

Brazing is used to join copper tubing in refrigeration and air-conditioning systems.

Examples:

- Refrigerant pipe connections.
- Copper fittings.
- Heat exchanger components.

**11.3 Automotive industry**

Brazing is used in the manufacture and repair of suitable vehicle components.

Examples:

- Radiators.
- Heat exchangers.
- Certain metal assemblies.

**11.4 Electrical and electronic industries**

Brazing is used in the manufacture of certain electrical and electronic components.

Examples:

- Electrical contacts.
- Copper connections.
- Specialised electrical assemblies.

**11.5 Metal fabrication**

Brazing is used in joining different fabricated metal components.

Examples:

- Metal frames.
- Sheet metal enclosures.
- Metal brackets.
- Suitable decorative metalwork.

**11.6 Aerospace industry**

Specialised brazing processes are used in the manufacture of certain aircraft and aerospace components.

Examples:

- Heat exchangers.
- Turbine assemblies.
- Specialised metal structures.

**11.7 Agricultural equipment**

Brazing may be used in suitable fabrication and repair work involving agricultural equipment.

Examples:

- Certain pipe assemblies.
- Suitable metal fittings.
- Light fabricated components.

**11.8 Domestic and commercial applications**

Examples include:

- Metal furniture components.
- Decorative metal items.
- Certain kitchen equipment.
- Metal containers.
- Suitable household fittings.

**12.0 MAINTENANCE OF BRAZING TOOLS AND EQUIPMENT**

**12.1 Meaning of maintenance**

Maintenance is the process of inspecting, cleaning, servicing, adjusting and repairing tools and equipment to keep them in good working condition.

Proper maintenance improves safety, accuracy, efficiency and the working life of brazing equipment.

**12.2 Importance of maintaining brazing tools**

1. Improves the safety of workshop operations.
2. Prevents equipment failure.
3. Extends the lifespan of tools.
4. Improves the quality of brazed joints.
5. Reduces repair and replacement costs.
6. Improves efficiency.
7. Prevents gas leakage.
8. Ensures accurate operation of equipment.

**12.3 Maintenance of oxyacetylene equipment**



**A. Maintenance of oxygen and acetylene cylinders**

1. Store cylinders upright and secure them.
2. Protect cylinders from excessive heat.
3. Keep cylinders away from oil and grease.
4. Ensure cylinder valves are protected.
5. Keep cylinders in well-ventilated storage areas.
6. Prevent cylinders from falling.
7. Check cylinders for visible damage.
8. Use the correct gas identification and labelling.

**B. Maintenance of pressure regulators**

1. Inspect regulators regularly.
2. Check gauges for damage.
3. Ensure connections are secure.
4. Keep regulators free from dirt.
5. Never apply oil or grease to oxygen regulators.
6. Replace damaged regulators through an authorised technician.
7. Store regulators appropriately when not in use.

**C. Maintenance of gas hoses**

1. Inspect hoses for cracks and cuts.
2. Check connections for leakage.
3. Keep hoses away from sharp edges.
4. Prevent hoses from coming into contact with hot metal.
5. Avoid twisting or crushing hoses.
6. Replace damaged hoses with approved replacements.
7. Store hoses neatly.

**D. Maintenance of brazing torches**

1. Clean the torch externally after use.
2. Inspect the torch for damage.
3. Check connections.
4. Keep the nozzle clean.
5. Use the correct nozzle-cleaning tools.
6. Do not enlarge nozzle openings using unsuitable objects.
7. Have defective torches serviced by qualified personnel.

**E. Maintenance of flashback arrestors**

1. Inspect the devices regularly.
2. Check their installation and condition.
3. Replace them according to manufacturer instructions.
4. Do not bypass safety devices.
5. Have faulty devices replaced by an authorised technician.

**12.4 Maintenance of other brazing tools**

| Tool | Maintenance practice |
|---|---|
| Brazing rods | Store in a dry, clean place |
| Flux containers | Keep closed and labelled |
| Wire brushes | Remove accumulated dirt and store dry |

| | |
|---|---|
| Files | Clean after use and store properly |
| Clamps | Clean, inspect and lubricate suitable moving parts |
| Vice | Clean, lubricate and inspect jaws |
| Tongs | Clean and inspect for damage |
| Measuring tools | Wipe clean and store safely |
| Safety goggles | Clean lenses and check for damage |
| Protective gloves | Clean and replace damaged gloves |

**12.5 Storage of brazing equipment**

1. Store gas cylinders in designated, ventilated locations.
2. Separate oxygen cylinders from fuel gas cylinders according to applicable storage requirements.
3. Store brazing rods in a dry environment.
4. Keep flux in sealed containers.
5. Store cleaning materials in designated locations.
6. Keep hoses neatly arranged.
7. Protect tools from moisture and corrosion.
8. Return all tools to their designated storage areas.

**13.0 SAFETY PRECAUTIONS WHEN CARRYING OUT BRAZING**

Brazing involves high temperatures, flammable gases, chemical fluxes, fumes and hot metal. Therefore, proper safety measures must be observed.



**13.1 Personal safety precautions**

1. Wear appropriate eye protection.

2. Wear heat-resistant gloves.
3. Wear a suitable protective apron.
4. Wear protective footwear.
5. Avoid loose clothing.
6. Tie back long hair.
7. Use suitable respiratory protection where required.
8. Avoid touching heated components with bare hands.

**13.2 Workshop safety precautions**

1. Ensure adequate ventilation.
2. Keep the working area clean.
3. Remove flammable materials.
4. Provide suitable fire extinguishers.
5. Display appropriate safety signs.
6. Keep unauthorised persons away from the brazing area.
7. Use suitable fire-resistant working surfaces.
8. Ensure emergency exits are accessible.

**13.3 Gas equipment safety precautions**

1. Inspect the cylinders before use.
2. Secure cylinders upright.
3. Use the correct regulators.
4. Inspect hoses and connections.
5. Check for leaks using approved methods.
6. Fit appropriate flashback arrestors.
7. Never use oil or grease on oxygen fittings.
8. Keep cylinders away from heat sources.
9. Close cylinder valves when equipment is not in use.
10. Follow the approved shutdown procedure.

**13.4 Safety when handling flux and filler metals**

1. Read the manufacturer's safety information.
2. Avoid direct skin contact with harmful fluxes.
3. Avoid inhaling fumes.
4. Use gloves when handling chemicals.
5. Store flux in labelled containers.
6. Wash hands after handling flux.
7. Remove flux residues appropriately.

8. Dispose of chemical waste safely.

**13.5 Environmental precautions**

1. Avoid releasing harmful fumes into enclosed spaces.
2. Use suitable extraction systems where necessary.
3. Dispose of waste materials correctly.
4. Prevent chemical contamination of soil and water.
5. Avoid unnecessary wastage of filler metals.
6. Keep the workshop clean after the operation.

**14.0 BRAZING PROJECT WORK AND PRACTICAL ACTIVITIES**

Project work allows learners to apply the knowledge, skills and attitudes acquired during brazing lessons.

Through practical activities, learners develop creativity, problem-solving skills, communication, collaboration and responsibility.

**14.1 Project 1: Making a brazed lap joint using sheet metal**



**Project objective**

To produce a sound lap joint by applying the correct brazing procedure.

**Materials required**

- Two suitable metal sheets.
- Appropriate brazing filler rod.
- Suitable flux.
- Cleaning materials.

**Tools and equipment**

- Steel rule.
- Scriber.
- Try square.
- Tin snips or suitable sheet metal cutting equipment.
- File.
- Wire brush.
- Clamps.
- Approved brazing torch equipment.
- PPE.

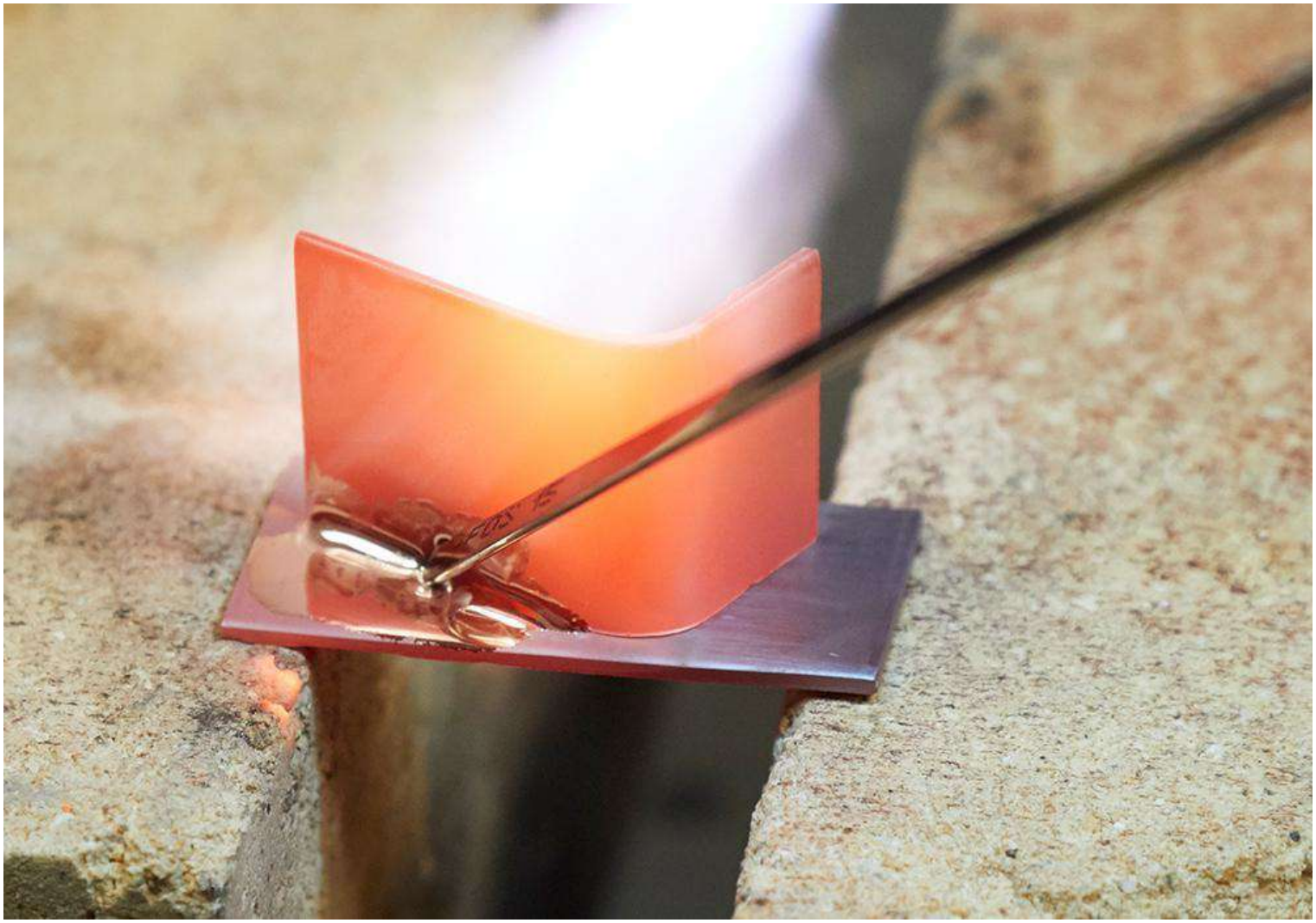
**Procedure**

1. Study the project drawing.
2. Measure the required sheet dimensions.
3. Mark out the components.
4. Cut the sheets.
5. Remove sharp edges.
6. Clean the joint surfaces.
7. Arrange the sheets to form a lap joint.
8. Maintain the recommended clearance.
9. Apply suitable flux.
10. Secure the sheets using clamps.
11. Heat the joint uniformly.
12. Introduce the filler metal.
13. Allow the filler to flow through the joint.
14. Remove the flame.
15. Allow controlled cooling.
16. Clean the joint.
17. Inspect the finished work.

**Expected outcome**

A properly aligned lap joint with continuous filler-metal flow and no visible cracks or major imperfections.

**14.2 Project 2: Producing a brazed T-joint**



**Objective**

To develop skills in positioning, heating and brazing components at right angles.

**Procedure**

1. Select suitable metal sheets.
2. Measure and cut the sheets.
3. Clean the joint surfaces.
4. Arrange the sheets to form a T-joint.
5. Check the angle using a try square.
6. Secure the sheets using a suitable jig.
7. Apply flux.
8. Heat the joint uniformly.
9. Introduce the filler rod.
10. Allow the filler to flow into the joint.
11. Remove the heat source.
12. Allow the joint to cool.
13. Clean and inspect the work.

**Expected outcome**

A well-aligned T-joint with a continuous and sound brazed connection.

### 14.3 Project 3: Making a brazed metal box



**Objective**

To apply brazing skills in producing a simple fabricated metal container.

**Materials**

- Suitable metal sheets.
- Brazing filler metal.
- Appropriate flux.

**Procedure**

1. Prepare a working drawing of the metal box.
2. Determine the dimensions.
3. Mark out the base and side panels.
4. Cut the sheets.
5. Form the required bends.
6. Clean the joint areas.
7. Assemble the panels.
8. Secure the panels in position.
9. Apply flux where required.
10. Braze the corner joints.
11. Allow controlled cooling.

12. Remove flux residues.
13. Inspect the joints.
14. Check the box dimensions and alignment.

**Expected outcome**

A neatly fabricated metal box with properly formed brazed corner joints.

### 14.4 Project 4: Brazing a copper pipe joint



**Objective**

To demonstrate the use of brazing in joining suitable copper pipes and fittings.

**Procedure**

1. Select the correct pipe and fitting.
2. Cut the pipe to the required length.
3. Remove burrs.
4. Clean the pipe and fitting surfaces.
5. Check the fitting clearance.
6. Apply the appropriate flux where required.
7. Assemble the pipe and fitting.
8. Heat the joint uniformly.
9. Introduce the correct filler metal.
10. Allow the filler to flow into the joint.
11. Remove the heat source.
12. Allow controlled cooling.

13. Clean the joint.
14. Inspect the joint.
15. Carry out an appropriate leak test if the component is intended for fluid service.

**14.5 Suggested practical learning activities**

| **Activity** | **Skills developed** |
|---|---|
| Identifying brazing equipment | Tool recognition |
| Identifying filler rods | Material selection |
| Identifying fluxes | Chemical selection |
| Cleaning sheet metal | Surface preparation |
| Preparing a lap joint | Joint preparation |
| Brazing a T-joint | Joint fabrication |
| Inspecting brazed joints | Quality control |
| Maintaining brazing tools | Equipment care |
| Producing a metal box | Project planning and fabrication |

**14.6 Assessment of brazing practical work**

The teacher may assess learners using the following criteria:

1. Correct selection of tools and equipment.
2. Correct identification of parent metals.
3. Proper measurement and marking out.
4. Correct preparation of joint surfaces.
5. Correct selection of filler metal.
6. Appropriate selection and application of flux.
7. Proper positioning of components.
8. Safe handling of heating equipment.
9. Correct application of filler metal.
10. Quality of the finished joint.
11. Proper cleaning and inspection.
12. Proper maintenance and storage of tools.

**PART TWO: TOPICAL REVISION QUESTIONS**

SECTION A – 30 MARKS

**SECTION A: MULTIPLE-CHOICE QUESTIONS**

**Instructions:** Answer all questions. Each question carries 1 mark. Choose the correct answer from the four alternatives provided.

**Question 1**

A metal fabrication workshop is required to join two copper components without melting the parent metals. The technician selects a process that uses a filler metal melting above 450°C. Which process should be used?

A. Soldering

B. Brazing

C. Fusion welding

D. Riveting

**Question 2**

During a brazing operation, the molten filler metal moves into the narrow gap between two metal surfaces. Which principle explains this movement?

A. Plastic deformation

B. Magnetic attraction

C. Capillary action

D. Thermal expansion

**Question 3**

A learner notices that filler metal is not spreading properly over the surface of a copper sheet. Which condition is most likely responsible?

A. Excessive surface cleanliness

B. Contamination by grease and oxide

C. Correct joint clearance

D. Uniform heating

**Question 4**

A technician is brazing copper pipe fittings in a refrigeration workshop. Which filler metal would be suitable for copper-to-copper joints when recommended by the manufacturer?

A. Copper-phosphorus filler rod

B. Ordinary steel welding electrode

C. Aluminium solder

D. Cast iron filler rod

**Question 5**

Which statement correctly describes the parent metal during brazing?

A. It is completely melted.

B. It is converted into a gas.

C. It remains solid while the filler metal melts.

D. It is removed before the filler is applied.

**Question 6**

A learner is preparing a steel component for brazing. Which tool is most suitable for removing loose surface oxides?

A. Hacksaw

B. Wire brush

C. Centre punch

D. Cold chisel

**Question 7**

A workshop technician applies flux before heating a metal joint. What is the main purpose of this substance?

A. To increase the thickness of the parent metal.

B. To prevent oxidation and improve wetting.

C. To cool the joint rapidly.

D. To increase the weight of the component.

**Question 8**

Which component of an oxyacetylene system reduces the high cylinder pressure to a suitable working pressure?

A. Torch nozzle

B. Gas hose

C. Pressure regulator

D. Flashback arrestor

**Question 9**

An oxyacetylene torch produces a flame with approximately balanced oxygen and acetylene supplies. What type of flame is produced?

A. Oxidising flame

B. Neutral flame

C. Carburising flame

D. Smoky flame

**Question 10**

A brazing technician is joining thin metal sheets. Which advantage makes brazing particularly suitable for the operation?

A. It requires melting the parent metals.

B. It always produces a rough surface.

C. It can reduce parent-metal distortion compared with fusion welding.

D. It does not require heat.

**Question 11**

Which of the following is a characteristic of silver brazing filler rods?

A. They are made entirely from aluminium.

B. They contain silver and other alloying elements.

C. They are always used without flux.

D. They are used only for joining cast iron.

**Question 12**

A learner applies too much heat to a thin metal sheet during brazing. Which defect is most likely to occur?

A. Distortion

B. Improved alignment

C. Increased dimensional accuracy

D. Perfect wetting

**Question 13**

Which joint is formed when one metal sheet overlaps another?

A. Butt joint

B. T-joint

C. Lap joint

D. Edge joint

**Question 14**

Two sheet metal components are arranged at right angles to form the shape of the letter T. Which joint is being prepared?

A. Lap joint

B. T-joint

C. Butt joint

D. Edge joint

**Question 15**

Which instrument is most appropriate for checking whether two components form a right angle before brazing?

A. Steel rule

B. Try square

C. Scriber

D. Wire brush

**Question 16**

A brazed joint contains numerous small holes. What is the defect known as?

A. Distortion

B. Porosity

C. Oxidation

D. Excessive overlap

**Question 17**

Which of the following is a likely cause of incomplete filling in a brazed joint?

A. Correct joint clearance

B. Sufficient heating

C. Insufficient heating

D. Proper surface preparation

**Question 18**

A technician is joining aluminium sheets. Which type of filler and flux should be selected?

A. Ordinary steel filler and borax only.

B. Aluminium-compatible filler and suitable aluminium flux where required.

C. Copper-phosphorus filler and ordinary oil.

D. Cast iron filler and water.

**Question 19**

What is the main purpose of a flashback arrestor?

A. To increase the temperature of the flame.

B. To prevent the flame from travelling backwards through the gas system.

C. To reduce the size of the metal sheet.

D. To increase filler metal flow.

**Question 20**

A learner uses a file before brazing a sheet metal joint. What is the main purpose?

A. To melt the sheet.

B. To remove burrs and smooth rough edges.

C. To increase the joint temperature.

D. To apply flux.

**Question 21**

Which of the following is a suitable application of brazing?

A. Joining copper plumbing pipes.

B. Producing wooden furniture.

C. Cutting thick steel plates.

D. Painting metal surfaces.

**Question 22**

A technician wants to hold two sheet metal components firmly in position during brazing. Which equipment is most suitable?

A. Clamps

B. Scriber

C. Centre punch

D. Emery cloth

**Question 23**

What is likely to happen when the joint clearance is excessively wide?

A. Capillary action may become ineffective.

B. The parent metals will always melt.

C. The filler metal will become a gas.

D. The joint will automatically become stronger.

**Question 24**

Which of the following is a good practice when storing brazing filler rods?

A. Exposing them to rain.

B. Keeping them in oily water.

C. Storing them in a clean and dry place.

D. Leaving them scattered on the floor.

**Question 25**

Which defect results when the molten filler metal fails to spread properly over the parent metal?

A. Poor wetting

B. Distortion

C. Excessive penetration

D. Mechanical polishing

**Question 26**

A brazing operator is about to use oxygen equipment. Which practice is unsafe?

A. Inspecting the regulator.

B. Checking hoses for leaks.

C. Applying oil or grease to oxygen fittings.

D. Securing the cylinder upright.

**Question 27**

Why should flux residues be removed after brazing?

A. They may cause corrosion or other damage.

B. They increase the thickness of the sheet.

C. They improve the colour of every metal.

D. They make the joint melt again.

**Question 28**

Which of the following is the most appropriate way of assessing the appearance of a brazed joint?

A. Visual inspection.

B. Measuring the workshop temperature only.

C. Weighing the gas cylinders.

D. Checking the colour of the filler rod before use.

**Question 29**

A learner is assigned a project to produce a small metal box using brazing. Which joint is particularly useful for joining the meeting side panels?

A. Corner joint

B. Butt joint only

C. Edge joint only

D. Straight lap joint only

**Question 30**

Which action demonstrates responsible environmental practice after brazing?

A. Pouring chemical residues into a drainage channel.

B. Leaving used flux containers open.

C. Disposing of chemical waste using approved procedures.

D. Burning all waste materials in the workshop.

SECTION B – 50 MARKS

**SECTION B: STRUCTURED QUESTIONS**

**Instructions:** Answer all questions. Show clear explanations and use labelled diagrams where necessary.

**QUESTION 1: INTRODUCTION AND PRINCIPLES OF BRAZING (8 MARKS)**

A metal fabrication enterprise in Kenya receives an order to manufacture copper and brass components for a commercial plumbing installation. The workshop supervisor recommends brazing because the components must be joined without melting the parent metals.

a) Define brazing. (2 marks)

b) Explain three characteristics of brazing that distinguish it from fusion welding. (3 marks)

c) Explain how capillary action contributes to the formation of a brazed joint. (3 marks)

**QUESTION 2: TOOLS, EQUIPMENT AND FILLER MATERIALS (8 MARKS)**

A Grade 11 learner is preparing to carry out a practical brazing exercise using oxyacetylene equipment.

a) Identify four components of oxyacetylene equipment used during brazing. (4 marks)

b) State two functions of brazing flux. (2 marks)

c) Give two examples of brazing filler metals and state one suitable application for each. (2 marks)

**QUESTION 3: BRAZING PROCEDURE (10 MARKS)**

A workshop is required to join two thin copper sheets using a lap joint. The quality of the finished component depends on correct preparation and heating.

a) Describe six steps involved in preparing the copper sheets before brazing. (6 marks)

b) Explain four steps involved in applying filler metal and completing the brazed joint. (4 marks)

**QUESTION 4: TYPES OF JOINTS AND THEIR APPLICATIONS (8 MARKS)**

A metal fabrication workshop manufactures sheet metal containers, brackets and metal enclosures.

a) Explain four types of joints that can be produced through brazing of suitable sheet metal components. (4 marks)

b) State four applications of brazing in metal fabrication and engineering industries. (4 marks)

**QUESTION 5: DEFECTS AND QUALITY CONTROL (8 MARKS)**

During an inspection of brazed metal sheets, a quality-control technician identifies joints with holes, cracks, incomplete filler flow and distorted surfaces.

a) Identify four defects that may occur in brazed joints. (4 marks)

b) Explain four measures that can be taken to prevent defects during brazing. (4 marks)

**QUESTION 6: MAINTENANCE AND WORKSHOP SAFETY (8 MARKS)**

A school metal technology workshop has recently purchased oxyacetylene equipment for practical brazing lessons. The workshop technician is required to ensure that the equipment remains safe and serviceable.

a) Explain four maintenance practices for oxyacetylene brazing equipment. (4 marks)

b) State four safety precautions that must be observed during brazing operations. (4 marks)

**PART THREE: MARKING SCHEME**

**SECTION A: MULTIPLE-CHOICE ANSWERS (30 MARKS)**

Each correct answer carries 1 mark.

| Question | Answer |
|---|---|
| 1 | B |
| 2 | C |
| 3 | B |
| 4 | A |
| 5 | C |
| 6 | B |
| 7 | B |
| 8 | C |
| 9 | B |
| 10 | C |
| 11 | B |
| 12 | A |
| 13 | C |
| 14 | B |
| 15 | B |
| 16 | B |
| 17 | C |
| 18 | B |
| 19 | B |
| 20 | B |
| 21 | A |
| 22 | A |
| 23 | A |
| 24 | C |
| 25 | A |
| 26 | C |
| 27 | A |
| 28 | A |
| 29 | A |
| 30 | C |

SECTION A: 30/30 MARKS

**SECTION B: STRUCTURED MARKING SCHEME (50 MARKS)**

**QUESTION 1: INTRODUCTION AND PRINCIPLES OF BRAZING (8 MARKS)**

**a) Define brazing. (2 marks)**

Brazing is a thermal metal-joining process in which two or more parent metal components are joined by melting a suitable filler metal with a liquidus temperature above 450°C, without melting the parent metals. (2 marks)

**b) Explain three characteristics of brazing that distinguish it from fusion welding. (3 marks)**

Award 1 mark for each correctly explained characteristic.

1. Parent metals remain solid during brazing, unlike fusion welding where the parent metal is melted.
2. Brazing uses a separate filler metal that melts at a lower temperature than the parent metals.
3. Molten filler metal flows into the joint through capillary action.

**c) Explain how capillary action contributes to the formation of a brazed joint. (3 marks)**

Award 1 mark for each point.

1. Two clean metal surfaces are arranged close together with a suitable clearance.
2. Molten filler metal wets the surfaces and is drawn into the gap by capillary forces.
3. The filler metal solidifies on cooling to form a permanent joint.

**QUESTION 2: TOOLS, EQUIPMENT AND FILLER MATERIALS (8 MARKS)**

**a) Identify four components of oxyacetylene equipment. (4 marks)**

Award 1 mark each.

1. Oxygen cylinder.
2. Acetylene cylinder.
3. Pressure regulators.
4. Gas hoses.
5. Brazing torch.
6. Torch nozzle.
7. Flashback arrestors.

Any four.

**b) State two functions of brazing flux. (2 marks)**

Award 1 mark each.

1. Removes or dissolves oxide films from metal surfaces.
2. Prevents further oxidation during heating.
3. Improves wetting of the parent metal.
4. Promotes the flow of molten filler metal.

Any two.

**c) Give two examples of brazing filler metals and state one suitable application for each. (2 marks)**

Award 1 mark for each correct combination.

| Filler metal | Application |
|---|---|
| Brass brazing rod | Joining suitable steel components |
| Silver brazing alloy | Joining copper pipes and suitable stainless steel components |
| Copper-phosphorus rod | Joining copper-to-copper pipes |
| Aluminium brazing rod | Joining suitable aluminium components |
| Nickel-based filler | Specialised heat exchangers and engineering components |

Any two correct combinations.

**QUESTION 3: BRAZING PROCEDURE (10 MARKS)**

**a) Describe six steps involved in preparing copper sheets before brazing. (6 marks)**

Award 1 mark for each well-described step.

1. **Measurement:** Measure the copper sheets according to the required dimensions.
2. **Marking out:** Mark the cutting dimensions and overlap allowance.
3. **Cutting:** Cut the sheets using suitable cutting tools.
4. **Deburring:** Remove sharp edges and burrs using a file.
5. **Cleaning:** Remove oxides and dirt using a suitable wire brush or abrasive paper.
6. **Degreasing:** Remove grease and oil using a suitable cleaning agent.
7. **Fitting:** Arrange the sheets to form the required lap joint.
8. **Clearance:** Maintain the correct joint clearance.
9. **Flux application:** Apply suitable flux to the joint surfaces where required.
10. **Clamping:** Secure the sheets to maintain alignment.

Any six.

**b) Explain four steps involved in applying filler metal and completing the brazed joint. (4 marks)**

Award 1 mark each.

1. **Heating:** Heat the joint uniformly using the appropriate flame.
2. **Applying filler:** Introduce the correct brazing rod into the heated joint.
3. **Filler flow:** Allow the molten filler metal to flow into the joint through capillary action.
4. **Cooling:** Remove the flame and allow the joint to cool without disturbing it.
5. **Cleaning:** Remove flux residues using the recommended method.
6. **Inspection:** Examine the joint for cracks, porosity and incomplete filling.

Any four.

**QUESTION 4: TYPES OF JOINTS AND THEIR APPLICATIONS (8 MARKS)**

**a) Explain four types of joints that can be produced through brazing. (4 marks)**

Award 1 mark for each correct explanation.

1. **Lap joint:** Formed when one metal sheet overlaps another and the overlapping surfaces are brazed together.
2. **Butt joint:** Formed when two metal sheets meet edge to edge in the same plane and are joined using filler metal.
3. **T-joint:** Formed when one metal component meets another at approximately 90 degrees, forming the shape of the letter T.
4. **Corner joint:** Formed when two metal sheets meet at an angle to form a corner.
5. **Edge joint:** Formed when two sheet metal edges are arranged together and joined using filler metal.

Any four.

**b) State four applications of brazing. (4 marks)**

Award 1 mark each.

1. Joining copper plumbing pipes.
2. Joining refrigeration and air-conditioning components.
3. Manufacturing suitable automotive radiator assemblies.
4. Joining metal sheet enclosures.
5. Manufacturing suitable heat exchangers.
6. Joining electrical contacts.
7. Producing suitable metal frames and brackets.
8. Manufacturing specialised aerospace components.

Any four.

**QUESTION 5: DEFECTS AND QUALITY CONTROL (8 MARKS)**

**a) Identify four defects that may occur in brazed joints. (4 marks)**

Award 1 mark each.

1. Porosity.
2. Cracking.
3. Incomplete filling.
4. Poor wetting.
5. Oxidation.
6. Distortion.
7. Excessive filler metal.
8. Flux inclusions.

Any four.

**b) Explain four measures that can be taken to prevent defects during brazing. (4 marks)**

Award 1 mark each for a correct measure with explanation.

1. **Proper cleaning:** Remove oil, grease and oxides to improve wetting.
2. **Correct heating:** Heat the joint uniformly to prevent [illegible] filling and overheating.

3. **Correct joint clearance:** Maintain the recommended gap to allow capillary flow.
4. **Suitable filler metal:** Select a compatible filler to ensure proper bonding.
5. **Correct flux:** Use flux suitable for the parent and filler metals.
6. **Controlled cooling:** Follow the appropriate cooling procedure to reduce thermal stresses.
7. **Proper clamping:** Hold components securely to prevent distortion and movement.
8. **Correct filler application:** Apply sufficient filler metal without excessive accumulation.

Any four.

**QUESTION 6: MAINTENANCE AND WORKSHOP SAFETY (8 MARKS)**

**a) Explain four maintenance practices for oxyacetylene brazing equipment. (4 marks)**

Award 1 mark each.

1. **Cylinder maintenance:** Store cylinders upright, secure them and protect them from excessive heat.
2. **Regulator maintenance:** Inspect gauges and connections regularly and replace damaged regulators.
3. **Hose maintenance:** Check hoses for cracks, damage and gas leaks.
4. **Torch maintenance:** Clean the torch and nozzle using approved cleaning tools.
5. **Flashback arrestor maintenance:** Inspect and replace faulty devices according to manufacturer instructions.
6. **General storage:** Store equipment in clean, dry and designated locations.

Any four.

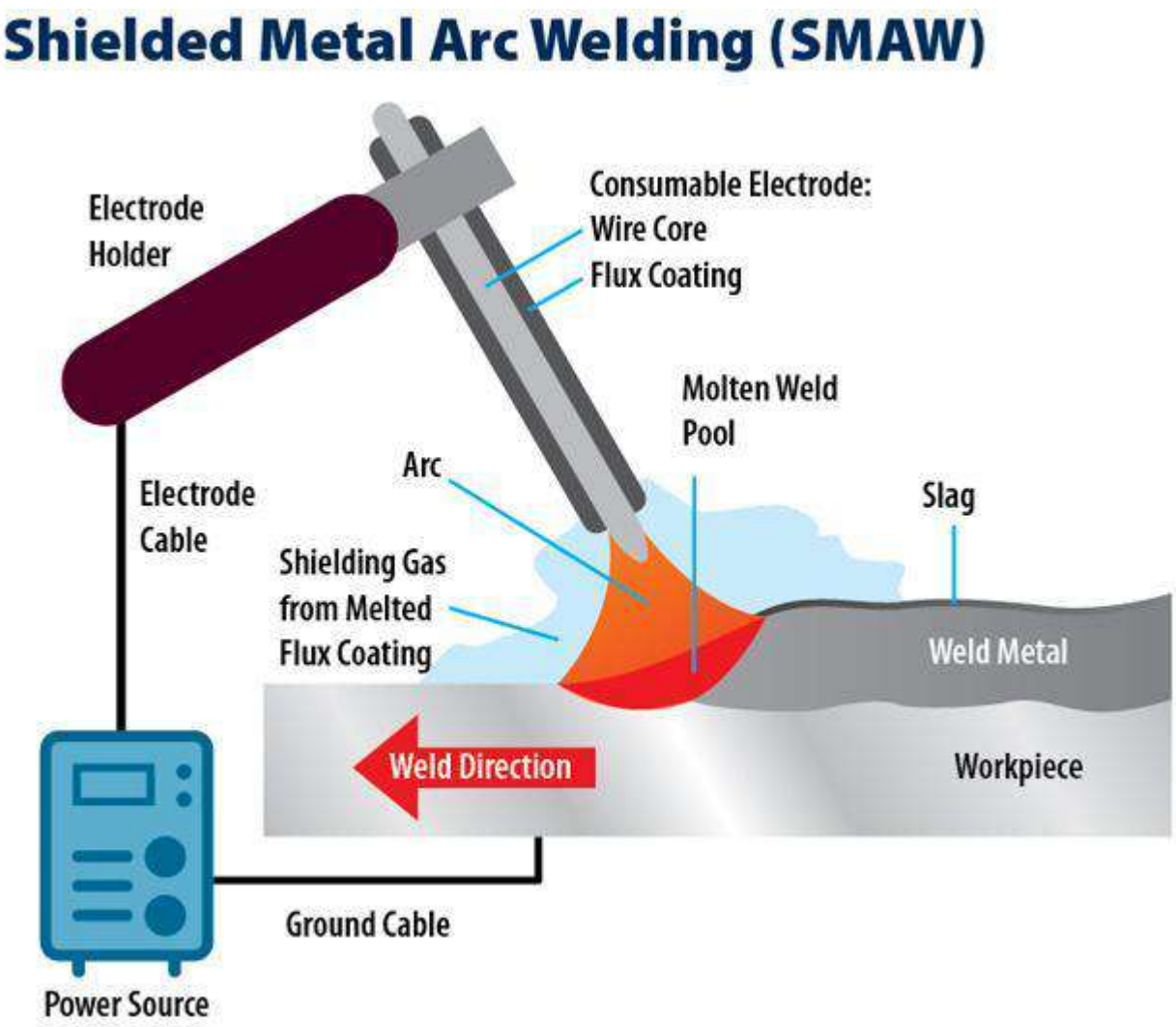
**b) State four safety precautions during brazing. (4 marks)**

Award 1 mark each.

1. Wear suitable eye protection and heat-resistant gloves.
2. Ensure adequate workshop ventilation.
3. Keep flammable materials away from the brazing area.
4. Inspect hoses and connections for gas leaks before operation.
5. Secure gas cylinders upright.
6. Never apply oil or grease to oxygen equipment.
7. Keep a suitable fire extinguisher accessible.
8. Use an approved spark lighter.
9. Keep unauthorised persons away from the brazing area.
10. Follow the approved shutdown procedure.

Any four.




Shielded Metal Arc Welding (SMAW)
Electrode Holder
Consumable Electrode:
Wire Core
Flux Coating
Molten Weld Pool
Arc
Electrode Cable
Slag
Shielding Gas from Melted Flux Coating
Weld Metal
Weld Direction
Workpiece
Ground Cable
Power Source



## 1.0 INTRODUCTION TO MANUAL METAL ARC WELDING

Manual Metal Arc Welding (MMAW) is one of the most widely used metal joining processes in engineering, fabrication, construction, repair and maintenance workshops.

It is commonly used in Kenya by:

- Metal fabrication workshops.
- Construction companies.
- Agricultural machinery repair workshops.
- Vehicle body repair workshops.
- Steel gate and window fabricators.
- Water tank and steel structure manufacturers.
- Industrial maintenance departments.

MMAW is also known as:

- Shielded Metal Arc Welding (SMAW).
- Stick welding.
- Manual electrode arc welding.
- Electric arc welding using a flux-coated electrode.

The process uses electrical energy to generate intense heat that melts the edges of metal pieces and a consumable electrode, forming a permanent joint after cooling.

### 1.1 Definition of Manual Metal Arc Welding

Manual Metal Arc Welding is a thermal metal joining process in which an electric arc is produced between a flux-coated consumable electrode and a metal workpiece to generate heat that melts the metal and forms a permanent welded joint.

**Important terms**

1. **Manual:** The welder controls the movement of the electrode by hand.
2. **Metal:** The materials being joined are metallic materials, commonly mild steel.
3. **Arc:** A sustained electrical discharge between the electrode and the workpiece.
4. **Welding:** The process of joining two or more metal components through heat, pressure or both.

### 1.2 Meaning of Thermal Joining Process

A thermal joining process is a method of joining materials using heat to soften or melt the materials at the joint.

In MMAW:

- Electrical energy is converted into heat energy.
- The heat melts the electrode tip and the edges of the workpieces.
- Molten electrode metal forms the weld metal.
- The molten metal solidifies on cooling.
- A strong permanent joint is produced.

### 1.3 Importance of Manual Metal Arc Welding in Society

Manual metal arc welding is important because it provides an effective way of manufacturing, repairing and maintaining metallic structures and equipment.

Its importance includes:

1. **Construction of buildings:** Used to join steel reinforcement components, structural steel members, roof trusses and support frames.
2. **Agricultural machinery repair:** Used to repair ploughs, trailers, cultivators, wheelbarrows and other farm equipment.
3. **Vehicle repairs:** Used in repairing vehicle chassis, brackets, metal frames and other suitable steel components.
4. **Fabrication of gates:** Used to join metal bars, hinges, frames and decorative steel components.
5. **Water infrastructure:** Used to fabricate and repair suitable steel pipes, tanks and support structures.
6. **Manufacturing industries:** Used in producing metal products, machinery frames and industrial equipment.
7. **Employment creation:** Provides opportunities for self-employment and employment in welding and fabrication enterprises.
8. **Maintenance of school facilities:** Can be used to repair desks, metal doors, window frames and workshop equipment.
9. **Economic development:** Supports the growth of construction, manufacturing and engineering industries.
10. **Recycling and repair:** Enables damaged metal components to be repaired instead of being discarded.

**Kenyan context:** A metalwork artisan in Kilgoris can use MMAW to fabricate school desks, repair farm trailers, construct gates and make steel window frames for local customers.

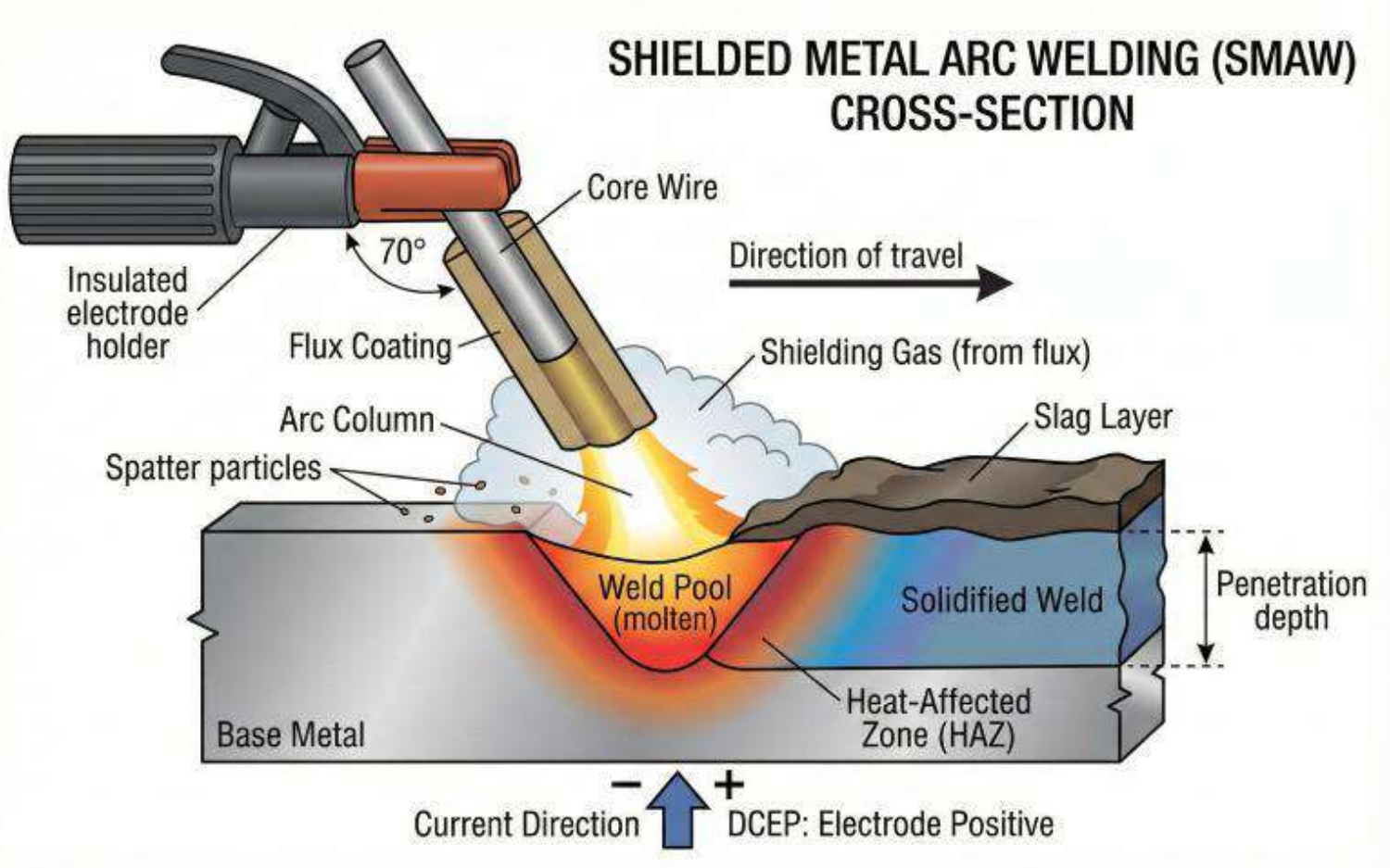
## 2.0 PRINCIPLE OF OPERATION OF MANUAL METAL ARC WELDING

**2.1 How Manual Metal Arc Welding Works**

MMAW operates on the principle of an electric arc generated between an electrode and a workpiece.

The process involves the following stages:

1. **Power supply:** The welding machine supplies low-voltage, high-current electrical energy.
2. **Electrode connection:** The electrode is held in an electrode holder connected to the power source.
3. **Workpiece connection:** The workpiece is connected to the welding circuit through the earth or work clamp.
4. **Arc initiation:** The welder briefly touches the electrode against the workpiece and withdraws it slightly to establish an arc.
5. **Heat generation:** The electric arc produces intense heat, melting the electrode tip and the edges of the workpiece.
6. **Formation of molten pool:** The melted electrode metal and workpiece metal form a molten weld pool.
7. **Shielding:** The flux coating decomposes and produces shielding gases and slag that protect the molten weld metal from atmospheric contamination.
8. **Electrode movement:** The welder moves the electrode along the joint at a controlled speed.
9. **Solidification:** The molten metal cools and solidifies to form the welded joint.
10. **Slag removal:** After cooling, the slag covering the weld is removed using a chipping hammer and wire brush where appropriate.




**2.2 Main Components of an MMAW System**

The main components include:

- Welding power source.

- Electrode holder.
- Flux-coated electrode.
- Welding cables.
- Work or earth clamp.
- Workpiece.
- Protective equipment.

**2.3 The Electric Arc**

An electric arc is a continuous electrical discharge that occurs between the electrode and the workpiece when the welding circuit is completed.

**Characteristics of an electric arc:**

1. Produces very high temperatures.
2. Generates intense light.
3. Produces ultraviolet and infrared radiation.
4. Melts the electrode and base metal.
5. Requires a suitable electrical power source.
6. Produces sparks, fumes and spatter.

**Importance of the electric arc**

- Provides the heat needed for melting metals.
- Enables fusion between the electrode metal and the workpiece.
- Determines the rate at which the metal melts.
- Influences weld penetration and weld quality.

**2.4 Functions of the Flux Coating**

The flux coating is a layer of special chemical materials covering the metal core of a welding electrode.

Its functions include:

1. Producing shielding gases that protect molten metal from oxygen and nitrogen in the atmosphere.
2. Forming slag that covers the molten weld pool.
3. Stabilising the electric arc.
4. Helping to remove impurities from the molten metal.
5. Reducing oxidation of the weld metal.
6. Improving the appearance of the finished weld.
7. Controlling the transfer of molten metal from the electrode to the workpiece.
8. Introducing alloying elements into the weld metal in some electrode types.

**Note:** The flux coating is essential to the MMAW process. An electrode with a damaged or unsuitable coating may produce poor-quality welds.

**3.0 TOOLS AND EQUIPMENT USED IN MANUAL METAL ARC WELDING**

The successful performance of MMAW requires suitable tools, equipment and accessories.

These items are used for preparing materials, establishing the electric arc, controlling the welding process and cleaning the finished joint.

**3.1 Welding Power Source**




A welding power source is an electrical machine that supplies the current and voltage required to produce and maintain an electric arc.

**Functions:**

1. Supplies electrical energy for welding.
2. Controls the welding current.
3. Provides suitable output characteristics for stable arc operation.
4. May provide either alternating current (AC), direct current (DC), or both, depending on the machine.

5. Enables the welder to adjust current according to electrode size and welding conditions.

**Types of welding power sources:**

a) Transformer welding machine

- Uses a transformer to reduce mains voltage to a suitable welding voltage.
- Commonly supplies AC welding current.
- Usually heavier than small inverter machines.

b) Rectifier welding machine

- Converts AC electrical input into DC output.
- Provides direct current for welding.
- Can provide a relatively stable arc.

c) Inverter welding machine

- Uses electronic circuits to control electrical power.
- Usually lightweight and portable.
- Common in modern fabrication workshops.
- Often allows easy adjustment of welding current.

**3.2 Electrode Holder**




An electrode holder is an insulated device used to grip and hold the welding electrode during the welding operation.

**Functions:**

1. Holds the electrode firmly.
2. Conducts welding current to the electrode.
3. Enables the welder to control the electrode angle.
4. Allows the electrode to be changed safely when the machine is switched off and appropriate procedures are followed.

**Characteristics of a good electrode holder:**

- Strong gripping jaws.
- Proper electrical insulation.
- Good electrical conductivity.
- Comfortable handle.
- Heat-resistant construction.
- No exposed live conductive parts that could cause electric shock.

**3.3 Welding Cables**




Welding cables are flexible electrical conductors used to connect the welding machine to the electrode holder and work clamp.

**Types:**

1. Electrode cable: Carries welding current from the power source to the electrode holder.

2. Work-return cable: Completes the electrical circuit by connecting the work clamp to the power source.

**Functions:**

- Transmit welding current.
- Complete the welding circuit.
- Allow the welder to work at a suitable distance from the machine.

**Care of welding cables:**

- Avoid dragging cables over sharp metal edges.
- Keep cables away from hot surfaces.
- Inspect insulation regularly.
- Replace damaged cables.
- Avoid excessive bending and twisting.
- Keep electrical connections clean and tight.

**3.4 Work Clamp (Earth Clamp)**




A work clamp is a device used to connect the workpiece or welding table electrically to the welding power source.

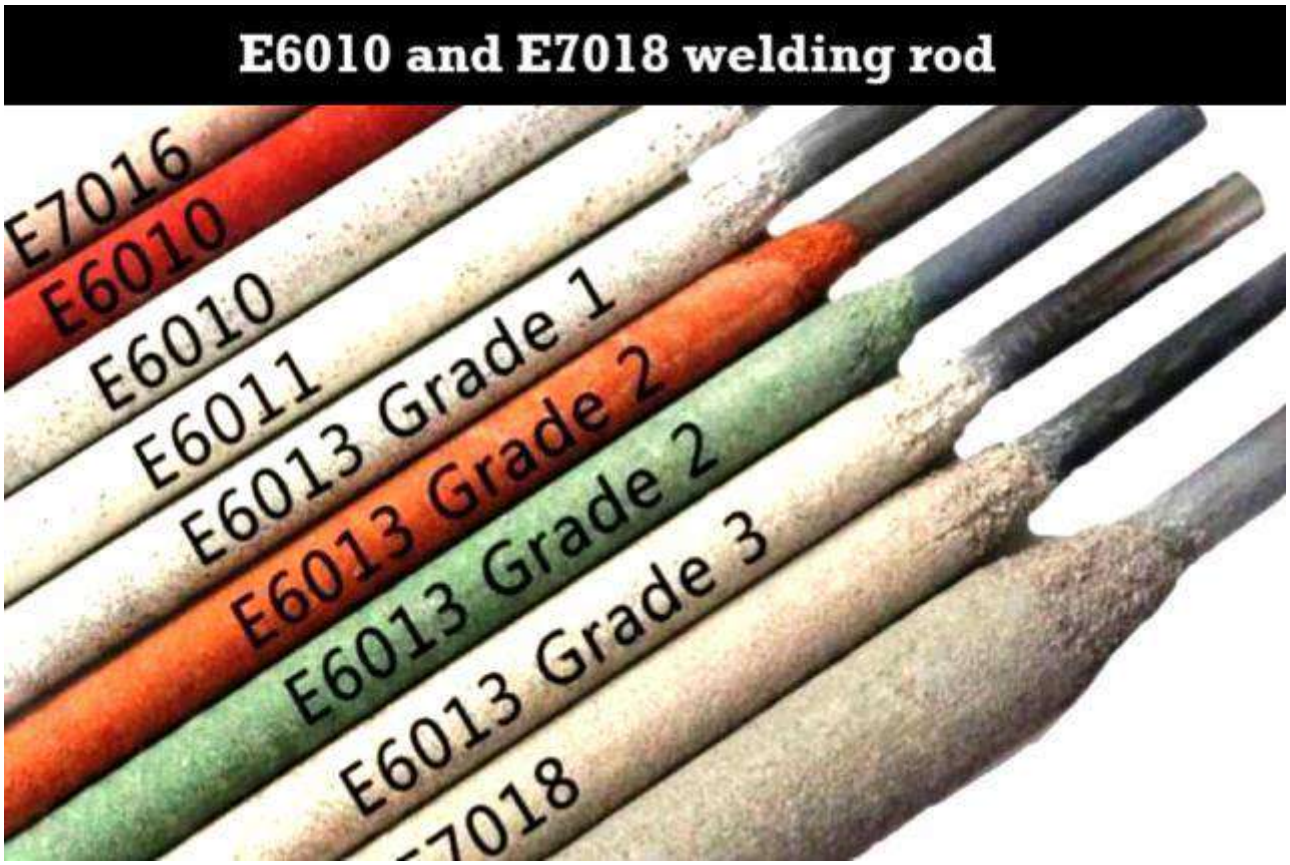
**Functions:**

1. Completes the electrical welding circuit.
2. Provides a reliable return path for the welding curre...

3. Helps maintain a stable arc.
4. Reduces the risk of unwanted electrical heating at poor connections.

**Important:** The work clamp should be attached to a clean, suitable metal surface close to the welding area.

**3.5 Welding Electrodes**




A welding electrode is a metal rod coated with flux, used to conduct current and supply filler metal during MMAW.

**Main parts of a coated electrode:**

1. Metal core wire: Supplies filler metal to the weld.
2. Flux coating: Protects and stabilises the welding process.
3. Bare gripping end: Provides electrical contact with the electrode holder.

**Types of welding electrodes according to coating characteristics:**

a) Rutile electrodes

- Contain a high proportion of titanium dioxide in their coating.
- Generally provide easy arc striking.
- Produce relatively smooth weld beads.
- Commonly used for general fabrication.

b) Basic or low-hydrogen electrodes

- Designed to produce weld metal with low hydrogen content when correctly stored and handled.
- Used for applications where weld quality and resistance to hydrogen cracking are important.
- Often require controlled storage and drying according to the manufacturer's instructions.

c) Cellulosic electrodes

- Have coatings containing cellulose.
- Produce a forceful arc.
- Commonly used in certain pipe-welding applications.

d) Acid electrodes

- Have coatings containing iron oxides and other minerals.
- Produce particular slag and weld-metal characteristics.
- Their use depends on the application and electrode specification.

**3.5.1 Electrode Identification**

Electrodes are classified using codes that indicate their properties.

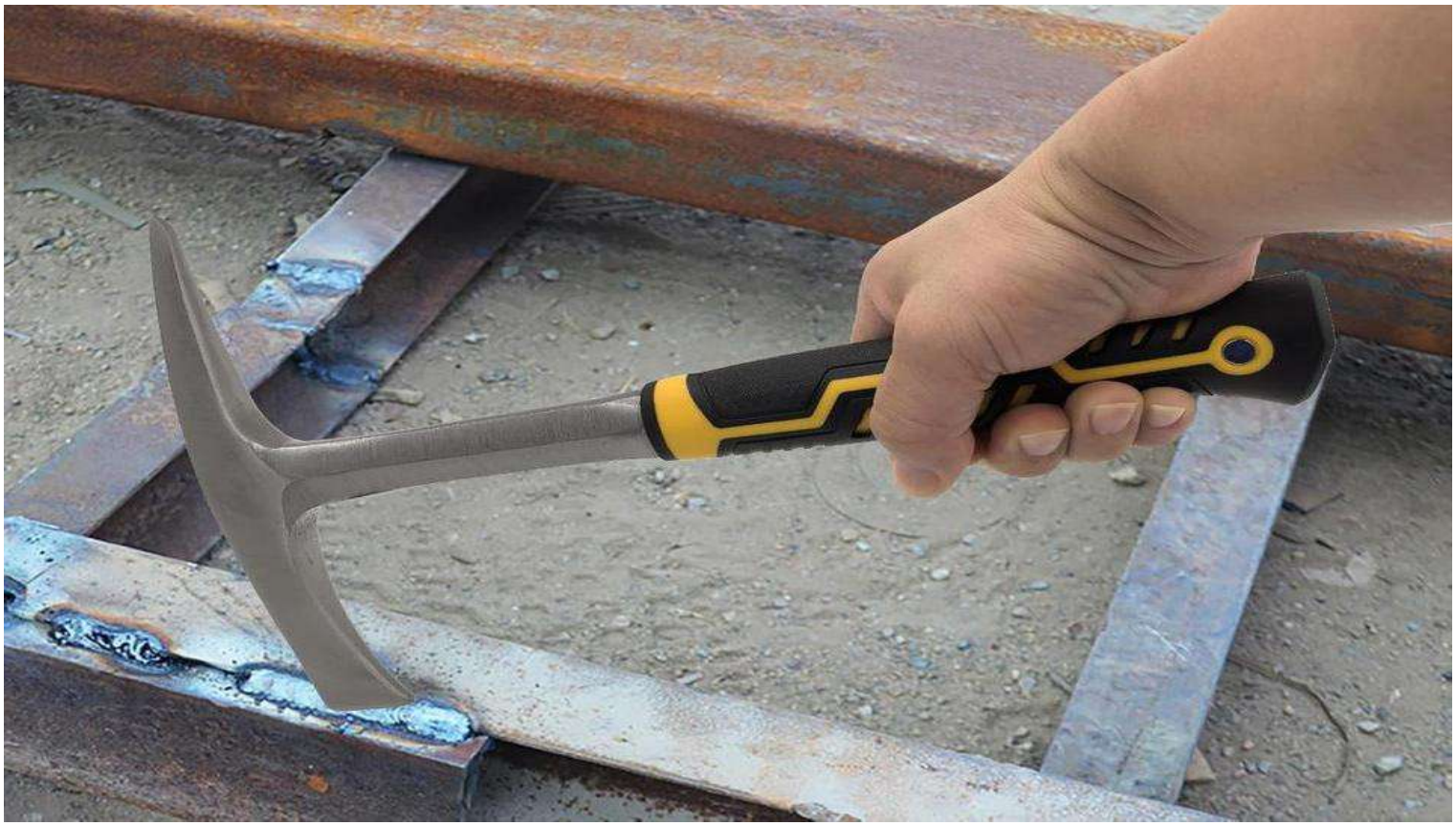
For example, an electrode marked **E6013** can be interpreted as follows:

- E – Electrode.
- 60 – Minimum tensile strength of 60,000 pounds per square inch (approximately 414 MPa).
- 1 – Suitable for all common welding positions, subject to the manufacturer's classification.
- 3 – Indicates the type of coating and current characteristics.

Another example is E7018, a low-hydrogen electrode commonly used in structural steel fabrication.

**Note:** Always select electrodes according to the base metal, joint design, welding position, power source and manufacturer's specifications.

**3.6 Chipping Hammer**



A chipping hammer is a hand tool used to remove slag from the surface of a completed weld.

**Functions:**

- Removes solidified slag.

- Exposes the weld bead for inspection.
- Helps identify surface defects.
- Prepares the weld for further cleaning or additional passes.

**3.7 Wire Brush**

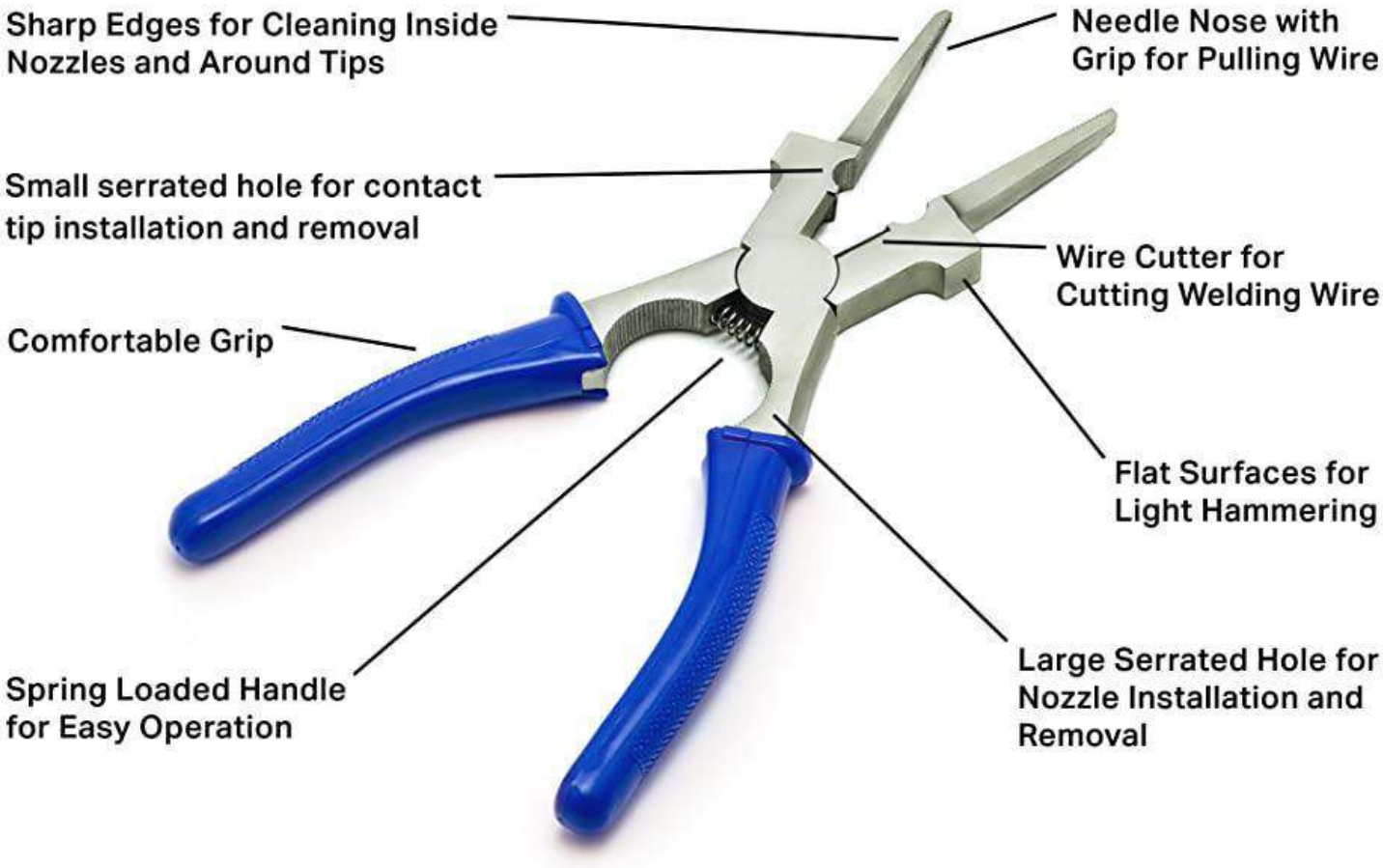


A wire brush is a cleaning tool fitted with steel wires used to remove loose slag, rust and surface dirt.

**Functions:**

1. Cleans the weld surface.
2. Removes loose slag after chipping.
3. Removes surface contamination.
4. Prepares metal for inspection or further welding.

**3.8 Welding Pliers**

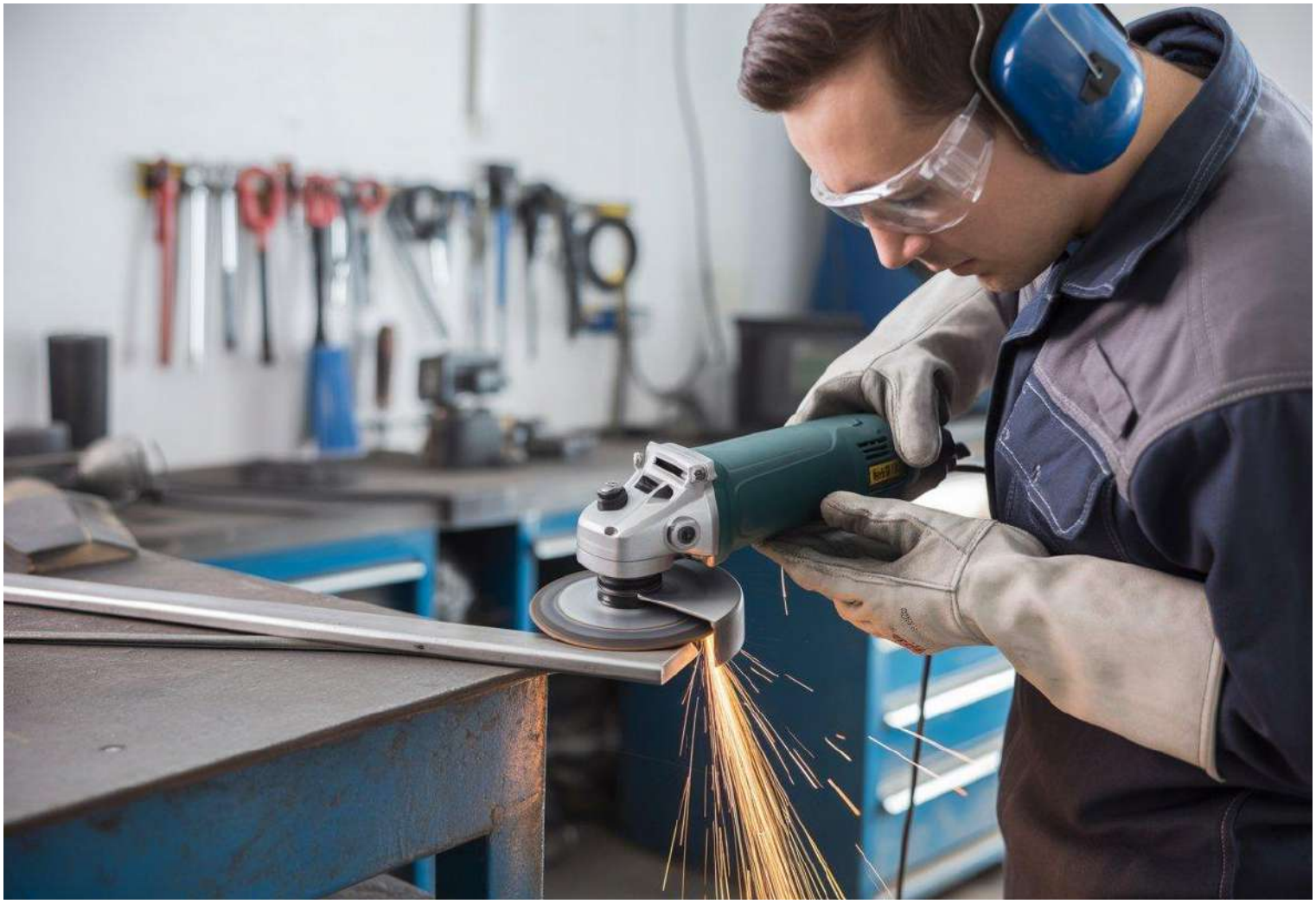



Welding pliers are hand tools used for handling and cleaning welding components.

**Uses:**

- Removing hot electrode stubs using appropriate safe procedures.
- Removing spatter.
- Holding small metal components.
- Cleaning welding nozzles where applicable.
- Handling suitable welding accessories.

**3.9 Angle Grinder**



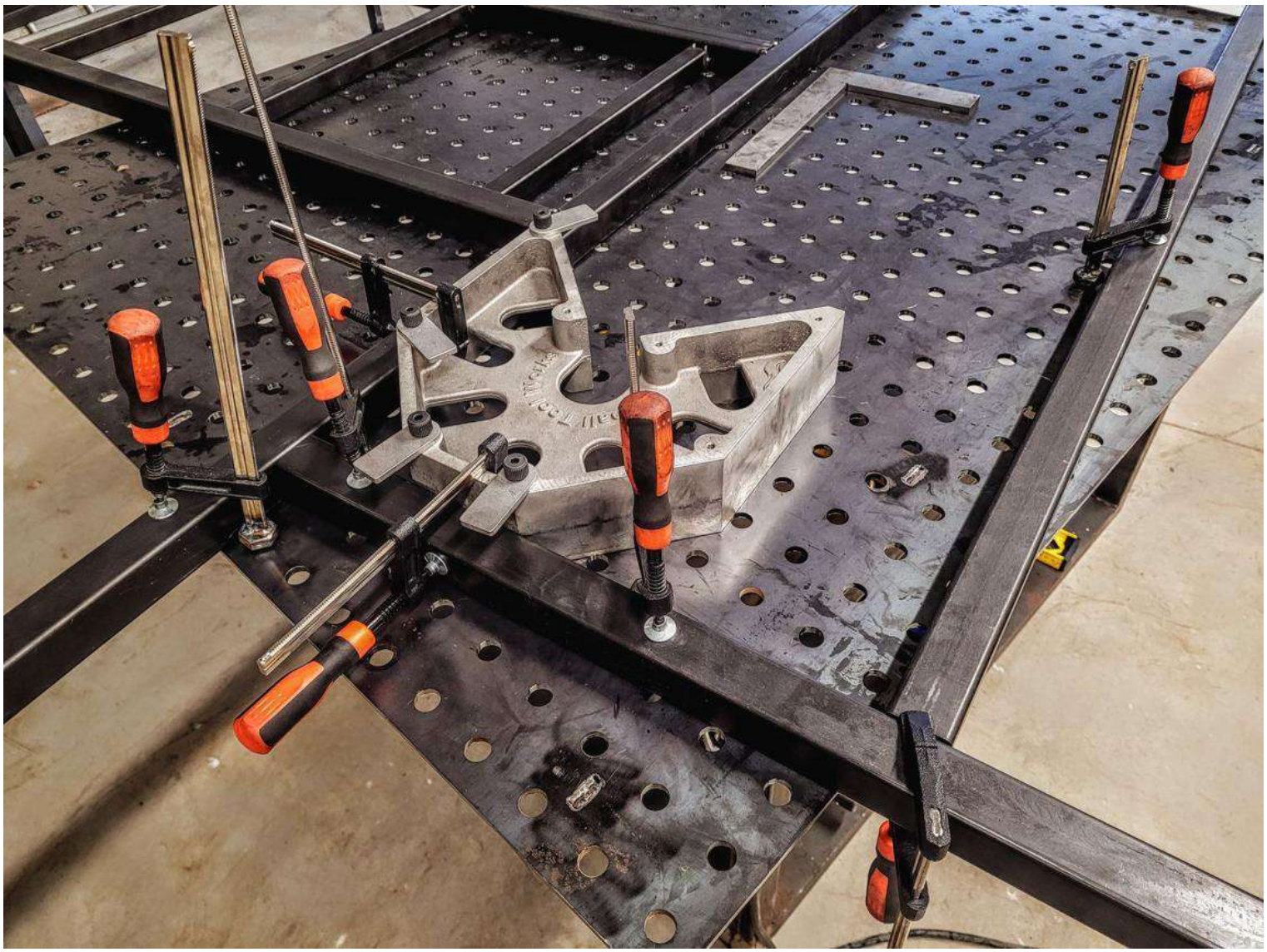
An angle grinder is a portable power tool used for grinding, cutting and finishing metal surfaces.

**Uses in MMAW:**

- Preparing metal edges.
- Removing rust, paint and scale.
- Beveling thick metal plates.
- Grinding weld reinforcements where specified.
- Removing surface irregularities.

**Safety:** Use the correct disc, guard, side handle and eye/face protection. Never use a cutting disc for side grinding.

### 3.10 Welding Table and Clamps



A welding table is a strong working surface used to support metal components during welding.

Clamps are devices used to hold the workpieces in the required position.

**Functions:**

- Support the workpieces.
- Maintain correct alignment.
- Reduce movement during welding.
- Help maintain accurate dimensions.
- Improve the quality of the finished joint.

### 4.0 PERSONAL PROTECTIVE EQUIPMENT (PPE) USED IN MMAW

Personal Protective Equipment refers to clothing and protective devices worn by a welder to protect the body against injuries and hazards associated with welding.

Welding exposes the operator to intense heat, ultraviolet radiation, infrared radiation, sparks, molten metal, fumes and electric shock.

PPE must be worn throughout the welding operation.

**4.1 Types of PPE Used in Manual Metal Arc Welding**







**1. Welding helmet**

A welding helmet is a protective head covering fitted with a special dark filter lens.

**Functions:**

- Protects the face and eyes from intense arc radiation.
- Prevents eye injuries caused by ultraviolet and infrared rays.
- Protects the face from sparks and hot metal particles.
- Reduces the risk of arc eye (welder's flash).
- Protects the head and neck from some welding spatter.

**Important considerations:**

- Use the correct shade of filter for the welding current and process.
- Ensure the viewing lens is clean and undamaged.
- Replace cracked or damaged lenses.
- Do not look directly at an active welding arc without suitable eye protection.

**2. Leather welding gloves**

These are heat-resistant gloves designed to protect the hands during welding.

**Functions:**

- Protect the hands against burns.
- Protect the skin from sparks and spatter.
- Reduce exposure to hot metal surfaces.
- Provide a better grip when handling welding equipment.

**3. Leather apron or welding jacket**

A leather apron or suitable welding jacket protects the upper body and clothing.

**Functions:**

- Protects the chest and abdomen from sparks.
- Reduces the risk of burns.
- Protects ordinary clothing from damage.
- Provides a barrier against hot metal particles.

**4. Safety boots**

Safety boots are protective footwear designed for workshop activities.

**Functions:**

- Protect the feet from falling metal objects.
- Reduce the risk of foot injuries.
- Protect against hot metal spatter.
- Provide a firm grip on the workshop floor.

**Recommended features:**

- Heat-resistant construction.
- Strong protective toe caps.
- Slip-resistant soles.
- Suitable electrical protection for the working environment.

**5. Safety goggles**

Safety goggles protect the eyes during grinding, chipping and wire brushing.

**Functions:**

- Prevent metal particles from entering the eyes.
- Protect against flying slag.
- Protect against dust and grinding debris.

**Note:** Ordinary safety goggles are not a substitute for a suitable welding helmet during arc welding.

**6. Respiratory protection**

Suitable respiratory protective equipment is used where welding fumes cannot be adequately controlled through ventilation and extraction.

**Functions:**

- Reduces inhalation of harmful welding fumes.
- Protects the respiratory system against airborne contaminants.
- Provides additional protection where risk assessments identify respiratory hazards.

Respirators must be suitable for the particular welding contaminants and properly fitted. They do not replace effective ventilation.

**7. Ear protection**

Earplugs or earmuffs are worn where noise levels are excessive.

**Functions:**

- Protect hearing.
- Reduce exposure to grinding noise.
- Reduce exposure to hammering and workshop machinery noise.

**8. Safety glasses**

Safety glasses with suitable side protection are worn during metal workshop activities and under a welding helmet where appropriate.

**Functions:**

- Protect against flying particles.
- Protect the eyes during metal preparation.
- Provide additional eye protection when removing slag.

**4.2 Importance of Wearing PPE**

1. Prevents workplace injuries.
2. Reduces the risk of eye damage.
3. Prevents burns from sparks and molten metal.
4. Protects the skin against harmful radiation.
5. Reduces exposure to welding fumes.
6. Protects the feet against falling objects.
7. Improves the welder's confidence when working.
8. Promotes a safe working environment.
9. Reduces workshop accidents and medical expenses.
10. Encourages professional working habits.

**5.0 SAFETY MEASURES DURING MANUAL METAL ARC WELDING**

Welding is a potentially dangerous workshop activity. Proper safety measures must be observed before, during and after welding.

**5.1 Electrical Safety**

Electrical hazards can result in electric shock, burns and fires.

Safety precautions include:

1. Inspect the welding machine before use.
2. Ensure welding cables have intact insulation.
3. Do not use damaged electrode holders.
4. Keep hands and gloves dry.
5. Avoid welding in wet conditions.
6. Ensure electrical connections are secure.
7. Switch off the power source before making adjustments or repairs.
8. Use properly installed and maintained electrical supplies.
9. Avoid touching exposed live electrical conductors.
10. Ensure the welding machine is properly earthed according to the manufacturer's instructions.
11. Do not wrap live welding cables around the body.
12. Do not attempt electrical repairs unless trained and authorised.

**5.2 Protection Against Arc Radiation**

The welding arc produces intense ultraviolet and infrared radiation.

Precautions include:

- Wear a suitable welding helmet.
- Use the correct filter shade.
- Protect exposed skin.
- Use welding screens to protect nearby learners and workers.
- Never observe welding directly with unprotected eyes.
- Ensure people in the workshop use suitable eye protection.

**Arc eye:** A painful eye condition caused by exposure to ultraviolet radiation from a welding arc. It may cause watering, redness, irritation and a sensation similar to having sand in the eyes.

**5.3 Fire Prevention**

Welding produces sparks and molten metal particles that can ignite combustible materials.

Safety measures include:

1. Remove paper, petrol, oil, sawdust and other flammable materials from the welding area.
2. Keep suitable fire extinguishers accessible.
3. Provide a designated welding area.
4. Use welding screens to contain sparks.
5. Never weld near flammable liquids or gases.
6. Inspect the area for smouldering materials after welding.
7. Do not weld on sealed containers that may contain flammable substances.
8. Follow approved procedures for hot work.
9. Maintain a safe distance from gas cylinders.
10. Ensure that a trained person is available to respond to a fire emergency.

**5.4 Ventilation and Fume Control**

Welding produces fumes and gases that may be harmful when inhaled.

Precautions include:

- Work in a well-ventilated area.
- Use local exhaust ventilation where available.
- Position extraction equipment to capture fumes at their source.
- Avoid placing the head directly above the weld.
- Use appropriate respiratory protection where required.
- Never weld in confined spaces without an authorised confined-space safety procedure.
- Identify coatings such as paint, galvanising and oil before welding because they may produce hazardous fumes.

**5.5 Mechanical Safety**

1. Clamp workpieces firmly before welding.
2. Use suitable lifting methods when handling heavy plates.
3. Keep hands away from sharp metal edges.

4. Use guards on grinding machines.
5. Do not wear loose clothing.
6. Keep the workshop floor free from cables and metal offcuts.
7. Use appropriate tools for cleaning welds.
8. Do not touch recently welded metal with bare hands.
9. Clearly identify hot workpieces.
10. Maintain good housekeeping.

**5.6 Safety When Handling Gas Cylinders**

Although MMAW does not require shielding gas cylinders, gas cylinders may be present in a workshop where other welding processes are performed.

- Store cylinders upright and secure them.
- Keep them away from excessive heat.
- Keep oxygen cylinders away from oil and grease.
- Use appropriate regulators.
- Do not allow cylinders to fall or be struck.
- Close cylinder valves when not in use.

**5.7 General Workshop Safety Rules**

- Follow the teacher's or workshop supervisor's instructions.
- Do not operate welding equipment without permission and training.
- Never engage in horseplay.
- Keep emergency exits accessible.
- Know the location of the first-aid kit.
- Report accidents immediately.
- Switch off the machine after completing the work.
- Allow hot metal to cool in a designated area.



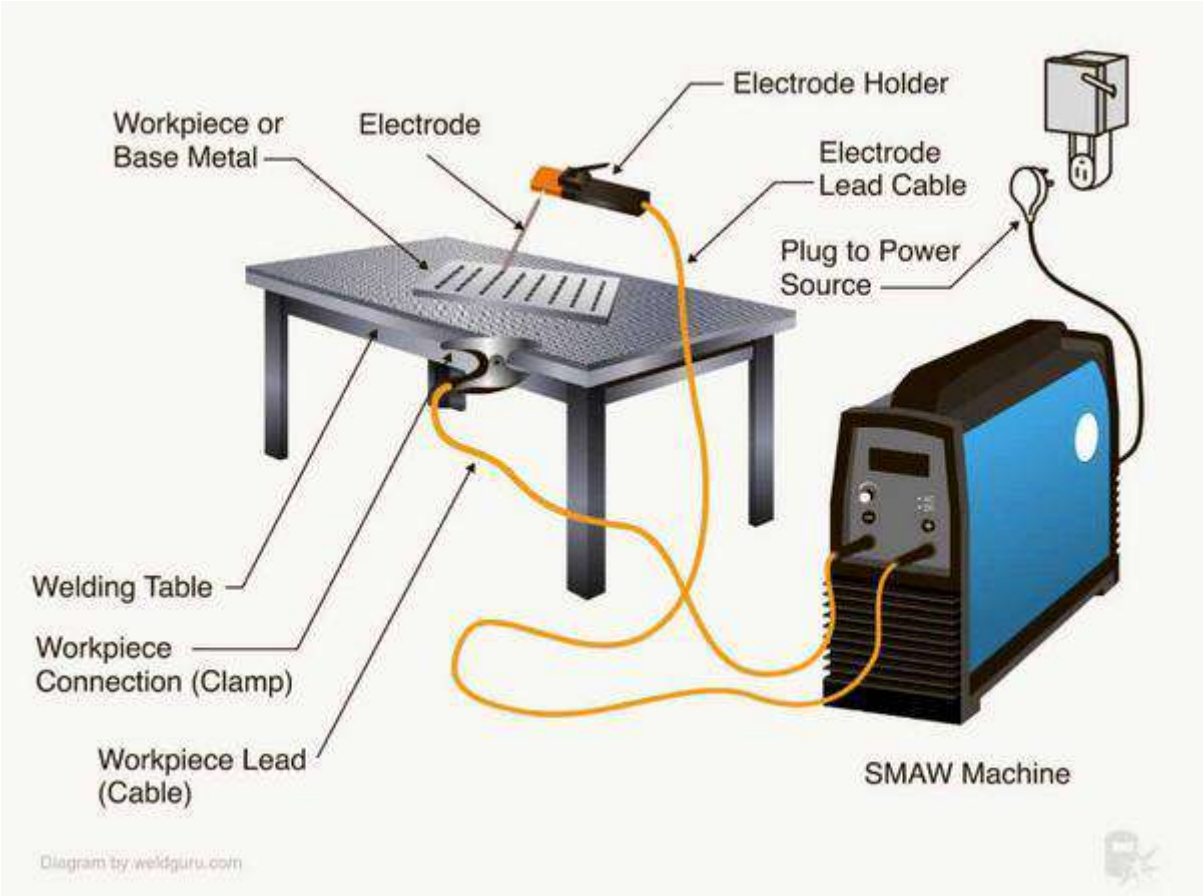
## 6.0 WELDING CIRCUIT AND CONNECTIONS

A welding circuit is the complete electrical path through which current flows during the welding operation.

### 6.1 Main Parts of a Welding Circuit

1. Welding power source.
2. Electrode cable.
3. Electrode holder.
4. Welding electrode.
5. Workpiece.
6. Work-return cable.
7. Work clamp.

### 6.1.1 Arrangement of a Welding Circuit




The electrical current flows through the welding circuit as follows:

1. Current leaves the welding power source.
2. It travels through the electrode cable.
3. It passes through the electrode holder.
4. It reaches the electrode.
5. The electric arc transfers energy to the workpiece.
6. Current passes through the workpiece and work-return connection.
7. It returns to the power source to complete the circuit.

### 6.2 Alternating Current (AC) Welding

Alternating current is electrical current that changes its direction periodically.

**Characteristics:**

- Changes direction repeatedly.
- Commonly supplied by transformer welding machines.
- Does not have fixed positive and negative electrode terminals.
- Suitable for electrodes designed for AC operation.

**Advantages:**

1. AC welding machines may have relatively simple construction.
2. Transformer machines can be durable.
3. Suitable for many general welding applications.
4. AC may reduce magnetic arc blow in some welding situations.

**Disadvantages:**

1. Some electrodes are unsuitable for AC operation.
2. Arc starting may be difficult with some electrode types.
3. Arc stability depends on the welding machine and electrode.
4. Some applications require the specific characteristics of DC welding.

### 6.3 Direct Current (DC) Welding

Direct current is electrical current that flows in one direction.

In DC welding, the welder can select the polarity according to the electrode manufacturer's recommendations and the welding requirements.

**Characteristics:**

- Current flows in one direction.
- Has positive and negative terminals.
- Allows selection of electrode-positive or electrode-negative connections.
- Commonly available in inverter and rectifier welding machines.

**Advantages:**

1. Generally provides stable arc characteristics with suitable electrodes.
2. Allows different polarity arrangements.
3. Can make arc initiation easier with some electrodes.
4. Offers flexibility in welding different materials and positions.

**Disadvantages:**

1. Some DC welding setups may experience magnetic arc blow.
2. Certain electrodes are designed for specific polarity arrangements.
3. Machine selection and maintenance may be more demanding depending on design.

## 7.0 POLARITY IN MANUAL METAL ARC WELDING

Polarity refers to the direction of direct electrical current flow in a welding circuit.

It determines whether the electrode or the workpiece is connected to the positive or negative terminal of the DC welding power source.

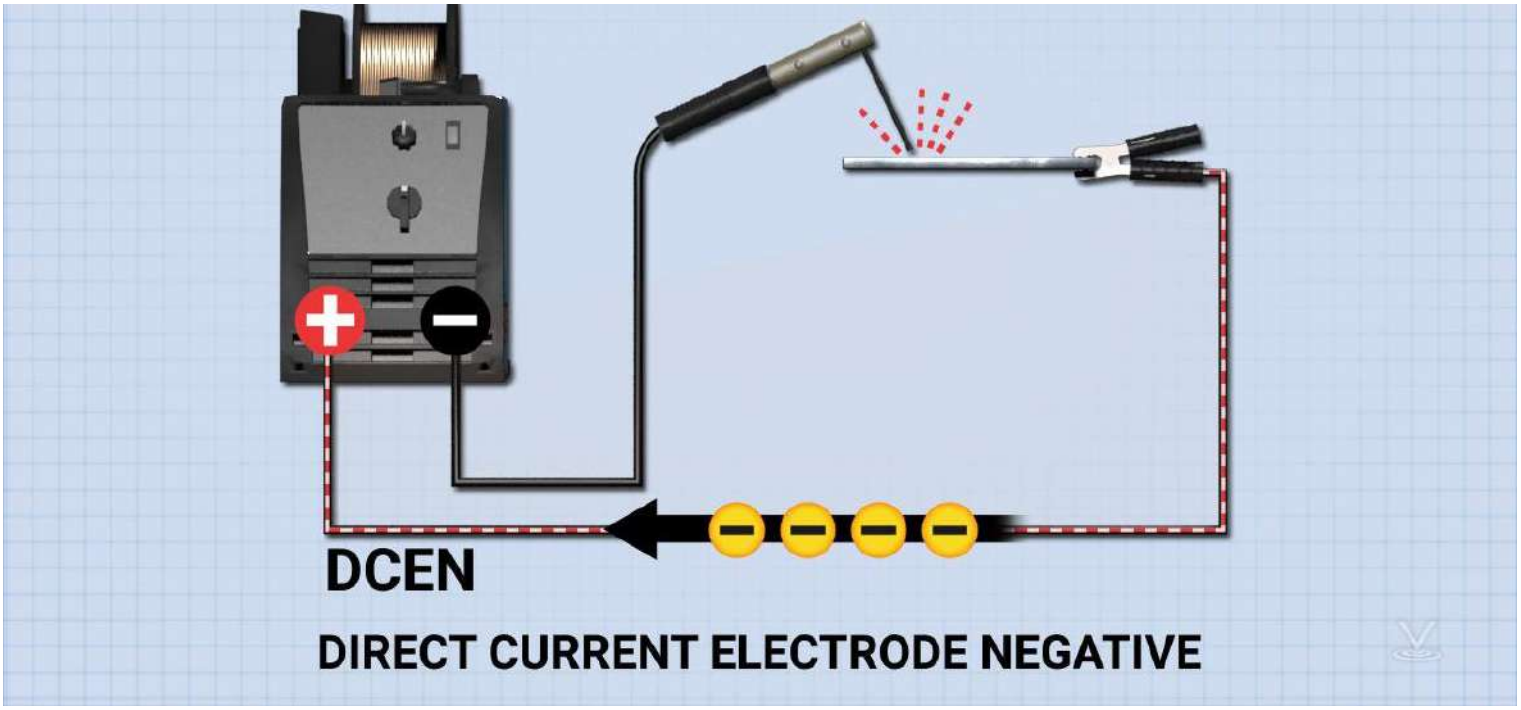
There are two main DC polarity arrangements.

### 7.1 Straight Polarity (DCEN)

Straight polarity is also called Direct Current Electrode Negative (DCEN).

In this arrangement:

- The electrode is connected to the negative terminal.
- The workpiece is connected to the positive terminal.




**Characteristics:**

1. Electrons flow from the negative electrode towards the positive workpiece.
2. It produces a particular heat distribution between the electrode and workpiece.
3. Its penetration and melting characteristics depend on the electrode and operating conditions.
4. It is suitable for electrodes specified for DCEN operation.

**Uses:**

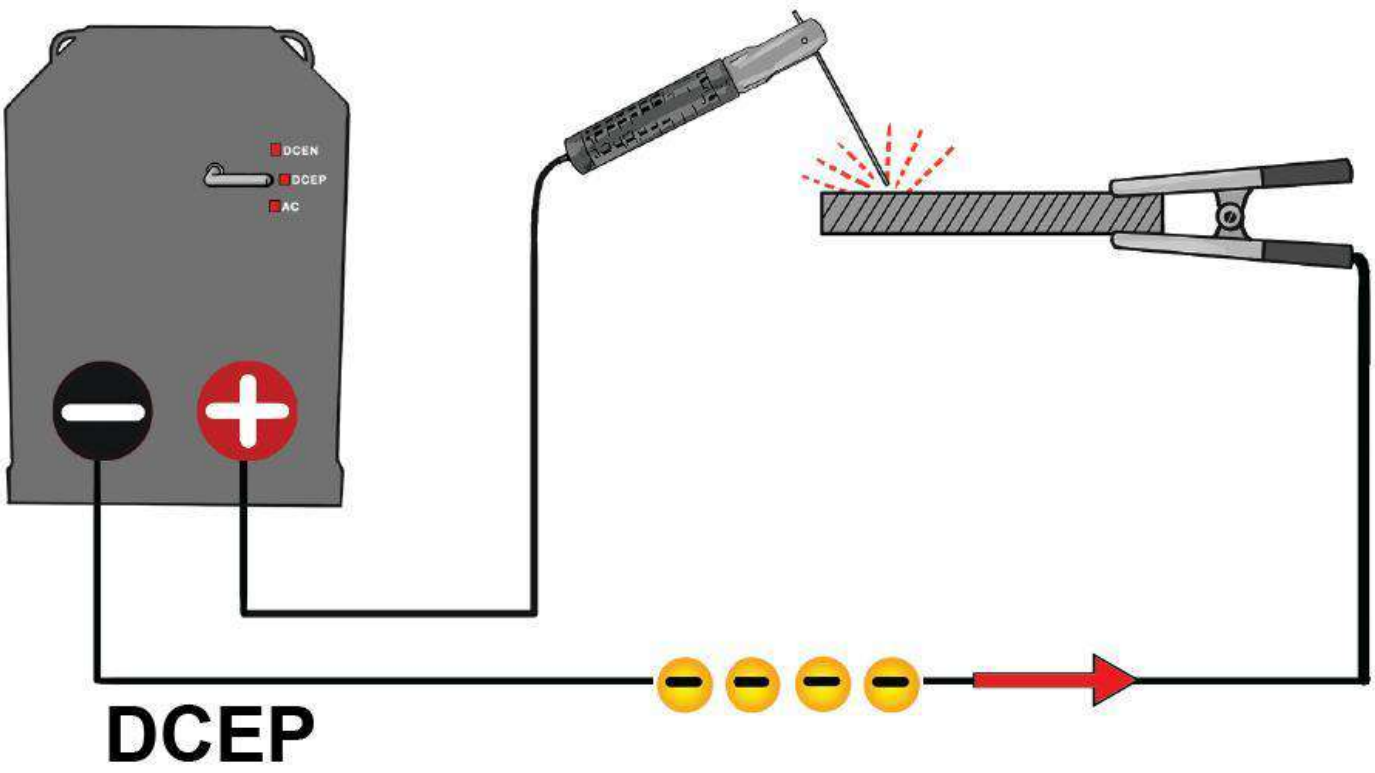
- Welding with electrodes designed for DCEN.
- Applications where the electrode manufacturer recommends this connection.

### 7.2 Reverse Polarity (DCEP)

Reverse polarity is also called Direct Current Electrode Positive (DCEP).

In this arrangement:

- The electrode is connected to the positive terminal.
- The workpiece is connected to the negative terminal.




**Characteristics:**

1. Electrons flow from the negative workpiece towards the positive electrode.
2. The heat distribution differs from DCEN.
3. It may provide suitable penetration and metal transfer characteristics for certain electrodes.
4. It is widely used with many common MMAW electrodes.

**Uses:**

- Welding with electrodes designed for DCEP.
- Fabrication and repair tasks requiring the characteristics specified for electrode-positive operation.

**7.3 Differences Between Straight and Reverse Polarity**

| **Straight polarity (DCEN)** | **Reverse polarity (DCEP)** |
|---|---|
| Electrode connected to negative terminal. | Electrode connected to positive terminal. |
| Workpiece connected to positive terminal. | Workpiece connected to negative terminal. |
| Also called electrode negative. | Also called electrode positive. |
| Electrons flow from electrode to workpiece. | Electrons flow from workpiece to electrode. |
| Used with electrodes designed for DCEN. | Used with electrodes designed for DCEP. |

**Important workshop note:** The choice of polarity must be guided by the electrode classification and manufacturer's instructions. Do not assume that one polarity always produces deeper penetration than the other for every electrode.

### 7.4 Procedure for Setting Welding Polarity

1. Switch off the welding machine.
2. Identify the positive and negative output terminals.
3. Read the electrode manufacturer's polarity recommendation.
4. For DCEN, connect the electrode cable to the negative terminal and the work-return cable to the positive terminal.
5. For DCEP, connect the electrode cable to the positive terminal and the work-return cable to the negative terminal.
6. Tighten the connections properly.
7. Check the cables for damage.
8. Ensure the work clamp is attached to a clean metal surface.
9. Switch on the machine.
10. Select the appropriate welding current.
11. Test the setup using a suitable scrap piece of metal.

**Safety:** Polarity connections should only be changed when the welding machine is switched off.

## 8.0 WELDING ELECTRODES AND THEIR SELECTION

Electrode selection is an important factor in achieving strong, reliable and good-quality welded joints.

### 8.1 Factors to Consider When Selecting Welding Electrodes

1. **Type of base metal:** The electrode should be compatible with the material being welded.
2. **Thickness of metal:** Electrode diameter should be suitable for the thickness of the workpiece.
3. **Welding position:** Some electrodes are suitable for all positions, while others have limitations.
4. **Welding current:** The electrode must be compatible with AC or DC and the available polarity.
5. **Mechanical properties:** The electrode should provide the required strength and toughness.
6. **Joint design:** The electrode should suit the type of joint being made.
7. **Operating conditions:** The environment and service conditions of the finished product must be considered.
8. **Manufacturer's recommendations:** Always follow the electrode specification.

### 8.2 Common Electrode Sizes

Electrodes are available in different diameters and lengths.

Examples of common electrode diameters include:

- 2.0 mm.
- 2.5 mm.
- 3.2 mm.
- 4.0 mm.
- 5.0 mm.

The appropriate diameter depends on the electrode type, base-metal thickness, joint design and welding position.

### 8.3 Electrode Storage and Handling

Proper storage prevents moisture absorption and damage to electrode coatings.

**Storage practices:**

1. Store electrodes in a dry environment.
2. Keep electrodes in their original packaging until needed.
3. Use suitable storage ovens for electrodes that require controlled moisture levels.
4. Follow the manufacturer's instructions for drying and rebaking.
5. Avoid dropping electrodes.
6. Do not use electrodes with severely damaged coatings.
7. Keep different electrode types properly labelled.
8. Protect electrodes from oil, grease and other contaminants.

**Why moisture is dangerous:** Moisture in some electrode coatings can introduce hydrogen into the weld metal and contribute to hydrogen cracking, particularly in susceptible steels and welding conditions.

## 9.0 PREPARATION OF MATERIALS BEFORE WELDING

Proper preparation is necessary to obtain a sound welded joint.

### 9.1 Inspection of Workpieces

Before welding, the welder should:

1. Identify the type of metal.
2. Check the dimensions of the workpieces.
3. Inspect for cracks and excessive corrosion.
4. Check the thickness of the metal.
5. Determine the required joint type.
6. Identify any coatings that may produce harmful fumes.
7. Confirm that the materials are suitable for welding.

### 9.2 Cleaning of Metal Surfaces

Metal surfaces should be cleaned before welding.

**Methods of cleaning:**

- Wire brushing.
- Grinding.
- Filing.
- Scraping.
- Degreasing using suitable approved cleaning agents.

**Materials removed include:**

- Rust.
- Paint.
- Oil.

- Grease.
- Dirt.
- Moisture.
- Mill scale where necessary.

**Importance of cleaning:**

1. Reduces weld contamination.
2. Improves fusion.
3. Reduces porosity.
4. Improves the appearance of the weld.
5. Helps prevent defects.
6. Improves the reliability of the joint.

**9.3 Marking Out**

Marking out involves transferring the required dimensions and joint positions onto the workpiece.

**Tools used:**

- Steel rule.
- Try square.
- Scriber.
- Centre punch.
- Divider.
- Measuring tape.

**Procedure:**

1. Study the drawing.
2. Measure the required dimensions.
3. Mark the joint position.
4. Check the alignment.
5. Confirm the measurements before cutting or welding.

**9.4 Cutting and Edge Preparation**

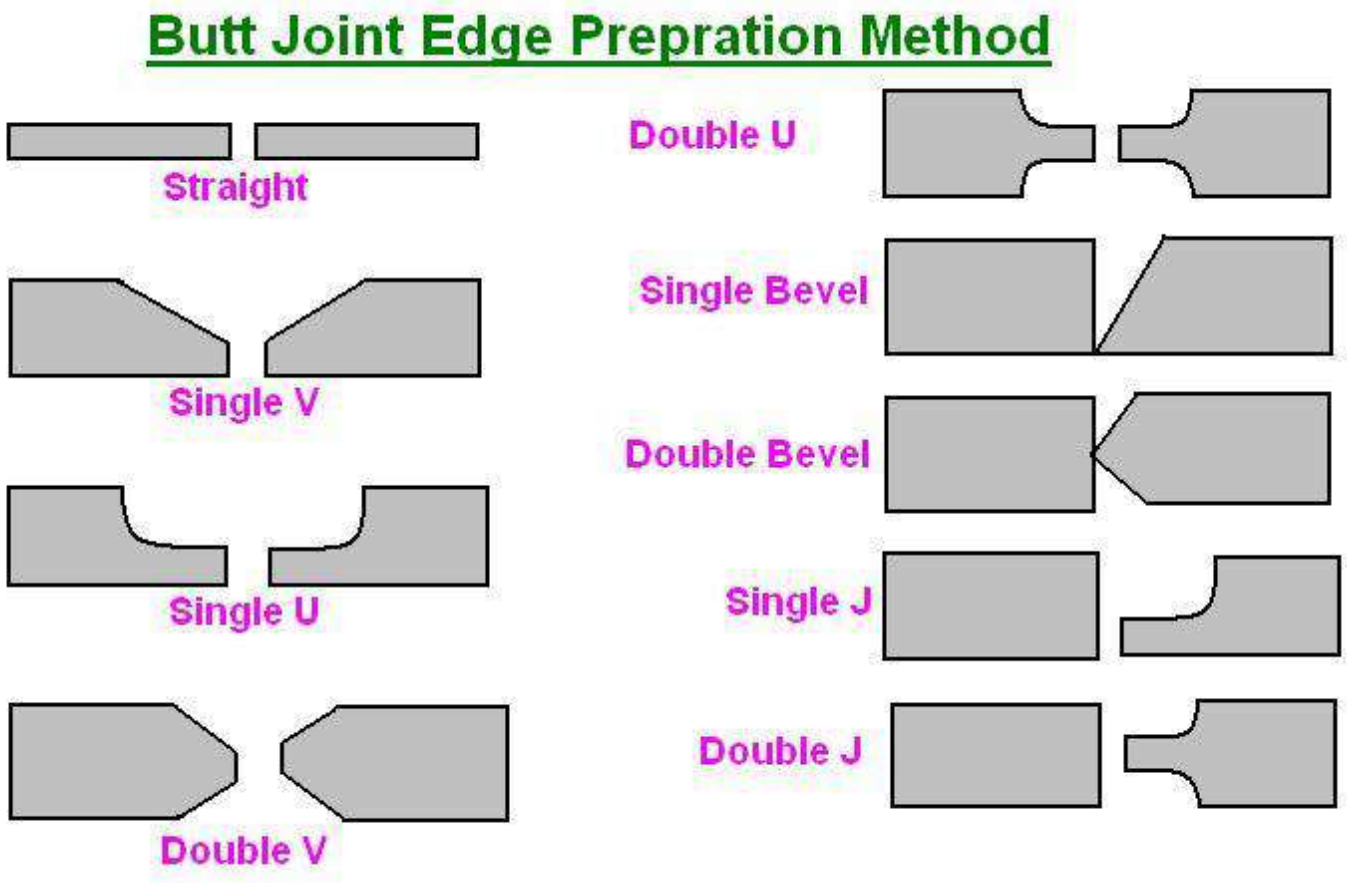
Metal pieces may require cutting or edge preparation before welding.

Common tools include:

- Hacksaw.
- Angle grinder.
- Power cutting machine.
- Shearing machine.
- Oxy-fuel cutting equipment where appropriate.

Edge preparation may include:

- Square edges.
- Single-V preparation.
- Double-V preparation.
- Single-bevel preparation.
- Double-bevel preparation.




**Importance of edge preparation:**

1. Provides access to the joint root.
2. Promotes proper fusion.
3. Helps achieve the required penetration.
4. Reduces the possibility of incomplete fusion.
5. Makes welding thick materials more effective.

**9.5 Tack Welding**

Tack welding is the process of making small temporary welds to hold components in their correct positions before completing the main weld.

**Importance:**

- Maintains correct alignment.
- Prevents movement during welding.
- Helps maintain joint dimensions.
- Reduces distortion.
- Supports accurate fabrication.

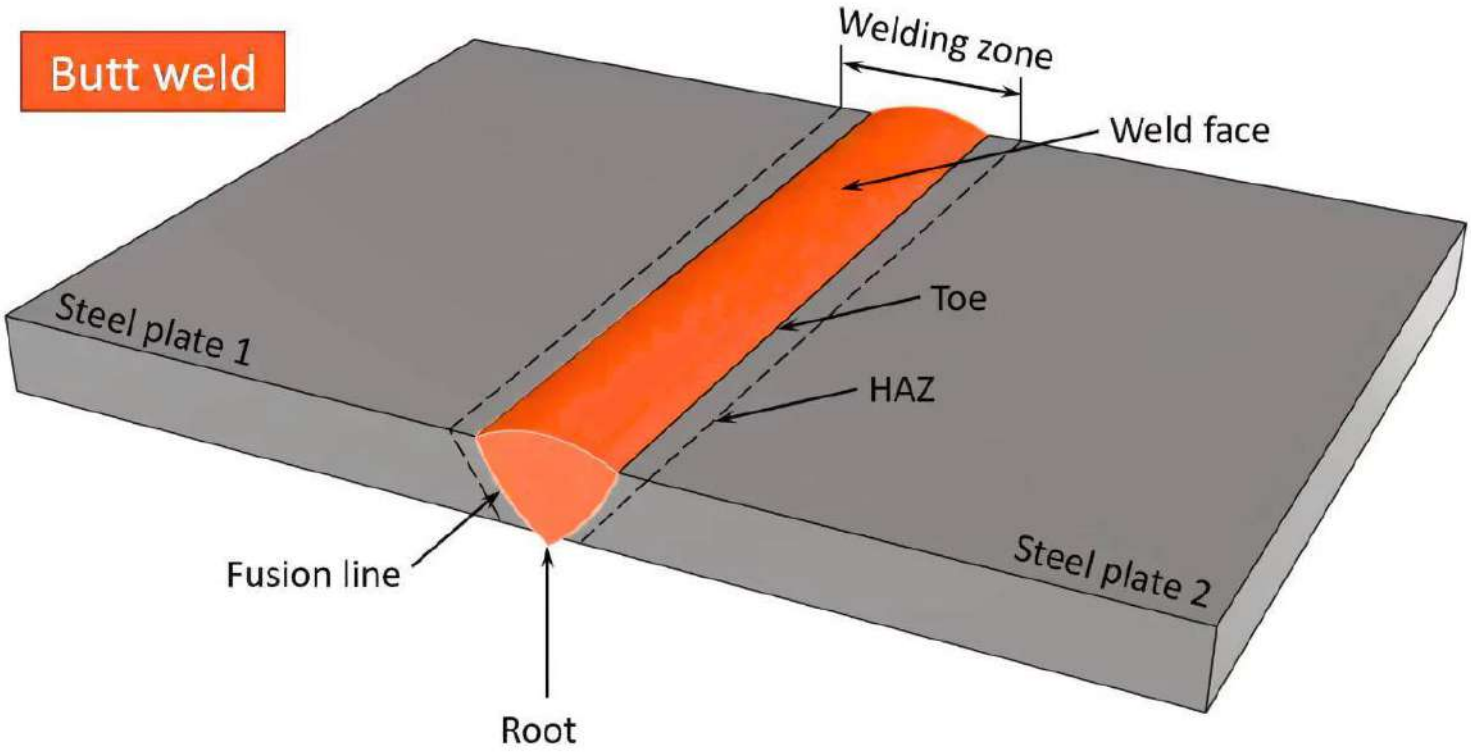
**Procedure:**

1. Align the workpieces.
2. Clamp them securely.
3. Check the dimensions.
4. Set the appropriate welding current.
5. Make small tack welds at suitable intervals.
6. Inspect the alignment.
7. Complete the main weld.

**10.0 TYPES OF WELDED JOINTS**

A welded joint is the connection formed when two or more metal components are joined by welding.

**10.1 Butt Joint**

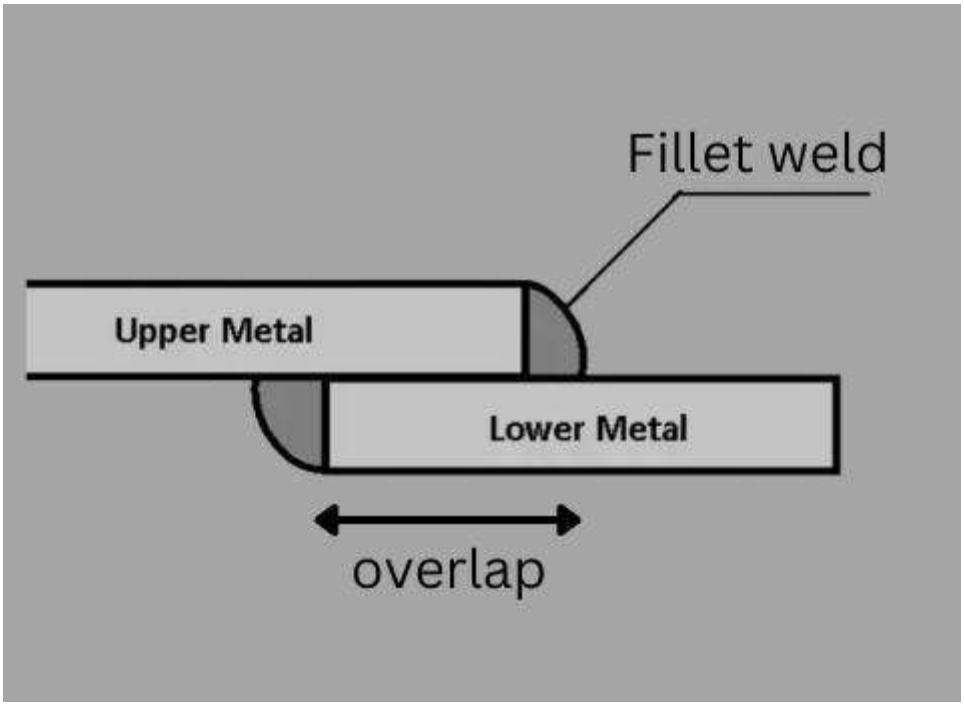



A butt joint is formed when two metal pieces are placed in the same plane with their edges facing each other and welded together.

**Applications:**

- Joining steel plates.
- Fabricating tanks.
- Making steel panels.
- Joining metal sheets and structural members.

**10.2 Lap Joint**

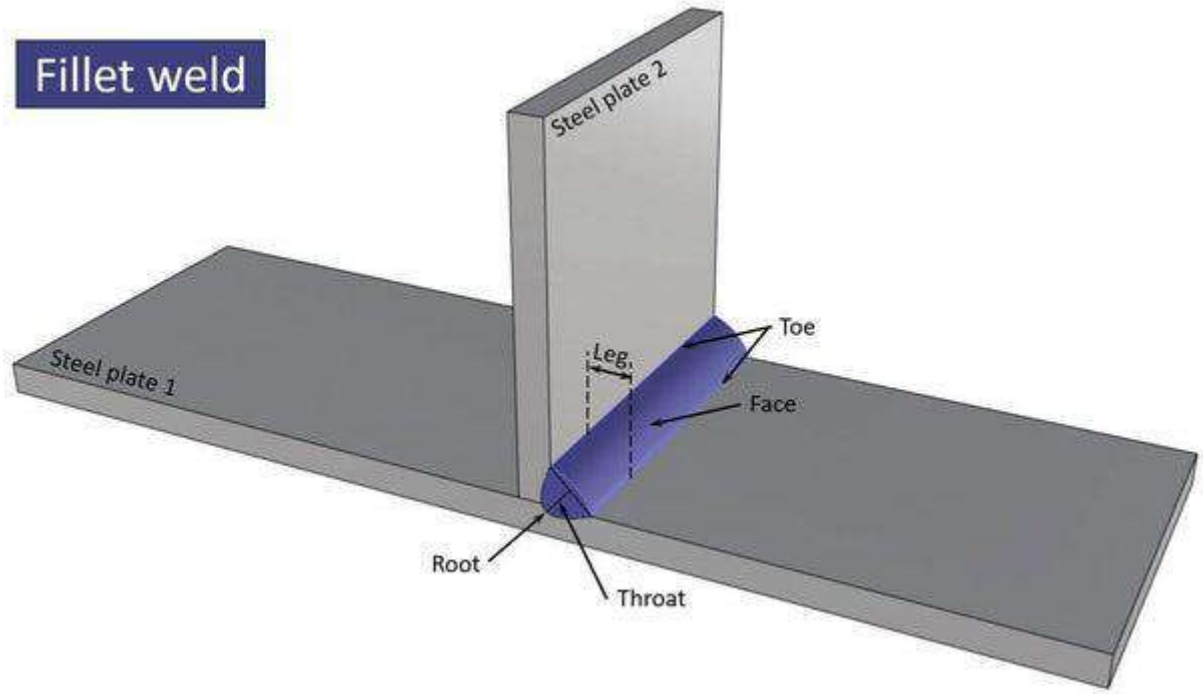



A lap joint is formed when two metal pieces overlap and are joined by welding along one or both edges.

**Applications:**

- Joining sheet metal.
- Fabricating brackets.
- Joining overlapping plates.
- Making metal enclosures.

**10.3 T-Joint**

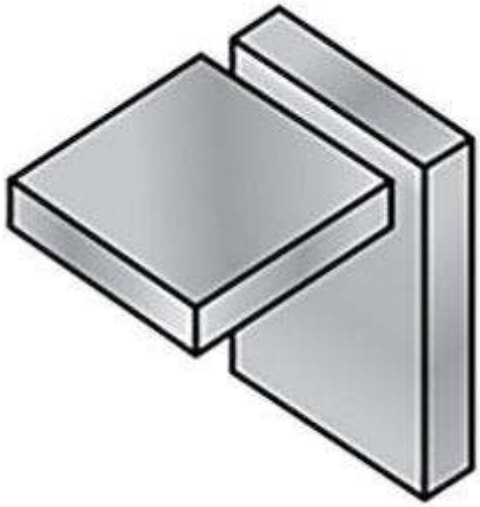



A T-joint is formed when one metal piece is placed approximately at right angles to another, forming the shape of the letter T.

**Applications:**

- Steel frames.
- Support brackets.
- Roof trusses.
- Structural fabrication.

**10.4 Corner Joint**

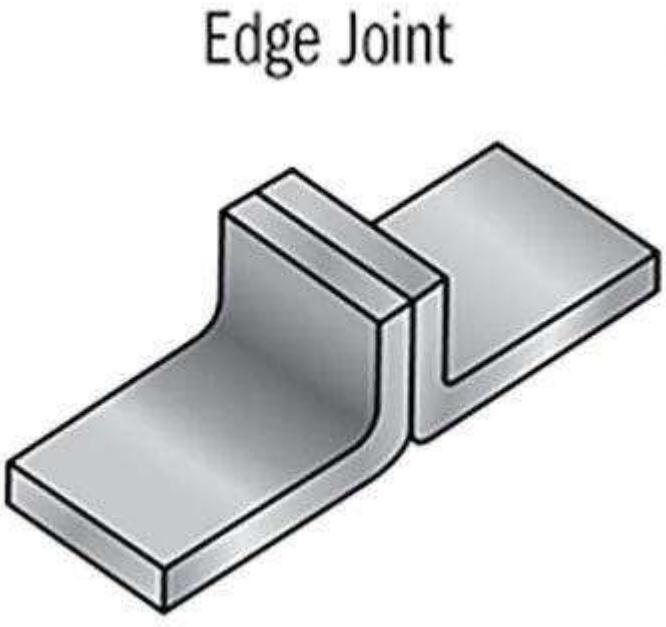


A corner joint is formed when two metal components meet at an angle to form a corner.

**Applications:**

- Metal boxes.
- Steel cabinets.
- Containers.
- Frames.

**10.5 Edge Joint**



An edge joint is formed when the edges of two parallel or nearly parallel metal pieces are brought together and welded.

**Applications:**

- Joining thin metal sheets.
- Fabricating light-gauge components.
- Manufacturing certain metal containers.

**11.0 WELDING POSITIONS IN MANUAL METAL ARC WELDING**

Welding position refers to the orientation of the workpiece and the direction in which welding is carried out.

The common welding positions are flat, horizontal, vertical and overhead.

**11.1 Flat Position (1G or 1F)**



Flat-position welding is carried out on the upper surface of a horizontal workpiece.

The welder holds the electrode above the joint while molten metal flows into the joint under gravity.

**Characteristics:**

- Welding is performed from above.
- Gravity helps keep molten metal in the joint.
- It is generally easier for beginners.
- Provides good control of the weld pool.

**Advantages:**

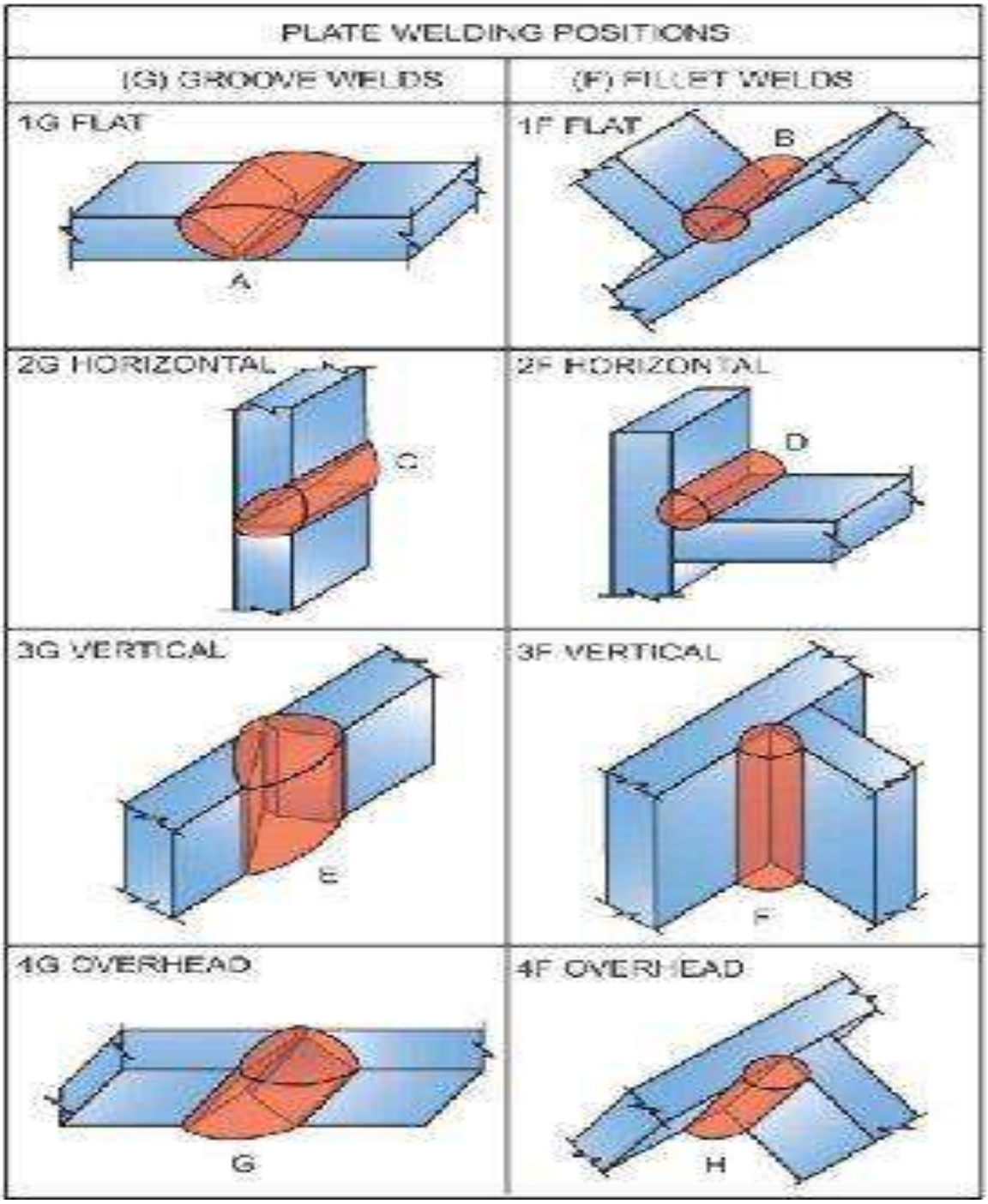
1. Easier to learn.
2. Better visibility of the weld pool.
3. Easier electrode manipulation.

4. Generally allows higher deposition rates.
5. Suitable for many fabrication tasks.

**Applications:**

- Welding flat steel plates.
- Fabricating metal tables.
- Joining steel frames.
- Making metal brackets.

**11.2 Horizontal Position (2G or 2F)**




Horizontal welding is carried out along a horizontal joint on a vertical or near-vertical surface.

**Characteristics:**

- The weld runs horizontally.
- Gravity tends to pull molten metal downwards.
- The welder must control the weld pool carefully.
- Electrode angle and movement are important.

**Applications:**

- Welding vertical steel plates along horizontal joints.
- Joining structural steel members.
- Fabricating metal frames.

**11.3 Vertical Position (3G or 3F)**



Vertical welding is performed along a joint that runs vertically.

The welding may progress upwards or downwards depending on the material, electrode and welding procedure.

**Characteristics:**

- The joint is vertical.
- Molten metal is affected by gravity.
- Requires careful control of electrode movement.
- Usually demands more skill than flat welding.

**Applications:**

- Fabrication of vertical steel structures.

- Repair of upright metal frames.
- Welding vertical seams.

**11.4 Overhead Position (4G or 4F)**



Overhead welding is performed on the underside of a joint, with the weld located above the welder.

**Characteristics:**

- Molten metal tends to fall due to gravity.
- Requires advanced control and skill.
- Presents a greater risk of falling hot spatter.
- Requires complete protective clothing.

**Applications:**

- Repairing overhead steel structures.
- Welding the underside of metal frames.
- Maintenance of certain industrial structures.

**Important:** The learner should first develop competence in flat welding before progressing to more difficult positions under supervision.

**12.0 STARTING AN ELECTRIC ARC**

Arc starting is the process of establishing an electric arc between the electrode and the workpiece.

The ability to start an arc correctly is an essential welding skill.

**12.1 Methods of Starting an Arc**

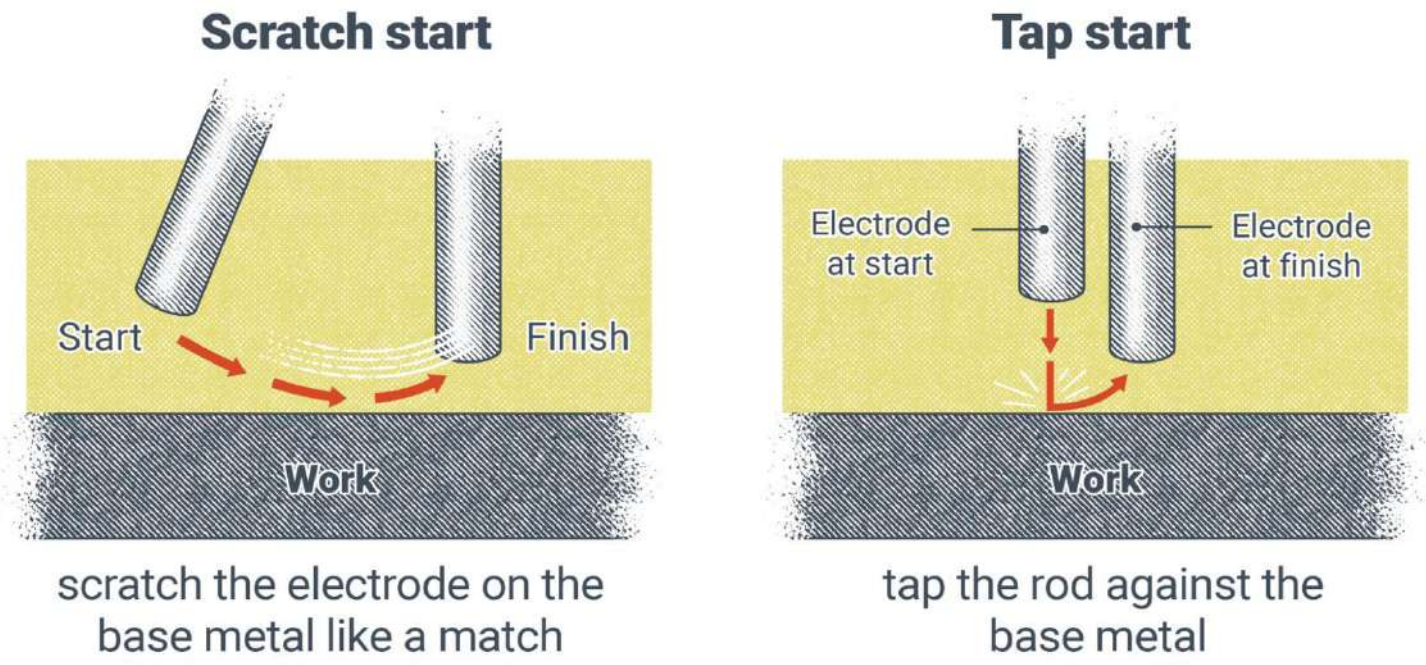
There are two common methods.

**A. Scratch method**

The scratch method involves briefly dragging the electrode tip across the workpiece, similar to striking a match.

**Procedure:**

1. Wear all appropriate PPE.
2. Secure the workpiece.
3. Check the welding circuit.
4. Hold the electrode at the recommended angle.
5. Briefly scratch the electrode tip against the workpiece.
6. Lift the electrode slightly to establish the arc.
7. Maintain a suitable arc length.
8. Begin moving the electrode along the joint.




scratch the electrode on the base metal like a match

tap the rod against the base metal

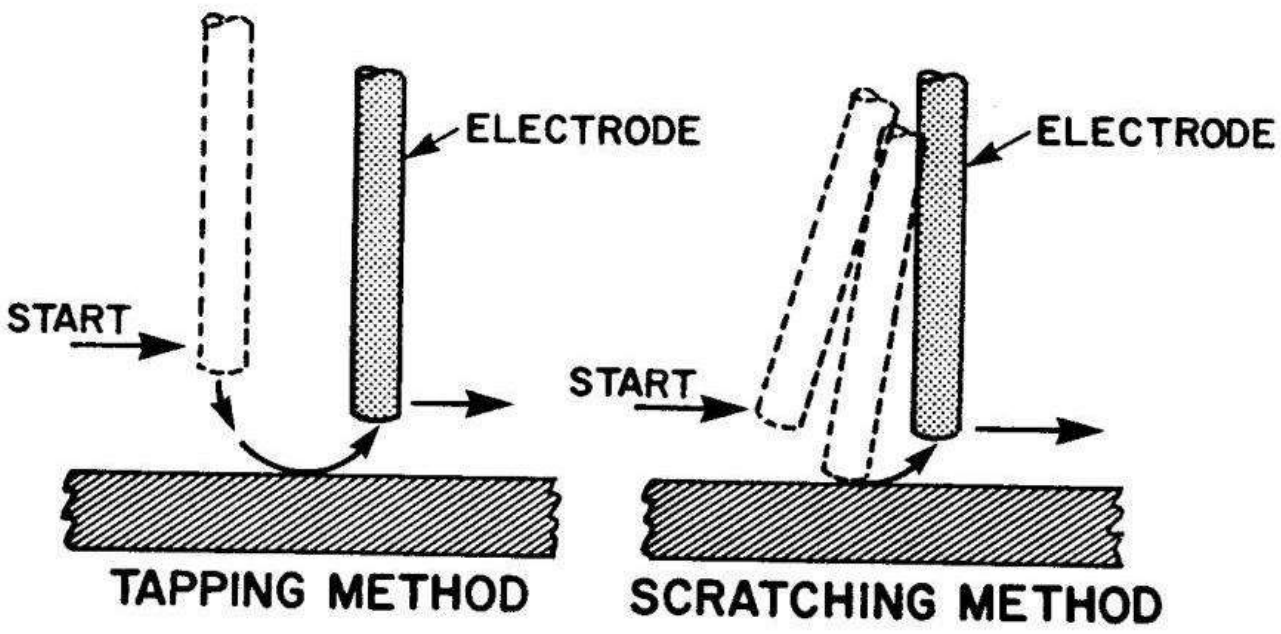
**B. Tapping method**

The tapping method involves briefly touching the electrode against the workpiece and immediately lifting it to establish an arc.

**Procedure:**

1. Hold the electrode correctly.
2. Position it above the starting point.

3. Lower it until it briefly touches the workpiece.
4. Lift it slightly to establish the arc.
5. Maintain the correct arc length.
6. Move the electrode along the joint.




**12.2 Arc Length**

Arc length is the distance between the tip of the electrode and the surface of the molten weld pool or workpiece.

**Importance of maintaining the correct arc length:**

1. Helps maintain arc stability.
2. Controls weld bead appearance.
3. Reduces excessive spatter.
4. Helps achieve suitable penetration.
5. Reduces the possibility of arc interruption.
6. Helps produce a uniform weld.

**Effects of incorrect arc length**

| **Arc condition** | **Possible effects** |
|---|---|
| Too long | Excessive spatter, unstable arc and possible porosity. |
| Too short | Electrode sticking, poor movement and possible lack of fusion. |
| Correct | More stable arc and better control of the weld pool. |

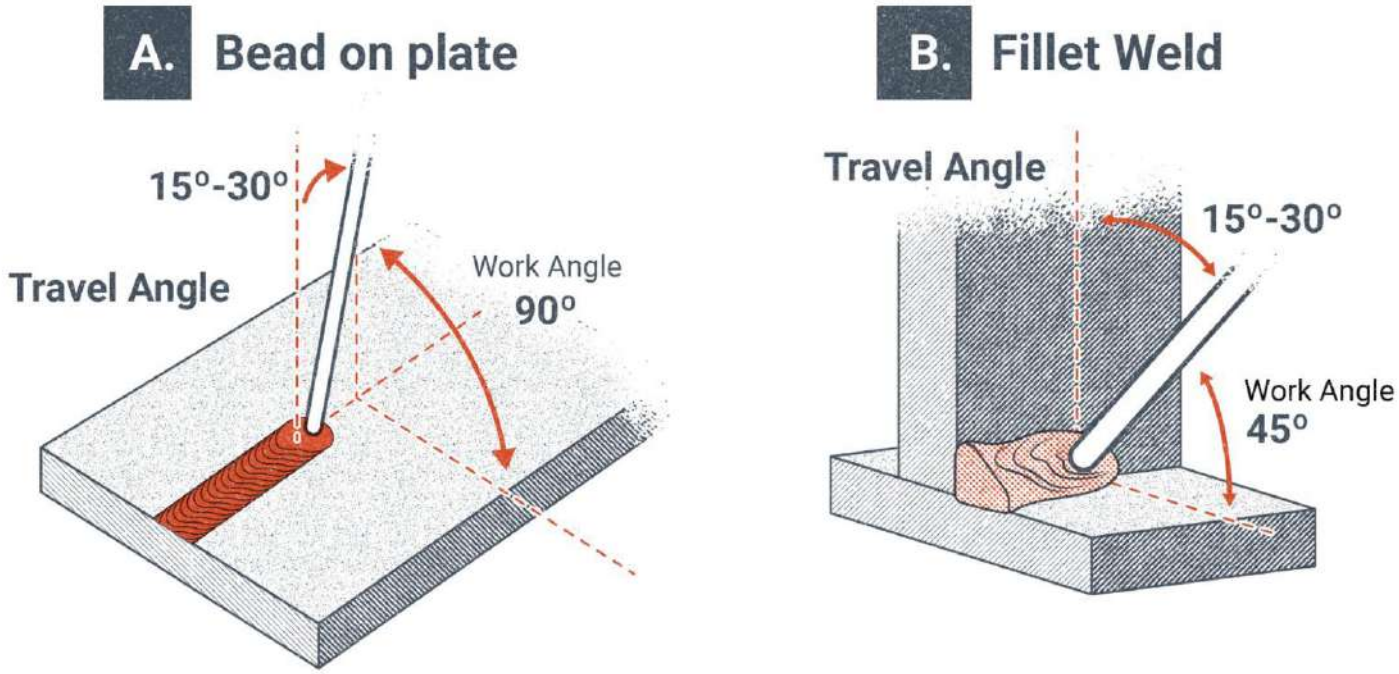
**12.3 Electrode Angle**

Electrode angle is the angle formed between the electrode and the workpiece or direction of welding.

It affects weld bead shape, penetration and control of molten metal.

Two important angles are:

1. Work angle: The angle of the electrode relative to the joint surfaces.
2. Travel angle: The angle of the electrode relative to the direction of travel.




**Factors affecting electrode angle:**

- Joint design.
- Welding position.
- Electrode type.
- Metal thickness.
- Direction of welding.
- Number of welding passes.

**13.0 PRACTICAL PROCEDURE FOR FLAT-POSITION MMAW**

Flat-position welding is one of the first practical skills learners should acquire in a metalwork workshop.

**13.1 Materials and Equipment Required**

- Two mild-steel plates.
- Suitable welding electrodes.
- Welding machine.
- Electrode holder.
- Work clamp.
- Welding cables.
- Welding table.
- Welding helmet.

- Leather gloves.
- Leather apron or jacket.
- Safety boots.
- Chipping hammer.
- Wire brush.
- Steel rule.
- Try square.
- Clamps.

**13.2 Procedure for Carrying Out a Flat-Position Weld**

**Step 1: Prepare the work area**

- Clear the welding area.
- Remove combustible materials.
- Ensure proper ventilation.
- Position welding screens.
- Check that a suitable fire extinguisher is available.

**Step 2: Prepare the workpieces**

- Select the required mild-steel plates.
- Measure the dimensions.
- Clean the metal surfaces.
- Remove rust, oil and paint.
- Prepare the joint edges where necessary.

**Step 3: Set up the welding machine**

- Inspect the welding machine.
- Check the cables and electrode holder.
- Connect the electrode and work cables correctly.
- Select the polarity recommended for the electrode.
- Adjust the current according to the electrode manufacturer's recommendations.

**Step 4: Secure the workpieces**

- Place the plates on the welding table.
- Align the edges.
- Use suitable clamps.
- Check the dimensions and joint gap.
- Tack weld where required.

**Step 5: Wear protective equipment**

- Wear the welding helmet.

- Put on welding gloves.
- Wear protective clothing.
- Put on safety boots.
- Use suitable respiratory protection where required.

**Step 6: Start the arc**

- Hold the electrode firmly.
- Position it above the starting point.
- Use the scratch or tapping method.
- Establish a stable arc.

**Step 7: Carry out welding**

- Maintain a suitable arc length.
- Maintain the appropriate electrode angle.
- Move the electrode at a steady speed.
- Control the molten weld pool.
- Maintain a reasonably uniform weld bead.

**Step 8: Stop welding**

- Withdraw the electrode correctly at the end of the weld.
- Allow the weld to cool sufficiently.
- Switch off the welding machine before changing connections or carrying out adjustments.

**Step 9: Remove slag**

- Use a chipping hammer to remove slag.
- Brush the weld with a wire brush.
- Clean the surrounding metal.

**Step 10: Inspect the joint**

- Check the weld bead.
- Look for visible defects.
- Assess the uniformity of the weld.
- Check the alignment of the workpieces.
- Seek teacher or supervisor assessment.







**14.0 PRACTICAL PROCEDURE FOR HORIZONTAL-POSITION MMAW**

Horizontal welding requires greater control of molten metal because gravity tends to pull the molten weld pool downwards.

**14.1 Materials and Equipment**

The equipment is similar to that used in flat-position welding.

Additional requirements may include:

- Vertical steel plate support.
- Suitable clamps.
- Positioning fixtures.
- Correct electrode for horizontal welding.

**14.2 Procedure**

1. Prepare and clean the workpieces.
2. Position the metal plates securely.
3. Ensure that the joint is horizontal.
4. Connect the welding equipment correctly.
5. Select suitable polarity and current.

6. Wear appropriate PPE.
7. Establish the electric arc.
8. Maintain a suitable arc length.
9. Hold the electrode at the recommended work and travel angles.
10. Control the molten metal to prevent excessive sagging.
11. Move the electrode steadily along the joint.
12. Stop the arc safely.
13. Allow the joint to cool.
14. Remove slag using a chipping hammer.
15. Clean the weld using a wire brush.
16. Inspect the finished joint.

**14.3 Challenges of Horizontal Welding**

1. Molten metal may sag due to gravity.
2. Excessive heat may cause poor bead shape.
3. Incorrect electrode angles may cause undercut.
4. Excessive travel speed may cause insufficient fusion.
5. Poor current settings may produce an irregular weld.
6. Inadequate cleaning may cause slag inclusions.

**14.4 Qualities of a Good Horizontal Weld**

- Uniform bead width.
- Consistent weld reinforcement.
- Good fusion with the base metal.
- No visible cracks.
- No excessive spatter.
- No excessive undercut.
- Proper alignment.
- Suitable penetration.

**15.0 WELDING PARAMETERS AND THEIR EFFECTS**

Welding parameters are the operating conditions selected to achieve the required weld quality.

**15.1 Welding Current**

Welding current is the flow of electric charge through the welding circuit, measured in amperes (A).

It determines the amount of electrical current used during welding.

**Effects of excessive current:**

- Excessive spatter.
- Excessive penetration in some conditions.

- Undercut.
- Burn-through on thin materials.
- Excessive electrode melting.

**Effects of insufficient current:**

- Electrode sticking.
- Poor arc stability.
- Lack of fusion.
- Poor penetration.
- Irregular weld bead.

**15.2 Arc Voltage**

Arc voltage is the electrical potential difference across the welding arc.

It is influenced by arc length and the characteristics of the welding power source.

**Effects of incorrect voltage:**

- Excessive voltage may result in a wide, flat bead and increased spatter.
- Low voltage may result in a short, unstable arc.
- Incorrect voltage conditions may contribute to poor weld appearance.

**15.3 Travel Speed**

Travel speed is the rate at which the electrode moves along the joint.

**Effects of excessive travel speed:**

- Narrow weld bead.
- Poor penetration.
- Lack of fusion.
- Incomplete filling of the joint.

**Effects of low travel speed:**

- Excessive weld reinforcement.
- Wide weld bead.
- Excessive heat input.
- Possible burn-through on thin materials.

**15.4 Electrode Diameter**

Electrode diameter is the thickness of the electrode core wire.

It influences the current range, metal deposition rate and suitability for particular material thicknesses.

**General guide:** Larger electrodes usually require higher current settings than smaller electrodes of similar type.

**15.5 Heat Input**

Heat input refers to the amount of energy transferred to the workpiece during welding per unit length of weld.

It is influenced by:

- Welding current.
- Arc voltage.
- Travel speed.
- Welding efficiency.

**Importance of controlling heat input:**

1. Helps control distortion.
2. Influences penetration.
3. Affects the properties of the weld and surrounding metal.
4. Helps reduce the risk of overheating.
5. Improves weld consistency.

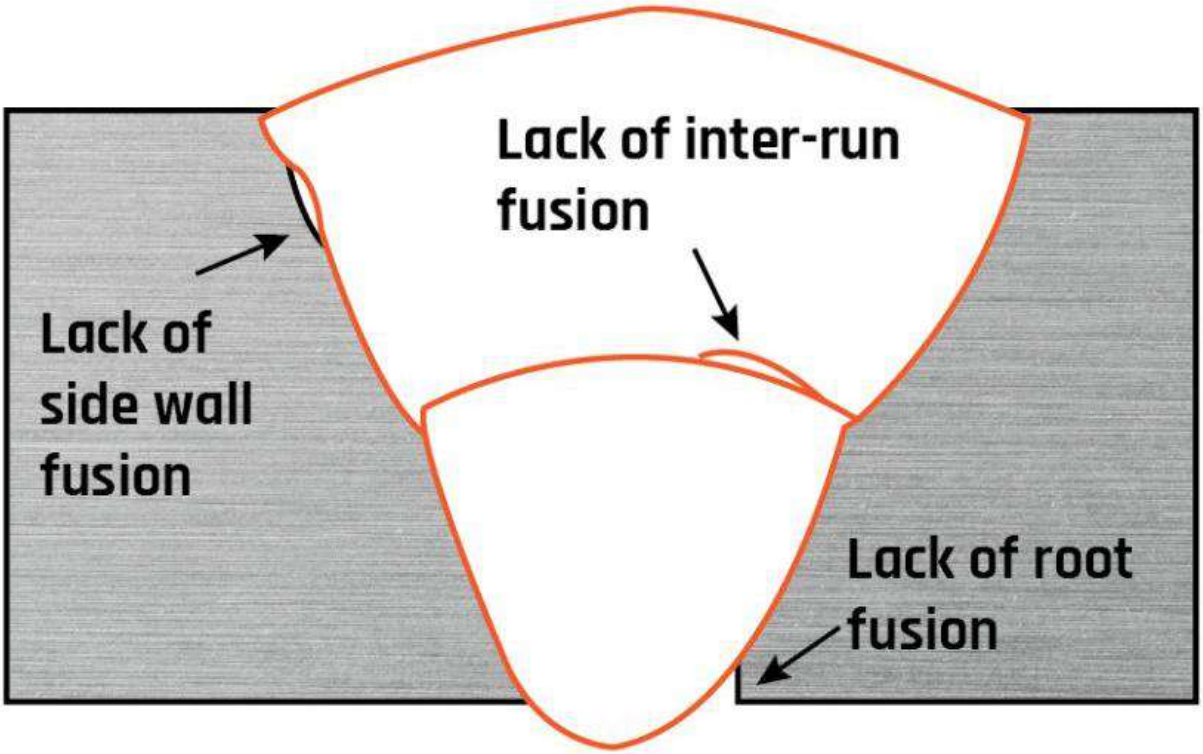
**16.0 WELD DEFECTS IN MANUAL METAL ARC WELDING**

A weld defect is an imperfection in a welded joint that reduces its quality or suitability for its intended application.

Weld defects may result from incorrect welding parameters, poor preparation, unsuitable electrodes, improper techniques or inadequate cleaning.

The learner should be able to identify, describe, explain the causes and suggest remedies for common weld defects.

**16.1 Lack of Fusion**




Lack of fusion is a welding defect in which the weld metal fails to fuse properly with the base metal or with a previous weld pass.

**Causes:**

1. Low welding current.
2. Excessive travel speed.
3. Incorrect electrode angle.

4. Poor joint preparation.
5. Inadequate cleaning.
6. Poor welding technique.

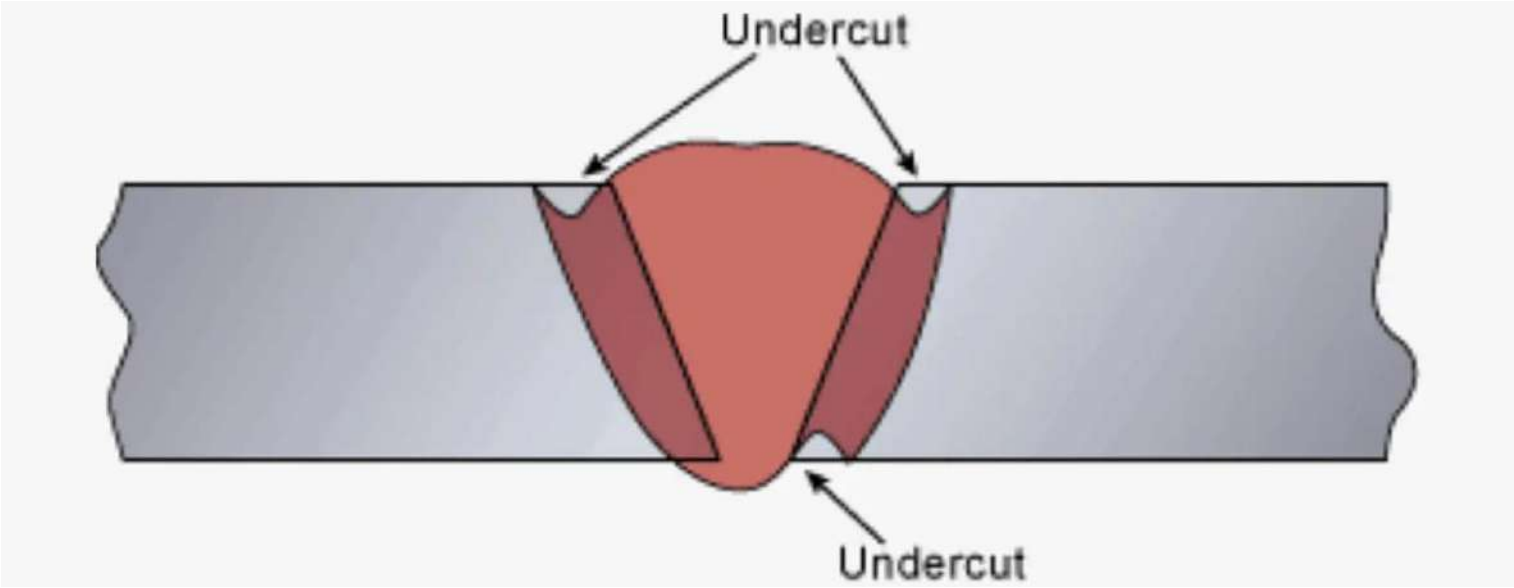
**Effects:**

- Reduces joint strength.
- Creates weak areas in the weld.
- May lead to premature failure.
- Can reduce resistance to service loading.

**Remedies:**

- Use the correct welding current.
- Clean the joint properly.
- Use suitable electrode angles.
- Reduce excessive travel speed.
- Prepare the joint correctly.
- Apply the correct welding technique.

**16.2 Undercut**




Undercut is a groove formed along the edge or toe of a weld that is not filled with weld metal.

**Causes:**

- Excessive welding current.
- Excessive travel speed.
- Incorrect electrode angle.
- Excessive arc length.
- Poor electrode manipulation.

**Effects:**

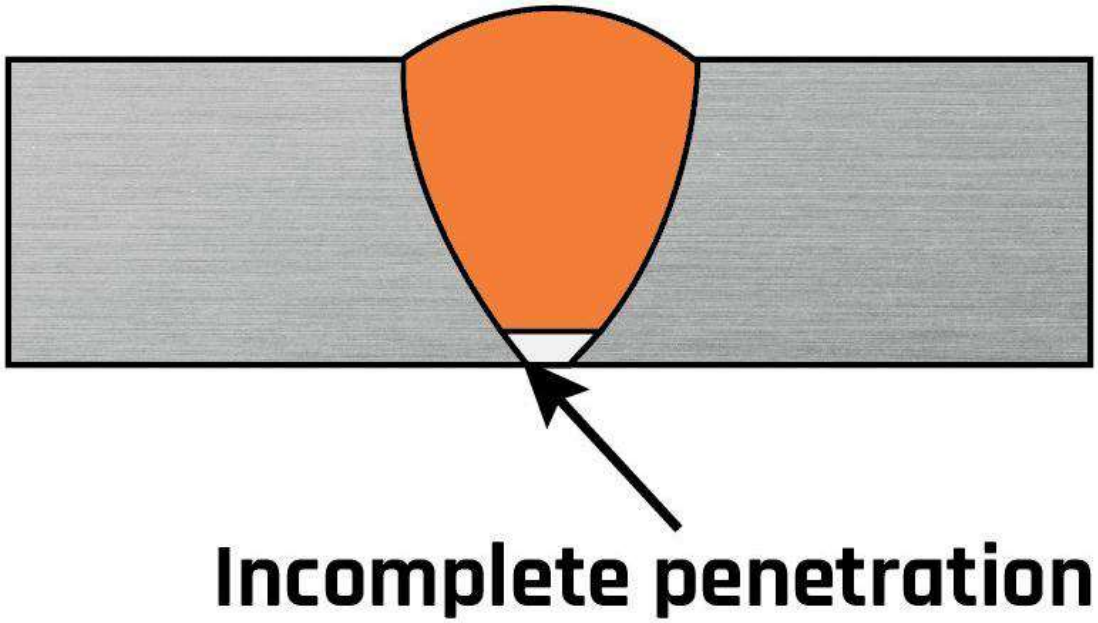
1. Reduces the effective thickness of the base metal.

2. Creates stress concentration points.
3. Weakens the welded joint.
4. May initiate cracks under repeated loading.

**Remedies:**

- Use the correct current.
- Maintain a suitable arc length.
- Control electrode movement.
- Use the correct travel speed.
- Avoid excessive weaving.

**16.3 Poor Penetration**




Poor penetration occurs when the weld metal does not extend sufficiently into the root of the joint.

It is also referred to as incomplete penetration when the required root penetration has not been achieved.

**Causes:**

1. Low welding current.
2. Excessive travel speed.
3. Incorrect electrode angle.
4. Small root gap.
5. Inadequate edge preparation.
6. Large electrode diameter for the joint conditions.

**Effects:**

- Reduces joint strength.
- Creates an incomplete connection at the root.
- May result in joint failure.
- Reduces the reliability of the weld.

**Remedies:**

- Provide suitable joint preparation.
- Use the correct root gap.
- Select an appropriate electrode.
- Adjust welding current correctly.
- Control the travel speed.

**16.4 Porosity**



Porosity is the formation of small cavities or holes in the weld metal caused by trapped gases during solidification.

**Causes:**

1. Moisture in electrodes.
2. Dirty workpiece surfaces.
3. Oil and grease contamination.
4. Rust and paint on the metal.
5. Excessive arc length.
6. Poor shielding caused by damaged flux coating.
7. Inadequate protection from draughts.

**Effects:**

- Reduces the effective cross-sectional area of the weld.

- May reduce mechanical strength.
- Can cause leakage in pressure-containing joints.
- May lead to rejection of the welded component.

**Remedies:**

- Use dry electrodes as recommended.
- Clean the workpiece.
- Maintain suitable arc length.
- Protect the welding area from strong draughts.
- Use electrodes with undamaged coatings.
- Follow the correct welding procedure.

**16.5 Slag Inclusion**




Slag inclusion is a defect in which non-metallic slag becomes trapped inside the weld metal or between successive weld passes.

**Causes:**

- Inadequate slag removal between passes.
- Incorrect electrode angle.
- Poor joint preparation.
- Incorrect welding technique.
- Insufficient heat input.
- Excessive weaving.

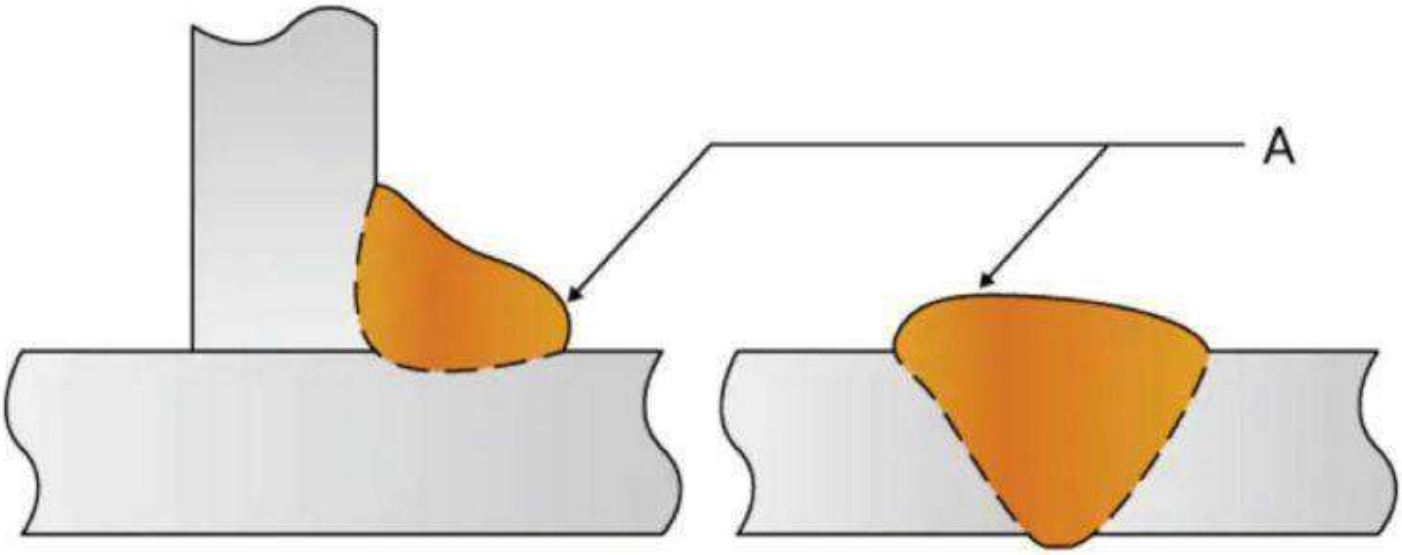
**Effects:**

1. Reduces weld strength.
2. Creates discontinuities inside the joint.
3. May lead to crack initiation.
4. Reduces the reliability of the welded structure.

**Remedies:**

- Remove slag between welding passes.
- Use the correct electrode angle.
- Maintain appropriate welding current.
- Prepare the joint correctly.
- Apply suitable welding techniques.

**16.6 Overlap**




A. Overlap

Overlap occurs when weld metal flows beyond the toe of the weld and lies on the surface of the base metal without proper fusion.

**Causes:**

1. Low travel speed.
2. Incorrect electrode angle.
3. Excessive deposition of weld metal.
4. Low welding current under certain conditions.
5. Poor manipulation of the electrode.

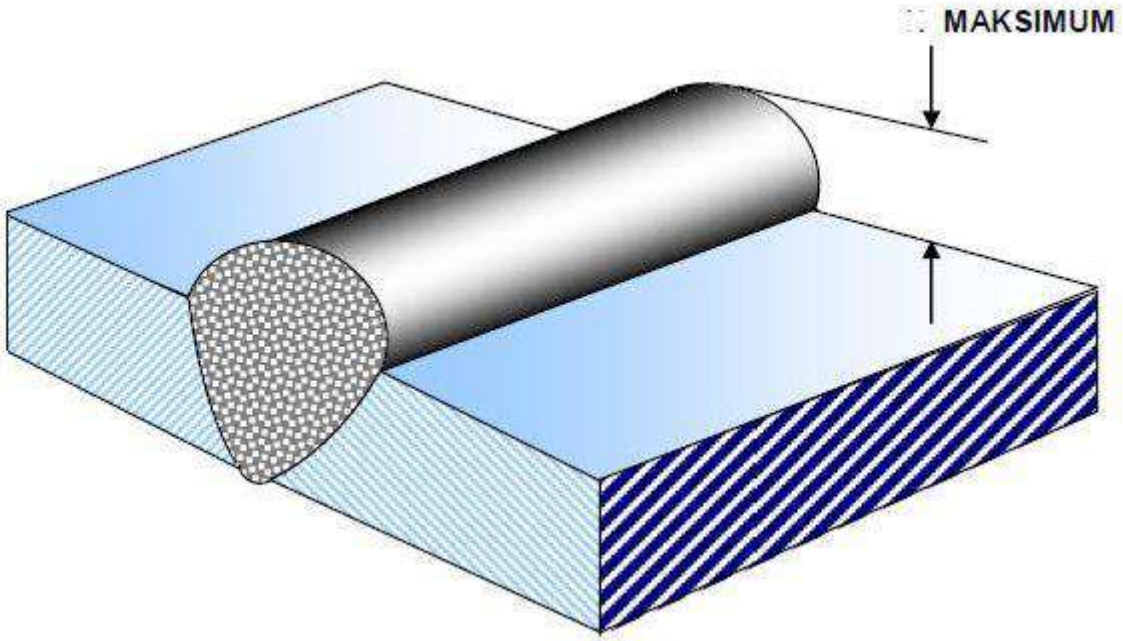
**Effects:**

- Produces an irregular weld profile.
- Creates areas of incomplete fusion.
- May cause stress concentration.
- Reduces the quality and reliability of the joint.

**Remedies:**

- Maintain a suitable travel speed.
- Use the correct electrode angle.
- Control the amount of deposited metal.
- Adjust the welding current appropriately.
- Use correct electrode manipulation.

**16.7 Build-up Edges (Excessive Weld Reinforcement)**




Build-up edges refer to excessive accumulation of weld metal along the weld edges or surface, producing an uneven or excessively raised weld profile.

This may result from poor control of deposited metal and welding movement.

**Causes:**

1. Excessive deposition of weld metal.
2. Very low travel speed.
3. Incorrect electrode manipulation.
4. Unsuitable welding parameters.
5. Poor control of the weld pool.

**Effects:**

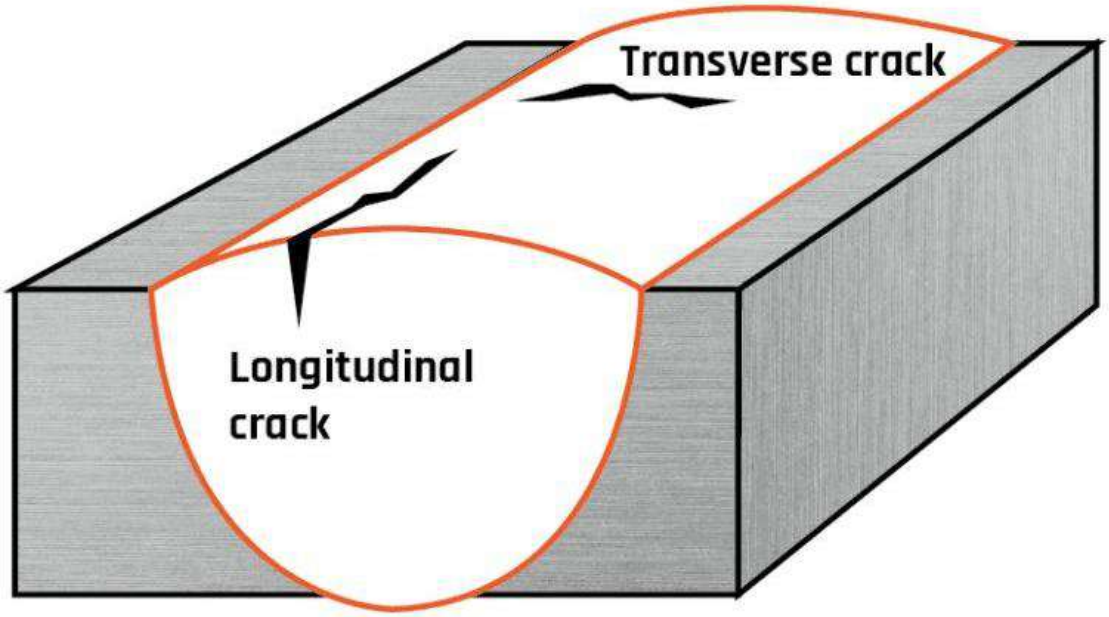
- Produces an uneven weld surface.
- May interfere with fitting of components.

- Increases the amount of finishing work required.
- May indicate poor welding technique.
- Can create stress concentrations depending on the weld profile.

**Remedies:**

- Control travel speed.
- Use suitable welding current.
- Maintain correct electrode movement.
- Deposit the correct amount of weld metal.
- Apply additional finishing where specified.

**16.8 Cracks**




A crack is a fracture or separation that occurs in the weld metal or heat-affected zone.

**Types of cracks:**

- Longitudinal cracks.
- Transverse cracks.
- Crater cracks.
- Hot cracks.
- Cold cracks.

**Causes:**

1. Excessive restraint of the joint.
2. Hydrogen contamination.
3. Incorrect welding procedure.
4. Rapid cooling in susceptible materials.
5. Poor joint design.
6. Inappropriate filler metal.

7. Unfilled weld craters.

**Effects:**

- Seriously reduces joint strength.
- Can cause sudden failure.
- May spread under loading.
- Makes the component unsafe for its intended purpose.

**Remedies:**

- Use suitable welding procedures.
- Select compatible electrodes.
- Follow appropriate preheating requirements where specified.
- Use correct joint design.
- Fill the crater properly.
- Control hydrogen according to the material and electrode requirements.

**16.9 Excessive Spatter**




Spatter refers to small droplets of molten metal scattered around the weld area.

Excessive spatter is undesirable because it affects weld appearance and increases cleaning requirements.

**Causes:**

- Excessive welding current.
- Long arc length.
- Incorrect polarity for the electrode.

- Unstable arc.
- Incorrect electrode manipulation.

**Remedies:**

- Adjust the current.
- Maintain a suitable arc length.
- Select the recommended polarity.
- Use the correct electrode.
- Maintain steady electrode movement.

**16.10 Summary of Common Weld Defects**

| Defect | Main characteristic | Common remedy |
|---|---|---|
| Lack of fusion | Weld metal fails to fuse with base metal or previous pass. | Correct current, angle and travel speed. |
| Undercut | Groove along weld toe. | Reduce excessive current and improve technique. |
| Poor penetration | Inadequate fusion at the root. | Improve edge preparation and parameters. |
| Porosity | Gas cavities in weld metal. | Clean metal and use dry electrodes. |
| Slag inclusion | Slag trapped inside weld. | Clean between passes. |
| Overlap | Weld metal flows over base metal without fusion. | Correct angle and travel speed. |
| Build-up edges | Excessive or uneven weld metal accumulation. | Control deposition and electrode movement. |
| Cracks | Fractures in weld metal or heat-affected zone. | Use a suitable welding procedure. |
| Excessive spatter | Excessive metal droplets around the weld. | Correct current and arc length. |

**Important quality note:** A weld may appear acceptable externally but still contain internal defects. Visual inspection alone cannot confirm complete internal soundness. Critical welds require appropriate inspection and testing procedures.

**17.0 INSPECTION AND TESTING OF MMAW JOINTS**

Inspection is the process of examining a welded joint to determine whether it meets the required quality standards.

Testing involves applying suitable methods to assess the properties, strength or soundness of a welded joint.

**17.1 Visual Inspection**

Visual inspection involves examining the surface of a welded joint using the eyes and suitable measuring tools.

**Features to inspect:**

1. Weld bead uniformity.
2. Weld width.
3. Weld reinforcement.
4. Surface cracks.
5. Undercut.
6. Overlap.
7. Visible porosity.
8. Excessive spatter.
9. Joint alignment.
10. Surface cleanliness.

**17.2 Destructive Testing**

Destructive testing involves subjecting a test specimen to a procedure that may permanently damage or destroy it.

Examples include:

**A. Bend test**

- A welded specimen is bent to assess the soundness and ductility of the weld.
- It may reveal lack of fusion, cracks and other discontinuities.

**B. Tensile test**

- A welded specimen is subjected to a pulling force.
- It helps determine the tensile strength of the welded joint.

**C. Impact test**

- A specimen is subjected to a sudden impact.
- It helps assess the toughness of the weld metal or joint.

**D. Fracture test**

- A specimen is broken using a suitable testing method.
- The fractured surface is examined for internal discontinuities.

**17.3 Non-Destructive Testing (NDT)**

Non-destructive testing involves examining a welded joint without destroying its usefulness.

Methods include:

1. Visual testing (VT).
2. Dye penetrant testing (PT).
3. Magnetic particle testing (MT).
4. Ultrasonic testing (UT).
5. Radiographic testing (RT).

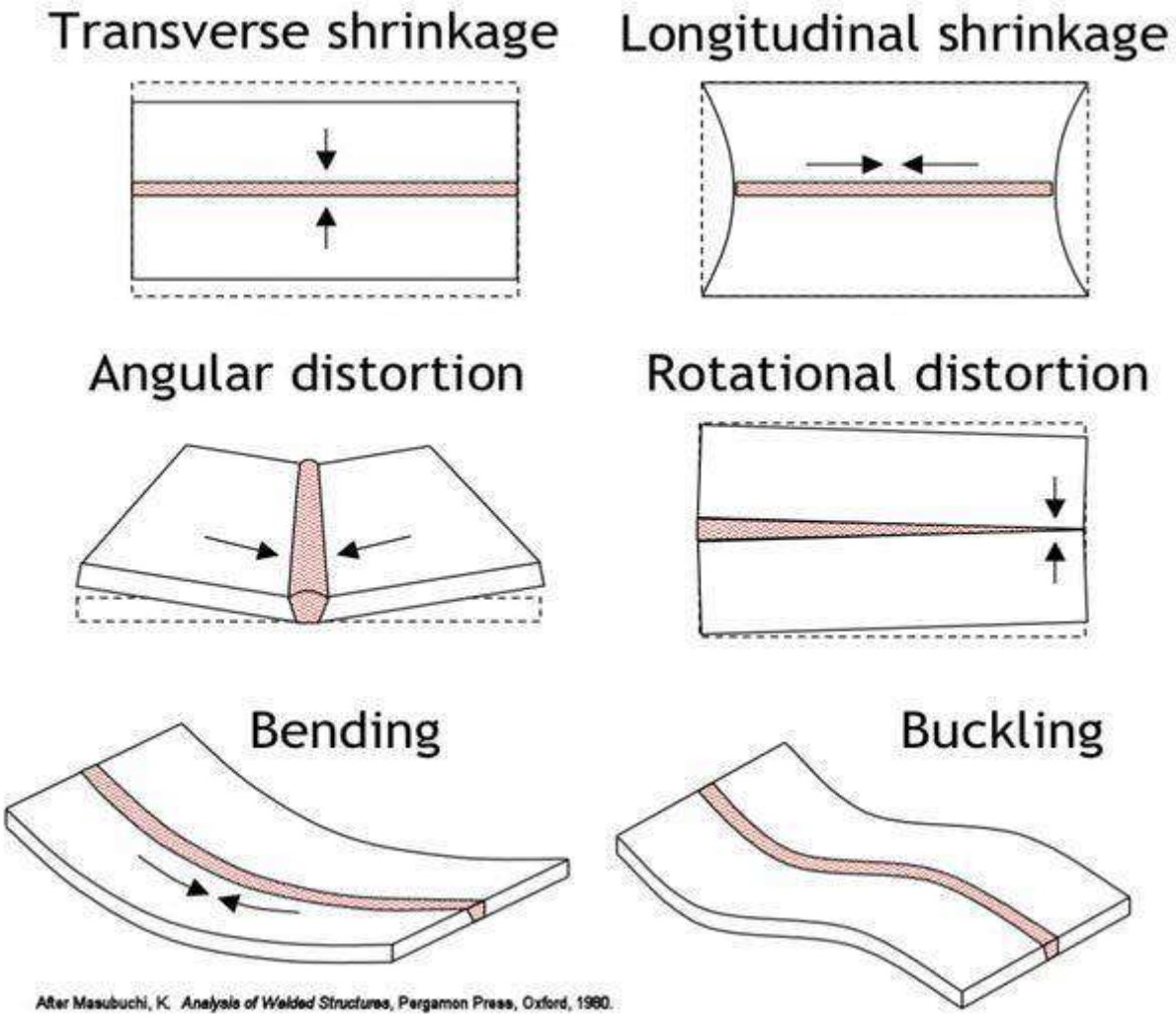
**Importance of inspection and testing:**

- Helps identify weld defects.
- Improves safety.
- Promotes product reliability.
- Helps determine whether welds meet specifications.
- Reduces the risk of structural failure.

**18.0 DISTORTION IN WELDING**

Distortion is the unwanted change in the shape or dimensions of a metal component caused by uneven heating and cooling during welding.

During welding, the heated metal expands. As it cools, it contracts. Uneven expansion and contraction may cause the workpiece to bend, twist or change shape.




**18.1 Types of Welding Distortion**

**1. Angular distortion**

This occurs when the two sides of a welded joint move at different angles due to uneven contraction.

**2. Longitudinal distortion**

This is distortion that occurs along the length of a welded component.

**3. Transverse distortion**

This occurs across the width of a welded joint due to contracting cooling.

**4. Bowing distortion**

This is the bending of a metal component along its length.

**5. Twisting distortion**

This occurs when a welded component rotates or twists out of its original shape.

**18.2 Causes of Welding Distortion**

1. Excessive heat input.
2. Uneven heating.
3. Poor joint design.
4. Incorrect welding sequence.
5. Excessive weld metal deposition.
6. Thin workpiece materials.
7. Improper clamping.
8. Unequal cooling rates.

**18.3 Methods of Controlling Distortion**

1. Use suitable welding current.
2. Apply the correct welding sequence.
3. Use clamps and fixtures.
4. Avoid unnecessary weld metal deposition.
5. Use intermittent welding where appropriate.
6. Balance welding on opposite sides of a joint where suitable.
7. Use suitable joint designs.
8. Allow controlled cooling.
9. Use an appropriate tack-welding arrangement.
10. Apply suitable pre-setting techniques where necessary.

**19.0 CARE AND MAINTENANCE OF MMAW TOOLS AND EQUIPMENT**

Maintenance is the process of keeping workshop tools and equipment in good working condition through cleaning, inspection, servicing and repair.

Proper maintenance improves equipment performance, safety and service life.

**19.1 Maintenance of Welding Machines**

**Daily care:**

- Switch off the machine after use.
- Keep the machine clean.
- Remove dust using approved methods.
- Inspect the casing.
- Check the cables and terminals.
- Store the machine in a dry area.

**Periodic maintenance:**

- Have electrical connections inspected by a qualified person.
- Check cooling fans and ventilation openings.
- Inspect internal components according to the manufacturer's schedule.
- Repair faults using authorised technicians.
- Maintain service records.

**19.2 Maintenance of Electrode Holders**

1. Clean the gripping jaws.
2. Inspect the insulation.
3. Check for loose connections.
4. Replace damaged holders.
5. Keep the handle dry.
6. Store in a suitable location.

**19.3 Maintenance of Welding Cables**

1. Inspect insulation regularly.
2. Remove dirt from connectors.
3. Replace damaged cables.
4. Avoid sharp bends.
5. Keep cables away from hot metal.
6. Store cables neatly after use.

**19.4 Maintenance of Work Clamps**

- Clean the contact surfaces.
- Remove rust and dirt.
- Inspect the gripping mechanism.
- Tighten loose connections.
- Replace damaged clamps.

**19.5 Maintenance of Chipping Hammers**

- Clean the hammer after use.
- Inspect the head for cracks.
- Check the handle for looseness.
- Replace damaged handles.
- Store in the toolbox.

**19.6 Maintenance of Wire Brushes**

- Remove accumulated slag.
- Keep the brush dry.

- Inspect the wire bristles.
- Replace worn brushes.
- Store in a clean and dry place.

**19.7 Maintenance of Welding Helmets**

1. Clean the helmet regularly.
2. Inspect the filter lens.
3. Replace cracked or damaged lenses.
4. Check the headband.
5. Ensure the helmet fits properly.
6. Store it in a protective case or suitable location.

**19.8 Importance of Proper Maintenance**

- Increases equipment lifespan.
- Reduces equipment breakdowns.
- Improves welding quality.
- Prevents electrical accidents.
- Reduces repair costs.
- Improves productivity.
- Promotes workshop safety.
- Ensures equipment is available when needed.

**20.0 COMMON PROBLEMS EXPERIENCED DURING MMAW AND THEIR SOLUTIONS**

| **Problem** | **Possible cause** | **Suggested solution** |
|---|---|---|
| Electrode sticking | Low current or short arc. | Adjust current and use correct arc length. |
| Arc difficult to start | Poor connections or unsuitable settings. | Check connections and settings. |
| Excessive spatter | High current or long arc. | Adjust current and arc length. |
| Porosity | Moisture or contamination. | Clean surfaces and use suitable dry electrodes. |
| Uneven weld bead | Irregular travel speed. | Practise steady electrode movement. |
| Undercut | Excessive current or incorrect angle. | Adjust parameters and technique. |
| Poor penetration | Inadequate heat or joint preparation. | Improve preparation and welding settings. |
| Slag inclusion | Inadequate cleaning. | Remove slag between passes. |

| | | |
|---|---|---|
| Machine overheating | Overloading or blocked ventilation. | Allow cooling and inspect the machine. |
| Cable overheating | Poor connections or unsuitable cable. | Switch off and have connections and cables checked. |

## 21.0 ENVIRONMENTAL CONSERVATION AND WASTE MANAGEMENT IN MMAW

Metal Technology learners should practise responsible use of resources and protect the environment.

Welding activities produce metal offcuts, used electrodes, slag, dust, packaging and other waste materials.

### 21.1 Types of Waste Produced During Welding

1. Metal offcuts.
2. Used electrode stubs.
3. Welding slag.
4. Grinding dust.
5. Damaged abrasive discs.
6. Empty electrode packaging.
7. Contaminated cleaning materials.
8. Used PPE that can no longer provide protection.

### 21.2 Proper Waste Management Practices

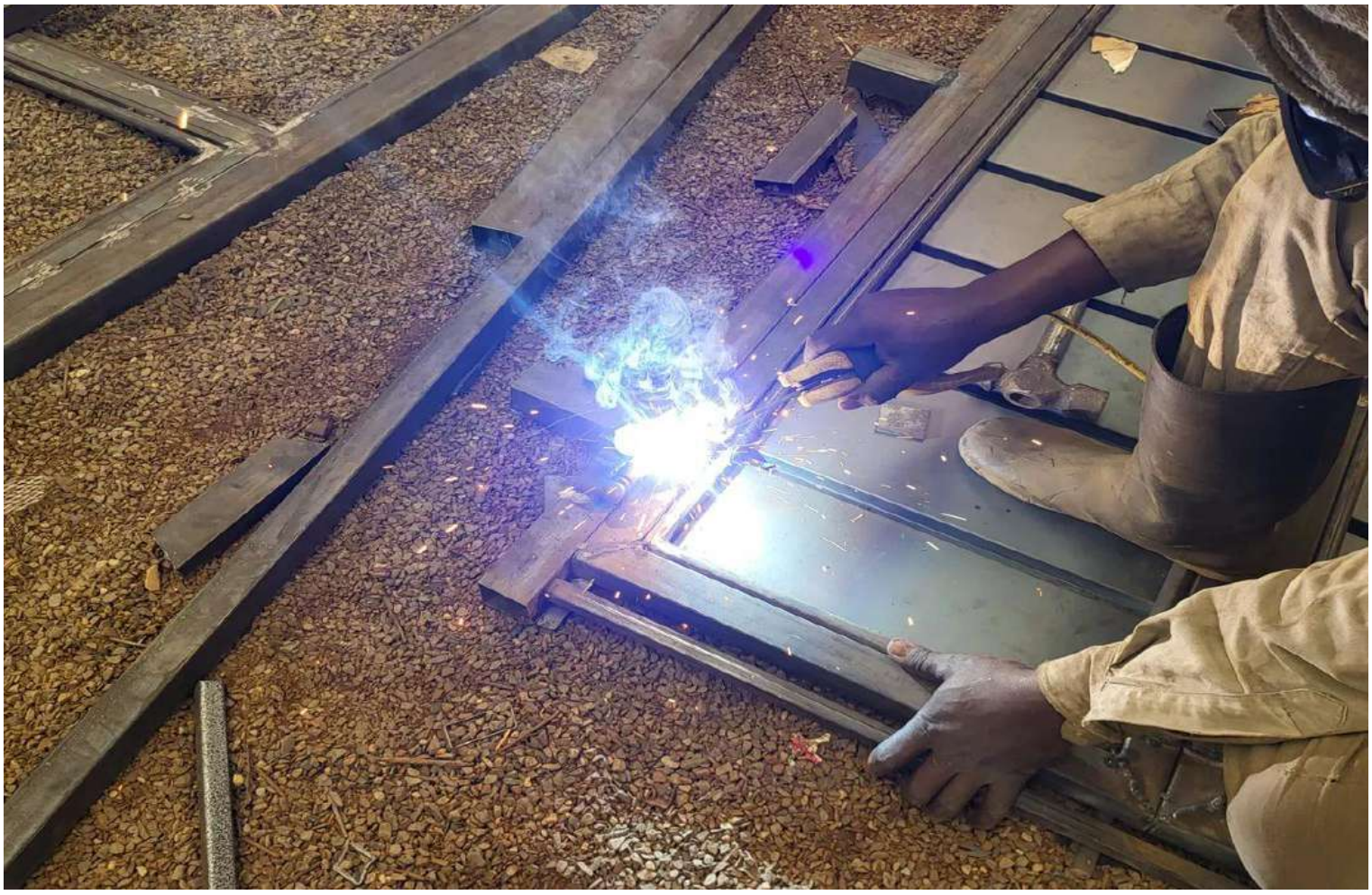
- Collect metal offcuts for recycling.
- Place used electrode stubs in designated containers.
- Dispose of slag according to workshop procedures.
- Collect grinding dust safely.
- Separate recyclable and non-recyclable waste.
- Avoid throwing metal waste onto the workshop floor.
- Keep waste away from drains and water sources.
- Dispose of contaminated materials appropriately.
- Reduce unnecessary electrode consumption.

### 21.3 Environmental Benefits of Proper Waste Management

1. Reduces environmental pollution.
2. Promotes recycling.
3. Conserves natural resources.
4. Reduces workshop accidents.
5. Promotes cleanliness.
6. Reduces unnecessary expenditure.
7. Encourages sustainable industrial practices.

## 22.0 APPLICATIONS OF MMAW IN THE KENYAN ECONOMY

Manual Metal Arc Welding contributes to the development of several sectors of the Kenyan economy.







**22.1 Agriculture**

MMAW is used to:

- Repair tractor implements.
- Repair trailers.
- Fabricate wheelbarrows.
- Manufacture metal animal feeders.
- Repair irrigation equipment.
- Fabricate farm gates and fencing components.

**22.2 Construction**

It is used in:

- Fabrication of steel roof trusses.
- Joining structural steel components.
- Fabrication of metal staircases.
- Making steel gates.
- Manufacturing steel support frames.
- Repairing metal structures.

**22.3 Transport**

It is used in:

- Repairing suitable vehicle components.
- Fabricating trailer frames.

- Repairing metal body structures.
- Manufacturing vehicle brackets.
- Repairing workshop equipment.

Safety-critical vehicle components should only be repaired using approved procedures by competent personnel.

**22.4 Education**

MMAW supports the education sector through the fabrication and repair of:

- School desks.
- Metal chairs.
- Laboratory stands.
- Storage cabinets.
- Workshop equipment.
- School gates.

**22.5 Entrepreneurship and Employment**

Learners can use welding skills to establish small-scale enterprises offering:

- Gate fabrication.
- Window frame fabrication.
- Metal furniture production.
- Agricultural equipment repair.
- General steel fabrication.
- Welding and maintenance services.

**Entrepreneurial example:** A Grade 11 learner who develops competence in MMAW can progress towards establishing a small fabrication enterprise that makes school desks, security gates and agricultural equipment for local customers.

**23.0 ENTREPRENEURIAL AND EMPLOYABILITY SKILLS DEVELOPED THROUGH MMAW**

Learning MMAW promotes practical, personal and social competencies.

**23.1 Creativity and Innovation**

Learners develop the ability to:

- Design new metal products.
- Develop solutions to practical problems.
- Modify existing products.
- Use locally available materials creatively.

**23.2 Critical Thinking and Problem-Solving**

Learners develop the ability to:

- Identify welding defects.
- Determine possible causes of defects.
- Select suitable welding procedures.

- Improve the quality of welded products.
- Solve fabrication challenges.

**23.3 Communication and Collaboration**

Learners develop the ability to:

- Share workshop responsibilities.
- Communicate technical instructions.
- Work in teams.
- Review other learners' products.
- Give and receive constructive feedback.

**23.4 Digital Literacy**

Learners can use digital resources to:

- Research welding techniques.
- Identify welding equipment.
- Study welding safety.
- Watch demonstrations.
- Compare welding procedures.
- Access technical information.

**23.5 Self-Efficacy**

Learners develop confidence by:

- Performing welding tasks.
- Evaluating their own work.
- Correcting mistakes.
- Learning new techniques.
- Completing practical projects.

**23.6 Environmental Responsibility**

Learners develop responsible habits through:

- Recycling metal waste.
- Conserving materials.
- Using electricity responsibly.
- Maintaining a clean workshop.
- Preventing unnecessary pollution.

## 24.0 PRACTICAL PROJECT: FABRICATION OF A SIMPLE METAL BRACKET USING MMAW



**Project description**

Learners are required to fabricate a simple metal bracket using manual metal arc welding.

The project provides an opportunity to apply measurement, marking out, cutting, preparation, welding, cleaning and inspection skills.

### 24.1 Materials Required

- Mild-steel flat bars or plates.
- Suitable welding electrodes.
- Welding consumables.
- Suitable cleaning materials.

### 24.2 Tools and Equipment

- Welding machine.
- Electrode holder.
- Work clamp.
- Steel rule.
- Try square.
- Scriber.
- Hacksaw or cutting machine.

- Angle grinder.
- Clamps.
- Chipping hammer.
- Wire brush.

**24.3 Procedure**

1. Study the bracket drawing.
2. Select suitable mild-steel materials.
3. Measure and mark the required dimensions.
4. Cut the components.
5. Remove sharp edges.
6. Clean the surfaces.
7. Position the components at the required angle.
8. Clamp the components.
9. Tack weld the components.
10. Check the dimensions and alignment.
11. Carry out the main welding operation.
12. Allow the bracket to cool.
13. Remove slag.
14. Clean the weld.
15. Inspect the finished product.
16. Apply suitable surface finishing where required.

**24.4 Assessment Criteria**

The teacher may assess the project using the following criteria:

| **Assessment area** | **Expected performance** |
|---|---|
| Measurement | Accurate dimensions. |
| Material preparation | Clean and properly prepared materials. |
| Joint alignment | Correct positioning of components. |
| Equipment setup | Safe and correct connections. |
| Arc starting | Ability to establish a stable arc. |
| Welding technique | Suitable arc length, angle and movement. |

| | |
|---|---|
| Weld quality | Uniform bead and acceptable fusion. |
| Finishing | Proper cleaning and removal of slag. |
| Safety | Correct use of PPE and safe workshop practices. |
| Maintenance | Proper care of tools and equipment. |

**REVISION QUESTIONS**

GRADE 11 METAL TECHNOLOGY

**STRAND 4.0: METAL JOINING AND FINISHING PROCESSES**

**SUB-STRAND 4.3: MANUAL METAL ARC WELDING**

The following questions assess knowledge, understanding, practical application, problem-solving, safety awareness and creativity in MMAW.

**SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)**

**Instructions:** Answer all questions. Choose the correct answer from the alternatives A, B, C and D.

**1.** Manual Metal Arc Welding is classified as a thermal joining process because it uses:

A. Mechanical pressure to join metals.

B. Heat generated by an electric arc to melt metals.

C. Adhesives to connect metal surfaces.

D. Chemical reactions without heat.

**2.** Which of the following is the main source of heat in MMAW?

A. Friction between two metals.

B. Burning of charcoal.

C. Electric arc.

D. Steam pressure.

**3.** The main function of the flux coating on a welding electrode is to:

A. Increase the weight of the electrode.

B. Protect the molten weld metal from atmospheric contamination.

C. Prevent the electrode from conducting electricity.

D. Reduce the thickness of the workpiece.

**4.** Which component holds the welding electrode during welding?

A. Work clamp.

B. Chipping hammer.

C. Electrode holder.

D. Wire brush.

**5.** The main function of the work clamp in MMAW is to:

A. Remove slag from the weld.

B. Complete the electrical welding circuit.

C. Hold the electrode.

D. Adjust the welding current.

**6.** Which PPE provides protection against harmful ultraviolet radiation from the welding arc?

A. Leather apron.

B. Safety boots.

C. Welding helmet with a suitable filter lens.

D. Cotton gloves.

**7.** Which of the following tools is mainly used to remove slag after welding?

A. Try square.

B. Chipping hammer.

C. Steel rule.

D. Centre punch.

**8.** An electrode marked E6013 has a minimum tensile strength classification of:

A. 6,000 psi.

B. 13,000 psi.

C. 60,000 psi.

D. 130,000 psi.

**9.** In straight polarity (DCEN), the electrode is connected to the:

A. Positive terminal.

B. Negative terminal.

C. Earth terminal only.

D. AC terminal.

**10.** In reverse polarity (DCEP), the workpiece is connected to the:

A. Positive terminal.

B. Negative terminal.

C. Electrode holder.

D. Transformer casing.

**11.** Which method involves dragging the electrode briefly across the workpiece to establish an arc?

A. Tapping method.

B. Scratch method.

C. Grinding method.

D. Filing method.

**12.** The distance between the electrode tip and the weld pool is known as:

A. Travel speed.

B. Root gap.

C. Arc length.

D. Electrode diameter.

**13.** Which welding position is generally easiest for beginners to practise?

A. Overhead position.

B. Vertical position.

C. Flat position.

D. Horizontal position.

**14.** Horizontal welding is challenging mainly because:

A. The electrode cannot conduct electricity.

B. Gravity tends to pull the molten weld metal downwards.

C. The welding machine cannot supply enough current.

D. The workpiece cannot be cleaned.

**15.** The process of making small temporary welds to hold components in position is called:

A. Grinding.

B. Tack welding.

C. Brazing.

D. Soldering.

**16.** Which of the following defects is characterised by small cavities or holes in the weld metal?

A. Undercut.

B. Overlap.

C. Porosity.

D. Distortion.

**17.** A groove formed along the toe of a weld that is not filled with weld metal is known as:

A. Porosity.

B. Undercut.

C. Slag inclusion.

D. Overlap.

**18.** Slag trapped inside a welded joint is referred to as:

A. Lack of fusion.

B. Slag inclusion.

C. Excessive spatter.

D. Distortion.

**19.** Which of the following is a major cause of porosity?

A. Proper cleaning of metal.

B. Use of suitable electrodes.

C. Moisture and contamination.

D. Correct arc length.

**20.** A weld defect in which weld metal fails to fuse with the base metal is called:

A. Lack of fusion.

B. Build-up edges.

C. Excessive reinforcement.

D. Spatter.

**21.** Which of the following is the most suitable tool for cleaning rust from a metal surface before welding?

A. Wire brush.

B. Centre punch.

C. Try square.

D. Divider.

**22.** What is the main purpose of using clamps during welding?

A. To increase the welding current.

B. To hold workpieces in the correct position.

C. To remove welding slag.

D. To increase electrode length.

**23.** Which of the following may cause excessive spatter during MMAW?

A. Correct arc length.

B. Clean workpiece.

C. Excessive current and long arc length.

D. Proper electrode selection.

**24.** The unwanted change in the shape of a metal component due to uneven heating and cooling is known as:

A. Penetration.

B. Distortion.

C. Fusion.

D. Deposition.

**25.** Which of the following is a non-destructive testing method?

A. Tensile testing.

B. Bend testing.

C. Impact testing.

D. Ultrasonic testing.

**26.** Which of the following is the correct way of maintaining welding cables?

A. Dragging them over sharp edges.

B. Keeping them near hot metal.

C. Inspecting insulation and replacing damaged cables.

D. Immersing them in water.

**27.** Which welding position involves welding on the underside of a joint?

A. Flat.

B. Horizontal.

C. Vertical.

D. Overhead.

**28.** A welder is likely to produce a narrow weld bead with insufficient penetration when:

A. Travel speed is excessively high.

B. Travel speed is too low.

C. The workpiece is properly cleaned.

D. The electrode is correctly selected.

**29.** Which of the following practices promotes environmental conservation in a welding workshop?

A. Disposing of metal offcuts in rivers.

B. Burning all workshop waste.

C. Collecting and recycling metal offcuts.

D. Throwing used electrodes on the floor.

**30.** A learner in Shimo la Tewa repairs a damaged steel trailer using MMAW. Which societal benefit does this demonstrate?

A. Increased dependence on imported equipment.

B. Application of welding skills to solve practical problems.

C. Elimination of the need for workshop safety.

D. Reduction in the importance of technical education.

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

**Instructions:**

- Answer all questions.
- Write your answers clearly.
- Use labelled diagrams where necessary.
- Observe the mark allocations provided.

**QUESTION 1: INTRODUCTION TO MMAW (8 MARKS)**

a) Define Manual Metal Arc Welding. (2 marks)

b) Explain three ways in which MMAW contributes to economic development in Kenya. (3 marks)

c) State three functions of the flux coating on a welding electrode. (3 marks)

**QUESTION 2: TOOLS, EQUIPMENT AND PPE (8 MARKS)**

a) Identify four tools or equipment used in MMAW. (4 marks)

b) Explain two functions of a welding helmet during welding. (2 marks)

c) State two maintenance practices for welding cables. (2 marks)

**QUESTION 3: WELDING CIRCUIT AND POLARITY (8 MARKS)**

a) Differentiate between straight polarity (DCEN) and reverse polarity (DCEP). (4 marks)

b) Explain the procedure for establishing an electric arc using the scratch method. (4 marks)

**QUESTION 4: WELDING POSITIONS AND PRACTICAL OPERATIONS (8 MARKS)**

a) Name four common welding positions used in MMAW. (4 marks)

b) Explain four steps followed when carrying out flat-position welding. (4 marks)

**QUESTION 5: WELD DEFECTS AND QUALITY CONTROL (9 MARKS)**

a) Define a weld defect. (1 mark)

b) Describe four common defects found in MMAW joints. (4 marks)

c) Explain four measures that can be taken to prevent weld defects. (4 marks)

**QUESTION 6: SAFETY, MAINTENANCE AND APPLICATIONS (9 MARKS)**

a) State three safety precautions that should be observed during MMAW. (3 marks)

b) Explain three reasons why proper maintenance of welding equipment is important. (3 marks)

c) Give three practical applications of MMAW in your community. (3 marks)

**MARKING SCHEME**

GRADE 11 METAL TECHNOLOGY

STRAND 4.0: METAL JOINING AND FINISHING PROCESSES

SUB-STRAND 4.3: MANUAL METAL ARC WELDING (MMAW)

**SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)**

Each correct answer carries 1 mark.

| Question | Answer |
|---|---|
| 1 | B |
| 2 | C |
| 3 | B |
| 4 | C |
| 5 | B |
| 6 | C |
| 7 | B |
| 8 | C |
| 9 | B |
| 10 | B |
| 11 | B |
| 12 | C |
| 13 | C |
| 14 | B |
| 15 | B |
| 16 | C |
| 17 | B |
| 18 | B |
| 19 | C |
| 20 | A |
| 21 | A |
| 22 | B |
| 23 | C |
| 24 | B |
| 25 | D |
| 26 | C |
| 27 | D |

| | |
|---|---|
| 28 | A |
| 29 | C |
| 30 | B |

TOTAL: 30 MARKS

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

**QUESTION 1: INTRODUCTION TO MMAW (8 MARKS)**

a) Define Manual Metal Arc Welding. (2 marks)

- Manual Metal Arc Welding (MMAW) is a metal joining process in which heat produced by an electric arc between a flux-coated consumable electrode and the workpiece melts the metal surfaces to form a joint. (2 marks)

b) Explain three ways in which MMAW contributes to economic development in Kenya. (3 marks)

Award 1 mark for each well-explained point.

1. Employment creation: Provides job opportunities for skilled welders in construction, manufacturing and repair industries.
2. Infrastructure development: Supports construction and maintenance of bridges, buildings, water tanks and metal structures.
3. Growth of small enterprises: Enables entrepreneurs to establish welding and metal fabrication workshops.
4. Equipment maintenance: Helps repair agricultural machinery, vehicles and industrial equipment.
5. Income generation: Enables skilled workers to earn income through welding services.

(Any 3 × 1 = 3 marks)

c) State three functions of the flux coating on a welding electrode. (3 marks)

1. Produces shielding gases that protect molten metal from atmospheric contamination.
2. Forms a slag layer that protects the cooling weld metal.
3. Helps stabilise the electric arc.
4. Helps remove impurities from the weld metal.
5. May introduce alloying elements into the weld metal.

(Any 3 × 1 = 3 marks)

Total: 8 marks

**QUESTION 2: TOOLS, EQUIPMENT AND PPE (8 MARKS)**

a) Identify four tools or equipment used in MMAW. (4 marks)

Award 1 mark for each correct response.

1. Welding machine.
2. Electrode holder.
3. Work clamp (earth clamp).
4. Welding cables.
5. Welding helmet.
6. Chipping hammer.

7. Wire brush.
8. Welding table.
9. Welding clamps.
10. Welding gloves.

(Any 4 × 1 = 4 marks)

b) Explain two functions of a welding helmet during welding. (2 marks)

1. Protects the eyes from harmful ultraviolet and infrared radiation produced by the welding arc. (1 mark)
2. Protects the face and eyes from sparks, heat and flying particles. (1 mark)

c) State two maintenance practices for welding cables. (2 marks)

1. Regularly inspect cables for damaged insulation and exposed conductors.
2. Replace damaged cables using suitable approved replacements.
3. Keep cables away from excessive heat and sharp edges.
4. Store cables properly to prevent unnecessary damage.
5. Keep cable connections clean and secure.

(Any 2 × 1 = 2 marks)

Total: 8 marks

**QUESTION 3: WELDING CIRCUIT AND POLARITY (8 MARKS)**

a) Differentiate between straight polarity (DCEN) and reverse polarity (DCEP). (4 marks)

| **Straight polarity (DCEN)** | **Reverse polarity (DCEP)** |
|---|---|
| Electrode is connected to the negative terminal. | Electrode is connected to the positive terminal. |
| Workpiece is connected to the positive terminal. | Workpiece is connected to the negative terminal. |
| Current flows from the negative electrode towards the positive workpiece in conventional current terms, it is opposite to electron flow. | Electrode and workpiece connections are reversed. |
| Heat distribution differs from that of DCEP. | Heat distribution differs from that of DCEN. |

Award 1 mark for each correct corresponding distinction.

b) Explain the procedure for establishing an electric arc using the scratch method. (4 marks)

Expected conceptual points:

1. The welding circuit is prepared and checked by a trained person under appropriate supervision. (1 mark)
2. The electrode is briefly brought into contact with the workpiece. (1 mark)
3. The electrode is moved away to establish an electric arc. (1 mark)
4. A stable arc is maintained as part of the supervised welding operation. (1 mark)

Practical application should only be demonstrated by a qualified instructor in a properly equipped welding workshop.

Total: 8 marks

**QUESTION 4: WELDING POSITIONS AND PRACTICAL OPERATIONS (8 MARKS)**

a) Name four common welding positions used in MMAW. (4 marks)

1. Flat position. (1 mark)
2. Horizontal position. (1 mark)
3. Vertical position. (1 mark)
4. Overhead position. (1 mark)

b) Explain four steps followed when carrying out flat-position welding. (4 marks)

1. Preparation of materials: The metal surfaces are cleaned to remove rust, oil, paint and other contaminants. (1 mark)
2. Setting up the joint: The workpieces are correctly aligned and secured using suitable clamps or fixtures. (1 mark)
3. Welding operation: A trained welder carries out the welding process in the flat position using appropriate equipment and approved procedures. (1 mark)
4. Finishing and inspection: Slag is removed using suitable tools, and the completed weld is inspected for quality and defects. (1 mark)

Total: 8 marks

**QUESTION 5: WELD DEFECTS AND QUALITY CONTROL (9 MARKS)**

a) Define a weld defect. (1 mark)

A weld defect is an imperfection or discontinuity in a welded joint that may reduce its strength, appearance or ability to perform its intended function. (1 mark)

b) Describe four common defects found in MMAW joints. (4 marks)

Award 1 mark for each correct description.

1. Porosity: Formation of small gas cavities or holes within the weld metal.
2. Undercut: A groove formed along the edge of a weld that is not adequately filled with weld metal.
3. Slag inclusion: Trapping of non-metallic slag within the weld metal.
4. Lack of fusion: Failure of the weld metal to properly fuse with the base metal or previous weld layer.
5. Cracking: Formation of fractures in the weld metal or adjacent heat-affected zone.
6. Overlap: Weld metal extends beyond the toe of the weld without properly fusing with the base metal.
7. Distortion: Unwanted change in the shape or dimensions of a component due to uneven heating and cooling.

(Any 4 × 1 = 4 marks)

c) Explain four measures that can be taken to prevent weld defects. (4 marks)

1. Proper cleaning: Remove rust, oil, grease, moisture and other contaminants before welding to reduce porosity.
2. Correct electrode selection: Use electrodes suitable for the type and thickness of metal being joined.
3. Proper equipment settings: Ensure welding current and other settings follow the recommended specifications.
4. Proper electrode storage: Store electrodes according to manufacturer recommendations to prevent moisture absorption.

5. Correct welding technique: Ensure appropriate arc length and travel speed under trained supervision.
6. Slag removal: Remove slag between successive weld passes to prevent slag inclusion.
7. Joint preparation: Ensure correct joint design and adequate preparation before welding.

(Any 4 × 1 = 4 marks)

Total: 9 marks

**QUESTION 6: SAFETY, MAINTENANCE AND APPLICATIONS (9 MARKS)**

a) State three safety precautions that should be observed during MMAW. (3 marks)

Award 1 mark for each correct response.

1. Wear appropriate PPE, including a welding helmet, leather gloves, protective clothing and safety boots.
2. Ensure adequate workshop ventilation to reduce exposure to welding fumes.
3. Keep flammable materials away from the welding area.
4. Inspect welding cables and connections for damage before use.
5. Use welding screens to protect nearby people from harmful arc radiation.
6. Keep a suitable fire extinguisher within reach.
7. Avoid touching hot metal with bare hands.
8. Ensure the welding area is dry to minimise electrical hazards.

(Any 3 × 1 = 3 marks)

b) Explain three reasons why proper maintenance of welding equipment is important. (3 marks)

1. Improves safety: Reduces the risk of electrical accidents caused by damaged cables and faulty connections. (1 mark)
2. Improves performance: Ensures welding equipment operates efficiently and produces quality welds. (1 mark)
3. Increases equipment lifespan: Prevents premature damage and reduces replacement costs. (1 mark)

c) Give three practical applications of MMAW in your community. (3 marks)

Award 1 mark for each correct application.

1. Repairing damaged agricultural machinery such as ploughs and trailers.
2. Fabricating metal gates, doors and window frames.
3. Repairing metal water tanks and storage containers.
4. Constructing steel structures and building components.
5. Repairing vehicle bodies and metal frames.
6. Fabricating wheelbarrows and other farm equipment.
7. Repairing metal fences and livestock enclosures.
8. Manufacturing metal furniture such as desks and chairs.

(Any 3 × 1 = 3 marks)

Total: 9 marks

**STRAND 4.0: METAL JOINING AND FINISHING PROCESSES**

**SUB-STRAND 4.4: PROJECT**

## 1.0 INTRODUCTION TO METAL TECHNOLOGY PROJECTS

A project in Metal Technology is a planned practical activity in which learners apply acquired knowledge, skills, attitudes and values to design and fabricate a useful metal product that addresses a real-life problem.

Projects enable learners to move beyond theoretical learning and apply metalworking skills to solve challenges within their schools, homes and communities.

In Grade 11, learners are expected to identify problems in their surroundings, suggest suitable metal products, plan their fabrication and produce functional items using locally available materials and workshop resources.

Metal Technology projects promote creativity, innovation, self-reliance, entrepreneurship and community development.

### 1.1 Meaning of a project

A **project** is a carefully planned activity undertaken to achieve a specific objective within a given period using available resources.

In Metal Technology, a project involves designing, preparing materials, cutting, shaping, joining, finishing and evaluating a metal product.

**Examples of Metal Technology projects include:**

1. Fabrication of metal dustbins for schools and markets.
2. Making metal window grills for residential buildings.
3. Fabrication of metal classroom desks and chairs.
4. Making metallic drying racks for homes.
5. Fabrication of wheelbarrows for farmers.
6. Making metal gates and security doors.
7. Fabrication of cooking stoves using sheet metal.
8. Making metal shelves for shops and stores.
9. Fabrication of water storage tank stands.
10. Making metal animal feeders and drinkers.
11. Fabrication of metal flower pots and garden stands.
12. Making metal toolboxes for workshops.
13. Fabrication of school noticeboards.
14. Making metal handwashing stands.
15. Fabrication of metal market stalls and display racks.

### 1.2 Importance of undertaking Metal Technology projects

Projects are important because they:

1. **Develop practical skills:** Learners acquire skills in measuring, marking out, cutting, bending, drilling, riveting, soldering and welding.
2. **Promote problem-solving:** Learners identify challenges and develop practical solutions using metalworking knowledge.

3. **Encourage creativity:** Learners develop original designs and improve existing products.
4. **Promote innovation:** Learners discover new ways of using locally available materials to produce useful items.
5. **Develop entrepreneurship:** Learners learn how to produce items for sale and generate income.
6. **Promote self-reliance:** Learners acquire skills that can enable them to establish small metal fabrication businesses.
7. **Encourage teamwork:** Learners collaborate when planning, fabricating and evaluating projects.
8. **Promote environmental conservation:** Learners can reuse suitable scrap metals and reduce waste.
9. **Develop communication skills:** Learners explain their designs, fabrication procedures and finished products.
10. **Promote community development:** Fabricated products address practical needs in schools, homes, farms and businesses.

### 1.3 Characteristics of a good Metal Technology project

A good project should have the following characteristics:

- **Purposeful:** It should address an identified need or problem.
- **Functional:** The finished item should perform its intended task.
- **Safe:** It should not expose users to unnecessary risks.
- **Durable:** It should withstand the conditions under which it is used.
- **Affordable:** Its production cost should be reasonable.
- **Attractive:** It should have a good appearance and appropriate finishing.
- **Practical:** It should be possible to fabricate using available skills, tools and equipment.
- **Resource-conscious:** It should make efficient use of available materials.
- **Environmentally responsible:** It should minimise waste and pollution.
- **Marketable:** Where appropriate, it should have potential customers.

## 2.0 IDENTIFICATION OF COMMUNITY PROBLEMS

### 2.1 Meaning of a community problem

A **community problem** is a challenge or difficulty experienced by people living in a particular geographical area or sharing common facilities and resources.

Community problems may affect individuals, families, schools, businesses, farmers and public institutions.

Metal Technology learners should observe their surroundings and identify challenges that can be addressed through the fabrication of metal products.

### 2.2 Sources of community problems

Community problems can be identified from different places, including:

1. **Schools:** Inadequate desks, damaged gates, lack of dustbins, insufficient storage shelves and poorly designed handwashing facilities.
2. **Homes:** Lack of cooking equipment, clothes-drying racks, security grills and storage facilities.
3. **Farms:** Inadequate animal feeders, wheelbarrows, farm tool storage facilities and irrigation equipment.
4. **Markets:** Poor display racks, inadequate waste containers and lack of secure storage facilities.

5. **Workshops:** Lack of toolboxes, working benches and equipment stands.
6. **Health facilities:** Inadequate waste containers, storage racks and equipment stands.
7. **Public institutions:** Damaged benches, inadequate noticeboards, gates and security barriers.
8. **Transport sector:** Lack of suitable metal ramps, parking barriers and repair stands.

**2.3 Methods of identifying community problems**

Learners can use the following methods:

**a) Observation**

- This involves carefully examining the surroundings to identify challenges that require practical solutions.
- Learners may visit schools, homes, farms, markets and workshops.
- They record the problems observed.
- They identify which problems can be solved using metal fabrication skills.

Example: Observing that a school compound lacks adequate waste disposal facilities.

**b) Interviews**

- Learners ask community members questions about the challenges they experience.
- They may interview teachers, farmers, shopkeepers, parents, artisans and local business owners.
- Information obtained helps learners understand the actual needs of the community.

Example: Interviewing farmers about difficulties experienced when transporting animal feeds and farm produce.

**c) Questionnaires**

- These are written questions given to selected people to collect information about their needs.
- Responses can be analysed to identify common problems.
- They are useful when collecting information from many community members.

**d) Group discussions and brainstorming**

- Learners share ideas about challenges affecting their community.
- Each learner suggests possible metal products that could address the problems.
- The group compares the ideas and identifies practical solutions.

**e) Community visits**

- Learners visit places where metal products are needed.
- They interact with potential users and observe the conditions under which the products will be used.
- They collect information about the required size, design, materials and expected cost.

**2.4 Examples of community problems and possible metalwork solutions**

| Community problem | Proposed metal product |
|---|---|
| Poor waste disposal | Metal dustbin |
| Inadequate school furniture | Metal desks and chairs |
| Lack of secure entrances | Metal gate |
| Poor storage of tools | Metal toolbox |
| Lack of clothes-drying facilities | Metal drying rack |
| Difficult transportation of farm produce | Wheelbarrow |
| Inadequate animal feeding facilities | Metal animal feeding trough |

| | |
|---|---|
| Lack of water storage support | Water tank stand |
| Poor arrangement of shop products | Metal display shelves |
| Inadequate handwashing facilities | Metal handwashing stand |
| Lack of secure windows | Metal window grills |
| Poor organisation of workshop materials | Metal storage rack |

**2.5 Factors to consider when identifying a community problem**

The following factors should be considered:

1. **Relevance:** The problem should affect the community and require attention.
2. **Urgency:** Priority should be given to problems requiring immediate solutions.
3. **Availability of materials:** Materials needed for the proposed solution should be accessible.
4. **Availability of skills:** The project should match the learners' metalworking abilities.
5. **Cost:** The cost of production should be manageable.
6. **Safety:** The proposed product should be safe to fabricate and use.
7. **Durability:** The solution should provide long-term benefits.
8. **Environmental impact:** The project should not cause unnecessary environmental damage.
9. **Community acceptance:** The intended users should appreciate and be willing to use the product.
10. **Income potential:** Where appropriate, the product should have potential for commercial production.

**3.0 PROPOSING AN ITEM TO SOLVE AN IDENTIFIED PROBLEM**

**3.1 Meaning of a proposed item**

A **proposed item** is a product suggested as a possible solution to an identified problem.

In Metal Technology, the proposed item should be capable of being designed and fabricated using metalworking processes and available resources.

For example, if a school experiences poor waste management due to inadequate waste containers, learners may propose fabricating a metal dustbin.

**3.2 Steps followed when proposing a suitable item**

1. Identify a problem affecting the community.
2. Investigate the causes and effects of the problem.
3. Consult the people affected by the problem.
4. Brainstorm possible solutions.
5. Identify metal products that could address the problem.
6. Compare the suggested products.
7. Select the most appropriate item.
8. Prepare a preliminary design.
9. Determine the materials and processes required.
10. Estimate the cost of producing the item.

**3.3 Factors to consider when selecting a project item**

**a) Availability of materials**

- Materials should be readily available within the locality.

- Locally available mild steel, aluminium and suitable recycled metal can reduce transportation costs.
- The selected materials should have the required properties.

**b) Availability of tools and equipment**

- The workshop should have the necessary tools and equipment.
- Learners should establish whether cutting, drilling, bending, welding and finishing equipment are available.
- Specialised equipment may increase the project cost.

**c) Level of technical skills**

- The project should match the learners' acquired knowledge and practical abilities.
- It should provide an opportunity to develop new skills without exposing learners to unreasonable risks.

**d) Cost of production**

- The cost of materials, labour, equipment use and finishing should be considered.
- The proposed item should be affordable to produce.

**e) Size and complexity**

- The size and design should be manageable within the available workshop space and project period.
- Extremely complicated designs may require advanced equipment and skills.

**f) Intended function**

- The item should effectively solve the identified problem.
- Its design should meet the requirements of the intended users.

**g) Safety requirements**

- The product should have no dangerous sharp edges or unstable components.
- Its fabrication should follow workshop safety procedures.

**h) Market demand**

- Where the item is intended for sale, learners should investigate whether potential customers need it.
- The product should offer value to the customer.

**3.4 Examples of proposed project items**

**Example 1: Metal dustbin**

- Identified problem: Poor waste disposal in a school.
- Proposed item: Metal dustbin.
- Materials: Mild steel sheet, metal strips and suitable hinges where required.
- Joining methods: Welding, riveting or bolting, depending on the design.
- Finishing: Grinding, cleaning, priming and painting.
- Expected benefit: Improved waste collection and cleanliness.

**Example 2: Metal wheelbarrow**

- Identified problem: Difficulty transporting farm produce and construction materials.
- Proposed item: Metal wheelbarrow.

- Materials: Mild steel sheet, steel tubes, wheel, axle and handles.
- Joining methods: Welding and bolting.
- Finishing: Grinding, priming and painting.
- Expected benefit: Easier transportation of materials.

**Example 3: Metal handwashing stand**

- Identified problem: Inadequate handwashing facilities in a school.
- Proposed item: Metal handwashing stand.
- Materials: Mild steel sections, sheet metal, bolts and corrosion-resistant fittings.
- Joining methods: Welding and bolting.
- Finishing: Cleaning, priming and painting.
- Expected benefit: Improved access to handwashing facilities.

## 4.0 PROJECT PLANNING AND DESIGN

Project planning involves organising all the activities and resources required to complete a project successfully.

A properly planned project reduces wastage, prevents unnecessary expenses and improves the quality of the finished product.

### 4.1 Importance of project planning

1. Helps learners identify the activities to be performed.
2. Ensures materials are available when required.
3. Helps determine the tools and equipment needed.
4. Promotes proper time management.
5. Helps estimate the total production cost.
6. Improves workshop safety.
7. Reduces material wastage.
8. Ensures that the final product meets the intended requirements.
9. Promotes teamwork and responsibility.
10. Provides a basis for evaluating project progress.

### 4.2 Main stages of project planning

**Stage 1: Problem identification**

- Identify the challenge experienced by the community.
- Collect information about its causes and effects.
- Establish whether the problem can be solved through metal fabrication.

**Stage 2: Selection of the project**

- Generate possible solutions.
- Compare their cost, usefulness and technical requirements.
- Select the most appropriate item.

**Stage 3: Preparation of the design**

- Produce sketches showing the appearance of the proposed item.
- Indicate important dimensions.
- Identify the different components.
- Show how the components will be joined.
- Consider the appearance, strength and functionality of the product.

**Stage 4: Material selection**

- Identify the metals and other materials required.
- Select materials according to their properties and intended application.
- Estimate the quantities needed.

**Stage 5: Selection of tools and equipment**

Identify the tools and equipment required for:

- Measuring and marking out.
- Cutting.
- Shaping and forming.
- Drilling.
- Joining.
- Finishing.
- Inspection.

**Stage 6: Preparation of the fabrication procedure**

- Arrange the manufacturing operations in the correct sequence.
- Indicate the processes to be used.
- Include quality checks and safety precautions.

**Stage 7: Cost estimation**

- Calculate the cost of materials.
- Estimate labour and other expenses.
- Determine the expected total production cost.

**Stage 8: Time scheduling**

- Allocate time for each activity.
- Identify important project completion dates.
- Ensure that the project is completed within the available period.

**4.3 Project design**

A project design is a visual and technical representation of the item to be fabricated.

It communicates the shape, dimensions, arrangement and construction details of the proposed product.

**Importance of project design**

1. Provides a clear picture of the intended product.
2. Guides the fabrication process.
3. Helps determine material requirements.
4. Reduces errors during production.
5. Helps communicate ideas to other team members.
6. Assists in estimating the production cost.
7. Provides a basis for checking the finished product.

**4.4 Qualities of a good project design**

- It should be clear and understandable.
- It should show the correct dimensions.
- It should be practical and functional.
- It should consider the strength of the product.
- It should minimise material wastage.
- It should be economical to produce.
- It should be easy to maintain.
- It should consider the safety of users.
- It should indicate suitable joining methods.
- It should be appropriate for the intended environment.

**4.5 Types of drawings used in project development**

1. **Freehand sketches:** Quick drawings used to communicate initial ideas.
2. **Orthographic drawings:** Drawings showing different views of an object, such as the front, top and side views.
3. **Isometric drawings:** Three-dimensional pictorial drawings used to show the general appearance of an object.
4. **Assembly drawings:** Drawings showing how different components fit together.
5. **Detail drawings:** Drawings showing individual components with their dimensions and manufacturing details.

**5.0 SELECTION OF MATERIALS, TOOLS AND EQUIPMENT**

Materials, tools and equipment should be selected according to the design, size, intended use and fabrication processes of the project.

**5.1 Materials used in Metal Technology projects**

**a) Mild steel**

- Mild steel is commonly used because it is relatively easy to cut, bend, drill and weld.
- It is suitable for making gates, frames, shelves, dustbins, desks and wheelbarrows.
- It is relatively affordable and widely available in Kenya.
- It requires protective finishing to prevent rusting.

**b) Galvanised steel**

- This is steel coated with a protective layer of zinc.
- It offers improved resistance to corrosion.
- It is suitable for certain outdoor products, roofing-related fabrications and storage containers.
- Care should be taken during heating and welding because zinc coatings can produce hazardous fumes.

**c) Aluminium**

- Aluminium is lightweight and naturally forms a protective oxide layer.
- It is used in window frames, light storage structures and other products requiring low weight.
- It requires appropriate joining techniques because it behaves differently from mild steel.

**d) Stainless steel**

- Stainless steel has good resistance to corrosion.
- It is suitable for products requiring cleanliness and durability.
- Examples include kitchen equipment, handwashing facilities and selected food-handling equipment.
- It is generally more expensive than mild steel.

**e) Cast iron**

- Cast iron is hard and has good compressive strength.
- It is used in selected machine bases, heavy components and traditional cooking equipment.
- It is brittle and requires specialised joining procedures.

**f) Recycled metal**

- Recycled metal can be obtained from suitable discarded metal products.
- It may reduce material costs.
- It should be inspected for cracks, excessive corrosion, contamination and other defects before reuse.

**5.2 Other materials used in project fabrication**

- Welding electrodes.
- Rivets.
- Bolts and nuts.
- Washers.
- Hinges.
- Metal primers.
- Paints.
- Abrasives.
- Cutting discs.
- Grinding discs.
- Fluxes and solders, where appropriate.
- Sealants and protective coatings.

### 5.3 Tools and equipment used in project fabrication

| Category | Tools and equipment | Main uses |
|---|---|---|
| Measuring | Steel rule, tape measure, try square | Measuring dimensions |
| Marking out | Scriber, centre punch, dividers | Marking lines and points |
| Holding | Bench vice, G-clamp, pliers | Holding work securely |
| Cutting | Hacksaw, snips, cutting machine | Cutting metal |
| Shaping | Hammers, files, stakes | Shaping and smoothing |
| Drilling | Electric drill, drill bits | Producing holes |
| Bending | Folding bars, bending machine | Forming metal |
| Joining | Welding machine, riveting tools | Joining components |
| Finishing | Files, grinders, abrasive paper | Removing rough edges |
| Inspection | Try square, steel rule, vernier caliper | Checking accuracy |

### 5.4 Factors to consider when selecting tools and equipment

1. Nature of the operation.
2. Type and thickness of the metal.
3. Accuracy required.
4. Availability of the equipment.
5. Cost of using the equipment.
6. Condition of the tools.
7. Safety requirements.
8. Skills of the operator.
9. Size and complexity of the project.
10. Maintenance requirements.

## 6.0 DEVELOPMENT OF A FABRICATION PROCEDURE

### 6.1 Meaning of fabrication

Fabrication is the process of converting raw materials into useful products through operations such as measuring, marking out, cutting, shaping, joining and finishing.

In Metal Technology, fabrication involves combining different metal components to produce a complete functional item.

### 6.2 Meaning of a fabrication procedure

A fabrication procedure is a systematic sequence of operations followed when manufacturing a metal product.

It describes the materials, tools, equipment, methods and safety precautions required at each stage.

### 6.3 Importance of preparing a fabrication procedure

- Ensures that operations follow the correct sequence.
- Reduces confusion during production.
- Promotes efficient use of materials.
- Minimises production errors.
- Improves the quality of the finished item.
- Helps allocate duties among group members.
- Promotes workshop safety.

- Makes it easier to monitor project progress.
- Helps estimate production time and costs.
- Provides a record that can be used in future projects.

**6.4 Main operations involved in metal fabrication**

**1. Measuring**

- Measuring involves determining the required dimensions of the metal components.
- It is carried out using tools such as steel rules and tape measures.
- Accurate measurement helps prevent incorrect component sizes.

**2. Marking out**

- Marking out involves transferring the required dimensions and shapes onto the metal surface.
- Tools such as scribers, punches, dividers and squares are used.
- Clear marking guides subsequent cutting and shaping operations.

**3. Cutting**

- Cutting involves separating unwanted metal or producing components of the required dimensions.
- Tools include hacksaws, snips and suitable cutting machines.
- The cutting method depends on the metal type and thickness.

**4. Shaping and forming**

- This involves changing the shape of metal without necessarily removing material.
- Processes include bending, folding, rolling and pressing.
- Shaping enables flat metal sheets and sections to form useful components.

**5. Drilling**

- Drilling is the process of producing circular holes in metal using a rotating drill bit.
- It is used when preparing components for bolting, riveting and other assembly operations.
- Workpieces should be securely clamped before drilling.

**6. Joining**

- Joining involves connecting two or more metal components to form a complete product.
- Methods include welding, brazing, soldering, riveting and bolting.
- The choice depends on the materials, design and intended application.

**7. Finishing**

- Finishing improves the appearance, surface quality and durability of the product.
- It may involve filing, grinding, cleaning, priming and painting.
- Appropriate finishing protects metal surfaces from corrosion.

**8. Inspection and testing**

- Inspection involves checking the product against the design requirements.
- Testing determines whether the product performs its intended function.

- Defects should be corrected before the product is presented to users.

**6.5 Fabrication planning table**

| Operation | Materials | Tools/equipment | Safety considerations |
|---|---|---|---|
| Measuring | Metal sheet/sections | Rule, tape measure | Handle sharp edges carefully |
| Marking out | Metal sheet | Scriber, square | Avoid careless handling of sharp tools |
| Cutting | Metal sheet | Snips/hacksaw | Wear eye protection |
| Bending | Metal sheet | Folding machine | Keep fingers clear of moving parts |
| Drilling | Metal components | Drill, bits | Clamp work securely |
| Joining | Metal components | Welding/riveting equipment | Use appropriate protective equipment |
| Finishing | Paint, primer, abrasives | File, grinder, brush | Avoid dust and harmful fumes |
| Inspection | Finished product | Measuring tools | Handle the product safely |

**7.0 PRACTICAL PROJECT: FABRICATION OF A METAL SCHOOL DUSTBIN**

This project demonstrates how learners can apply knowledge and skills acquired in Metal Joining and Finishing Processes to solve a problem in their community.

Model CBE practical project

**7.1 Project title**

Fabrication of a mild-steel dustbin for a school compound.

**7.2 Identification of the problem**

Many schools in Kenya experience challenges in maintaining cleanliness because of inadequate waste collection facilities.

Waste may be disposed of carelessly around classrooms, playgrounds, eating areas and school compounds.

This may result in:

- An untidy school environment.
- Blocked drainage systems.
- Unpleasant smells.
- Increased breeding of pests.
- Health and sanitation challenges.
- Poor environmental conservation practices.

**7.3 Proposed solution**

Learners propose fabricating a durable metal dustbin that can be placed at strategic points within the school compound.

The dustbin should be strong, easy to clean, stable and resistant to corrosion.

**7.4 Project objectives**

By completing this project, learners should be able to:

1. Identify a waste-management problem in the school community.
2. Design a suitable metal dustbin.
3. Select appropriate metal materials.
4. Identify the tools and equipment required.
5. Apply metal measuring and marking-out skills.
6. Cut and shape sheet metal.

7. Join the different components.
8. Apply suitable finishing techniques.
9. Evaluate the finished dustbin.
10. Demonstrate how the product can improve waste management.

**7.5 Materials required**

1. Mild-steel sheet.
2. Mild-steel strips or angle sections.
3. Suitable hinges, if a hinged lid is incorporated.
4. Welding electrodes, where welding is selected.
5. Bolts and nuts, where bolting is required.
6. Metal primer.
7. Appropriate paint.
8. Abrasive materials.
9. Suitable handles.
10. Other materials specified by the design.

**7.6 Tools and equipment required**

- Steel rule.
- Tape measure.
- Try square.
- Scriber.
- Centre punch.
- Ball-peen hammer.
- Tin snips or suitable cutting equipment.
- Bench vice.
- G-clamps.
- Folding equipment.
- Welding machine, if welding is used.
- Drill and drill bits.
- Files.
- Angle grinder.
- Paintbrush.

**7.7 Suggested fabrication procedure**

**Step 1: Prepare the design**

- Sketch the proposed dustbin.
- Determine its height, width and depth.

- Identify the parts, including the body, base, lid and supporting components.
- Indicate the joining and finishing methods.

**Step 2: Select the materials**

- Select suitable mild-steel sheet and supporting sections.
- Check the metal for excessive rust, cracks and other defects.
- Ensure the material thickness is appropriate for the intended use.

**Step 3: Measure and mark out**

- Transfer the required dimensions onto the sheet metal.
- Use a steel rule and try square to obtain accurate measurements.
- Mark the cutting and folding lines clearly.

**Step 4: Cut the components**

- Cut the sheet metal according to the design.
- Remove unnecessary material.
- Check that the components have the correct dimensions.

**Step 5: Form the components**

- Bend or fold the sheet metal to form the sides and body.
- Prepare the base and lid.
- Ensure the corners and edges are properly aligned.

**Step 6: Join the components**

- Assemble the body and base.
- Use an appropriate joining method, such as welding or riveting.
- Attach the supporting sections.
- Fit the lid and handles where provided.
- Check the strength of the joints.

**Step 7: Finish the product**

- Remove sharp edges and unwanted projections.
- Grind and smooth rough joints.
- Clean the metal surface.
- Apply a suitable metal primer.
- Allow the primer to dry according to the manufacturer's instructions.
- Apply an appropriate protective paint.

**Step 8: Inspect the finished product**

Check that:

- The dustbin has the correct dimensions.
- The base is stable.

- The joints are secure.
- The lid operates properly, if fitted.
- There are no dangerous sharp edges.
- The paint is evenly applied.
- The product is suitable for its intended use.

**Step 9: Present the finished product**

- Display the dustbin to classmates and the teacher.
- Explain the problem it addresses.
- Describe the materials and fabrication processes used.
- Demonstrate how it is used.
- Receive feedback and suggest possible improvements.

**7.8 Quality requirements for the finished dustbin**

A good dustbin should:

1. Have sufficient strength.
2. Be stable when placed on the ground.
3. Have secure joints.
4. Be easy to empty.
5. Be easy to clean.
6. Have smooth and safe edges.
7. Have an appropriate protective coating.
8. Be resistant to normal outdoor conditions.
9. Have adequate capacity for its intended location.
10. Be convenient for users.

**8.0 WORKSHOP SAFETY DURING PROJECT FABRICATION**

Workshop safety involves observing procedures and precautions that prevent accidents, injuries and damage to equipment during practical activities.

**8.1 Importance of workshop safety**

- Prevents injuries and accidents.
- Protects learners and instructors.
- Prevents damage to tools and equipment.
- Promotes efficient working conditions.
- Prevents fires and other emergencies.
- Reduces exposure to harmful substances.
- Promotes responsible use of workshop facilities.

**8.2 Personal protective equipment (PPE)**



**Safety goggles**

Protect the eyes against flying metal particles, sparks and dust during cutting, grinding and drilling.



**Protective apron**

Protects the body and clothing from sparks, hot particles and dirt.



**Protective gloves**

Protect hands when handling metal sheets and sharp materials. Gloves should not be worn near rotating machinery where they could become entangled.



**Safety boots**

Protect feet against falling objects, sharp metal and workshop hazards.



**Welding helmet**

Protects the face and eyes from intense welding light, ultraviolet radiation and sparks.

**8.3 General safety precautions**

1. Wear suitable protective equipment.
2. Keep the workshop clean and organised.
3. Use tools only for their intended purposes.
4. Inspect tools before use.
5. Clamp workpieces securely.
6. Avoid wearing loose clothing near rotating machinery.
7. Keep flammable materials away from welding and grinding areas.
8. Ensure adequate workshop ventilation.
9. Use suitable welding screens to protect nearby people.
10. Switch off machines after use.
11. Handle hot metal using appropriate tools.
12. Keep emergency exits accessible.
13. Report accidents and unsafe conditions immediately.
14. Follow the teacher's instructions.
15. Never operate unfamiliar machinery without proper instruction and supervision.

**8.4 Environmental safety considerations**

- Collect and separate metal offcuts for reuse or recycling

- Dispose of used abrasive materials appropriately.
- Avoid pouring chemicals, oils and paints into drainage systems.
- Store paints, solvents and other chemicals safely.
- Provide adequate ventilation during painting and welding.
- Prevent unnecessary noise and dust pollution.
- Use materials efficiently to minimise waste.

**9.0 FABRICATION OF OTHER COMMUNITY-BASED METAL PROJECTS**

Apart from the metal dustbin, learners can fabricate other useful products to address challenges experienced in their communities.

These projects provide opportunities to apply metal joining, shaping, forming and finishing techniques.

**9.1 Fabrication of a metal handwashing stand**



**Problem identified:** Inadequate handwashing facilities in schools, markets and public institutions.

**Proposed solution:** Fabrication of a metal stand to support a water container fitted with a tap.

**Materials required:**

1. Mild-steel square tubes.
2. Flat steel bars.
3. Mild-steel sheet.
4. Bolts and nuts.
5. Welding electrodes.
6. Metal primer.
7. Protective paint.
8. Suitable water container and tap.

**Tools and equipment:**

- Tape measure.
- Steel rule.
- Try square.
- Scriber.
- Hacksaw or metal cutting machine.
- Bench vice.
- Welding machine.
- Angle grinder.
- Drill.
- Paintbrush.

**Fabrication procedure:**

1. Prepare a design showing the height, width and arrangement of the stand.
2. Measure the steel sections according to the design.
3. Mark out the cutting positions.
4. Cut the steel sections to the required lengths.
5. Prepare the supporting frame.
6. Assemble the frame and check its alignment.
7. Join the components by suitable welding or bolting methods.
8. Fabricate a support platform for the water container.
9. Smooth the joints and remove sharp edges.
10. Apply a suitable primer and protective paint.
11. Fit the water container and tap securely.
12. Test the stability and usability of the stand.

**Expected benefits:**

- Promotes personal hygiene.
- Improves access to handwashing facilities.
- Supports disease prevention.
- Provides a durable water-container support.
- Can be fabricated for sale to schools and institutions.

**9.2 Fabrication of a metal drying rack**



**Problem identified:** Lack of adequate clothes-drying facilities in homes, boarding schools and institutions.

**Proposed solution:** Fabrication of a metal clothes-drying rack.

**Materials required:**

- Mild-steel tubes.
- Mild-steel rods.
- Flat steel bars.
- Bolts and nuts.
- Welding electrodes.
- Metal primer.
- Paint.

**Fabrication procedure:**

1. Draw the proposed drying rack.
2. Determine its height, width and length.
3. Select appropriate metal sections.
4. Measure and mark out the sections.
5. Cut the components to the required dimensions.
6. Prepare the supporting legs.
7. Arrange the horizontal drying rods.
8. Join the components using suitable welding or bolting techniques.
9. Check the alignment and stability.
10. Smooth rough surfaces.
11. Apply a protective coating.
12. Test the rack by placing suitable loads on it.

**Expected benefits:**

- Provides convenient clothes-drying facilities.
- Saves space.
- Reduces dependence on improvised drying structures.
- Can provide an income-generating opportunity.

**9.3 Fabrication of a metal tool rack**




**Problem identified:** Poor storage and arrangement of tools in workshops and institutions.

**Proposed solution:** Fabrication of a metal storage rack.

**Materials required:**

- Mild-steel angle bars.
- Mild-steel sheet.
- Flat bars.
- Bolts and nuts.
- Welding electrodes.
- Primer and paint.

**Fabrication procedure:**

1. Determine the required dimensions.
2. Prepare an orthographic or isometric drawing.
3. Select suitable steel sections.
4. Measure and mark the components.
5. Cut the angle bars and sheet metal.
6. Prepare the vertical supports.
7. Assemble the horizontal shelves.
8. Join the frame using welding or bolting.
9. Check that the rack is square and stable.
10. Smooth the joints and edges.
11. Apply primer and paint.
12. Test the rack using suitable loads.

**Expected benefits:**

- Improves workshop organisation.
- Reduces loss of tools.
- Makes tools easier to access.
- Promotes proper storage practices.

**9.4 Fabrication of a metal animal feeder**



**Problem identified:** Poor feeding arrangements for livestock in farms.

**Proposed solution:** Fabrication of a metal animal feeder.

**Materials required:**

- Suitable galvanised sheet or other appropriate metal.
- Flat steel bars.
- Supporting steel sections.
- Rivets or bolts.
- Suitable protective finishing materials.

**Fabrication procedure:**

1. Identify the type and size of livestock.
2. Determine the required feeder capacity.
3. Prepare a design with suitable dimensions.
4. Select materials that are appropriate for animal feeding.
5. Measure and mark out the sheet metal.
6. Cut the components.
7. Fold and shape the feeder.
8. Join the edges using suitable methods.
9. Prepare supporting legs or brackets.
10. Smooth all edges to prevent injuries.
11. Apply an appropriate corrosion-resistant finish where suitable.
12. Inspect the feeder for stability, cleanliness and safety.

**Expected benefits:**

- Reduces feed wastage.
- Improves feeding arrangements.
- Makes feeding easier.
- Supports livestock management.
- Provides opportunities for local fabrication businesses.

**9.5 Fabrication of a metal water tank stand**



**Problem identified:** Lack of suitable support structures for elevated water storage tanks.

**Proposed solution:** Fabrication of a strong metal water tank stand.

**Materials required:**

- Structural steel sections.
- Steel plates.
- Bracing members.
- Bolts and nuts.
- Welding electrodes.
- Suitable protective coating.

**Fabrication procedure:**

1. Determine the required tank capacity.
2. Establish the total load, including the weight of water and tank.
3. Prepare a suitable engineering design.
4. Select structural steel sections.
5. Cut and prepare the members.
6. Assemble the vertical supports.
7. Fit horizontal members.
8. Install diagonal bracing.
9. Join the members using appropriately designed welded or bolted connections.
10. Inspect the joints and alignment.
11. Apply corrosion protection.
12. Have the design and completed structure checked by a qualified person before loading.

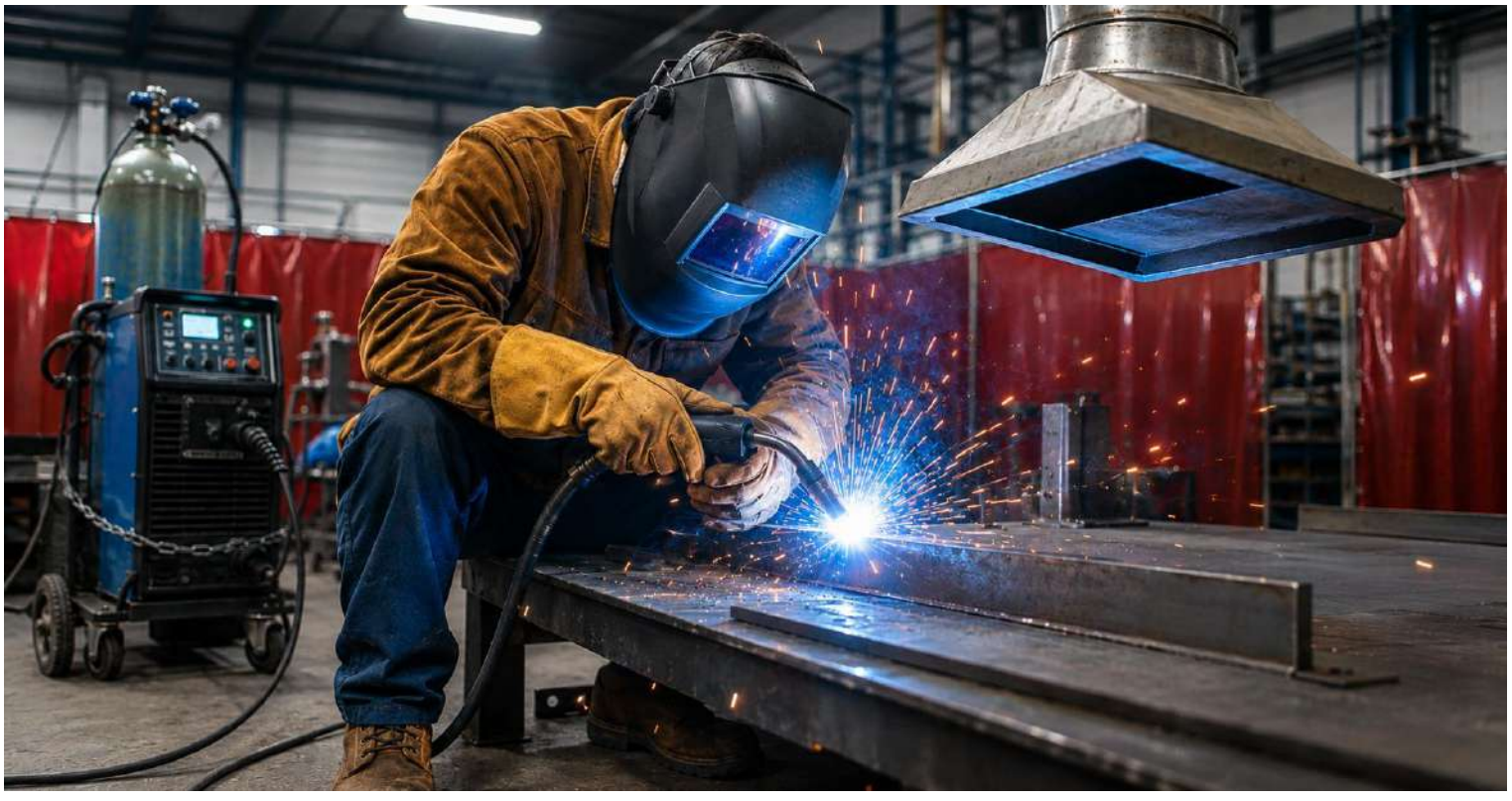
**Important safety consideration:** Elevated water tank stands carry substantial loads. Their design must consider structural strength, stability, foundations, wind forces and safe access. Learners should not independently design or test full-size elevated tank supports without qualified engineering supervision.

## 10.0 APPLICATION OF METAL JOINING PROCESSES IN PROJECT FABRICATION

Metal joining is an important stage in the fabrication of many community-based products.

The joining method selected depends on the type of metal, product design, required strength, operating conditions and available equipment.

### 10.1 Welding



Welding is a permanent metal joining process in which two or more metal components are joined by heating, with or without the use of pressure and filler material.

**Applications in projects:**

- Joining metal dustbin bodies.
- Fabricating gates and window grills.
- Joining steel frames.
- Making metal shelves.
- Fabricating wheelbarrows.
- Joining structural supports.

**Advantages:**

1. Produces strong joints when correctly performed.
2. Suitable for many metal fabrication projects.
3. Can be used to join components of different shapes.
4. Produces permanent joints.
5. Can be economical for suitable production work.

**Limitations:**

1. Requires trained operators.
2. May cause distortion due to heating.
3. Requires protective equipment.
4. Some materials require specialised welding procedures.
5. Weld defects may weaken the finished product.

**10.2 Brazing**



Brazing is a metal joining process in which a filler metal is heated above 450°C and distributed between closely fitting components without melting the parent metals.

**Applications:**

- Joining certain metal tubes.
- Repairing selected metal components.
- Joining suitable dissimilar metals.
- Fabricating certain light metal assemblies.

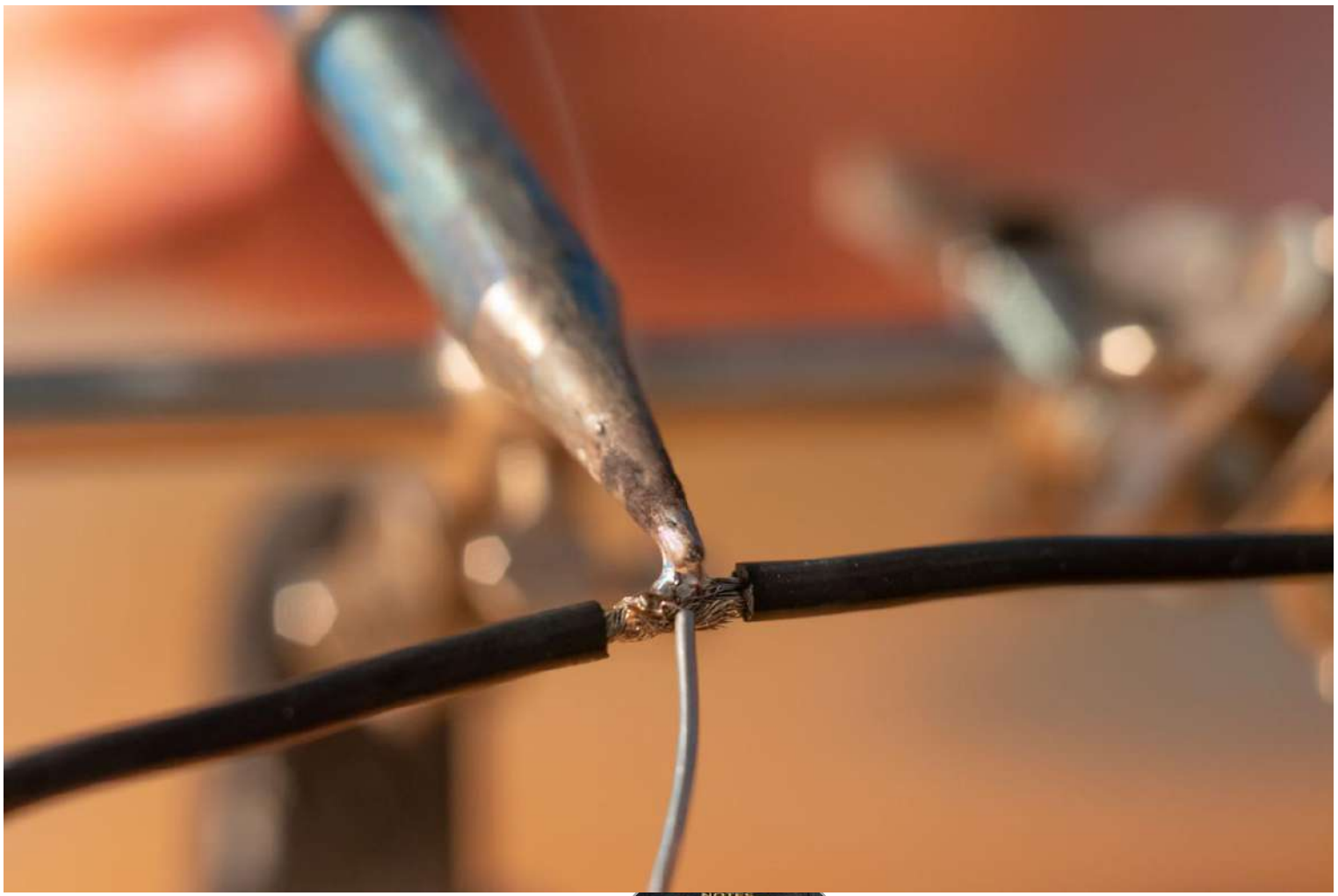
**Advantages:**

- Can join different metals.
- Produces relatively neat joints.
- Causes less distortion than some fusion welding processes.
- Can be used for thin components.

**Limitations:**

- Requires proper joint clearance.
- Joint strength depends on design and materials.
- Requires appropriate heating and filler materials.
- May not be suitable for high-temperature service conditions.

**10.3 Soft soldering**



Soft soldering is a joining process in which a low-melting-point filler metal is heated below 450°C and used to join metal surfaces without melting the parent metals.

**Applications:**

- Joining certain thin metal sheets.
- Making light-duty metal assemblies.
- Electrical and electronic connections.
- Repairing suitable small metal components.

**Advantages:**

- Requires relatively low temperatures.
- Suitable for delicate components.
- Can produce neat joints.
- Requires relatively simple equipment.

**Limitations:**

- Joints generally have lower strength than welded joints.
- Not suitable for heavy structural work.
- May not withstand high temperatures.
- Requires clean surfaces and suitable flux.

**10.4 Riveting**



Riveting is a mechanical joining process in which a rivet is inserted through aligned holes in two or more components and its end is formed to hold them together.

**Applications:**

- Joining sheet-metal dustbins.
- Fabricating light metal containers.
- Joining thin sheet-metal panels.
- Making selected metal covers and casings.

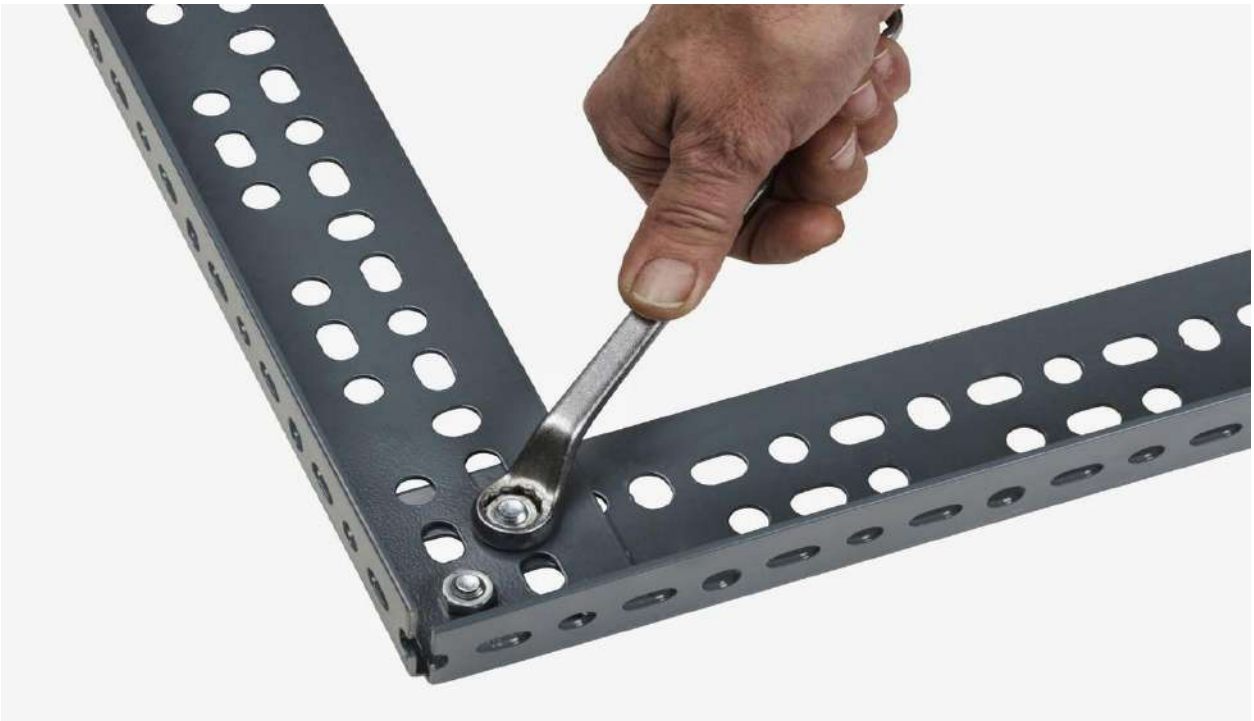
**Advantages:**

1. Does not require high temperatures.
2. Can join certain dissimilar materials.
3. Suitable for sheet-metal work.
4. Can be inspected visually.
5. Useful where welding may cause excessive distortion.

**Limitations:**

1. Requires holes to be produced.
2. Rivets may add weight.
3. Some joints are difficult to dismantle.
4. Incorrect riveting can produce loose joints.

**10.5 Bolting**



Bolting is a mechanical joining process in which components are held together using bolts, nuts and, where necessary, washers.

**Applications:**

- Joining metal shelves.

- Assembling workshop benches.
- Fixing detachable supports.
- Joining metal frames.
- Attaching machine components.

**Advantages:**

- Joints can be dismantled.
- Easy to assemble and maintain.
- Does not require heating.
- Suitable for many structural assemblies.

**Limitations:**

- Requires accurately aligned holes.
- Bolts may loosen under vibration.
- Protruding fasteners may affect appearance.
- Regular inspection may be necessary.

**10.6 Selection of appropriate joining methods**

| Joining method | Nature of joint | Suitable project application |
|---|---|---|
| Welding | Permanent | Gates and steel frames |
| Brazing | Permanent | Suitable metal tube assemblies |
| Soft soldering | Permanent, relatively light-duty | Thin metal and electrical work |
| Riveting | Mechanical joint | Sheet-metal containers |
| Bolting | Usually detachable | Shelves and frame assemblies |

## 11.0 METAL FINISHING PROCESSES IN PROJECT FABRICATION

### 11.1 Meaning of metal finishing

Metal finishing refers to processes applied to the surface of a metal product to improve its appearance, surface quality, corrosion resistance and service life.

Finishing is an important stage because fabricated metal products may be exposed to moisture, chemicals, friction and other environmental conditions.

### 11.2 Importance of metal finishing

1. Improves the appearance of products.
2. Protects metals against corrosion.
3. Increases the service life of fabricated items.
4. Removes rough surfaces and sharp projections.
5. Makes products easier to clean.

6. Improves customer satisfaction.
7. Enhances the commercial value of products.
8. Improves resistance to wear in suitable applications.
9. Provides identification through colour coding.
10. Makes products more attractive to potential buyers.

**11.3 Common finishing methods**

**a) Filing**



- Filing involves removing small amounts of metal using a file.
- It is used to smooth edges and remove minor irregularities.
- It helps improve the fit of components.
- It is commonly applied after cutting and drilling.

**b) Grinding**



- Grinding involves removing excess metal using an abrasive wheel or disc.
- It is used to smooth welds and remove unwanted projections.
- It can prepare surfaces for further finishing.
- Suitable eye, face and hearing protection should be used.

**c) Sanding**

- Sanding involves rubbing a surface using abrasive paper or suitable sanding equipment.
- It removes minor surface irregularities.
- It helps prepare metal surfaces for painting.
- Different abrasive grades may be used depending on the required surface quality.

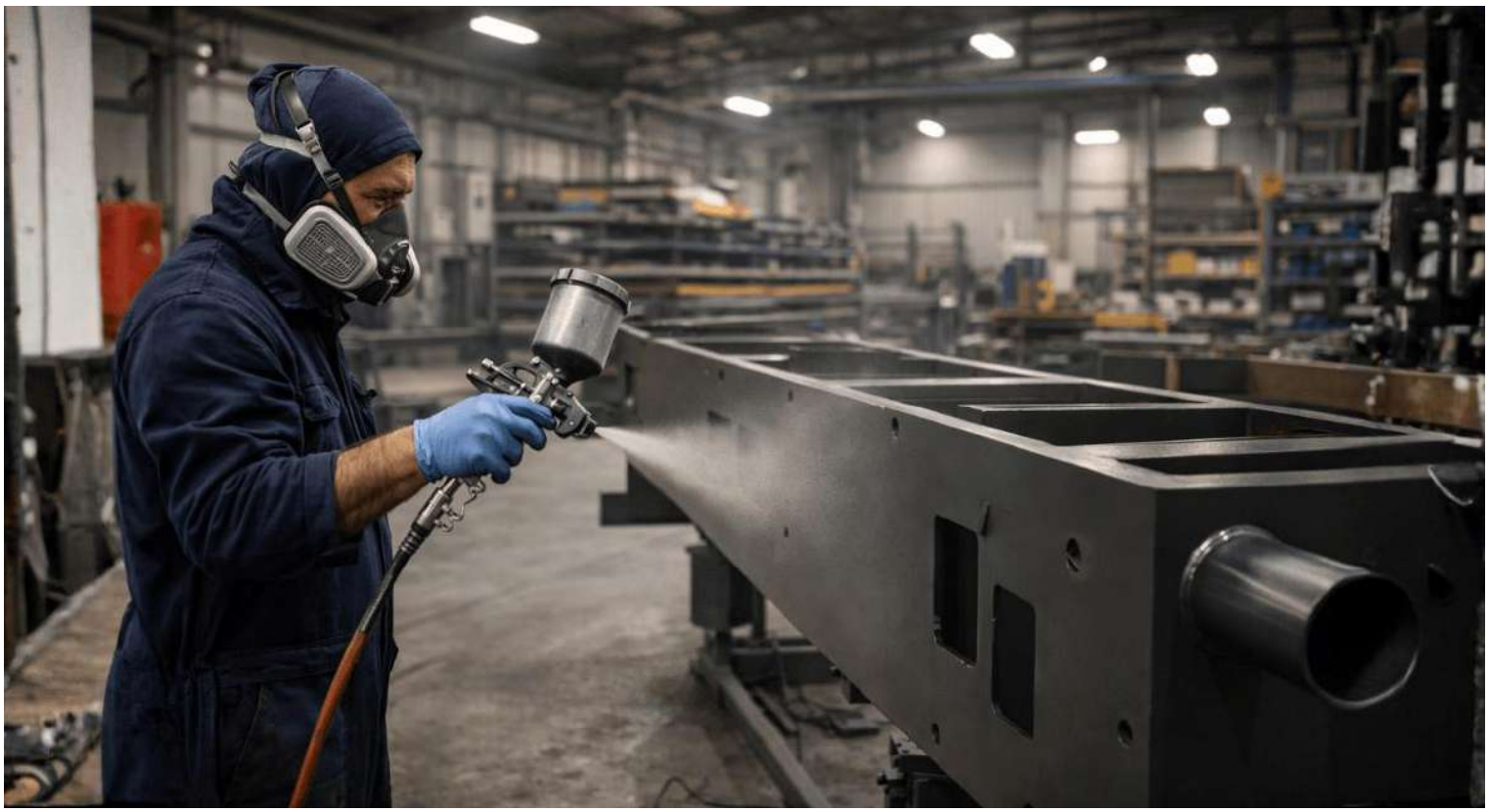
**d) Priming**



- Priming involves applying an appropriate preparatory coating to a metal surface before painting.
- It improves the adhesion of the topcoat.

- Certain primers provide corrosion protection.
- The correct primer should be selected for the metal and coating system.

**e) Painting**



- Painting involves applying a protective or decorative coating to a metal surface.
- It improves appearance.
- It helps protect suitable metals from corrosion.
- It allows products to be finished in different colours.

**f) Galvanising**



- Galvanising is the process of coating steel or iron with zinc.
- The zinc layer provides corrosion protection.
- It is suitable for selected outdoor metal products.
- It is commonly used for steel structures and other components exposed to weather.

**g) Polishing**

- Polishing involves improving the smoothness and appearance of a metal surface.
- It may be performed using abrasive materials and polishing compounds.
- It is suitable for decorative metal products and selected stainless-steel components.

**11.4 Factors affecting the selection of a finishing method**

1. Type of metal.
2. Intended use of the product.
3. Environmental conditions.
4. Required appearance.
5. Cost of finishing.
6. Expected service life.
7. Availability of finishing materials.
8. Maintenance requirements.
9. Surface condition.
10. Safety and environmental considerations.

**12.0 QUALITY CONTROL AND EVALUATION OF THE FINISHED PROJECT**

**12.1 Meaning of quality control**

Quality control is the process of checking and monitoring a product during and after fabrication to ensure that it meets the required standards and design specifications.

It helps identify defects and prevent poor-quality products from reaching users.

**12.2 Importance of quality control**

- Ensures the product performs its intended function.
- Improves durability.
- Promotes customer satisfaction.
- Reduces material wastage.
- Prevents costly repairs.
- Improves safety.
- Enhances the reputation of the fabricator.
- Helps maintain consistent production standards.

**12.3 Quality checks during fabrication**

**1. Dimensional accuracy**

- Check whether the dimensions match the design.
- Use appropriate measuring instruments.
- Correct errors before joining components.

**2. Alignment**

- Check whether components are correctly positioned.

- Use squares and other suitable measuring tools.
- Ensure that the product is properly assembled.

**3. Joint quality**

- Examine welded, riveted or bolted joints.
- Check for visible cracks, looseness and incomplete connections.
- Ensure that joints are appropriate for the intended loads.

**4. Surface quality**

- Inspect the product for rough edges and unwanted projections.
- Check for dents, scratches and uneven surfaces.
- Remove defects before applying finishing materials.

**5. Stability**

- Check whether the item stands or operates correctly.
- Ensure that its supporting structure is adequate.
- Investigate any signs of wobbling or deformation.

**6. Functional performance**

- Test the product under safe and appropriate conditions.
- Confirm that moving parts operate correctly.
- Establish whether the product solves the identified problem.

**12.4 Common defects in fabricated metal products**

| Defect | Description | Possible corrective action |
|---|---|---|
| Distortion | Change in shape during fabrication | Correct forming and control heat input |
| Porosity | Small holes in a weld | Correct welding conditions and surface preparation |
| Cracks | Fractures in metal or joints | Remove defective material and repair appropriately |
| Sharp edges | Dangerous unfinished edges | File or grind appropriately |
| Misalignment | Components are incorrectly positioned | Realign before final joining |
| Corrosion | Deterioration of metal surfaces | Clean and apply suitable protection |
| Loose rivets | Riveted joint is not secure | Replace or correctly refit rivets |
| Uneven paint | Inconsistent coating | Prepare the surface and reapply coating |

**12.5 Project evaluation**

Project evaluation involves assessing the planning, fabrication, performance and overall success of the finished product.

Learners should consider:

- Whether the project solved the identified problem.
- Whether the design was suitable.
- Whether the materials were properly selected.
- Whether the joining methods were appropriate.
- Whether the product was safely fabricated.
- Whether the finishing was satisfactory.
- Whether the project was completed within the planned time.
- Whether the project stayed within the estimated budget.
- Whether users are satisfied with the product.
- What improvements could be made.

## 13.0 PRESENTATION AND DEMONSTRATION OF THE FABRICATED ITEM

### 13.1 Meaning of project presentation

Project presentation is the process of displaying a completed product and explaining its design, purpose, materials, fabrication procedures and benefits to an audience.

In Grade 11 Metal Technology, learners are expected to present their fabricated products to classmates, teachers and other relevant members of the community.

### 13.2 Importance of presenting fabricated products

1. Enables learners to communicate their ideas.
2. Demonstrates the practical skills acquired.
3. Provides an opportunity to receive feedback.
4. Promotes confidence and public speaking skills.
5. Allows learners to explain the usefulness of their products.
6. Encourages creativity and innovation.
7. Helps learners identify areas requiring improvement.
8. Promotes appreciation of practical work.
9. Provides opportunities to identify potential customers.
10. Encourages collaboration and peer learning.

### 13.3 Information to include during project presentation

A good project presentation should include the following:

**a) Project title**

- State the name of the fabricated item.
- Give a brief description of the product.

**b) Problem identified**

- Explain the community problem that motivated the project.
- Describe the people affected by the problem.

- Explain why the problem needed a solution.

**c) Proposed solution**

- Explain the item selected.
- Describe how the item addresses the identified problem.

**d) Materials used**

- Identify the different materials used.
- Explain why the materials were selected.

**e) Tools and equipment**

- Identify the tools and equipment used.
- Explain their functions in the fabrication process.

**f) Fabrication procedures**

- Explain the operations followed.
- Describe the joining and finishing methods used.
- Explain the safety precautions observed.

**g) Challenges encountered**

- Explain difficulties experienced during fabrication.
- Describe how the challenges were addressed.

**h) Benefits of the product**

- Explain how the item benefits the community.
- Identify its potential users.

**i) Cost of production**

- Explain the estimated production cost.
- Discuss possible selling prices where applicable.

**j) Recommendations**

- Suggest improvements that could be made to the product.
- Explain how similar projects could be undertaken in future.

**13.4 Methods of presenting a fabricated project**

1. **Oral presentation:** Explaining the project to an audience.
2. **Practical demonstration:** Showing how the product operates.
3. **Exhibition:** Displaying fabricated items during school or community events.
4. **Portfolio presentation:** Displaying project drawings, photographs, cost estimates and fabrication records.
5. **Group presentation:** Different learners explain various stages of the project.
6. **Digital presentation:** Using photographs, slides or videos to explain the project.

**13.5 Qualities of an effective project presentation**

- Clear communication.

- Proper organisation of information.
- Accurate technical explanations.
- Confidence.
- Appropriate use of metalworking terminology.
- Ability to answer questions.
- Demonstration of the product's functionality.
- Respect for audience contributions.

## 14.0 INCOME GENERATION THROUGH METAL TECHNOLOGY PROJECTS

Metal Technology provides opportunities for learners to develop entrepreneurial skills and generate income through the production and sale of useful metal products.

Entrepreneurship involves identifying business opportunities, organising resources, producing goods or services and managing activities to generate value.

### 14.1 Meaning of income generation

Income generation is the process of earning money through productive activities such as manufacturing, selling goods and providing services.

In Metal Technology, learners can generate income by fabricating metal products and offering metalworking services.

### 14.2 Ways of generating income through Metal Technology projects

**1. Selling fabricated products**

Learners can produce metal items and sell them to individuals, schools, institutions and businesses.

Examples:

- Metal dustbins.
- Metal shelves.
- Metal gates.
- Window grills.
- Metal drying racks.
- Wheelbarrows.
- Metal toolboxes.
- Animal feeders.

**2. Offering metal repair services**

Learners with appropriate training and supervision can provide services such as:

- Repairing broken metal furniture.
- Repairing metal gates.
- Repairing damaged shelves.
- Replacing worn metal components.
- Repairing selected agricultural tools.

**3. Customised fabrication**

This involves producing metal products according to the specific needs and designs of customers.

Examples:

- Fabricating school desks according to school requirements.
- Producing customised shop shelves.
- Making metal security doors.
- Producing specially designed display stands.

**4. Participating in exhibitions**

- Learners can display their products during school exhibitions and community events.
- Potential customers can inspect the products.
- Exhibitions provide opportunities to receive orders.

**5. Working with local artisans**

- Learners can collaborate with established metal fabricators.
- They can learn production and business management skills.
- Such partnerships may provide opportunities for apprenticeship and employment.

**6. Establishing small metal fabrication enterprises**

Learners who acquire appropriate skills may eventually establish businesses dealing with:

- Metal fabrication.
- Welding services.
- Metal furniture production.
- Metal repair services.
- Decorative metalwork.
- Agricultural equipment fabrication.

**14.3 Factors to consider when selling fabricated products**

1. Quality of the product.
2. Cost of production.
3. Customer needs.
4. Market demand.
5. Product durability.
6. Competition.
7. Selling price.
8. Transportation costs.
9. Availability of materials.
10. Customer service and after-sales support.

**14.4 Cost estimation in metal fabrication**

Cost estimation involves calculating the expected expenditure required to manufacture a particular product.

It helps the fabricator determine the selling price and expected profit.

**Main components of production cost**

**a) Material cost**

The amount spent on purchasing metal sheets, steel sections, electrodes, bolts, paint and other materials.

**b) Labour cost**

The amount paid for work performed during fabrication.

**c) Equipment and operational costs**

These may include:

- Electricity consumption.
- Machine usage.
- Maintenance.
- Workshop expenses.
- Cutting and grinding consumables.

**d) Transportation cost**

The amount spent transporting materials to the workshop and delivering finished products to customers.

**e) Other expenses**

These may include packaging, marketing and administrative expenses.

**14.5 Example of cost estimation for a metal dustbin**

The following figures are illustrative estimates for classroom calculations, not current supplier quotations.

| Item | Estimated cost (KSh) |
|---|---|
| Mild-steel sheet | 1,500 |
| Steel strips | 350 |
| Hinges and handles | 250 |
| Welding electrodes | 250 |
| Primer and paint | 450 |
| Abrasives and cutting materials | 250 |
| Labour | 700 |
| Electricity and equipment | 200 |
| Transport | 200 |
| Total production cost | 4,150 |

**14.6 Calculation of selling price and profit**

Suppose the dustbin is sold at KSh 5,200.

**Profit = Selling price − Total production cost**

$$= 5{,}200 - 4{,}150$$

$$= KSh\ 1{,}050$$

Therefore, the profit made from selling one dustbin is KSh 1,050.

**Profit percentage on cost**

$$= \frac{ProfitP}{roduction\ cost} \times 100\%$$

$$= \frac{1{,}050}{4{,}150} \times 100\%$$

$$= 25.3\%$$

This shows that proper costing is important when planning income-generating metal fabrication projects.

**14.7 Benefits of income generation through Metal Technology**

- Promotes self-employment.
- Creates employment opportunities.
- Improves financial independence.
- Encourages innovation.
- Promotes the development of small businesses.
- Supports local industries.
- Reduces dependence on imported products where local production is viable.
- Encourages the use of locally available resources.
- Improves living standards.
- Contributes to national economic development.

**15.0 ENTREPRENEURSHIP AND MARKETING OF FABRICATED PRODUCTS**

**15.1 Meaning of marketing**

Marketing is the process of identifying customer needs, promoting products, communicating their value and making them available to potential buyers.

In Metal Technology, marketing helps fabricators attract customers and sell their finished products.

**15.2 Methods of marketing fabricated products**

**a) Direct selling**

- The fabricator approaches potential customers and presents the products.
- Customers can inspect the product before purchasing.
- This method is suitable for local markets and institutions.

**b) Posters and notices**

- Posters can be displayed in schools, shops and community centres.
- They should include the product name, benefits and contact details of the business.

**c) Social media marketing**

- Products can be promoted through appropriate social media platforms.
- Photographs and short videos can demonstrate product features.
- Digital platforms can help reach customers beyond the immediate locality.

**d) Exhibitions and trade fairs**

- Fabricators display products at exhibitions.
- Customers can compare different products.
- Exhibitions provide opportunities to obtain orders.

**e) Referrals**

- Satisfied customers may recommend products to other people.
- Good workmanship and customer service encourage referrals.

**f) Partnerships**

- Fabricators can collaborate with schools, farmers, construction businesses and local traders.
- Partnerships can provide regular customers and production opportunities.

**15.3 The marketing mix in Metal Technology**

The marketing mix refers to the main factors that a business considers when marketing its products.

It is commonly explained using the four Ps.

| Element | Meaning | Metal Technology example |
|---|---|---|
| Product | The item being offered | Metal school desk |
| Price | Amount charged | KSh 4,500 per desk |
| Place | Where the product is sold | Workshop or direct delivery |
| Promotion | How customers are informed | Posters and social media |

**15.4 Qualities of a successful Metal Technology entrepreneur**

A successful entrepreneur should demonstrate:

1. Creativity.
2. Innovation.
3. Patience.
4. Honesty.
5. Financial discipline.
6. Good communication.
7. Problem-solving skills.
8. Time management.
9. Commitment to quality.
10. Willingness to learn.
11. Ability to take calculated risks.
12. Customer-care skills.
13. Responsibility.
14. Teamwork.
15. Proper business management.

## 16.0 PROJECT DOCUMENTATION AND RECORD KEEPING

### 16.1 Meaning of project documentation

Project documentation is the systematic recording of information about the planning, implementation, progress and completion of a project.

It provides evidence of the work undertaken and the skills applied.

### 16.2 Importance of project documentation

1. Provides a record of project activities.
2. Helps monitor progress.
3. Supports assessment of learner performance.
4. Helps identify challenges encountered.
5. Provides information for future projects.
6. Supports cost monitoring.
7. Promotes accountability.
8. Helps communicate project achievements.
9. Provides evidence of acquired competencies.
10. Supports reflection and improvement.

### 16.3 Important project records

**a) Project proposal**

Contains:

- Project title.
- Background information.
- Identified problem.
- Proposed solution.
- Project objectives.
- Expected benefits.

**b) Design drawings**

Contain:

- Initial sketches.
- Orthographic drawings.
- Isometric drawings.
- Dimensions.
- Component details.
- Joining arrangements.

**c) Materials list**

Shows all materials required for the project and their estimated quantities.

**d) Tools and equipment list**

Identifies the tools and equipment needed for the different fabrication operations.

**e) Cost estimate**

Shows the expected expenses for materials, labour, transportation and other costs.

**f) Work schedule**

Indicates the activities to be completed and the time allocated to each activity.

**g) Safety record**

Records the safety precautions followed and any incidents or hazards identified.

**h) Progress report**

Shows the activities completed, challenges encountered and work remaining.

**i) Photographic evidence**

Shows important stages of project development, from planning to the finished product.

**j) Evaluation report**

Explains whether the project achieved its objectives and identifies areas requiring improvement.

**16.4 Sample project work schedule**

| Activity | Week 1 | Week 2 | Week 3 | Week 4 |
|---|---|---|---|---|
| Problem identification | ✓ | | | |
| Project selection | ✓ | | | |
| Drawing and planning | ✓ | | | |
| Material preparation | | ✓ | | |
| Cutting and shaping | | ✓ | | |
| Joining and assembly | | ✓ | ✓ | |
| Finishing | | | ✓ | |
| Inspection and testing | | | ✓ | |
| Presentation | | | | ✓ |
| Evaluation | | | | ✓ |

## 17.0 CHALLENGES EXPERIENCED DURING METAL TECHNOLOGY PROJECTS

Learners may encounter different challenges during project implementation.

### 17.1 Common challenges and possible solutions

| Challenge | Possible solution |
|---|---|
| Inadequate funds | Prepare a realistic budget and seek approved support |
| Shortage of materials | Identify alternative suitable materials |
| Lack of specialised equipment | Use available appropriate equipment under supervision |
| Limited technical skills | Seek guidance and practise relevant operations |
| Material wastage | Improve measurement and marking-out accuracy |
| Poor joining quality | Improve preparation and joining techniques |
| Time limitations | Prepare and follow a realistic work schedule |
| Design errors | Review drawings before fabrication |
| Machine breakdown | Carry out proper maintenance and report faults |
| Safety risks | Follow workshop safety procedures |
| High production costs | Minimise waste and improve resource management |
| Limited market access | Use exhibitions and appropriate digital marketing |

### 17.2 Importance of learning from project challenges

- Develops resilience.
- Encourages critical thinking.
- Improves decision-making.
- Promotes innovation.
- Develops independence.
- Improves future project planning.
- Encourages responsible use of resources.

## 18.0 APPLICATION OF CORE COMPETENCIES IN METAL TECHNOLOGY PROJECTS

The Grade 11 project should provide opportunities for learners to develop the core competencies promoted under Kenya's Competency-Based Education framework.

| Core competency | Application in the project |
|---|---|
| Communication and collaboration | Discussing ideas, sharing duties and presenting products |
| Critical thinking and problem-solving | Identifying community problems and selecting suitable solutions |
| Creativity and imagination | Designing original and useful metal products |
| Citizenship | Fabricating products that address community needs |
| Digital literacy | Using digital tools for research, drawings and marketing |
| Learning to learn | Acquiring new fabrication techniques and reflecting on progress |
| Self-efficacy | Demonstrating confidence when completing and presenting projects |

**18.1 Values developed through project work**

**Responsibility**

- Taking care of tools and equipment.
- Completing assigned duties.
- Following safety procedures.

**Integrity**

- Using materials honestly.
- Keeping accurate project records.
- Reporting challenges truthfully.

**Respect**

- Listening to other learners.
- Appreciating different ideas.
- Respecting workshop rules.

**Unity**

- Working cooperatively.
- Sharing responsibilities.
- Supporting team members.

**Patriotism**

- Using acquired skills to address local community problems.
- Supporting local production and development.

**Environmental conservation**

- Recycling suitable metal materials.
- Minimising waste.

- Disposing of workshop waste responsibly.

## 19.0 SUGGESTED LEARNING EXPERIENCES AND KEY INQUIRY QUESTIONS

### 19.1 Suggested learning experiences

Learners should be guided to:

1. Brainstorm problems in their locality that can be solved using metal joining skills.
2. Conduct community observations to identify practical needs.
3. Interview selected community members to understand their challenges.
4. Discuss possible metal products that can address identified problems.
5. Compare different project proposals.
6. Select an appropriate project using locally available resources.
7. Prepare sketches and technical drawings.
8. Identify the materials, tools and equipment required.
9. Develop a fabrication procedure.
10. Estimate the cost of production.
11. Observe workshop safety requirements.
12. Fabricate the selected item.
13. Inspect and test the finished product.
14. Present the fabricated item to classmates.
15. Demonstrate how the product is used.
16. Explore ways of generating income through sales and services.
17. Reflect on challenges and possible improvements.

### 19.2 Suggested key inquiry questions

1. What societal problems can be solved using knowledge and skills acquired in the study of metal joining processes?
2. How can locally available metal materials be used to address community needs?
3. What factors should be considered when selecting a Metal Technology project?
4. How can proper project planning improve the quality of fabricated products?
5. Which joining and finishing methods are suitable for different metal products?
6. How can metal fabrication contribute to environmental conservation?
7. How can learners use their metalworking skills to generate income?
8. Why is quality control important when fabricating metal products?

**REVISION QUESTIONS**

**Strand:** 4.0 Metal Joining and Finishing Processes

**Sub-Strand:** 4.4 Project

**SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)**

**Answer all questions.**

**1.** What is a project in Metal Technology?

A. A process of purchasing metal materials.

B. A planned activity involving the production of an item to achieve a specific objective.

C. An activity involving only the repair of machines.

D. A process of storing workshop tools.

**2.** Which of the following is the main purpose of identifying community problems before undertaking a project?

A. To increase workshop expenses.

B. To avoid using locally available materials.

C. To establish a need that can be addressed through fabrication.

D. To reduce the number of learners in a group.

**3.** Which method involves asking community members questions to collect information about their needs?

A. Grinding.

B. Interviewing.

C. Filing.

D. Welding.

**4.** A school experiences poor waste management due to inadequate waste containers. Which project would best address this problem?

A. Metal window grill.

B. Metal toolbox.

C. Metal dustbin.

D. Metal drying rack.

**5.** Which of the following should be considered when selecting a Metal Technology project?

A. Availability of materials.

B. Colour of the workshop walls.

C. Number of windows in the workshop.

D. Distance between classrooms.

**6.** What is the main purpose of preparing a project design?

A. To increase the amount of metal required.

B. To provide a guide for fabrication.

C. To eliminate inspection.

D. To avoid measuring materials.

**7.** Which drawing shows the front, top and side views of an object?

A. Isometric drawing.

B. Freehand sketch.

C. Orthographic drawing.

D. Pictorial sketch only.

**8.** Which material is commonly used to fabricate school gates and metal shelves because of its weldability and availability?

A. Mild steel.

B. Rubber.

C. Wood.

D. Glass.

**9.** Which tool is most suitable for measuring the length of a long metal section?

A. Centre punch.

B. Tape measure.

C. Ball-peen hammer.

D. Cold chisel.

**10.** Which tool is used to mark lines on a metal surface?

A. Scriber.

B. Welding helmet.

C. Spanner.

D. Paintbrush.

**11.** Which operation involves separating unwanted metal from a workpiece?

A. Polishing.

B. Cutting.

C. Painting.

D. Priming.

**12.** What is the main purpose of drilling during fabrication?

A. To smooth metal surfaces.

B. To produce holes in metal.

C. To protect metal against corrosion.

D. To remove paint.

**13.** Which joining method uses heat to permanently join metal components by melting the parent metal?

A. Bolting.

B. Riveting.

C. Welding.

D. Filing.

**14.** Which joining process uses a filler metal that melts above 450°C without melting the parent metals?

A. Soft soldering.

B. Brazing.

C. Fusion welding.

D. Mechanical riveting.

**15.** Which joining method is most suitable where components may need to be dismantled for maintenance?

A. Welding.

B. Brazing.

C. Bolting.

D. Soft soldering.

**16.** Which process involves joining metal components using a formed metal fastener inserted through aligned holes?

A. Riveting.

B. Grinding.

C. Polishing.

D. Painting.

**17.** Which finishing process involves removing unwanted metal using an abrasive wheel?

A. Soldering.

B. Grinding.

C. Riveting.

D. Drilling.

**18.** What is the main purpose of applying metal primer before painting?

A. To increase the thickness of the metal sheet.

B. To improve coating adhesion and provide suitable surface protection.

C. To make the metal softer.

D. To remove the need for surface preparation.

**19.** Which finishing process involves coating steel with zinc to protect it against corrosion?

A. Filing.

B. Sanding.

C. Galvanising.

D. Polishing.

**20.** Which personal protective equipment is particularly important when carrying out arc welding?

A. Cotton cap.

B. Welding helmet.

C. Ordinary spectacles.

D. Sandals.

**21.** Which of the following is a suitable workshop safety practice?

A. Wearing loose clothing near rotating machines.

B. Leaving sharp metal pieces on the floor.

C. Clamping workpieces securely before drilling.

D. Using damaged electrical cables.

**22.** What is the main purpose of quality control in metal fabrication?

A. To increase production wastage.

B. To ensure products meet required specifications.

C. To reduce the number of fabrication processes.

D. To eliminate the need for design drawings.

**23.** What is porosity in a welded joint?

A. Excessive smoothness of a weld.

B. Small holes or cavities within a weld.

C. A perfectly aligned joint.

D. A protective coating on a weld.

**24.** Which activity is most appropriate when evaluating a finished project?

A. Ignoring the original design.

B. Checking whether the product performs its intended function.

C. Disposing of all remaining materials.

D. Avoiding feedback from users.

**25.** Which of the following is an effective way of presenting a fabricated project?

A. Hiding the finished product.

B. Displaying the product and explaining its fabrication procedure.

C. Avoiding questions from the audience.

D. Removing the project drawings.

**26.** A learner spends KSh 3,500 producing a metal shelf and sells it for KSh 4,500. What is the profit?

A. KSh 500.

B. KSh 1,000.

C. KSh 3,500.

D. KSh 8,000.

**27.** Which of the following is an example of income generation through Metal Technology?

A. Selling fabricated metal shelves.

B. Leaving metal products unused.

C. Disposing of usable metal offcuts.

D. Avoiding customer communication.

**28.** Which element of the marketing mix refers to the amount charged for a fabricated product?

A. Product.

B. Place.

C. Price.

D. Promotion.

**29.** What is the main importance of project documentation?

A. To increase project complexity.

B. To provide records of project activities and progress.

C. To replace practical fabrication.

D. To eliminate project evaluation.

**30.** Which core competency is mainly developed when learners brainstorm and design solutions to community problems?

A. Critical thinking and problem-solving.

B. Memorisation only.

C. Passive learning.

D. Individual competition only.

**SECTION B: STRUCTURED QUESTIONS (50 MARKS)**

**Answer ALL questions.**

**QUESTION 1: PROJECT IDENTIFICATION AND SELECTION (8 MARKS)**

a) Define the term project as used in Metal Technology. (2 marks)

b) State THREE methods that learners can use to identify problems in their community. (3 marks)

c) State THREE factors to consider when selecting a suitable Metal Technology project. (3 marks)

**QUESTION 2: PROJECT PLANNING AND DESIGN (8 MARKS)**

a) Explain FOUR importance of preparing a project design before fabrication. (4 marks)

b) Differentiate between the following types of drawings:

i. Orthographic drawing. (2 marks)

ii. Isometric drawing. (2 marks)

**QUESTION 3: MATERIALS, TOOLS AND FABRICATION (8 MARKS)**

a) Identify FOUR materials that can be used when fabricating a metal dustbin. (4 marks)

b) State FOUR tools or equipment used during the fabrication of a metal dustbin and give one use of each. (4 marks)

**QUESTION 4: METAL JOINING AND FINISHING (8 MARKS)**

a) Explain FOUR metal joining methods that can be applied when fabricating community-based metal products. (4 marks)

b) Explain FOUR reasons why metal finishing is important in project fabrication. (4 marks)

**QUESTION 5: PROJECT IMPLEMENTATION AND SAFETY (9 MARKS)**

A group of Grade 11 learners has been assigned to fabricate a metal handwashing stand for their school.

a) Outline FIVE major operations they should follow when fabricating the handwashing stand. (5 marks)

b) State FOUR workshop safety precautions they should observe during fabrication. (4 marks)

**QUESTION 6: PROJECT EVALUATION AND ENTREPRENEURSHIP (9 MARKS)**

A learner fabricates a metal tool rack at a total production cost of KSh 3,600. The learner sells it for KSh 4,800.

a) Calculate the profit made from selling the tool rack. (2 marks)

b) State THREE methods the learner can use to market similar fabricated products. (3 marks)

c) Explain FOUR benefits of undertaking income-generating Metal Technology projects in the community. (4 marks)

**MARKING SCHEME / ANSWERS**

**SECTION A: MULTIPLE-CHOICE ANSWERS**

| Question | Answer | Question | Answer |
|---|---|---|---|
| 1 | B | 16 | A |
| 2 | C | 17 | B |
| 3 | B | 18 | B |
| 4 | C | 19 | C |
| 5 | A | 20 | B |
| 6 | B | 21 | C |
| 7 | C | 22 | B |
| 8 | A | 23 | B |
| 9 | B | 24 | B |
| 10 | A | 25 | B |
| 11 | B | 26 | B |
| 12 | B | 27 | A |
| 13 | C | 28 | C |
| 14 | B | 29 | B |
| 15 | C | 30 | A |

**SECTION B: SUGGESTED ANSWERS AND MARKING GUIDE**

**QUESTION 1: PROJECT IDENTIFICATION AND SELECTION (8 MARKS)**

**a) Definition of a project (2 marks)**

- A project is a planned activity undertaken to achieve a specific objective using available resources. (2 marks)

**b) Methods of identifying community problems (3 marks)**

Award 1 mark each for any THREE:

1. Observation.
2. Interviews.

3. Questionnaires.
4. Brainstorming.
5. Group discussions.
6. Community visits.
7. Consultation with community members.

**c) Factors considered when selecting a project (3 marks)**

Award 1 mark each for any THREE:

1. Availability of materials.
2. Availability of tools and equipment.
3. Cost of production.
4. Technical skills required.
5. Safety requirements.
6. Intended function.
7. Durability.
8. Market demand.
9. Time available.
10. Environmental impact.

**QUESTION 2: PROJECT PLANNING AND DESIGN (8 MARKS)**

**a) Importance of project design (4 marks)**

Award 1 mark each for any FOUR well-explained points:

1. Provides a visual representation of the intended product.
2. Guides the fabrication process.
3. Helps determine the dimensions of components.
4. Helps estimate the quantity of materials required.
5. Reduces fabrication errors.
6. Facilitates communication among project members.
7. Helps determine suitable joining methods.
8. Supports accurate cost estimation.

**b) Differences between drawings**

i. **Orthographic drawing (2 marks)**

- A technical drawing showing an object in separate two-dimensional views, such as the front, top and side views. (2 marks)

ii. **Isometric drawing (2 marks)**

- A pictorial drawing representing an object in three dimensions, showing its length, width and height in one view. (2 marks)

**QUESTION 3: MATERIALS, TOOLS AND FABRICATION (8 MARKS)**

**a) Materials used in fabricating a metal dustbin (4 marks)**

Award 1 mark each for any FOUR:

1. Mild-steel sheet.
2. Mild-steel strips.
3. Steel angle sections.
4. Hinges.
5. Bolts and nuts.
6. Welding electrodes.
7. Metal primer.
8. Protective paint.
9. Handles.
10. Abrasive materials.

**b) Tools and their uses (4 marks)**

Award 1 mark for each correctly matched tool and use.

| **Tool/equipment** | **Use** |
|---|---|
| Steel rule | Measuring metal components |
| Scriber | Marking lines on metal |
| Try square | Checking right angles |
| Hacksaw | Cutting metal |
| Tin snips | Cutting sheet metal |
| Bench vice | Holding workpieces |
| Welding machine | Joining metal components |
| Angle grinder | Smoothing welded joints |
| Electric drill | Producing holes |
| File | Smoothing metal edges |

**QUESTION 4: METAL JOINING AND FINISHING (8 MARKS)**

**a) Metal joining methods (4 marks)**

Award 1 mark each for any FOUR correctly explained methods.

1. **Welding:** Joining metals through heat, with or without pressure and filler material.

2. **Brazing:** Joining metals using a filler metal that melts above 450°C without melting the parent metals.
3. **Soft soldering:** Joining metals using a low-melting-point filler metal below 450°C.
4. **Riveting:** Joining components using rivets inserted through aligned holes.
5. **Bolting:** Joining components using bolts, nuts and washers.

**b) Importance of metal finishing (4 marks)**

Award 1 mark each for any FOUR:

1. Protects metal surfaces against corrosion.
2. Improves the appearance of products.
3. Increases product durability.
4. Removes rough edges and projections.
5. Makes products easier to clean.
6. Improves the commercial value of products.
7. Improves surface quality.
8. Enhances customer satisfaction.

**QUESTION 5: PROJECT IMPLEMENTATION AND SAFETY (9 MARKS)**

**a) Major fabrication operations (5 marks)**

Award 1 mark each for any FIVE correctly explained operations:

1. Preparing the design and dimensions.
2. Selecting suitable materials.
3. Measuring and marking out metal components.
4. Cutting metal sections to the required dimensions.
5. Shaping and forming the components.
6. Drilling holes where necessary.
7. Joining components through welding or bolting.
8. Smoothing rough edges and joints.
9. Applying primer and protective paint.
10. Inspecting and testing the finished product.

**b) Workshop safety precautions (4 marks)**

Award 1 mark each for any FOUR:

1. Wear appropriate personal protective equipment.
2. Ensure adequate workshop ventilation.
3. Clamp workpieces securely before cutting or drilling.
4. Use tools and machines correctly.
5. Keep flammable materials away from welding areas.
6. Handle hot metal using appropriate tools.

7. Maintain a clean and organised workshop.
8. Switch off equipment after use.
9. Use appropriate welding screens.
10. Follow the teacher's instructions.

**QUESTION 6: PROJECT EVALUATION AND ENTREPRENEURSHIP (9 MARKS)**

**a) Calculation of profit (2 marks)**

Given:

- Production cost = KSh 3,600.
- Selling price = KSh 4,800.

Formula:

Profit=Selling price−Production cost

=4,800−3,600

Profit=KSh 1,200

Award:

- Correct formula and substitution – 1 mark.
- Correct answer – 1 mark.

**b) Marketing methods (3 marks)**

Award 1 mark each for any THREE:

1. Direct selling.
2. Social media marketing.
3. Posters and notices.
4. Exhibitions and trade fairs.
5. Customer referrals.
6. Partnerships with institutions.
7. Product demonstrations.
8. Online advertising.

**c) Benefits of income-generating projects (4 marks)**

Award 1 mark each for any FOUR well-explained points:

1. **Self-employment:** Learners can establish small metal fabrication businesses.
2. **Job creation:** Fabrication businesses can employ other people.
3. **Financial independence:** Income from sales can improve individual and family livelihoods.
4. **Community development:** Locally fabricated products address community needs.
5. **Entrepreneurship development:** Learners develop business and management skills.
6. **Local industrial development:** Promotes production using locally available resources.
7. **Innovation:** Encourages the development of new products.

8. **Economic growth:** Contributes to income generation and economic activities.

## 22.0 SUMMARY OF THE SUB-STRAND

The Grade 11 Metal Technology project enables learners to apply metal joining and finishing knowledge and skills to solve real-life problems.

Through project work, learners are expected to:

1. Identify problems within their communities.
2. Investigate the needs of potential users.
3. Propose suitable metal products.
4. Select projects based on available resources.
5. Prepare designs and fabrication procedures.
6. Identify materials, tools and equipment.
7. Apply appropriate metalworking processes.
8. Observe workshop safety requirements.
9. Fabricate useful and durable products.
10. Apply suitable finishing techniques.
11. Inspect and evaluate finished products.
12. Present their work to an audience.
13. Explore opportunities for income generation.
14. Appreciate the contribution of Metal Technology to community development.

# GRADE 11

# METAL TECHNOLOGY NOTES

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