DI03000161: Manufacturing Engineering-I

GTU Course Presentation

July 25, 2026

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Introduction to Manufacturing Processes

- **Manufacturing** is the process of converting raw materials into finished products having value.
- It involves the application of physical and chemical processes to alter the geometry, properties, and appearance of a starting material.
- Classification of manufacturing processes:
    - Casting Processes
    - Forming Processes
    - Machining Processes
    - Joining Processes

What is Metal Casting?

- **Casting** is one of the oldest manufacturing processes.
- It is a process in which molten metal is poured into a mold cavity that contains a hollow shape of the desired part.
- The molten metal is allowed to solidify, taking the shape of the mold cavity.
- The solidified part is known as a **casting**, which is then broken out or removed from the mold.

Advantages of Metal Casting

- Complex shapes, both internal and external, can be produced easily.
- Very large and heavy parts (weighing up to several tons) can be cast.
- It is highly adaptable to mass production (e.g., automobile engine blocks).
- Casting can be performed on any metal that can be heated to its liquid state.
- Some metals with low machinability can only be manufactured via casting.
- Generally, it is a very economical process with very little material waste.

Limitations of Metal Casting

- Limitations on mechanical properties: Cast parts often have porosity and lower strength compared to forged parts.
- Poor dimensional accuracy and surface finish for certain casting methods (like sand casting).
- Safety hazards associated with handling molten metals at very high temperatures.
- Environmental problems (dust, smoke, and heat generation).
- Possibility of internal defects which are hard to detect without non-destructive testing.

Applications of Metal Casting

- **Automotive Industry:** Engine blocks, cylinder heads, transmission housings, pistons.
- **Aerospace Industry:** Turbine blades, aircraft frame components.
- **Heavy Machinery:** Machine tool beds, agricultural equipment components.
- **Piping and Plumbing:** Valves, pipes, fittings.
- **Household items:** Frying pans, decorative pieces, door handles.

Basic Steps in Sand Casting Process

1. **Pattern Making:** Creating a physical model of the casting (pattern) with appropriate allowances.
2. **Core Making:** Preparing cores if internal cavities are required.
3. **Molding:** Preparing the mold cavity using sand and the pattern.
4. **Melting and Pouring:** Melting the metal and pouring it into the mold.
5. **Solidification and Cooling:** Allowing the molten metal to freeze and cool down.
6. **Fettling and Cleaning:** Removing the casting from the mold, cutting off gating systems, and cleaning the surface.
7. **Inspection:** Checking for defects and dimensional accuracy.

What is a Pattern?

- A **pattern** is a replica or model of the object to be cast, used to prepare the cavity into which molten metal will be poured.
- **Difference between Pattern and Casting:**
  - A pattern is slightly larger than the casting to compensate for metal shrinkage and machining.
  - It contains core prints if internal cavities are required.
  - It may have allowances for draft and distortion.
- The quality and accuracy of a casting depend significantly on the pattern used.

Pattern Materials

- The selection of pattern material depends on the number of castings, casting process, and desired dimensional accuracy.
- **Common Pattern Materials:**
  - **Wood:** Teak, mahogany, pine. Cheap, easy to shape, but absorbs moisture and wears out quickly. Used for small quantities.
  - **Metal:** Cast iron, aluminum, brass. Durable, accurate, no moisture absorption. Used for mass production.
  - **Plastic:** Epoxy resins, polyurethane. Lightweight, high strength, moisture resistant. Good for complex shapes.
  - **Wax:** Used in investment casting. Excellent surface finish, melts out easily.

Types of Patterns

- **Solid or Single Piece Pattern:** Made without joints, partings, or loose pieces. Used for simple shapes and small-scale production.
- **Split Pattern:** Made in two halves (cope and drag) split along the parting line. Alignment is ensured by dowel pins. Used for intricate castings.
- **Match Plate Pattern:** The halves of a split pattern are mounted on opposite sides of a metal plate. Gates and runners are also attached. Excellent for mass production.
- **Cope and Drag Pattern:** Similar to match plate but cope and drag halves are mounted on separate plates. Used for very large castings.

Types of Patterns (Continued)

- **Sweep Pattern:** Uses a wooden board shaped to the profile of the casting, swept around a central axis to create symmetrical molds (e.g., bells, large bowls).
- **Loose Piece Pattern:** Patterns with removable parts (loose pieces) to allow withdrawal from the mold when the shape overhangs or has undercuts.
- **Gated Pattern:** Sections of the gating system are attached to the pattern. Eliminates hand cutting of gates.
- **Skeleton Pattern:** A ribbed framework made of wood, filled with loam sand, used for very large, simple castings to save material cost.

Pattern Allowances

- A pattern is never made exactly the same size as the final casting. Specific modifications are made, known as **Pattern Allowances**.
- Types of Pattern Allowances:
  1. Shrinkage or Contraction Allowance
  2. Machining or Finish Allowance
  3. Draft or Taper Allowance
  4. Shake or Rapping Allowance
  5. Distortion or Camber Allowance

1. Shrinkage (Contraction) Allowance

- Almost all cast metals shrink or contract volumetrically during cooling from liquid state to room temperature.
- To compensate for this reduction in size, the pattern is made slightly larger than the required casting.
- Shrinkage occurs in three stages:
  - Liquid shrinkage (compensated by risers)
  - Solidifying shrinkage (compensated by risers)
  - **Solid shrinkage** (compensated by **shrinkage allowance** on the pattern)
- It is expressed in mm/m. Example: Cast Iron (10 mm/m), Aluminum (13-15 mm/m).

2. Machining & 3. Draft Allowances

- **Machining (Finish) Allowance:**
    - Castings have rough surfaces and may require machining for exact dimensions.
    - Extra metal is provided on the pattern, which is later removed by machining.
    - Depends on the metal, casting method, and size of the part.
- **Draft (Taper) Allowance:**
    - Vertical faces of the pattern are given a slight taper to facilitate easy withdrawal from the sand without damaging the mold cavity.
    - Usually ranges from 1° to 3°.
    - Inner surfaces require more draft than outer surfaces.

4. Shake & 5. Distortion Allowances

- **Shake (Rapping) Allowance:**
  - Before withdrawal, a pattern is lightly rapped (tapped) to loosen it from the sand.
  - This enlarges the mold cavity slightly.
  - To compensate, the pattern is made slightly smaller. (It is a negative allowance).
- **Distortion (Camber) Allowance:**
  - Castings with irregular shapes (like U, V, or long flat shapes) tend to distort or warp during cooling due to uneven shrinkage.
  - The pattern is intentionally distorted in the opposite direction so that the final casting becomes straight after cooling.

Numerical Problem 1: Shrinkage Allowance

Problem: Calculate the dimensions of a pattern for a cast iron rectangular block of size $100 \times 60 \times 40$ mm. The shrinkage allowance for cast iron is 10 mm/m.

Solution:

- Shrinkage allowance = 10 mm per 1000 mm = 1%.
- For Length (L): $100 + (100 \times 0.01) = 100 + 1 = 101$ mm.
- For Width (W): $60 + (60 \times 0.01) = 60 + 0.6 = 60.6$ mm.
- For Height (H): $40 + (40 \times 0.01) = 40 + 0.4 = 40.4$ mm.
- **Pattern dimensions:** $101 \times 60.6 \times 40.4$ mm.

Numerical Problem 2: Machining & Shrinkage

Problem: A steel casting of size $200 \times 100 \times 50$ mm requires machining on all surfaces. Machining allowance is 2 mm/surface and shrinkage allowance is 20 mm/m. Find the pattern dimensions.

Solution:

- First, apply machining allowance (add 2 mm to each face $\rightarrow$ 4 mm to each dimension):
  - $L' = 200 + 4 = 204$ mm
  - $W' = 100 + 4 = 104$ mm
  - $H' = 50 + 4 = 54$ mm
- Next, apply shrinkage allowance (20 mm/m = 2%):
  - Pattern $L = 204 + (204 \times 0.02) = 204 + 4.08 = 208.08$ mm
  - Pattern $W = 104 + (104 \times 0.02) = 104 + 2.08 = 106.08$ mm
  - Pattern $H = 54 + (54 \times 0.02) = 54 + 1.08 = 55.08$ mm

Introduction to Patterns

- **Definition:** A pattern is a replica or model of the object to be cast, used to prepare the cavity into which molten material will be poured during the casting process.
- It is the principal tool during the casting process.
- **Key Differences between Pattern and Casting:**
  - A pattern is slightly larger than the casting to compensate for metal shrinkage.
  - Patterns carry additional projections called *core prints* if the casting requires a cavity.
  - A pattern may not have all the exact holes or details of the final casting, which are often machined later.

Functions of a Pattern

- To shape the mold cavity and produce a casting of the desired shape and size.
- To establish the parting line and parting surfaces in the mold.
- To accommodate gating systems (sprue, runner, gates) for the flow of molten metal.
- To provide core prints for accurately positioning cores in the mold cavity.
- To minimize casting defects by appropriate design and provision of allowances.

Pattern Materials

The selection of pattern material depends on the number of castings, the degree of accuracy, and the casting process. Common materials include:

1. **Wood**
   - Most common (Teak, Pine, Mahogany).
   - Easily worked, light weight.
   - Prone to moisture absorption and warpage.
2. **Metal**
   - Cast iron, Aluminum, Brass.
   - Durable, high accuracy, wear resistant.
   - Expensive, difficult to repair.
3. **Plastics (Epoxy Resins)**
   - Moisture resistant, lightweight.
   - High dimensional stability.
4. **Wax**
   - Used in Investment Casting.
   - Melts out to leave a cavity.

Types of Patterns

Patterns are classified based on their complexity, production quantity, and casting process:

1. Single Piece (Solid) Pattern
2. Split Pattern
3. Match Plate Pattern
4. Cope and Drag Pattern
5. Gated Pattern
6. Loose Piece Pattern
7. Sweep Pattern
8. Skeleton Pattern

Types of Patterns: Single Piece & Split Pattern

Single Piece (Solid) Pattern

- Simplest type, made from a single block.
- Used for simple shapes and small-scale production.
- The mold is entirely in one box (usually the drag).

Split (Two-Piece) Pattern

- Split into two pieces along the parting line.
- One half is in the cope (upper) and the other in the drag (lower).
- Dowel pins are used to align the two halves.
- Used for intricate shapes where withdrawal from the mold is difficult.

Types of Patterns: Match Plate & Cope/Drag Pattern

Match Plate Pattern

- Split pattern halves are mounted on opposite sides of a metallic or wooden plate (match plate).
- Gates and runners are usually integral with the plate.
- Used for mass production and machine molding.

Cope and Drag Pattern

- Similar to a split pattern, but the two halves are mounted on separate plates.
- The cope and drag parts of the mold are made independently, often on different machines.
- Ideal for heavy and large castings.

Types of Patterns: Other Specialized Patterns

- **Gated Pattern:** Sections of the gating system are attached directly to the pattern. Eliminates manual cutting of gates, saving time.
- **Loose Piece Pattern:** Used when the pattern cannot be drawn straight out of the mold. Portions of the pattern (loose pieces) remain in the mold and are removed separately.
- **Sweep Pattern:** Used to create symmetrical or circular molds without a full 3D pattern. A wooden board (sweep) is rotated around a central spindle.
- **Skeleton Pattern:** Made of wooden strips forming a skeleton of the desired shape. Used for very large castings to save material costs.

Pattern Allowances

A pattern must be designed with specific dimensions added or subtracted to compensate for metallurgical and mechanical effects during casting. These dimensional modifications are called **Pattern Allowances**.

Five main types of allowances:

1. Shrinkage or Contraction Allowance
2. Draft or Taper Allowance
3. Machining or Finish Allowance
4. Distortion or Camber Allowance
5. Rapping or Shake Allowance

Shrinkage (Contraction) Allowance

- Metals shrink as they cool from liquid to solid state at room temperature.
- Liquid and solidification shrinkage are compensated by risers.
- **Solid shrinkage** (reduction in size of the solid metal as it cools) is compensated by making the pattern larger.
- **Rule of Thumb:** The pattern size is increased by a specific percentage depending on the metal.
- *Example:* Cast Iron ($\approx$ 10 mm/m), Steel ($\approx$ 20 mm/m), Aluminum ($\approx$ 13 mm/m).

Draft and Machining Allowances

Draft (Taper) Allowance

- A slight taper given to the vertical faces of the pattern.
- Facilitates easy withdrawal of the pattern without damaging the mold walls.
- Generally 1° to 3° for exterior surfaces and 3° to 5° for interior surfaces.

Machining (Finish) Allowance

- Castings typically have rough surfaces and may not meet precise dimensional tolerances.
- Extra material is added to the pattern so that the casting can be machined to final dimensions.
- Depends on the metal, casting method, and size of the casting (usually 2 to 5 mm).

Distortion and Rapping Allowances

Distortion (Camber) Allowance

- Castings with uneven thickness (e.g., U, V, or T shapes) tend to distort due to uneven cooling rates.
- The pattern is intentionally distorted in the opposite direction so that the final casting remains straight after cooling.

Rapping (Shake) Allowance

- Before withdrawal, the pattern is struck (rapped) slightly to separate it from the mold sand.
- This enlarges the mold cavity slightly.
- Therefore, a small negative allowance (reduction in pattern size) is provided for precise dimensions.
- Often negligible for small castings.

Numerical Problem 1: Shrinkage Allowance

Problem: A cast iron part has final dimensions of $100 \times 50 \times 20$ mm. Calculate the dimensions of the pattern if the shrinkage allowance for cast iron is 10 mm/m. (Ignore other allowances).

Solution:

- Shrinkage allowance = 10 mm per 1000 mm = 0.01 (or 1%).
- Length of pattern $= 100 + (100 \times 0.01) = 101$ mm.
- Width of pattern $= 50 + (50 \times 0.01) = 50.5$ mm.
- Thickness of pattern $= 20 + (20 \times 0.01) = 20.2$ mm.

The dimensions of the pattern will be $101 \times 50.5 \times 20.2$ mm.

Numerical Problem 2: Combined Allowances

Problem: An aluminum cube of 200 mm side is to be cast. A machining allowance of 2 mm per face is required. The shrinkage allowance for aluminum is 13 mm/m. Determine the size of the wooden pattern.

Solution:

- **Step 1: Machining Allowance.** Each dimension needs machining on two opposite faces. Dimension after adding machining allowance $= 200 + (2 \times 2) = 204$ mm.
- **Step 2: Shrinkage Allowance.** Shrinkage is added to the already machined dimensions. Shrinkage $= 13$ mm/m $= 0.013$ mm/mm. Final Pattern Dimension $=$ $204 + (204 \times 0.013) = 204 + 2.652 = 206.652$ mm.

The wooden pattern should be a cube of side 206.652 mm.

Summary

- A **pattern** is a crucial tool for creating the mold cavity.
- The choice of **pattern material** (wood, metal, plastic, wax) affects durability and precision.
- Different **pattern types** (single piece, split, match plate, etc.) are chosen based on part complexity and production volume.
- **Pattern allowances** (shrinkage, draft, machining, distortion, rapping) are critical for ensuring the final casting meets dimensional requirements.
- Accurate calculation of allowances prevents defects and reduces post-processing costs.

Introduction to Cores

- **Core** is a sand shape (or form) inserted into a mould to produce the internal cavities or features of a casting that cannot be shaped by the pattern alone.
- **Need/Purpose of Cores:**
  - To form hollow internal cavities in the casting (e.g., inside of a pipe or an engine cylinder).
  - To form features that are too difficult to mold using a pattern (e.g., deep recesses or undercuts).
  - To form a part of the gating system.
  - To strengthen or improve a particular interior surface of the mould.
- Cores are usually made of special sand mixtures because they are subjected to severe thermal and mechanical conditions during the pouring of molten metal.

Types of Cores

Based on the state of sand used:

- **Green Sand Cores:** Formed by the pattern itself in the mould using green sand; used for relatively simple features.
- **Dry Sand Cores:** Made separately in core boxes, baked to develop strength, and then placed in the mould; widely used for complex internal cavities.

Based on position in the mould:

- **Horizontal Core:** Placed horizontally at the parting line.
- **Vertical Core:** Placed vertically in the mould.
- **Balanced Core:** Supported only at one end.
- **Hanging Core (Cover Core):** Suspended from the cope (upper part of the mould).
- **Drop Core:** Used when a hole is not in line with the parting surface.

Essential Characteristics of a Good Core

- **Permeability:** Must allow gases generated during pouring to escape, preventing gas defects.
- **Refractoriness:** Must withstand high temperatures without melting or fusing with the casting.
- **Strength:** Must be strong enough to withstand the hydrodynamic forces of molten metal without breaking or eroding.
- **Collapsibility:** Must lose its strength and easily collapse after the metal solidifies, preventing hot tears in the casting and allowing easy removal.
- **Dimensional Stability:** Must retain its shape accurately during baking and casting.

Introduction to Moulding Sand

- **Moulding Sand** is the primary material used for making moulds in sand casting processes. It primarily consists of silica (SiO_2).
- **Types of Moulding Sand:**
  - **Natural Sand:** Found in nature (riverbeds, etc.); contains natural clay (5-20%) and water; used for light castings.
  - **Synthetic Sand:** Artificially prepared by mixing pure silica sand with specific amounts of binders (like bentonite) and moisture. Offers better control over properties and is used in mechanized foundries.
  - **Loam Sand:** Contains a high percentage of clay (up to 50%) and moisture; used for very large and heavy castings without using standard patterns.
  - **Facing Sand, Backing Sand, System Sand:** Types based on their usage location in the mould.

Properties of Moulding Sand (1/2)

- **Refractoriness:** Ability of the sand to withstand high temperatures of molten metal without fusing or breaking down.
- **Permeability (Porosity):** Ability to allow gases (air, steam, and gases generated during pouring) to escape through the mould. Poor permeability causes defects like blowholes.
- **Flowability:** Ability of sand to flow and pack uniformly around the pattern when rammed, capturing fine details.
- **Collapsibility:** Ability of the mould to collapse easily and offer low resistance as the casting solidifies and shrinks, preventing hot tears.

Properties of Moulding Sand (2/2)

- **Green Strength:** Strength of the sand in its wet (green) condition. It must be sufficient to hold the mould shape after pattern withdrawal and during handling.
- **Dry Strength:** Strength of the sand after the moisture is evaporated by the hot metal. Prevents mould wall collapse during pouring.
- **Hot Strength:** Strength of the sand at elevated temperatures to prevent enlargement or distortion of the mould cavity.
- **Adhesiveness:** Ability of sand particles to stick to the sides of the moulding box (flask).
- **Cohesiveness:** Ability of sand particles to stick to each other.

Binders in Moulding Sand

- **Binders** are added to the moulding sand to impart strength and cohesiveness by binding the sand grains together.
- **Types of Binders:**
  - **Clay Binders:** Most commonly used. Examples include Bentonite, Kaolinite, Fireclay. They require water to develop binding properties.
  - **Organic Binders:** Include linseed oil, dextrin, molasses, and synthetic resins (phenolic, furan). These are primarily used in core making because they provide excellent collapsibility after burning out.
  - **Inorganic Binders:** Include sodium silicate and Portland cement. Used in special processes like the CO_2 moulding process.

The Base Material of the Foundry

- Dry sand, on its own, is useless for manufacturing.
- Without a binding agent, a dry sand mould instantly collapses into dust upon pattern removal.
- To create a rigid, stable mould capable of withstanding molten metal, a specific chemical mixture is required.
- **Essential Components:** Base Sand, Binders, and Moisture.

Types of Moulding Sand

1. Green Sand

- The absolute industry standard.
- "Green" refers to the sand being "wet" (contains moisture) when metal is poured.
- **Composition:** Silica sand ($75\% - 85\%$), Clay ($5\% - 11\%$), Water ($2\% - 8\%$).
- **Advantages:** Incredibly cheap and highly recyclable.

Types of Moulding Sand (Continued)

2. Dry Sand

- Identical to Green Sand, but the entire mould is baked in an industrial oven at 200°C.
- Water is evaporated, leaving a rock-hard, dry ceramic shell.
- **Advantages:** Produces zero steam when metal is poured, reducing gas defects.
- **Disadvantages:** Expensive and time-consuming to bake massive moulds.

Types of Moulding Sand (Continued)

3. Loam Sand

- Heavy, mud-like paste containing up to 50% clay.
- Smeared like plaster onto a brick skeleton instead of being rammed into a flask.
- Used for massive, one-off castings (e.g., church bells).

4. Core Sand (Oil Sand)

- Used exclusively for making cores.
- Pure silica sand mixed with chemical resins or Linseed oil, baked until rock-hard.

Essential Properties of Moulding Sand

1. **Refractoriness**
   - The most critical property of moulding sand.
   - Must withstand extreme thermal shock (up to 1600°C).
   - Must not melt or chemically fuse with the liquid metal.

2. **Permeability (Porosity)**
   - Ability to vent high-pressure steam generated by wet green sand.
   - Steam must escape through the back of the mould.
   - Poor permeability forces steam into the liquid metal, causing blowholes.

Essential Properties (Continued)

3. Green Strength

- Ability of the wet sand to rigidly hold the complex cavity shape.
- Walls must not collapse under their own gravity after pattern removal.

4. Dry Strength

- Heat from molten metal instantly bakes the first millimeter of sand.
- The baked crust must resist the violent erosive force of the rushing liquid metal.

Essential Properties (Continued)

5. Collapsibility

- As metal cools and freezes, it shrinks.
- The sand mould must become brittle and yield (collapse) slightly.
- If the sand remains rock-hard, the shrinking metal will tear itself apart (Hot Tearing).

Binders and Additives

Binders: The chemical "glue" providing strength.

- **Clay (Bentonite):** Most common inorganic binder for Green Sand. Forms a sticky paste with water to lock sand grains together.
- **Organic Resins / Oils:** Used primarily for Cores. Bake rock-hard, but instantly burn to ash upon metal contact for perfect collapsibility.

Binders and Additives (Continued)

Additives:

- Specialized chemicals mixed in tiny amounts to solve specific problems.
- **Coal Dust (Sea Coal):** Burns when hot metal hits, producing a barrier of carbon gas.
- Prevents the sand from fusing to the metal.
- Results in a significantly smoother surface finish on the final casting.

Introduction to Mould Making Equipments

- Mould making involves the preparation of the mold cavity to receive molten metal.
- Depending on the scale of production, mould making can be done manually using hand tools or mechanically using moulding machines.
- **Hand Moulding:** Suitable for small quantity production, intricate shapes, and large-sized castings where automation is not feasible.
- **Machine Moulding:** Employed for mass production to achieve higher production rates, uniform ramming, and better dimensional accuracy.
- The choice of equipment depends on the size of the casting, the number of castings required, and the type of sand used.

Common Hand Moulding Tools (1/3)

- **Shovel:** Used for mixing and conditioning the foundry sand and for transferring the sand into the moulding box or flask.
- **Riddle:** A standard sieve or screen used to remove foreign materials (like nails, splinters of wood, etc.) from the moulding sand to ensure fine sand is placed next to the pattern.
- **Rammer:** Used for packing or ramming the sand tightly around the pattern within the flask.
  - *Hand Rammers:* Peen rammer, Butt rammer.
  - *Pneumatic Rammers:* Used for large moulds to save time and manual effort.

Common Hand Moulding Tools (2/3)

- **Strike-off Bar:** A straight piece of wood or metal used to level the top surface of the mould by striking off excess sand after ramming.
- **Trowel:** A flat metal blade with a handle, used for smoothing and finishing the flat surfaces of the mould and for repairing damaged portions.
- **Slick:** A small double-ended tool having flat and spoon-shaped ends, used for repairing and finishing small surfaces, corners, and edges of the mould.
- **Lifter:** An L-shaped tool used for cleaning and extracting loose sand from deep, narrow pockets in the mould.

Common Hand Moulding Tools (3/3)

- **Sprue Pin:** A tapered wooden or metal pin used to make a hole in the cope (top half of the mould) through which molten metal is poured.
- **Draw Spike:** A pointed steel rod that is driven into the wooden pattern to lift it carefully out of the sand mould.
- **Swab:** A small brush or sponge used to apply water around the edges of the pattern before its removal, which prevents the sand from crumbling.
- **Bellows:** A hand-operated device used to blow away loose sand particles from the pattern and the mould cavity.

Moulding Machines

- Moulding machines automate the sand ramming and pattern drawing processes, significantly increasing productivity.
- Major functions performed by moulding machines:
  1. Ramming of sand.
  2. Rolling over the mould (inversion).
  3. Drawing the pattern out of the mould.
- **Common Types of Moulding Machines:**
  - Squeezer Machine
  - Jolt Machine
  - Jolt-Squeezer Machine
  - Sand Slinger

Types of Moulding Machines

- **Squeezer Machine:** Applies pressure to the top of the sand to pack it into the flask. Ramming is hardest at the surface and decreases towards the pattern. Suitable for shallow patterns.
- **Jolt Machine:** The table carrying the flask and sand is raised and dropped repeatedly (jolted) on a solid base. Sand packs tightly around the pattern at the bottom but loosely at the top.
- **Jolt-Squeezer Machine:** Combines both jolting and squeezing actions to achieve uniform sand density throughout the mould.
- **Sand Slinger:** Throws sand into the flask at high speed. The kinetic energy of the sand packs it uniformly. Ideal for very large moulds.

Introduction to Melting Furnaces

- Melting is a crucial step in the casting process where solid metal is heated above its melting point to a liquid state.
- The molten metal must be heated to a *pouring temperature* (superheated) to ensure it flows easily and fills the mould cavity completely before freezing.
- **Selection criteria for a furnace:**
  - Type of metal or alloy to be melted.
  - Melting temperature required.
  - Capacity (amount of metal to be melted).
  - Cost of equipment, operation, and maintenance.
  - Environmental and emission regulations.

Crucible Furnace

- One of the oldest and simplest types of melting furnaces.
- The metal is placed inside a **crucible** (made of refractory material like clay and graphite), which is heated from the outside.
- Since the heat is applied externally, the molten metal does not come into direct contact with the fuel or combustion gases, preventing contamination.
- Ideal for melting non-ferrous metals such as aluminum, copper, brass, and bronze.
- **Types based on operation:**
  1. Lift-out crucible furnace.
  2. Stationary (bale-out) crucible furnace.
  3. Tilting crucible furnace.

Pit Furnace

- A type of lift-out crucible furnace constructed in a pit below the floor level.
- **Construction & Working:**
  - Consists of a cylindrical steel shell lined with refractory bricks.
  - Solid fuel (like coke) is placed at the bottom on a grate.
  - The crucible containing the metal is placed on a refractory block over the fuel bed.
  - Coke is packed around the crucible and ignited. Air is supplied through the grate (natural or forced draft).
  - Once melted, the crucible is lifted out using tongs, and the metal is poured into moulds.
- **Applications:** Mainly used in small foundries for melting small quantities of non-ferrous metals.

Electric Furnaces

- Electric furnaces use electrical energy to produce the heat required for melting metals.
- They offer excellent control over temperature and metal composition with minimal contamination.
- Highly preferred for melting high-grade steel, cast iron, and specific non-ferrous alloys.
- **Main Types:**
  - **Electric Arc Furnace:** Heat is generated by an electric arc struck between carbon/graphite electrodes and the metal charge (Direct Arc) or between the electrodes themselves (Indirect Arc).
  - **Induction Furnace:** Uses electromagnetic induction to generate heat directly within the metal charge, providing excellent mixing action and pure melts.

Cupola Furnace: Introduction

- The cupola furnace is the most widely used furnace for melting **cast iron**.
- It is a vertical, cylindrical shaft furnace that operates on a continuous melting principle.
- **Advantages:**
  - Simple and economical to construct and operate.
  - High melting rate and continuous supply of molten metal.
  - High thermal efficiency since the combustion gases preheat the descending charge.
  - Requires less floor space compared to other furnaces of the same capacity.
- **Limitations:** Close control of temperature and metal composition is difficult; carbon and sulfur pickup from coke is inevitable.

Construction of Cupola Furnace

- **Shell:** A vertical cylindrical steel shell lined inside with refractory fire bricks.
- **Foundation:** Supported on cast iron legs; the bottom is closed by two hinged cast iron drop doors.
- **Wind Box & Tuyeres:** Air (blast) for combustion is supplied from a blower through a circular wind box into the furnace via openings called **tuyeres**.
- **Tap Hole & Slag Hole:** The metal tap hole is at the lowest point (front) to draw molten metal, while the slag hole is located slightly higher at the rear to remove impurities (slag).
- **Charging Door:** Located in the upper half of the furnace for feeding the charge (metal, coke, and flux).

Working of Cupola Furnace

1. **Preparation:** The bottom doors are closed, and a sand bed is rammed at the bottom, sloping towards the tap hole.
2. **Lighting the fire:** Wood is ignited on the sand bed, followed by the addition of a thick bed of coke (bed charge).
3. **Charging:** Alternate layers of pig iron (and scrap), coke, and flux (limestone) are fed through the charging door up to the level of the door.
4. **Melting:** The air blast is turned on. The coke burns rapidly, producing intense heat. The metal melts and trickles down through the coke bed to the well.
5. **Slagging and Tapping:** The flux melts and combines with impurities to form slag, which floats on the molten metal. Slag and metal are drawn off through their respective holes.

Zones in a Cupola Furnace

- **Well Zone:** The space between the sand bed and the bottom of the tuyeres. It acts as a reservoir for the molten metal and slag.
- **Combustion Zone (Oxidation Zone):** Located just above the tuyeres. Here, oxygen reacts with carbon in coke to form CO_2, releasing maximum heat. Temperatures reach up to $1900^\circ C$.
- **Reducing Zone:** Above the combustion zone. CO_2 reacts with hot coke to form CO, causing a drop in temperature and preventing oxidation of the metal charge.
- **Melting Zone:** The first layer of the metal charge. The metal absorbs heat and melts at around $1600^\circ C$.
- **Preheating Zone:** Extends from the melting zone to the charging door. The hot exhaust gases preheat the descending solid charge layers, improving efficiency.

Introduction to Mould Making Equipments

- Mould making requires various tools and equipments to properly prepare the sand, ram it around the pattern, and finish the mould cavity.
- These equipments are broadly classified into:
  - **Hand Tools:** Used manually for small to medium scale production or custom castings.
  - **Moulding Flasks:** Containers used to hold the sand mould.
  - **Moulding Machines:** Used in mass production to automate and speed up the moulding process, providing uniform ramming.

Hand Tools in Mould Making (1/4)

- **Shovel:** Used for mixing and tempering moulding sand and for moving the sand from the pile to the flask.
- **Riddle:** A sieve or screen used to remove large lumps, foreign particles, and to ensure fine sand is placed next to the pattern (facing sand).
- **Rammer:** Used for packing or ramming the sand around the pattern.
  - *Peen:* The wedge-shaped end used for ramming in corners and confined spaces.
  - *Butt:* The flat end used for ramming large, flat areas.

Hand Tools in Mould Making (2/4)

- **Strike-off Bar:** A straight wooden or metal bar used to scrape off the excess sand from the top of the flask after ramming to make it level.
- **Sprue Pin:** A tapered wooden or metal pin used to make a hole in the cope (top half) through which molten metal is poured (sprue).
- **Vent Wire:** A thin steel wire used to pierce small holes in the rammed sand to allow gases and steam to escape during pouring.

- **Trowel:** Consists of a flat metal blade with a handle. Used for smoothing surfaces, shaping, and repairing the mould.
- **Slick:** A small double-ended tool used for repairing and finishing small surfaces, corners, and edges of the mould.
- **Lifter:** An L-shaped tool used to clean out loose sand from deep sections of the mould cavity and for patching.

Hand Tools in Mould Making (4/4)

- **Swab:** A small brush or sponge used to apply water around the edges of the pattern before drawing it, preventing sand edges from crumbling.
- **Draw Spike:** A pointed steel pin or screw that is driven into a wooden pattern to lift (draw) it out of the sand mould.
- **Bellows:** Used to blow away loose sand particles from the mould cavity and pattern surfaces.

Moulding Flasks (Boxes)

- A moulding flask is a rigid frame used to hold the sand mould intact.
- Usually consists of two parts:
  - **Cope:** The upper half.
  - **Drag:** The lower half.
  - **Cheek:** An intermediate part used for complex castings (three-part moulds).
- **Types of Flasks:**
  - *Box Flask:* Solid, rigid frame used for heavy castings. Remains with the mould during pouring.
  - *Snap Flask:* Hinged on one corner and has a latch on the opposite corner. Removed before pouring, allowing one flask to make many moulds.

Moulding Machines

- Hand moulding is slow and requires skilled labor. For mass production, moulding machines are used.
- Functions of moulding machines:
  - Packing (ramming) the sand evenly and firmly.
  - Withdrawing the pattern from the mould without damaging it.
- Main types of moulding machines:
  - Squeeze Machine
  - Jolt Machine
  - Jolt-Squeeze Machine
  - Sand Slinger

Types of Moulding Machines

- **Squeeze Machine:** Uses a mechanical or pneumatic press to squeeze the sand from the top. Sand is denser at the top and less dense near the pattern.
- **Jolt Machine:** Lifts the flask and drops it repeatedly on a solid table. Sand is denser at the bottom (near pattern) and less dense at the top.
- **Jolt-Squeeze Machine:** Combines jolting and squeezing actions. Provides uniform sand density throughout the mould depth.
- **Sand Slinger:** Throws sand into the flask at high speed using a rotating impeller. It fills and rams the mould simultaneously, used for very large moulds.

Introduction to Melting Furnaces

- **Purpose:** Melting furnaces are used to heat solid metals to their molten state for pouring into molds.
- **Selection Criteria:** The choice of furnace depends on:
  - The type of alloy being melted (ferrous vs. non-ferrous).
  - The melting temperature required.
  - The required melting rate and capacity.
  - Economic considerations (fuel cost, equipment cost).
  - Quality control requirements (purity, temperature control).

Crucible Furnace

- **Concept:** One of the oldest and simplest types of melting furnaces. The metal is melted inside a refractory container called a **crucible**.
- **Heating Method:** The crucible is heated from the outside using a burner (gas or oil) or solid fuel (coke or coal).
- **Types:**
  - **Lift-out type:** The crucible is completely removed from the furnace for pouring.
  - **Stationary (Bale-out) type:** The crucible remains fixed, and metal is ladled out.
  - **Tilting type:** The entire furnace tilts to pour out the molten metal.

Crucible Furnace: Advantages & Limitations

Advantages:

- Low initial installation cost.
- Simple in construction and operation.
- Flexibility to change alloys quickly by swapping crucibles.
- Ideal for melting non-ferrous metals like aluminum, copper, and brass.

Limitations:

- Low melting capacity (small batch sizes).
- Lower thermal efficiency compared to other furnaces.
- The crucible has a limited lifespan and needs frequent replacement.

Pit Furnace

- **Concept:** A specific type of lift-out crucible furnace that is installed partially or completely below the floor level (in a pit).
- **Construction:**
  - Usually cylindrical, lined with refractory bricks.
  - A grate at the bottom holds the solid fuel (coke) or a burner is positioned to heat the crucible.
  - The crucible sits on a pedestal in the center.
- **Operation:** Solid metal is placed in the crucible, fuel is burned around it, and once molten, the crucible is lifted out using tongs.
- **Applications:** Primarily used for small-scale foundries melting non-ferrous alloys.

Electric Furnace

- **Concept:** Uses electrical energy for heating, providing excellent control over temperature and atmosphere.
- **Types of Electric Furnaces:**
    1. **Direct Arc Furnace:** Electric arcs form between carbon electrodes and the metal charge itself. High heat transfer, used for melting steel and cast iron.
    2. **Indirect Arc Furnace:** The arc is struck between two electrodes above the metal, and heat is transferred by radiation.
    3. **Induction Furnace:** Uses an alternating magnetic field to induce eddy currents in the metal, generating heat internally.

Induction Furnace (Most Common Electric Furnace)

- **Principle:** Based on electromagnetic induction. A water-cooled copper coil surrounds a refractory crucible containing the metal. High-frequency AC current creates a changing magnetic field, inducing eddy currents that heat and melt the metal.
- **Advantages:**
  - Very clean melting process (no combustion gases).
  - Excellent temperature control and uniform composition due to electromagnetic stirring.
  - High thermal efficiency and rapid melting.
- **Applications:** Melting high-quality steels, cast irons, and non-ferrous alloys where purity is critical.

Cupola Furnace

- **Concept:** A tall, cylindrical vertical shaft furnace specifically designed for melting **cast iron**.
- **Construction:**
  - Outer shell made of steel plates, lined internally with refractory bricks.
  - Features a charging door near the top, wind box and tuyeres (nozzles for air blast) near the bottom.
  - Tap hole at the lowest point for molten metal, and a slag hole slightly above it.
- **Charge:** Alternate layers of Pig Iron (metal), Coke (fuel), and Limestone (flux).

Cupola Furnace: Operation & Zones

Working Principle: Air is blasted through tuyeres to burn the coke, generating intense heat. The hot gases rise, melting the descending iron. The limestone acts as a flux to remove impurities as slag.

Zones in a Cupola:

1. **Crucible/Hearth Zone:** Collects the molten metal and slag.
2. **Combustion (Oxidation) Zone:** Where air meets coke, producing maximum heat (1500°C to 1900°C).
3. **Reducing Zone:** CO_2 is reduced to CO, preventing oxidation of the metal.
4. **Melting Zone:** Solid iron melts.
5. **Preheating Zone:** Ascending hot gases preheat the descending charge.

Cupola Furnace: Advantages & Limitations

Advantages:

- Very high melting capacity (can operate continuously).
- Low cost of operation and low initial cost compared to its capacity.
- Most economical method for producing large quantities of cast iron.

Limitations:

- Only suitable for melting cast iron (ferrous metals).
- Close temperature control is difficult.
- Carbon content of the metal tends to increase as it is in direct contact with coke.

Comparison of Furnaces

Feature	Crucible/Pit Furnace	Electric Furnace	Cupola Furnace
Primary Use	Non-ferrous alloys	High-quality steels, CI, alloys	Cast Iron
Energy Source	Coke, Oil, Gas	Electricity	Coke
Temp. Control	Moderate	Excellent	Poor to Moderate
Metal Purity	Good	Very High	Average (picks up C, S)
Cost	Low installation	High initial cost	Economical for high volume

Need for Melting Furnaces

- **Primary Purpose**: To melt the solid metal or alloy to a specific pouring temperature suitable for casting.
- **Key Requirements**:
  - Must achieve the required superheat temperature efficiently.
  - Minimize heat loss and energy consumption.
  - Prevent contamination of the molten metal (e.g., oxidation, absorption of harmful gases).
  - Allow for easy and precise temperature control.
- **Fuel Sources Used**: Solid (Coke, Coal), Liquid (Furnace Oil), Gas (Natural Gas), or Electrical Energy.

Types of Furnaces in Foundries

Common Types Based on Scale and Metal

Depending on the metal to be melted and the production scale, the following furnaces are widely used:

1. **Crucible Furnace** (For non-ferrous metals, small to medium scale)
2. **Pit Furnace** (A specific traditional type of crucible furnace)
3. **Electric Furnace** (Induction or Arc - for precise control and high-quality alloy steels)
4. **Cupola Furnace** (Specifically designed for cast iron, large-scale production)

Note: This lecture focuses on Crucible and Pit Furnaces. Electric and Cupola furnaces will be covered in the next lecture.

Crucible Furnace: Introduction

- **Concept**: The solid metal charge is placed inside a refractory container called a *crucible*. Heat is applied to the exterior of the crucible to melt the metal inside.
- **Key Characteristic**: Indirect heating. The fuel and combustion gases *do not* come into direct contact with the molten metal.
- **Primary Advantage**: Prevents contamination of the melt from fuel impurities, ensuring higher quality metal.
- **Application**: Ideal for non-ferrous metals like Aluminum, Brass, and Bronze.
- **Crucible Material**: Usually made of graphite and clay, or silicon carbide, designed to withstand high thermal shock and temperatures.

Classification of Crucible Furnaces

Crucible furnaces are classified based on how the crucible is handled and heated:

Lift-out Crucible

The crucible is completely removed from the furnace using special tongs to pour the molten metal directly into the moulds. Used for very small batches.

Tilting Crucible

The furnace itself is mounted on trunnions (pivots). The entire furnace assembly is tilted using a wheel or hydraulic mechanism to pour the metal into a ladle.

Advantages and Limitations of Crucible Furnaces

Advantages:

- Simple construction and easy to operate.
- Low initial setup and capital cost.
- High purity of metal as there is no contact with fuel or combustion gases.
- Flexible: Easy to change alloys simply by switching out the crucible.

Limitations:

- Low thermal efficiency because heat transfer through the crucible wall is slow.
- Limited capacity (usually restricted to 200–300 kg per batch).
- The crucible has a limited lifespan (subject to thermal fatigue) and requires frequent replacement.

Pit Furnace: Concept and Construction

- **What is it?** A traditional type of lift-out crucible furnace that is constructed completely or partially *below ground level* in a pit.
- **Construction Details**:
  - **Outer Shell**: Made of steel, heavily lined with refractory bricks.
  - **Grate**: Located at the bottom to support the solid fuel (usually coke).
  - **Crucible Placement**: The crucible rests on a refractory pedestal (base block) in the center.
  - **Fuel Space**: Coke is densely packed in the annular space around the crucible.
  - **Ash Pit**: Provided below the grate to collect ash and allow air draft.

Pit Furnace: Working Principle

1. A fire is initially started on the grate using wood and a small amount of coke.
2. Once the fire is steadily burning, the crucible containing the metal charge is placed on the central base block.
3. Additional coke is fed into the annular space between the crucible and the refractory furnace wall.
4. Combustion air is supplied (naturally through a chimney draft or via a forced blower) from below the grate.
5. Heat from the burning coke conducts through the crucible wall to melt the metal charge.
6. Once the pouring temperature is reached, the crucible is lifted out using long tongs by two operators and carried to the pouring area.

Pit Furnace: Pros, Cons & Applications

Advantages

- Placement in a pit makes it easier to lift the heavy crucible out manually (better ergonomics compared to an above-ground lift-out furnace).
- Extremely cheap to build and operate, making it suitable for very small foundries.

Limitations and Applications

Limitations

- Very slow melting rate and poor thermal efficiency.
- High physical labor required for lifting the crucible, feeding coke, and cleaning ash.
- Accurate temperature control is practically impossible.

Applications

Used primarily in small-scale, traditional foundries for melting small quantities of brass, bronze, and aluminum.

Lecture Summary

- **Melting Furnaces** are essential for heating metal to a molten state for casting. They must be efficient and minimize metal contamination.
- **Crucible Furnaces** melt metal indirectly inside a refractory container, preventing contamination from combustion gases. They are classified into lift-out, stationary, and tilting types.
- **Pit Furnaces** are a specific type of lift-out crucible furnace built below ground level, using solid fuel like coke.
- Both Pit and Crucible furnaces are best suited for small quantities of **non-ferrous metals** due to their limited batch capacity and moderate thermal efficiency.

Introduction to Casting Defects

- A casting defect is an irregularity in the metal casting process that is very undesirable.
- Defects can be avoided or minimized by proper mold design, selection of molding sand, and proper pouring techniques.
- Sometimes, defects can be tolerated if they do not compromise the structural integrity or functional requirements of the part.
- **Effects of Casting Defects:**
  - Decreased mechanical strength and fatigue life.
  - Poor surface finish affecting aesthetics and function.
  - Material wastage and increased production costs due to rework or rejection.

Classification of Casting Defects

Casting defects are broadly classified into the following categories:

1. **Gas Defects:** Blowholes, Pinholes, Porosity.
2. **Shrinkage Defects:** Shrinkage cavities.
3. **Molding Material Defects:** Cuts, washes, scabs, drops, swell, penetration.
4. **Pouring Metal Defects:** Misrun, cold shut.
5. **Metallurgical Defects:** Hot tears, hot spots.

Gas Defects: Blowholes and Porosity

Blowholes: Smooth, round voids appearing inside the casting or on the surface.

- **Causes:**
  - Excessive moisture in the molding sand.
  - Low permeability of sand preventing gas escape.
  - Insufficient venting in the mold.
- **Remedies:**
  - Control moisture content in the sand.
  - Improve sand permeability.
  - Provide adequate vent holes in the mold and cores.

Shrinkage Defects

Shrinkage Cavity: A depression or void caused by the volumetric contraction of metal during solidification.

- **Causes:**
  - Inadequate or improperly placed risers.
  - High pouring temperature leading to excessive liquid shrinkage.
  - Uneven solidification rates across the casting.
- **Remedies:**
  - Design a proper gating and risering system (directional solidification).
  - Use chills to promote uniform cooling in thicker sections.
  - Control the pouring temperature.

Molding Material Defects: Drops and Scabs

Drop: An irregular deformation caused when a piece of molding sand falls into the mold cavity.

- **Causes:** Low green strength, improper ramming, or inadequate reinforcement.
- **Remedies:** Improve sand strength, ram properly, use gaggers for support.

Scab: Rough, irregular projections on the casting surface caused by sand expansion.

- **Causes:** Insufficient addition of combustible additives (like coal dust), uneven heating.
- **Remedies:** Mix combustible additives in sand to allow expansion, ensure uniform ramming.

Molding Material Defects: Cuts/Washes and Swell

Cuts and Washes: Erosion of molding sand by the fast-flowing molten metal.

- **Causes:** High velocity of molten metal, low strength of molding sand.
- **Remedies:** Improve gating system design to reduce metal velocity, increase sand binders.

Swell: Enlargement of the casting due to the yielding of the mold wall under metallostatic pressure.

- **Causes:** Inadequate or soft ramming of sand.
- **Remedies:** Ensure proper and uniform ramming to increase mold wall strength.

Pouring Metal Defects: Misrun and Cold Shut

Misrun: Molten metal solidifies before completely filling the mold cavity, leaving unfilled sections.

- **Causes:** Low pouring temperature, slow pouring rate, too thin sections.

Cold Shut: Two streams of molten metal meet but fail to fuse together completely, forming a weak joint.

- **Causes:** Lack of fluidity, low pouring temperature, inadequate gating system.

Remedies for Both:

- Increase pouring temperature to enhance fluidity.
- Optimize the gating system for faster and smoother filling.
- Avoid excessively thin casting sections.

Metallurgical Defects: Hot Tears

Hot Tears (Hot Cracks): Irregular cracks appearing at junctions or cross-sections due to restricted contraction during cooling.

- **Causes:**
  - High restraint from the mold or core preventing natural shrinkage.
  - Abrupt changes in cross-section creating stress concentrations.
- **Remedies:**
  - Increase mold and core collapsibility (use organic binders).
  - Provide adequate fillets at sharp corners and junctions.
  - Ensure uniform cooling to minimize internal stresses.

Summary of Casting Defects

- Understanding the root cause of casting defects is critical for improving yield and product quality.
- Most defects can be prevented by:
  - Maintaining optimal sand properties (strength, permeability, moisture).
  - Designing effective gating and risering systems.
  - Controlling process parameters like pouring temperature and rate.
- Advanced techniques like simulation software are now widely used to predict and eliminate defects before actual pouring.

Introduction to Foundry Safety

- Foundries present a highly hazardous environment due to the presence of molten metals, heavy machinery, and toxic fumes.
- Ensuring safety is paramount to prevent severe injuries, fatalities, and occupational diseases.
- Key hazards include thermal burns, respiratory issues from silica dust, noise-induced hearing loss, and physical injuries from heavy lifting.
- Implementing a robust safety culture and strict adherence to protocols are essential for a safe working environment.

Major Hazards in Casting Processes

Physical Hazards

- Extreme heat and thermal radiation.
- Splashing of molten metal.
- Heavy lifting and repetitive strain.
- High noise levels from furnaces and shakeout.

Chemical & Respiratory Hazards

- Silica dust (risk of silicosis).
- Toxic fumes from binders and coatings.
- Carbon monoxide (CO) from combustion.
- Metal fumes (zinc, lead, etc.).

Personal Protective Equipment (PPE)

Essential PPE for Foundry Workers

Proper PPE acts as the last line of defense against workplace hazards.

- **Head & Face:** Hard hats, full-face shields (tinted for furnace work), and safety goggles.
- **Body:** Aluminized or flame-retardant aprons and jackets to protect against radiant heat and splashes.
- **Hands:** Heavy-duty, heat-resistant leather or aluminized gloves.
- **Feet:** Steel-toed boots with metatarsal guards and heat-resistant soles. Leggings/spats to prevent metal ingress.
- **Respiratory:** N95 masks or specialized respirators depending on dust and fume levels.

Safety During Melting and Pouring

- **Furnace Operation:** Ensure the furnace is regularly inspected for refractory lining wear. Avoid overcharging.
- **Moisture Elimination:** Never introduce wet scrap, tools, or charge materials into molten metal. Moisture causes rapid expansion and steam explosions.
- **Pouring Practices:**
  - Use appropriate lifting tackles and ladles.
  - Ensure ladles are pre-heated and completely dry.
  - Maintain a clear path from the furnace to the moulds.
  - Stand to the side during pouring, avoiding the direct line of potential splashes.

Safety in Sand Handling and Moulding

- **Dust Control:** Use Local Exhaust Ventilation (LEV) systems at sand mixing, shakeout, and fettling stations to control silica dust.
- **Housekeeping:** Regularly wet-sweep or vacuum floors to prevent the accumulation of airborne dust.
- **Machine Safety:** Ensure all moulding machines, conveyors, and mullers have proper guarding. Implement Lockout/Tagout (LOTO) procedures during maintenance.
- **Chemical Handling:** Handle core binders, resins, and catalysts with care, using appropriate chemical-resistant gloves and ensuring good ventilation.

Safety in Fettling and Cleaning

Post-Casting Hazards

Fettling involves removing gates, risers, and excess metal, which presents mechanical and respiratory risks.

- **Abrasive Wheels:** Inspect grinding wheels for cracks before use (ring test). Ensure wheel guards are in place and properly adjusted.
- **Vibration:** Limit exposure time to hand-arm vibration from pneumatic chipping hammers to prevent White Finger Syndrome.
- **Eye Protection:** High-impact face shields and safety glasses are mandatory to protect against flying metal chips and sparks.

Emergency Procedures and First Aid

- **Burn Management:** For minor burns, cool with water immediately. For severe burns, do not remove adhered clothing; seek immediate medical attention.
- **Eye Injuries:** Use emergency eye-wash stations immediately if dust or chemicals enter the eyes. Do not rub the eyes.
- **Fire Safety:** Keep appropriate fire extinguishers (Class D for combustible metals, Class ABC for general fires) easily accessible. Ensure escape routes are unobstructed.
- **Training:** Conduct regular safety drills and ensure that all workers are trained in basic first aid and emergency response protocols.

The Mathematics of Foundry Economics

- A foundry operates as a business where profitability relies on precise estimations.
- Before accepting a contract (e.g., casting 1,000 engine blocks), engineers must mathematically calculate:
  - Exact cost of raw materials.
  - Energy required for melting.
  - Dimensions of the wooden pattern (accounting for shrinkage and machining).
- Efficiency is heavily tied to the design of the gating system and risers.

1. Calculating Pattern Allowances (Shrinkage)

Shrinkage Allowance

The pattern must be built larger than the final part to account for the metal shrinking as it cools from a liquid to a solid. Shrinkage is typically expressed as a percentage or as "mm per meter."

Formula:

$$\text{Pattern Dimension} = \text{Final Part Dimension} + \text{Shrinkage Allowance}$$

Example Problem 1: Shrinkage Allowance

Problem: A company needs a cast iron rectangular block with a final required length of 500 mm. The liquid cast iron shrinks at a rate of 1%. Calculate the exact length the wooden pattern must be carved to.

Solution:

1. Calculate the shrinkage amount:

$$\text{Shrinkage} = 1\% \text{ of } 500 \text{ mm} = 0.01 \times 500 = 5 \text{ mm}$$

2. Add the shrinkage to the final dimension:

$$\text{Pattern Length} = 500 \text{ mm} + 5 \text{ mm} = 505 \text{ mm}$$

Answer: The wooden pattern must be exactly 505 mm long.

Additional Allowances

Machining Allowance

If additional operations like machining are required, the allowance must be added on top of the shrinkage allowance.

Example:

- Using the previous 500 mm block (Pattern: 505 mm).
- If a Machining Allowance of 2 mm per side is required.
- Total additional length $= 2$ mm $+ 2$ mm $= 4$ mm.
- Final Pattern Length $= 505$ mm $+ 4$ mm $= 509$ mm.

2. Cost Estimation in Casting

- The total cost of a casting is not just the price of the raw metal.
- It must include the metal required for the **entire mould**, which includes the massive Gates and Risers, even though they are cut off and recycled later.

General Cost Formula:

$$\begin{aligned}\text{Total Cost} = {} & \text{Material Cost} + \text{Melting Cost} \\ & + \text{Moulding Labor Cost} + \text{Fettling Cost}\end{aligned}$$

Example Problem 2: Cost Estimation (1/2)

Problem: A foundry is casting a steel gear. Calculate the total cost to produce one gear given the following:

- The final solid gear weighs 10 kg.
- The required gating system and risers weigh an additional 4 kg.
- Raw steel costs Rs. 50 per kg.
- The electrical energy cost to melt the steel in the furnace is Rs. 20 per kg.
- The labor cost to ram the sand mould and clean the final part is Rs. 150 per mould.

Example Problem 2: Solution (2/2)

Solution:

1. **Calculate the Total Weight** of metal that MUST be melted:

$$10\ \text{kg (Gear)} + 4\ \text{kg (Gating/Riser)} = 14\ \text{kg}$$

2. **Calculate Material Cost** for 14 kg of steel:

$$14\ \text{kg} \times \text{Rs. } 50/\text{kg} = \text{Rs. } 700$$

3. **Calculate Melting Energy Cost** for 14 kg of steel:

$$14\ \text{kg} \times \text{Rs. } 20/\text{kg} = \text{Rs. } 280$$

4. **Find Total Cost** by adding the fixed Labor Cost (Rs. 150):

$$700\ \text{(Material)} + 280\ \text{(Melting)} + 150\ \text{(Labor)} = \text{Rs. } 1130$$

Answer: The total cost to produce one gear is Rs. 1130.

Introduction to Foundry Safety

- Foundries and metal casting environments present unique and severe safety hazards.
- Workers are exposed to extreme temperatures, heavy machinery, toxic fumes, and hazardous materials.
- Implementing rigorous **safety precautions** is essential to prevent accidents, injuries, and fatalities.
- A safe working environment also improves productivity, morale, and reduces operational downtime.
- Safety involves hazard recognition, proper procedures, and the use of protective equipment.

Types of Hazards in Metal Casting

- Hazards in a foundry can be broadly classified into four main categories:
  1. **Thermal Hazards:** Extreme heat, molten metal splashes, and hot surfaces.
  2. **Chemical Hazards:** Toxic fumes, silica dust, binder chemicals, and gases (e.g., CO).
  3. **Physical Hazards:** Noise, vibration, flying particles, and heavy moving machinery.
  4. **Ergonomic Hazards:** Heavy lifting, repetitive motions, and awkward postures during molding.

Thermal Hazards and Precautions

- **Sources:** Molten metal (often exceeding 1000°C), furnaces, hot castings, and radiant heat.
- **Risks:** Severe burns, heat stroke, and heat exhaustion.
- **Precautions:**
  - Keep moisture and water strictly away from molten metal to prevent steam explosions.
  - Ensure proper ventilation to reduce ambient heat.
  - Use appropriate heat-resistant Personal Protective Equipment (PPE).
  - Allow sufficient cooling time before handling castings.

Chemical Hazards and Precautions

- **Sources:** Silica sand (respirable crystalline silica), fumes from melting, resins, and organic binders.
- **Risks:** Respiratory diseases (e.g., Silicosis), metal fume fever, and poisoning.
- **Precautions:**
  - Install effective exhaust systems and local ventilation at pouring and shakeout stations.
  - Use proper respiratory protection (e.g., N95 masks or respirators).
  - Handle chemical binders and resins with proper gloves and refer to Material Safety Data Sheets (MSDS).
  - Implement dust suppression techniques (e.g., spraying water where permissible).

Physical and Ergonomic Hazards

- **Physical Hazards:**
  - High noise levels from furnaces, shakeout, and grinding machines.
  - Flying metal chips and sand particles during fettling.
  - Moving cranes, ladles, and forklift trucks.
- **Ergonomic Hazards:**
  - Manual lifting of heavy sand boxes, patterns, and castings.
- **Precautions:**
  - Wear earplugs/muffs and safety goggles.
  - Use mechanical lifting aids (cranes, hoists) for heavy loads.
  - Maintain clear walkways and proper lighting.

Personal Protective Equipment (PPE)

- The use of proper PPE is a mandatory final line of defense against foundry hazards.
- **Eye and Face:** Face shields and safety glasses with side shields to protect against splashes and flying debris.
- **Head:** Hard hats to protect against falling objects and overhead cranes.
- **Respiratory:** Dust masks, half-face respirators, or supplied-air hoods depending on exposure levels.
- **Hearing:** Earplugs or earmuffs to prevent noise-induced hearing loss.

PPE for Body and Extremities

- **Body Protection:**
  - Aluminized clothing or flame-resistant jackets/aprons to reflect radiant heat and protect against splashes.
  - Avoid synthetic fabrics (like polyester) that can melt into the skin; use heavy cotton or wool.
- **Hand and Arm:**
  - Heat-resistant leather or Kevlar gloves and sleeves.
- **Foot and Leg:**
  - Steel-toed safety boots with metatarsal guards.
  - Foundry leggings or spats to prevent molten metal from entering footwear.

Safety during Pattern Making & Sand Preparation

- **Pattern Making:**
  - Use guards on woodworking machines (saws, lathes).
  - Ensure proper dust extraction for wood dust to prevent respiratory issues and fire hazards.
  - Safely handle and store paints, varnishes, and adhesives.
- **Sand Preparation:**
  - Avoid raising dust during sand mixing and mulling.
  - Keep hands and loose clothing away from rotating mullers and mixers.
  - Ensure the sand has the correct moisture content to avoid defects that could lead to dangerous pouring conditions.

Safety during Melting and Pouring

- **Melting (Furnaces):**
  - Inspect furnace linings regularly for cracks or wear to prevent metal breakouts.
  - **Never** charge damp or wet scrap into the molten bath; it will cause a catastrophic steam explosion.
  - Pre-heat tools (skimmers, ladles) before introducing them into molten metal.
- **Pouring:**
  - Clear the pouring area of any trip hazards and unauthorized personnel.
  - Do not overfill ladles.
  - Pour smoothly to avoid splashing and turbulent flow.
  - Ensure molds are properly clamped or weighted to prevent lifting and metal leakage.

Safety during Fettling and Cleaning

- **Shakeout:**
  - Wait for the casting to solidify and cool sufficiently before shakeout.
  - Use local exhaust ventilation to capture the massive amount of dust generated.
- **Fettling (Grinding, Chipping, Cutting):**
  - Always wear face shields and safety glasses to protect against flying metal chips.
  - Inspect grinding wheels for cracks before use (ring test); never over-speed a wheel.
  - Ensure workpiece is securely clamped during cutting or grinding.
  - Wear hearing protection due to high noise levels.

General Safety Rules in the Foundry

- Maintain good **housekeeping**: Keep floors clean, dry, and free of obstacles.
- Ensure emergency exits are clear and accessible at all times.
- Fire extinguishers and first aid kits must be readily available and regularly inspected.
- Provide regular safety training and drills for all personnel.
- Implement a strict Lockout/Tagout (LOTO) procedure during machine maintenance.
- Always report near-misses and accidents to prevent future occurrences.

Summary

- Metal casting poses significant thermal, chemical, physical, and ergonomic hazards.
- Moisture near molten metal is a prime cause of deadly explosions and must be strictly avoided.
- Proper use of PPE (aluminized suits, safety boots, respirators, face shields) is non-negotiable.
- Safety is a continuous process involving proper training, correct procedures at every stage (molding, melting, pouring, fettling), and maintaining a clean workspace.
- Adhering to safety protocols ensures a productive and hazard-free manufacturing environment.

Introduction to Cost Estimation

- **Cost Estimation** is the process of predicting the financial cost of manufacturing a product before it is actually produced.
- **Why is it important?**
  - To determine the selling price of the product.
  - To check the economic viability of manufacturing.
  - To bid for tenders or provide quotes to customers.
  - To evaluate alternative manufacturing methods.
- Cost estimation in foundries involves two main areas: **Pattern Making** and the **Casting Process** itself.

Elements of Cost in Manufacturing

Major Cost Components

The total cost of a product is the sum of several cost elements:

1. **Direct Material Cost:** Cost of raw materials directly used in the product (e.g., wood for pattern, pig iron for casting).
2. **Direct Labour Cost:** Wages paid to workers directly involved in making the product (e.g., pattern maker, moulder).
3. **Direct Expenses:** Specific expenses incurred directly for the product (e.g., special tooling).
4. **Overheads (Indirect Costs):** Factory overheads, administrative overheads, selling and distribution overheads (e.g., rent, power, supervisor salary).

Cost Estimation in Pattern Making

The total cost of a pattern includes:

- **Material Cost:** Volume of the pattern $\times$ Density of material $\times$ Rate per unit weight.
- **Labour Cost:** Estimated time taken $\times$ Labour rate per hour.
- **Overheads:** Usually taken as a percentage of the direct labour cost or direct material cost.

Formula

Total Pattern Cost = Direct Material Cost + Direct Labour Cost + Overheads

Numerical Problem 1: Pattern Making

Problem Statement: Calculate the total cost of making a wooden pattern. The details are as follows:

- Volume of wooden pattern = 1500 cm^3
- Density of wood = 0.7 g/cm^3
- Cost of wood = Rs. 150 per kg
- Time required to make the pattern = 10 hours
- Wage rate of pattern maker = Rs. 80 per hour
- Factory overheads = 50% of direct labour cost

Solution to Problem 1

Step 1: Calculate Direct Material Cost

- Mass of pattern = Volume $\times$ Density = $1500 \times 0.7 = 1050$ g = 1.05 kg
- Material Cost = 1.05 kg $\times$ Rs. 150/kg = Rs. 157.50

Step 2: Calculate Direct Labour Cost

- Labour Cost = 10 hours $\times$ Rs. 80/hour = Rs. 800

Step 3: Calculate Overheads

- Overheads = 50% of Labour Cost = 0.5×800 = Rs. 400

Step 4: Total Cost

- Total Cost = Material Cost + Labour Cost + Overheads
- Total Cost = $157.50 + 800 + 400$ = **Rs. 1357.50**

Cost Estimation in Casting Process

Estimating the cost of a casting involves several stages:

1. **Cost of Metal:** Cost of raw metal (pig iron, scrap, etc.) minus the recovery value of return scrap (runners, risers, rejected castings).
2. **Melting Cost:** Cost of fuel (coke, electricity), fluxes, and melting labour.
3. **Moulding and Core Making Cost:** Cost of sand, binders, and labour for making moulds and cores.
4. **Fettling and Cleaning Cost:** Labour and machining cost for cleaning the casting and removing gates/risers.
5. **Overheads:** Factory and administrative expenses.

Numerical Problem 2: Casting Process

Problem Statement: Estimate the total cost of producing 100 cast iron components.

- Weight of each casting = 5 kg
- Cost of cast iron = Rs. 60 per kg
- Process scrap (runners/risers) = 20% of net weight
- Scrap return value = Rs. 20 per kg
- Melting and pouring cost = Rs. 15 per kg of metal melted
- Moulding and fettling cost = Rs. 20 per casting
- Overheads = 25% of total direct cost

Solution to Problem 2 (Part 1)

Step 1: Calculate Weights

- Net weight of 100 castings $= 100 \times 5 = 500$ kg
- Weight of process scrap $= 20\%$ of 500 kg $= 100$ kg
- Total metal required to melt $= 500 + 100 = 600$ kg

Step 2: Calculate Direct Material Cost

- Cost of raw metal $= 600$ kg $\times$ Rs. $60/\text{kg} =$ Rs. $36,000$
- Return value of scrap $= 100$ kg $\times$ Rs. $20/\text{kg} =$ Rs. $2,000$
- Net Direct Material Cost $= 36,000 - 2,000 =$ Rs. $34,000$

Solution to Problem 2 (Part 2)

Step 3: Calculate Processing Costs

- Melting & pouring cost $= 600$ kg $\times$ Rs. $15/\text{kg} =$ Rs. $9,000$
- Moulding & fettling cost $=$
  100 castings $\times$ Rs. $20/\text{casting} =$ Rs. $2,000$

Step 4: Calculate Total Direct Cost and Overheads

- Total Direct Cost $=$ Net Material Cost $+$ Melting Cost $+$ Moulding Cost
- Total Direct Cost $= 34,000 + 9,000 + 2,000 =$ Rs. $45,000$
- Overheads $= 25\%$ of $45,000 = 0.25 \times 45,000 =$ Rs. $11,250$

Step 5: Final Total Cost

- Total Production Cost $=$ Total Direct Cost $+$ Overheads
- Total Production Cost $= 45,000 + 11,250 =$ **Rs. 56,250**

Summary

- **Cost Estimation** is essential for pricing and evaluating the economic feasibility of manufacturing processes.
- Total cost comprises **Direct Material**, **Direct Labour**, **Direct Expenses**, and **Overheads**.
- Pattern making costs heavily depend on the volume of the material and the labor hours required by skilled pattern makers.
- Casting costs must account for the actual metal poured, the return value of process scrap, and the costs associated with melting, moulding, and finishing operations.

Introduction to Metal Joining

- **Metal Joining Process:** It is the process of joining two or more metal parts either temporarily or permanently to form a single continuous assembly.
- While casting and forming create shapes from raw materials, joining processes assemble multiple parts into a complex final product.
- It is essential in fabrication, construction, aerospace, automotive, and everyday consumer products.
- Joining can be achieved through various mechanisms, including mechanical interlocking, atomic bonding (welding/brazing), and adhesive bonding.

Classification of Metal Joining Processes

Metal joining processes are primarily classified into three main categories:

1. **Mechanical Fastening:** Temporary or semi-permanent joining using bolts, nuts, screws, rivets, etc.
2. **Adhesive Bonding:** Joining using polymeric adhesives (glues, epoxies) which form surface bonds.
3. **Welding and Allied Processes (Metallurgical Joining):** Permanent joining by achieving an atomic or molecular bond between materials. Includes Welding, Soldering, and Brazing.

What is Welding?

- **Welding** is a localized coalescence (fusion or joining together) of metals or non-metals produced by heating the materials to the welding temperature, with or without the application of pressure, and with or without the use of filler metal.
- The basic objective is to create a homogenous bond between the two parts being joined.
- **Autogenous Welding:** Welding without the use of filler metal (e.g., solid-state welding, some TIG welding).
- **Homogeneous Welding:** Welding using a filler metal of the same composition as the base metal.
- **Heterogeneous Welding:** Welding using a filler metal of a different composition (e.g., Brazing, Soldering).

Broad Classification of Welding Processes

Based on the state of the base metal during the joining process, welding is classified into:

- **Liquid State Welding (Fusion Welding):**
  - Base metals are heated to their melting point.
  - No pressure is applied.
  - Filler material is often added.
  - Examples: Arc welding, Gas welding, Thermit welding.
- **Solid State Welding (Pressure Welding):**
  - Base metals are not melted; they are kept in a solid state (plastically deformed).
  - Pressure is applied to create the bond.
  - Examples: Friction welding, Forge welding, Explosion welding.
- **Solid/Liquid State Welding:**
  - Base metal remains solid, but a filler metal is melted and distributed by capillary action.
  - Examples: Soldering, Brazing.

Detailed Classification of Metal Joining Processes

- **Arc Welding:** Shielded Metal Arc Welding (SMAW), Metal Inert Gas (MIG), Tungsten Inert Gas (TIG), Submerged Arc Welding (SAW).
- **Gas Welding:** Oxy-acetylene welding.
- **Resistance Welding:** Spot welding, Seam welding, Projection welding.
- **Thermo-chemical Welding:** Thermit welding.
- **Solid State Welding:** Friction, Ultrasonic, Explosive welding.
- **Radiant Energy Welding:** Electron Beam Welding (EBW), Laser Beam Welding (LBW).
- **Allied Processes:** Soldering, Brazing, Adhesive Bonding.

Advantages and Limitations of Welding

Advantages:

- Creates a permanent, exceptionally strong joint (often stronger than the base metal).
- Usually the most economical way to join components.
- Not restricted to the factory environment; can be performed in the field.

Limitations:

- Involves high energy and is inherently dangerous (burns, fumes, radiation).
- Welded joints cannot be easily disassembled (unlike nuts/bolts).
- The heating and cooling cycles can cause residual stresses and distortion in the assembly.
- Requires highly skilled labor to achieve quality joints.

Introduction to Resistance Welding

- **Resistance Welding (RW)** is a group of welding processes wherein coalescence is produced by the heat obtained from resistance of the work to electric current in a circuit of which the work is a part, and by the application of pressure.
- No filler metal is required.
- Heat generated is given by Joule's Law: $H = I^2 Rt$
- Where:
  - H = Heat generated (Joules)
  - I = Current (Amperes)
  - R = Resistance of the system (Ohms)
  - t = Time of current flow (seconds)

Principle of Resistance Welding

- The electrical resistance of the joint causes the temperature to rise locally.
- The highest resistance is usually at the interface between the two faying surfaces.
- Pressure is applied initially to hold the workpieces, and then increased to forge the heated metal.
- Water-cooled copper electrodes are used to conduct current and apply pressure.
- Examples: Spot welding, seam welding, projection welding.

Resistance Spot Welding (RSW)

- A process in which contacting metal surfaces are joined by the heat obtained from resistance to electric current.
- **Mechanism:**
  - Workpieces are held together under pressure by two electrodes.
  - A high current is passed for a short duration.
  - A localized weld "nugget" is formed at the interface.
- **Applications:** Widely used in the automotive industry for sheet metal joining (e.g., car bodies).

Resistance Seam Welding (RSEW)

- A variation of spot welding where wheel-shaped electrodes are used instead of pointed electrodes.
- The wheels roll along the workpieces, producing a continuous weld seam or a series of overlapping spot welds.
- **Advantages:** Produces leak-proof joints.
- **Applications:** Manufacturing of fuel tanks, drums, and exhaust systems.

Resistance Projection Welding (RPW)

- In this process, the welding current and force are localized at predetermined points by projections, embossments, or intersections on the parts to be joined.
- **Features:**
  - Multiple welds can be made simultaneously.
  - Extends the life of electrodes as they have flat surfaces.
  - Easier to weld parts of different thicknesses.
- **Applications:** Attaching nuts, bolts, and studs to metal sheets.

Upset Welding (UW) and Flash Welding (FW)

- **Upset Welding:**
  - Parts are brought into solid contact under pressure, and current is passed until the joint is heated, followed by forging pressure.
- **Flash Welding:**
  - Parts are brought close together, and an arc (flashing) is created to melt the surfaces. Then they are rapidly pushed together under high pressure.
- **Applications:** Joining of wires, tubes, and rings.

Advantages and Disadvantages of Resistance Welding

Advantages:

- High speed and easily automated.
- No filler metal or flux needed.
- Low operator skill required.
- Good dimensional accuracy.

Disadvantages:

- High initial equipment cost.
- Limited to lap joints (for spot/seam).
- Requires high power supply.
- Limited thickness of workpieces (usually < 6 mm).

Thermit Welding: Introduction

- **Thermit Welding (TW)** is a fusion welding process wherein coalescence is produced by heating with superheated liquid metal and slag resulting from a chemical reaction between a metal oxide and aluminum.
- It does not require an external heat source (like an electric arc or gas flame) to melt the metal.
- The heat is generated exothermically by the Thermit reaction.
- The most common mixture is iron oxide and aluminum powder in a ratio of about 3:1 by weight.

Working Principle of Thermit Welding

- The process relies on an exothermic chemical reaction.
- **Chemical Reaction:**
  $8Al + 3Fe_3O_4 \rightarrow 9Fe + 4Al_2O_3 + \text{Heat}$
- When ignited (usually by a magnesium ribbon), the aluminum reduces the iron oxide to molten iron.
- The reaction is highly exothermic, producing temperatures around $2500^\circ C$ to $3000^\circ C$.
- The molten iron acts as the filler metal, while the aluminum oxide forms a slag that floats to the top and protects the weld.

Thermit Welding: Equipment and Process

- **Equipment:**
  - A refractory-lined crucible for the reaction.
  - A sand mould built around the parts to be joined.
  - Tapping mechanism at the bottom of the crucible.
- **Steps:**
  1. The parts to be joined are aligned with a gap between them.
  2. A wax pattern is formed around the joint, and a sand mould is built around it.
  3. The mould is heated to melt out the wax (pre-heating the joint).
  4. The Thermit mixture in the crucible is ignited.
  5. Once the reaction is complete, the crucible is tapped, and the molten iron flows into the mould, fusing the parts.

Advantages and Limitations of Thermit Welding

Advantages:

- No external power supply is required.
- Highly portable, ideal for field repairs.
- Capable of welding very large and heavy sections.
- Low setup cost compared to heavy arc welding equipment.

Limitations:

- Applicable mostly to ferrous metals (steel and iron).
- Slow welding rate and time-consuming mould preparation.
- Only economical for heavy sections.
- Not suitable for thin sheets or precision work.

Applications of Thermit Welding

- Joining of heavy railway rails on site without removing them.
- Repair of large castings and forgings.
- Welding of thick steel pipes and large machine frames.
- Joining reinforcing steel bars (rebar) in construction.
- Splicing of large copper cables.

Types of Weld Joints

- The arrangement of the parts to be joined is known as the joint design.
- The five basic types of weld joints are:
  1. **Butt Joint:** Parts lie in the same plane and are joined at their edges.
  2. **Corner Joint:** Parts form a right angle and are joined at the corner of the angle.
  3. **Lap Joint:** Parts overlap each other.
  4. **Tee (T) Joint:** One part is perpendicular to the other, forming a 'T' shape.
  5. **Edge Joint:** Parts are parallel with at least one of their edges in common, and the joint is made at the common edge(s).

Safety Precautions in Metal Joining

- Welding and metal joining involve high heat, electric currents, and hazardous fumes.
- **Personal Protective Equipment (PPE):**
  - Welding helmets with appropriate dark filters to protect eyes from intense UV radiation.
  - Fire-resistant clothing, leather aprons, and thick gloves to protect against sparks and molten splatter.
  - Safety boots and ear protection.
- **Environmental Safety:**
  - Ensure proper ventilation to remove toxic fumes and gases.
  - Keep flammable materials away from the welding area.
  - Proper grounding of electrical welding equipment to prevent electric shock.

Cost Estimation in Gas and Arc Welding

- Estimating the cost of a welding operation is crucial for manufacturing economics.
- **Total Welding Cost** consists of:
  1. **Material Cost:** Cost of filler material (electrodes or filler rods), flux, and shielding gases (or fuel gases like oxygen and acetylene).
  2. **Labor Cost:** Direct wages paid to the welder based on time taken.
  3. **Power Cost:** Cost of electricity consumed during arc welding (based on Voltage, Current, and Time).
  4. **Overhead Cost:** Machine depreciation, maintenance, and indirect expenses.
- Proper calculation requires understanding deposition rates, duty cycle, gas consumption rates, and preparation time.

Cost Estimation Formulas

- **Volume of Weld Metal (V):** Calculated from the cross-sectional area of the joint and the length of the weld.
- **Weight of Weld Metal (W):** $W = V \times \rho$, where ρ is the density of the metal.
- **Electrode Consumption:**
  Weight of Electrodes Required $= \frac{\text{Weight of Weld Metal}}{\text{Deposition Efficiency}}$
- **Time for Welding:**
  Arc Time $= \frac{\text{Weight of Weld Metal}}{\text{Melting Rate}}$
- **Total Time:** Total Time $= \frac{\text{Arc Time}}{\text{Duty Cycle}} +$ Preparation Time
- **Gas Consumption Cost (for Gas Welding):**
  Cost $=$ (Rate of Oxygen $\times$ Volume of O_2) $+$
  (Rate of Acetylene $\times$ Volume of C_2H_2)

Introduction to Allied Joining Processes

- While welding is a prominent metal joining process, there are other essential techniques used when melting the base metal is undesirable.
- These are known as **allied processes** or **solid-liquid joining processes**.
- Key allied processes include:
    - Brazing
    - Soldering
    - Adhesive Bonding
- We will also discuss common **welding defects** and their remedies.

What is Brazing?

- **Definition:** Brazing is a metal joining process where a filler metal is heated above its melting point and distributed between two or more close-fitting parts by capillary action.
- The filler metal is brought slightly above its melting (liquidus) temperature while protected by a suitable atmosphere, usually a flux.
- **Key characteristics:**
  - Base metal does not melt.
  - Filler metal has a liquidus temperature **above** 450°**C** but below the solidus temperature of the base metal.
  - Joint strength depends on capillary action and metallurgical bond.

Advantages and Disadvantages of Brazing

Advantages:

- Can join dissimilar metals (e.g., copper to steel).
- Less thermal distortion and residual stress compared to welding.
- Can join components with widely different thicknesses.
- Multiple joints can be brazed simultaneously.

Disadvantages:

- Joint strength is generally lower than a welded joint.
- High temperature may affect the properties of the base metal.
- Requires precise joint clearances for capillary action.

What is Soldering?

- **Definition:** Soldering is similar to brazing but uses filler metals (solders) with lower melting points.
- **Key characteristics:**
  - Filler metal melts **below** 450°**C**.
  - Base metal remains solid.
  - Extensively used in the electronics industry (PCBs) and plumbing.
- **Soldering alloys:**
  - Traditionally Lead-Tin (Pb-Sn) alloys.
  - Modern shift towards Lead-free solders (e.g., Sn-Ag-Cu) due to environmental regulations.

Brazing vs. Soldering

Feature	Brazing	Soldering
Temperature	$> 450°C$	$< 450°C$
Joint Strength	Higher	Lower
Base Metal Alteration	May cause some changes	Negligible changes
Common Applications	Pipe fittings, heat exchangers	Electronics, light plumbing
Filler Metal Cost	Generally higher (Ag, Cu)	Lower (Sn, Pb)

Adhesive Bonding

- **Definition:** Joining two materials by means of an adhesive substance (e.g., epoxy, polyurethane, cyanoacrylate).
- **Advantages:**
  - Can join completely dissimilar materials (metals, plastics, composites).
  - Distributes stress evenly across the joint area.
  - No heat affected zone (HAZ) or thermal distortion.
- **Disadvantages:**
  - Limited to low operational temperatures.
  - Joint preparation is critical (surfaces must be extremely clean).
  - Curing time can be long.

Common Welding Defects

- Despite best practices, welding can introduce discontinuities or defects in the material.
- Major defects include:
  1. Porosity
  2. Slag Inclusion
  3. Incomplete Penetration
  4. Lack of Fusion
  5. Undercut
  6. Cracks

1. Porosity & 2. Slag Inclusion

Porosity:

- Gas trapped in the solidifying weld metal.
- *Causes:* Damp fluxes, oily base metal, inadequate shielding gas.
- *Remedies:* Bake electrodes, clean surfaces, optimize gas flow.

Slag Inclusion:

- Non-metallic solid material trapped inside the weld or between weld and base metal.
- *Causes:* Inadequate inter-pass cleaning, incorrect welding angle.
- *Remedies:* Thoroughly clean slag between passes, adjust electrode angle.

3. Incomplete Penetration & 4. Lack of Fusion

Incomplete Penetration:

- Weld metal does not extend through the full thickness of the joint.
- *Causes:* Low welding current, travel speed too fast, improper joint design.
- *Remedies:* Increase current, slow down, increase root gap.

Lack of Fusion:

- Failure of adjacent layers of weld metal or weld metal and base metal to fuse together.
- *Causes:* Insufficient heat input, incorrect electrode angle.
- *Remedies:* Increase current, properly direct the arc towards the root/sidewalls.

5. Undercut & 6. Cracks

Undercut:

- A groove melted into the base metal adjacent to the weld toe and left unfilled.
- *Causes:* Excessive current, travel speed too high.
- *Remedies:* Reduce current, slow travel speed, manipulate electrode carefully.

Cracks:

- The most serious defect (hot cracks or cold cracks).
- *Causes:* High residual stress, rapid cooling, hydrogen entrapment.
- *Remedies:* Preheating, post-weld heat treatment, use low-hydrogen electrodes.

Summary

- Allied joining processes like brazing and soldering are crucial for specific applications where melting the base metal is not feasible.
- Adhesive bonding offers unique advantages for joining dissimilar materials without heat.
- Understanding welding defects and their causes is essential for ensuring the structural integrity of welded joints.
- Proper process parameters and joint preparation are key to minimizing defects.

Introduction to Resistance Welding

- **Principle:** Heat is generated by the electrical resistance of the workpieces to the flow of heavy electric current.
- Pressure is applied mechanically to complete the weld.
- **Formula for Heat:** $H = I^2 \times R \times t$
  - $H =$ Heat generated
  - $I =$ Current (in Amperes)
  - $R =$ Resistance of the joint
  - $t =$ Time of current flow

Spot Welding: Setup and Working

- **Process:** Used to join overlapping sheets of metal.
- **Equipment:**
  - Copper electrodes (water-cooled)
  - Step-down transformer (low voltage, high current)
  - Pressure applying mechanism
- **Working Steps:**
  1. Sheets are placed between the electrodes.
  2. Pressure is applied.
  3. High current is passed for a fraction of a second.
  4. A weld "nugget" is formed at the interface.

Advantages and Limitations of Resistance Welding

Advantages

- Very fast and easily automatable.
- No filler metal or flux is required.
- Highly reproducible and reliable joints.

Limitations

- High initial equipment cost.
- Restricted to relatively thin materials (sheet metals).
- Requires high electric power.

Thermit Welding

- **Principle:** Uses an exothermic chemical reaction to produce molten metal for welding.
- **Thermit Mixture:** Usually a mixture of aluminum powder and iron oxide (ratio of 1:3 by weight).
- **Reaction:** $8Al + 3Fe_3O_4 \rightarrow 9Fe + 4Al_2O_3 + \text{Heat}$
- **Temperature:** Can reach up to $2500°\text{C} - 3000°\text{C}$.
- **Applications:** Repairing heavy steel castings, joining railway tracks.

Common Types of Weld Joints

Welded joints are classified based on how the parts are fitted together:

- Butt Joint
- Lap Joint
- T-Joint
- Corner Joint
- Edge Joint

(Refer to standard joint configurations)

Butt Joint vs Lap Joint

Butt Joint

- Parts lie in the same plane and are joined at their edges.
- Types: Square, Single V, Double V, U, and J groove.
- Used for high-strength applications in thicker plates.

Lap Joint

- Parts overlap each other.
- Types: Single transverse, double transverse, parallel.
- Commonly used with fillet welds and resistance spot welding.

Summary

- Resistance welding is highly efficient for sheet metals, relying on electrical resistance and pressure.
- Thermit welding is specialized for heavy duty repairs like railway tracks using exothermic reactions.
- Weld joints (Butt, Lap, T, Corner, Edge) are selected based on design requirements, material thickness, and application.

Introduction to Gas Welding

- **Gas Welding** is a fusion welding process where heat is produced by the combustion of a fuel gas mixed with oxygen.
- The most commonly used fuel gas is **acetylene** (C_2H_2) because it produces the highest flame temperature (up to 3200°C).
- Hence, it is widely known as **Oxy-Acetylene Welding** (OAW).
- A filler metal rod is generally used to add volume to the weld joint, although thin sections can be welded without filler metal.
- Flux is often applied to the filler rod or joint to remove oxides and prevent oxidation during heating.

Oxy-Acetylene Gas Welding: Equipment

A typical gas welding setup consists of:

- **Oxygen Cylinder:** Painted black. Stores oxygen at high pressure (around 15 MPa).
- **Acetylene Cylinder:** Painted maroon or red. Stores acetylene dissolved in liquid acetone (around 1.5 MPa) to prevent explosion.
- **Pressure Regulators:** Used to reduce the high cylinder pressure to the lower working pressure required for the torch.
- **Hoses:** Color-coded hoses (Black/Green for oxygen, Red/Maroon for acetylene) connect regulators to the torch.
- **Welding Torch:** Mixes the oxygen and acetylene in desired proportions and burns the mixture at its tip.
- **Safety Devices:** Flashback arrestors prevent the flame from traveling back into the hoses and cylinders.

Chemistry of Oxy-Acetylene Flame

The combustion of acetylene in oxygen occurs in two stages:

Primary Combustion (Inner Cone)

$C_2H_2 + O_2 \rightarrow 2CO + H_2 + \text{Heat}$

- This reaction occurs at the inner cone of the flame, producing extremely high temperatures ($> 3000^\circ$C).

Secondary Combustion (Outer Envelope)

$2CO + H_2 + 1.5O_2 \rightarrow 2CO_2 + H_2O + \text{Heat}$

- This reaction utilizes oxygen from the surrounding atmosphere to complete combustion.
- It forms the outer envelope of the flame, protecting the weld pool from oxidation by displacing atmospheric oxygen.

Types of Oxy-Acetylene Flames

Depending on the ratio of oxygen to acetylene supplied through the torch, three distinct types of flames can be produced:

1. **Neutral Flame:** Equal volumes of oxygen and acetylene.
2. **Oxidizing Flame:** Excess oxygen.
3. **Carburizing (Reducing) Flame:** Excess acetylene.

1. Neutral Flame

- **Ratio:** Oxygen to Acetylene ratio is approximately 1:1.
- **Characteristics:** Has a well-defined, luminous inner cone and a bluish outer envelope.
- **Temperature:** Reaches about 3200°C at the tip of the inner cone.
- **Effect on Metal:** It does not chemically alter the weld metal (neither oxidizes nor adds carbon).
- **Applications:** Most commonly used flame. Ideal for welding mild steel, stainless steel, cast iron, copper, and aluminum.

2. Oxidizing Flame

- **Ratio:** Higher proportion of oxygen than acetylene.
- **Characteristics:** The inner cone is shorter, more pointed, and slightly purplish compared to the neutral flame. It burns with a harsh, roaring sound.
- **Temperature:** Slightly hotter than a neutral flame (up to 3300°C).
- **Effect on Metal:** Excess oxygen can severely oxidize the weld metal, causing porosity and brittle welds in steels.
- **Applications:** Used for welding copper and copper alloys (like brass and bronze) where a protective slag of copper oxide prevents zinc vaporization.

3. Carburizing (Reducing) Flame

- **Ratio:** Higher proportion of acetylene than oxygen.
- **Characteristics:** Has three distinct zones: a luminous inner cone, a white intermediate "feather" (indicating unburned carbon), and a blue outer envelope.
- **Temperature:** Slightly lower than a neutral flame (around 3000°C).
- **Effect on Metal:** Excess carbon can dissolve into the molten metal, increasing its carbon content and making it hard but brittle.
- **Applications:** Used for welding high-carbon steels, alloy steels, and for hard-surfacing operations.

Gas Welding Techniques

There are two primary manual techniques used in gas welding:

Forehand (Leftward) Welding

- Torch points in the direction of welding.
- Filler rod precedes the torch.
- Good visibility of the weld pool.
- Suitable for thinner sections (up to 5mm).

Backhand (Rightward) Welding

- Torch points away from the direction of welding.
- Torch precedes the filler rod.
- Flame pre-heats the deposited metal, allowing slower cooling.
- Preferred for thicker plates (above 5mm).

Gas Cutting (Oxy-Fuel Cutting)

- **Principle:** Gas cutting relies on the rapid chemical reaction (oxidation) of the metal at high temperatures, rather than melting it.
- **Process:**
  1. The metal (typically low-carbon steel) is pre-heated to its kindling temperature (around 870°C, cherry red) using a neutral oxy-acetylene flame.
  2. A high-pressure jet of pure oxygen is directed at the heated spot.
  3. The iron oxidizes rapidly ($3Fe + 2O_2 \rightarrow Fe_3O_4 + \text{Heat}$). This exothermic reaction generates immense heat.
  4. The high-velocity oxygen stream blows away the molten iron oxide (slag), forming a clean cut (kerf).
- **Note:** Only reactive metals like steel can be cut this way. Cast iron, stainless steel, and aluminum cannot be easily gas cut.

Advantages and Limitations of Gas Welding

Advantages

- Highly versatile and portable equipment.
- Does not require electricity (ideal for remote locations).
- Temperature and heat input can be independently controlled (by flame adjustment).
- Slower heating and cooling rates compared to arc welding, reducing thermal stresses.

Limitations

- Not suitable for joining thick sections (slow process).
- Large heat-affected zone (HAZ) due to slow heating.
- Combustible gases pose safety and fire hazards.
- Reactive metals (like Titanium) cannot be gas welded without extensive shielding.

Introduction to Metal Joining

Definition

Metal joining is a controlled process used to fuse two or more metallic components into a single continuous solid, typically through the application of heat, pressure, or both.

- Essential for modern manufacturing, construction, and assembly.
- Forms a permanent or semi-permanent joint.
- Can be applied to similar or dissimilar metals.

Classification of Metal Joining Processes

Fusion Welding (Non-pressure)

- Arc Welding (SMAW, MIG, TIG, SAW)
- Gas Welding (Oxy-acetylene)
- Thermit Welding

Solid State (Pressure)

- Friction Welding
- Forge Welding

Resistance Welding

- Spot Welding
- Seam Welding
- Projection Welding

Low-Temperature Joining

- Soldering ($< 450°$C)
- Brazing ($> 450°$C)

Arc Welding: Principle of Operation

Working Principle

An electric arc is struck between an electrode and the workpiece. The intense heat generated (up to 6000°C) melts the base metal and the filler metal, creating a weld pool that solidifies to form the joint.

- **Power Supply:** Can be AC or DC (Direct Current).
- **Polarity:**
  - DCSP (Direct Current Straight Polarity): Workpiece is positive.
  - DCRP (Direct Current Reverse Polarity): Workpiece is negative.

Key Arc Welding Processes

Process	Characteristics	Applications
SMAW (Shielded Metal Arc)	Consumable flux-coated electrode	General construction, repair
MIG (Metal Inert Gas)	Consumable wire, inert shielding gas (Ar/He)	Automotive, robotics, sheet metal
TIG (Tungsten Inert Gas)	Non-consumable tungsten electrode, high quality	Aerospace, thin sections, aluminum
SAW (Submerged Arc)	Granular flux covers the arc, high deposition rate	Shipbuilding, heavy structural components

Table: Comparison of Arc Welding Techniques

Oxy-Acetylene Gas Welding

Process Overview

A fuel gas (usually Acetylene, C_2H_2) is mixed with Oxygen (O_2) in a specific ratio and ignited at the torch tip. The resulting flame melts the edges of the metals to be joined.

- **Chemical Reaction:** $C_2H_2 + 2.5O_2 \rightarrow 2CO_2 + H_2O + \text{Heat}$
- Maximum flame temperature reaches approximately 3200°C.
- Uses a filler rod if additional material is required.
- Flux is often used to prevent oxidation.

Types of Flames in Gas Welding

Neutral Flame

- Ratio: $O_2 : C_2H_2 \approx 1 : 1$
- Complete combustion.
- Used for most metals (mild steel, cast iron).

Carburizing Flame

- Excess acetylene.
- Has a distinct reducing zone.
- Used for high-carbon steels and hard-facing.

Oxidizing Flame

- Excess oxygen.
- Hottest flame.
- Used for copper alloys, brass, and bronze.

Resistance Welding

Working Principle

Joining is accomplished by applying pressure and passing a high current through the metal parts for a specified time. The resistance of the metal to the current flow generates heat at the faying surfaces.

- **Heat Generation Formula:** $H = I^2 Rt$
- **Spot Welding:** Used heavily in automotive assembly for joining sheet metal.
- Extremely fast, easily automated, requires no filler metal or shielding gas.

Safety Precautions in Metal Joining

Critical Hazards

Welding operations present multiple hazards including intense ultraviolet (UV) radiation, toxic fumes, extreme heat, and electrical shock.

Required Personal Protective Equipment (PPE):

- Welding helmet with appropriate UV/IR filter shade.
- Flame-resistant leather apron and gauntlet gloves.
- Safety boots with metatarsal guards.
- Adequate local exhaust ventilation to remove welding fumes.

Introduction to Brazing and Soldering

- **Brazing and Soldering** are metal joining processes where a filler metal is melted and drawn into a capillary gap between the mating surfaces of the parts to be joined.
- Unlike welding, the base metals are **not** melted.
- They are generally used for joining dissimilar metals, thin sections, and components where minimizing thermal distortion is critical.
- The distinction between brazing and soldering is primarily based on the melting temperature of the filler metal.

Difference Between Brazing and Soldering

Brazing	Soldering
Filler metal melts above 450°C (840°F)	Filler metal melts below 450°C (840°F)
Stronger joint compared to soldering	Relatively weaker joint
Used for high-strength applications (e.g., pipe fittings)	Used for electrical connections and sheet metal sealing
Common fillers: Copper-zinc (brass), Silver alloys	Common fillers: Lead-tin alloys, Lead-free tin alloys

Advantages and Limitations

Advantages:

- Can join dissimilar metals (e.g., copper to steel).
- Less thermal distortion and residual stress than welding.
- High production rates are possible (e.g., furnace brazing).
- Complex assemblies can be joined in a single operation.

Limitations:

- Joint strength is generally lower than that of a welded joint.
- Precise capillary gap (clearance) is strictly required.
- Parts must be thoroughly cleaned before joining (flux is often required).
- Color of filler metal may not match the base metal.

Role of Flux

- **Purpose:** To prevent oxidation of the base and filler metals during heating and to remove existing oxides.
- Flux promotes the wetting of the base metal by the molten filler metal, allowing capillary action to occur.
- After the joining process, flux residues must often be removed to prevent corrosion.
- **Common Flux Materials:**
  - Brazing: Borax, boric acid, fluorides.
  - Soldering: Rosin (for electrical), acid core (zinc chloride) for plumbing.

Joint Design for Brazing and Soldering

- Joints must be designed to provide a **capillary gap** (typically 0.025 mm to 0.25 mm).
- **Lap joints** are preferred over butt joints because they provide a larger surface area for bonding.
- The strength of the joint depends largely on the overlapping area.
- **Clearance considerations:**
  - Too tight: Filler metal cannot flow into the joint.
  - Too wide: Capillary action is lost, resulting in incomplete fill and weak joints.

Introduction to Process Selection

- The selection of a metal joining process (Welding, Brazing, or Soldering) depends on various factors:
  - The required strength of the joint.
  - The types of materials being joined (similar or dissimilar).
  - The thickness of the components.
  - Maximum allowable heat input (to prevent distortion).
  - Economic considerations (cost of equipment, consumables, and labor).
- Understanding the key differences among these processes is essential for making the right manufacturing choice.

Fundamental Differences

- **Welding:** Involves melting the base metals (and usually a filler metal) to form a strong, continuous joint. The temperature exceeds the melting point of the base metals.
- **Brazing:** Does not melt the base metal. A filler metal is melted at a temperature **above** 450°**C** but below the melting point of the base metal. Capillary action distributes the filler.
- **Soldering:** Similar to brazing, but the filler metal melts at a temperature **below** 450°**C**. Also relies on capillary action.

Comprehensive Comparison Table

Parameter	Welding	Brazing	Soldering
Base Metal Melting	Yes	No	No
Operating Temperature	High ($> 1000°C$)	Medium ($> 450°C$)	Low ($< 450°C$)
Joint Strength	Very High (often equal to base metal)	Moderate to High	Low
Joining Dissimilar Metals	Difficult	Very Easy	Easy
Thermal Distortion	High risk (due to high heat)	Low risk	Very low risk
Capillary Action	Does not apply	Essential	Essential
Pre-heating	Sometimes required	Usually required	Required

Welding vs Brazing

When to choose Welding?

- When maximum mechanical strength is required (e.g., structural frameworks, pressure vessels).
- When joining thick sections of identical metals.
- When the joint will be subjected to high temperatures in service.

When to choose Brazing?

- When joining dissimilar metals (e.g., steel to copper, cast iron to steel).
- When joining thin-walled tubes or delicate assemblies where welding heat would cause warping or burn-through.
- When a neat finish is required without post-weld grinding.

Brazing vs Soldering

When to choose Brazing?

- When higher strength and moderate temperature resistance is needed (e.g., automotive radiators, refrigeration tubes, bicycle frames).
- When the assembly undergoes moderate mechanical stress.

When to choose Soldering?

- When joining electrical and electronic components (e.g., PCBs, wires) where high heat would destroy the parts.
- For sealing joints in sheet metal work and plumbing, where strength is secondary to a leak-proof seal.
- When a temporary or easily repairable joint is desired.

Summary of Process Comparison

- **Welding** is the go-to for structural integrity and joining similar, thick metals but brings risks of distortion.
- **Brazing** offers an excellent middle ground, allowing the joining of dissimilar metals with less distortion while maintaining good strength.
- **Soldering** is specialized for low-temperature applications, perfect for electronics and leak-tight sealing rather than load-bearing.
- The optimal choice requires balancing mechanical requirements, material properties, and process economics.

What is Brazing?

- **Brazing** is a metal joining process in which two or more metal items are joined together by melting and flowing a filler metal into the joint.
- The filler metal has a lower melting point than the adjoining metal.
- Unlike welding, brazing does not involve melting the workpieces.
- The filler metal is drawn into the gap between the closely fitted parts by **capillary action**.
- It is performed at temperatures above 450°C but below the melting point of the base metals.

Principle of Brazing

- **Capillary Action:** The fundamental principle behind brazing is the capillary action which distributes the liquid filler metal between the surfaces of the base metals.
- **Wetting:** The liquid filler metal must "wet" the base metal. Fluxes are typically used to remove oxides and prevent further oxidation, allowing proper wetting.
- **Heat Source:** Heat is applied broadly to the joint area, bringing it up to the brazing temperature.
- **Cooling:** Once the filler metal is completely drawn into the joint, it is allowed to cool, creating a strong, permanent bond.

Common Brazing Filler Metals and Fluxes

Filler Metals

- **Copper-Zinc (Brass) alloys:** Commonly used for brazing steel, cast iron, and copper.
- **Silver alloys:** Excellent capillary action, used for joining dissimilar metals, fine precision assemblies.
- **Aluminum-Silicon alloys:** Used exclusively for brazing aluminum alloys.

Fluxes

- Function to dissolve solid metal oxides, protect the surface during heating, and assist wetting.
- Borax, boric acid, and various fluorides and chlorides are common ingredients in brazing fluxes.

Brazing Procedure: Step 1 to 3

1. **Surface Preparation (Cleaning):**
   - The joint surfaces must be completely clean and free of oil, grease, dirt, and oxides.
   - Chemical cleaning (solvents) or mechanical cleaning (wire brushing, emery paper) is used.
2. **Fit-up and Assembly:**
   - Parts must be precisely aligned and securely held together with proper clearances (typically 0.02 to 0.1 mm) to allow capillary action.
3. **Application of Flux:**
   - Flux is applied to the joint surfaces before heating to prevent oxidation and promote filler flow.

Brazing Procedure: Step 4 to 6

4. **Heating:**
   - The joint is heated uniformly using a torch, furnace, or induction heating to the required brazing temperature.
5. **Applying the Filler Metal:**
   - Once the base metal reaches the correct temperature, the filler rod is touched to the joint.
   - It melts and is drawn into the joint by capillary action.
6. **Cooling and Post-Brazing Cleaning:**
   - The assembly is allowed to cool slowly to avoid thermal stresses.
   - Remaining flux residues must be removed by washing with warm water or mechanical means to prevent corrosion.

Advantages of Brazing

- **Dissimilar Metals:** Easily joins dissimilar metals (e.g., steel to copper, cast iron to stainless steel).
- **Less Thermal Distortion:** Since base metals do not melt and temperatures are lower than welding, there is minimal warpage and residual stress.
- **Neat Appearance:** Produces smooth, neat joints requiring little or no finishing.
- **Complex Assemblies:** Allows for joining of complex assemblies or multiple joints simultaneously (e.g., in furnace brazing).
- **No Melting of Base Metal:** Preserves the mechanical properties of the base metal.

Limitations of Brazing

- **Joint Strength:** Generally, the joint strength is lower than that of a welded joint (limited by the strength of the filler metal).
- **Temperature Resistance:** Brazed joints lose strength at elevated temperatures since the filler metal has a relatively low melting point.
- **Joint Design Requirement:** Requires specially designed joints (mostly lap or clearance joints) to take advantage of capillary action.
- **Cost of Consumables:** Filler metals (especially those containing silver) and fluxes can be relatively expensive.

Applications of Brazing

- **Automotive Industry:** Joining tubes, radiators, and heat exchangers.
- **Refrigeration and Air Conditioning:** Joining copper tubes, condenser coils, and compressor parts.
- **Electrical and Electronics:** Assembling electrical contacts, joining bus bars, and attaching wires to terminals.
- **Tooling:** Joining carbide tips to steel shanks for cutting tools like lathe tools and drill bits.
- **Aerospace:** Joining complex components where minimizing thermal distortion is critical.

Introduction to Metal Joining

- Metal joining processes are essential in manufacturing to assemble multiple parts into a single functional unit.
- Classification of joining processes:
  - Permanent joining (e.g., Welding, Brazing, Soldering)
  - Temporary joining (e.g., Fastening with bolts, nuts, and screws)
- In this lecture, we focus on permanent metal joining techniques.

Classification of Welding Processes

Welding processes can be broadly classified into:

1. **Fusion Welding:** Base metals are melted to form a joint (with or without filler metal).
   - Arc Welding (SMAW, TIG, MIG)
   - Gas Welding (Oxy-Acetylene)
2. **Solid-State Welding:** Joining without melting the base metal (application of heat and/or pressure).
   - Friction Welding
   - Forge Welding
   - Ultrasonic Welding

Shielded Metal Arc Welding (SMAW)

- Also known as stick welding.
- Uses a consumable flux-coated electrode.
- The heat from an electric arc melts the electrode and the base metal.
- The flux coating provides a shielding gas to protect the weld pool from atmospheric contamination (oxidation).
- **Advantages:** Versatile, portable equipment, suitable for outdoor use.
- **Applications:** Construction, pipeline welding, maintenance and repair.

Oxy-Acetylene Welding

- Uses a combustion flame to melt the base metal and a filler rod.
- Fuel gas (acetylene) mixed with oxygen produces a high-temperature flame (up to 3200°C).
- Three types of flames based on oxygen-to-acetylene ratio:
  - Neutral Flame (equal ratio, most common)
  - Oxidizing Flame (excess oxygen)
  - Carburizing Flame (excess acetylene)
- **Applications:** Sheet metal fabrication, automotive repair.

Brazing and Soldering

When melting the base metal is not desirable or possible, brazing and soldering are used.

Brazing

- Filler metal melts above 450°C but below the melting point of the base metal.
- Joint strength is higher than soldering.

Soldering

- Filler metal melts below 450°C (e.g., Lead-Tin alloys).
- Primarily used for electrical connections and plumbing.

Both processes rely on capillary action to draw the molten filler metal into the joint clearance.

Welding Defects

Common defects encountered in welding processes include:

- **Porosity:** Gas entrapped in the solidifying weld metal.
- **Slag Inclusion:** Non-metallic solid material entrapped in the weld metal or between weld metal and base metal.
- **Incomplete Fusion:** Lack of fusion between weld metal and base metal.
- **Cracking:** Hot or cold cracking due to thermal stresses or shrinkage.
- **Undercut:** A groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

Summary

- Metal joining processes are critical for manufacturing complex assemblies.
- Fusion welding involves melting, whereas solid-state welding does not.
- Arc and gas welding are fundamental fusion processes.
- Brazing and soldering are used when base metal melting must be avoided.
- Understanding welding defects is essential for quality control.

Introduction to Safety in Welding

- Metal joining processes involve high temperatures, intense light, toxic fumes, and electrical hazards.
- Ensuring safety is paramount to prevent accidents, injuries, and long-term health issues.
- Key hazards include:
  - Electrical shock (Arc welding)
  - Fire and explosions (Gas welding)
  - Burns from spatter and hot metal
  - Exposure to UV and IR radiation
  - Inhalation of hazardous fumes and gases

Personal Protective Equipment (PPE)

- Proper PPE is the first line of defense against welding hazards:
  - **Welding Helmet:** Protects eyes and face from UV/IR radiation, sparks, and spatter. Must have an appropriate filter shade.
  - **Safety Glasses:** Worn under the helmet for additional protection against flying particles.
  - **Leather Gloves:** Flame-resistant gloves protect hands from burns, heat, and electric shock.
  - **Protective Clothing:** Heavy, flame-resistant aprons, jackets, and long pants without cuffs prevent spatter from getting trapped.
  - **Safety Shoes:** Steel-toed, rubber-soled boots protect against dropped objects and electrical shock.

Safety Precautions in Arc Welding

- **Electrical Safety:**
  - Ensure welding equipment is properly grounded.
  - Never weld in damp or wet conditions.
  - Keep welding cables dry and free of grease and oil.
  - Do not change electrodes with bare hands or wet gloves.
- **Radiation and Fume Safety:**
  - Always use a welding screen to protect others from arc flash.
  - Ensure adequate ventilation or local exhaust systems are used to remove toxic fumes.

Safety Precautions in Gas Welding

- **Cylinder Safety:**
  - Store oxygen and acetylene cylinders upright and secure them to a wall or cart.
  - Keep oxygen cylinders away from oil and grease (risk of spontaneous combustion).
  - Never crack open an acetylene cylinder valve near a welding operation or spark.
- **Hose and Torch Safety:**
  - Regularly inspect hoses for leaks using soapy water (never use a match).
  - Ensure flashback arrestors and check valves are installed on torches and regulators.
  - Purge lines before lighting the torch.

Fire and Explosion Prevention

- Remove all combustible materials from the welding area (at least 35 feet radius recommended).
- If combustibles cannot be moved, cover them with fire-resistant blankets.
- Keep a suitable fire extinguisher (e.g., dry chemical or CO_2) readily accessible.
- Never weld on containers that have held flammable liquids or gases without proper purging and cleaning.
- Maintain a "fire watch" during and after welding operations in critical areas.

Introduction to Cost Estimation

- Estimating the cost of a welding job accurately is essential for quoting, budgeting, and profitability.
- **Total Welding Cost** comprises several components:
  - Direct Material Cost (Base metal, filler metal, fluxes)
  - Direct Labour Cost (Wages of the welder)
  - Direct Expenses (Cost of power, gases)
  - Overheads (Factory, administrative, and selling overheads)

Elements of Welding Cost

- **Cost of Consumables:**
  - Electrodes (Arc welding) or Filler rods (Gas welding).
  - Flux (Submerged arc welding, brazing).
  - Shielding gases (TIG, MIG) or fuel gases (Oxy-acetylene).
- **Labour Cost:**
  - Calculated based on the time taken for joint preparation, actual welding, cleaning, and inspection.
  - Affected by the Operating Factor (Duty Cycle).
- **Power Cost (Arc Welding):**
  - Depends on voltage, current, arcing time, and machine efficiency.

Cost Estimation Formulas: Arc Welding

- **Weight of weld metal deposited (W):**

$$W = \text{Volume of weld} \times \text{Density of weld metal}$$

- **Weight of electrodes required:**

$$\text{Electrode required} = \frac{W}{\text{Deposition Efficiency} \times (1 - \text{Scrap Loss})}$$

- **Power Cost:**

$$\text{Power consumed (kWh)} = \frac{V \times I \times t}{1000 \times \eta}$$

where V = *Arc Voltage*, I = *Arc Current*,
t = *Arc time (hours)*, η = *Machine Efficiency*

Cost Estimation Formulas: Gas Welding

- **Cost of Gases:**
  - Volume of O_2 = Rate of consumption $\times$ Welding time
  - Volume of C_2H_2 = Rate of consumption $\times$ Welding time
  - Gas Cost = (Vol $O_2 \times$ Rate O_2) + (Vol $C_2H_2 \times$ Rate C_2H_2)
- **Cost of Filler Rod:**

$$\text{Weight of filler rod} = \frac{\text{Volume of weld} \times \text{Density}}{\text{Deposition Efficiency}}$$

- **Total Direct Cost:**

$$\begin{aligned}\text{Total Direct Cost} = \text{Material Cost} &+ \text{Labour Cost} \\ &+ \text{Direct Expenses}\end{aligned}$$

Introduction to Brazing and Soldering

- Welding involves melting the base metals, which can alter their properties and induce thermal stresses.
- **Brazing** and **Soldering** are alternatives that do *not* melt the base metals.
- They rely on the melting and flow of a **filler metal** into the joint through capillary action.
- **Key Advantages:**
  - Can join dissimilar metals (e.g., copper to steel).
  - Lower heat input, minimizing distortion.
  - Can join thin sections to thick sections.
  - Excellent for complex or delicate assemblies.

Brazing Process

- **Definition:** Joining process where a filler metal is heated above **450°C** (840°F) but below the solidus of the base metals.
- **Mechanism:** Filler metal is distributed between closely fitting surfaces by **capillary action**.
- **Brazing Flux:** Essential to dissolve solid metal oxides and prevent further oxidation during heating.
- **Joint Clearances:** Crucial for capillary action. Typical clearances range from 0.025 mm to 0.25 mm.

Types of Brazing Methods

- **Torch Brazing:** Uses an oxy-fuel gas flame. Common for repair and small-batch production.
- **Furnace Brazing:** Components are pre-assembled with filler metal and heated in a controlled atmosphere furnace. High production volume.
- **Induction Brazing:** Uses high-frequency alternating current to heat the joint. Fast and localized heating.
- **Dip Brazing:** Assemblies are immersed in a molten salt or molten metal bath. Provides uniform heating.

Soldering Process

- **Definition:** Similar to brazing, but the filler metal (solder) has a liquidus **below 450°C** (840°F).
- **Applications:** Extensive use in the electronics industry (PCB assembly), plumbing (copper pipes), and sheet metal work.
- **Common Solders:** Traditionally Tin-Lead (Sn-Pb) alloys. Due to toxicity, **Lead-free solders** (e.g., Tin-Silver-Copper or SAC) are now the industry standard.
- **Soldering Flux:** Usually rosin-based (electronics) or acid-based (plumbing) to remove oxide films.

Comparison: Welding, Brazing, and Soldering

Feature	Welding	Brazing	Soldering
Base Metal Melting	Yes	No	No
Filler Metal Temp.	High ($>$ Solidus)	$>450°$C	$<450°$C
Joint Strength	Highest (similar to base)	Moderate to High	Low
Distortion Risk	High	Low	Very Low
Capillary Action	No	Yes	Yes

Summary

- Metal joining encompasses a wide variety of techniques beyond traditional welding.
- **Brazing** and **soldering** offer solutions when melting the base metal is detrimental or when dissimilar metals must be joined.
- Proper **joint design** (relying on capillary action) and **surface preparation** (fluxing) are critical for successful brazing and soldering.
- Selection of the joining process depends on required joint strength, operating temperature, materials being joined, and production volume.

Introduction to Cost Estimation

- **Objective:** To determine the total expense incurred during a welding process.
- Accurate cost estimation is crucial for pricing, budgeting, and selecting the most economical welding method.
- It helps in comparing different processes (e.g., Gas vs. Arc welding) for a specific job.
- **Key Cost Elements:**
  - Direct Material Cost
  - Direct Labour Cost
  - Direct Expenses (Power, Fuel)
  - Overheads

Components of Welding Cost

1. Direct Material Cost

Includes base metal, filler rods/electrodes, flux, and gases (oxygen, acetylene, shielding gas).

2. Direct Labour Cost

Wages paid to the welder based on the time spent on the job.

3. Direct Expenses

Cost of electricity (for arc welding) or specific equipment hire.

4. Overheads

Indirect costs such as maintenance, depreciation of welding equipment, supervision, and factory rent.

Cost Estimation of Gas Welding

In gas welding (e.g., Oxy-Acetylene), the primary cost drivers are:

- **Cost of Gases:** Volume of oxygen and acetylene consumed $\times$ Rate per unit volume.
- **Cost of Filler Rod:** Weight of filler rod consumed $\times$ Rate per kg.
- **Labour Cost:** Welding time $\times$ Labour rate per hour.

Formulas:

- $\textit{Gas Consumption} = \text{Welding speed (m/hr) / Gas flow rate (liters/hr)}$
- $\textit{Welding Time} = \text{Length of weld / Welding speed}$

Numerical Problem 1: Gas Welding

Problem: Calculate the total cost of gas welding a 1-meter long joint.

- Oxygen consumption $= 0.6\,m^3/hr$, Rate $=$ Rs. $50/m^3$
- Acetylene consumption $= 0.5\,m^3/hr$, Rate $=$ Rs. $150/m^3$
- Filler rod used $= 0.2\,kg/m$, Rate $=$ Rs. 100/kg
- Welding speed $= 2\,m/hr$
- Welder's wage $=$ Rs. 80/hr

Solution: Numerical Problem 1

Step 1: Time required for welding

- Time = Length / Speed = $1\,m/2\,m/hr = 0.5\,hr$

Step 2: Cost of gases

- Oxygen cost $= 0.6 \times 0.5 \times 50 =$ Rs. 15
- Acetylene cost $= 0.5 \times 0.5 \times 150 =$ Rs. 37.5

Step 3: Cost of filler rod and Labour

- Filler rod cost $= 0.2\,kg \times 100 =$ Rs. 20
- Labour cost $= 0.5\,hr \times 80 =$ Rs. 40

Total Cost $= 15 + 37.5 + 20 + 40 =$ **Rs. 112.5**

Cost Estimation of Arc Welding

In arc welding, the major cost components are:

- **Cost of Electrodes:** (Weight of weld metal deposited / Deposition efficiency) $\times$ Rate per kg.
- **Power Cost:** Electrical energy consumed (kWh) $\times$ Rate per kWh.
- **Labour Cost:** (Arc time / Duty cycle) $\times$ Wage rate.

Power Calculation:

- Power (kW) $=$ (Voltage $\times$ Current) / (1000 $\times$ Efficiency of machine)
- Energy (kWh) $=$ Power $\times$ Arc time

Numerical Problem 2: Arc Welding

Problem: Calculate the total cost for arc welding a joint taking 2 hours of actual arc time.

- Current = $200\,A$, Voltage = $30\ V$
- Machine efficiency = 60%
- Duty cycle = 50% (i.e., Total time = Arc time / 0.5)
- Power rate = Rs. 10/kWh
- Electrode consumed = $1.5\,kg$, Rate = Rs. 120/kg
- Welder's wage = Rs. 100/hr

Solution: Numerical Problem 2

Step 1: Power Cost

- Power $= (200 \times 30)/(1000 \times 0.6) = 10\,kW$
- Energy consumed $= 10\,kW \times 2\,hr = 20\,kWh$
- Power Cost $= 20 \times 10 =$ Rs. 200

Step 2: Electrode Cost

- Electrode Cost $= 1.5\,kg \times 120 =$ Rs. 180

Step 3: Labour Cost

- Total time = Arc time / Duty cycle $= 2\,hr/0.5 = 4\,hr$
- Labour Cost $= 4 \times 100 =$ Rs. 400

Total Cost $= 200 + 180 + 400 =$ **Rs. 780**

Summary of Unit 2

- Explored the principles and applications of various Metal Joining Processes.
- Discussed Arc, Gas, and Resistance welding techniques in detail.
- Covered allied processes like Soldering and Brazing.
- Emphasized the importance of Safety Precautions.
- Learned to perform basic cost estimation for both Gas and Arc welding processes.

Introduction to Metal Forming

- **Metal Forming:** A manufacturing process in which solid metal is plastically deformed into a desired shape.
- Deformation occurs by applying forces that exceed the yield strength of the material but are below its fracture strength.
- No material is added or removed (unlike machining).
- **Significance:** Produces parts with high mechanical strength and minimum waste.
- Broadly classified based on the operating temperature:
  - Hot Working
  - Cold Working

Recrystallization Temperature

- The temperature at which new, stress-free grains are formed within a plastically deformed metal.
- It is a critical parameter distinguishing hot and cold working.
- Usually, the recrystallization temperature is about **0.3 to 0.6 times the melting temperature** of the metal (in Kelvin).
- Above this temperature, the metal is easier to deform and does not strain harden.

What is Hot Working?

- **Definition:** Plastic deformation of a metal carried out at a temperature **above its recrystallization temperature** and below its melting point.
- During hot working, the metal undergoes simultaneous deformation and recrystallization.
- No residual stresses are left in the metal.
- **Examples:** Hot rolling, hot forging, hot extrusion.

Advantages of Hot Working

- Requires less force and power for deformation due to lower yield strength at high temperatures.
- High degree of deformation can be achieved in a single step.
- Porosity in cast metal is largely eliminated.
- Grain structure is refined (coarse grains break down to fine grains), improving mechanical properties like toughness.
- Does not cause strain hardening; the metal remains ductile.

Disadvantages of Hot Working

- Poor surface finish due to rapid oxidation and scaling of the surface at high temperatures.
- Difficulty in maintaining close dimensional tolerances because of thermal expansion and subsequent contraction.
- Shorter tool life due to high heat transfer to the tooling.
- Handling of hot metal is difficult and requires special equipment.

What is Cold Working?

- **Definition:** Plastic deformation of a metal carried out at a temperature **below its recrystallization temperature**, typically at room temperature.
- The deformed grains do not recrystallize, leading to elongation of grains in the direction of working.
- **Examples:** Cold drawing, cold rolling, bending, spinning.

Advantages of Cold Working

- Excellent surface finish is obtained as there is no oxidation or scaling.
- Very close dimensional tolerances can be maintained.
- Strength and hardness increase due to **strain hardening** (work hardening).
- Easier handling since the process is usually done at room temperature.
- No heating equipment is required, saving energy.

Disadvantages of Cold Working

- Higher forces and heavier equipment are required for deformation.
- The amount of deformation possible in a single step is limited; intermediate annealing may be required.
- Ductility decreases due to strain hardening, making the metal brittle.
- Residual stresses are induced in the metal, which may require stress-relief annealing.

Differences: Hot vs. Cold Working (Part 1)

Aspect	Hot Working	Cold Working
Temperature	Above recrystallization temp.	Below recrystallization temp.
Force Required	Less force and power needed.	High force and heavier equipment needed.
Surface Finish	Poor, due to oxidation/scaling.	Excellent, smooth and clean surface.
Dimensional Accuracy	Poor, difficult to maintain close tolerances.	High, close tolerances can be maintained.

Differences: Hot vs. Cold Working (Part 2)

Aspect	Hot Working	Cold Working
Strain Hardening	Does not occur.	Occurs (strength & hardness increase).
Residual Stresses	No residual stresses setup in the metal.	Residual stresses are induced.
Ductility	Remains unchanged or improves.	Decreases significantly.
Grain Structure	Grains are refined and equiaxed.	Grains are distorted/elongated.

Summary of Lecture 29

- Metal forming shapes metals via plastic deformation without adding or removing material.
- Hot working is performed above the recrystallization temperature, yielding high deformation with low force but poor finish.
- Cold working is performed below the recrystallization temperature, providing excellent finish and strength, but requires higher forces.
- The choice between hot and cold working depends on the desired properties, surface finish, and extent of deformation required.

Introduction to Forging

- **Forging:** A bulk metal deformation process in which the work piece is compressed between two dies, using either impact or gradual pressure, to form the desired shape.
- One of the oldest metalworking processes (dating back to the blacksmith's anvil).
- Typically carried out at elevated temperatures (Hot Forging) to reduce the yield strength of the metal, though Cold Forging is also used for smaller components.
- **Significance:** Forging refines the grain structure and improves the physical properties of the metal, such as strength, ductility, and toughness.

Advantages and Limitations of Forging

Advantages

- Parts possess superior mechanical properties (high strength-to-weight ratio).
- Directional alignment of grains along the contour of the part (grain flow).
- Porosity and internal voids in the cast ingot are welded closed.
- High production rates and material saving compared to machining.

Limitations of Forging

Limitations

- High initial cost of dies and forging equipment.
- Complex shapes with undercuts are difficult or impossible to forge.
- Secondary machining is often required to achieve close tolerances and fine surface finish.

Classification of Forging Processes

Forging processes can be broadly classified based on the nature of force applied and the type of dies used:

- **Based on Force Application:**
  - **Drop Forging (Impact):** Repeated blows of a hammer are used.
  - **Press Forging (Gradual):** A slow, squeezing action is applied by a mechanical or hydraulic press.
- **Based on Die Type:**
  - **Open-Die Forging (Smith Forging):** Flat or simple contour dies.
  - **Closed-Die Forging (Impression-Die):** Dies have the negative impression of the final desired shape.

Open-Die Forging

- The simplest forging operation where the metal is compressed between two flat (or simple shaped) dies.
- **Characteristics:**
  - The workpiece is laterally unconstrained, allowing it to flow outward during compression.
  - Also known as *upsetting* or *flat-die forging*.
  - Often used to rough-shape large ingots before subsequent operations, or for producing small quantities of large components.
- **Barreling Effect:** Friction at the die-workpiece interface restricts horizontal expansion at the ends, causing the center to bulge out like a barrel.

Closed-Die Forging (Impression-Die)

- The workpiece is compressed between two mating dies that contain the inverse cavity of the desired part.
- As the dies close, the metal flows to completely fill the die cavity.
- **Flash:** A small amount of excess metal flows outward into a narrow gap between the die faces, forming a *flash*.
- **Role of Flash:** The flash cools rapidly, increasing in friction and resistance, which forces the remaining bulk metal to tightly fill every intricate detail of the die cavity.
- The flash is later trimmed off.
- Capable of producing complex shapes with close tolerances.

Drop Forging vs. Press Forging

Drop Forging	**Press Forging**
Impact force is applied via repeated hammer blows.	Gradual squeezing force is applied using a press.
Deformation is rapid and occurs primarily on the surface.	Deformation is slow and penetrates deep into the workpiece.
Cheaper equipment, but dies suffer higher impact stresses.	More expensive equipment, but longer die life.
Requires highly skilled operators.	Less operator skill required.
Used for smaller parts like spanners, levers.	Used for large, heavy components.

Forging Defects

Despite improving material properties, improper process control can lead to defects:

- **Cold Shuts (Laps):** Formed when two surfaces of metal fold against each other without welding completely, usually due to sharp corners or rapid chilling.
- **Scale Pits:** Shallow surface depressions caused by scale (oxide) that is not removed and gets forged into the surface.
- **Die Shift (Mismatch):** Occurs when the upper and lower dies are misaligned, causing asymmetric parts.
- **Incomplete Forging (Underfill):** The metal fails to completely fill the die cavity, often due to insufficient raw material or inadequate heating.
- **Flakes / Internal Cracks:** Caused by rapid cooling or excessive stress during deformation.

Applications of Forging

- Forging is universally used where high strength and reliability are critical.
- **Automotive Industry:** Crankshafts, connecting rods, camshafts, gears, steering knuckles, and axles.
- **Aerospace Industry:** Landing gear components, turbine disks, aircraft structural frames, and engine mounts.
- **Hand Tools:** Spanners, wrenches, pliers, hammers, and chisels.
- **General Engineering:** Crane hooks, valves, flanges, seamless rings, and large marine propeller shafts.

Summary of Lecture 30

- Forging shapes metal by applying compressive forces, resulting in superior grain structure and mechanical properties.
- **Open-die forging** is suited for simple, large parts, while **closed-die forging** produces complex parts and utilizes *flash* to ensure complete die filling.
- **Drop forging** relies on impact, whereas **press forging** uses continuous squeezing.
- Common defects like cold shuts, scale pits, and mismatch must be controlled through proper die design and temperature management.

Applications of Forging

- Forged components are used where **high strength, reliability, and fatigue resistance** are required.
- **Automotive Industry:** Crankshafts, connecting rods, camshafts, gears, steering knuckles, and axles.
- **Aerospace Industry:** Landing gear components, structural fuselage parts, and turbine discs.
- **Hand Tools:** Wrenches, pliers, hammers, and spanners.
- **Heavy Machinery:** Hooks, heavy duty shafts, and crane components.

Common Forging Defects (Part 1)

- **Cold Shuts (Laps):**
  - Occur when two surfaces of the metal fold against each other without welding together completely.
  - Caused by improper die design or sharp corners preventing smooth metal flow.
- **Incomplete Forging (Underfill):**
  - The die cavity is not completely filled, resulting in an undersized part.
  - Caused by using insufficient starting material, inadequate heating, or insufficient forging force.

Common Forging Defects (Part 2)

- **Scale Pits:**
  - Irregular depressions on the surface of the forged part.
  - Caused by hard oxide scale (formed during heating) getting pressed into the softer bulk metal during forging.
- **Internal Cracks:**
  - Internal ruptures or tears within the workpiece.
  - Caused by excessive secondary tensile stresses developing within the workpiece during severe deformation, or improper cooling rates.

What is Rolling?

- **Rolling** is a metal forming process in which metal stock is passed through one or more pairs of rolls to reduce thickness, make the thickness uniform, and/or impart a desired mechanical property.
- It is the most extensively used metal forming process.
- Most bulk metals (like ingots or billets) undergo rolling as the first step to convert them into usable shapes like plates, sheets, bars, or structural shapes.
- Can be performed as **Hot Rolling** (most common for bulk reduction) or **Cold Rolling** (for thin sheets and better surface finish).

Working Principle of Rolling

- The metal is fed into the gap (roll bite) between two revolving rolls.
- The gap between the rolls is **less than the initial thickness** of the workpiece.
- **Friction** between the rolls and the metal surface grips the metal and pulls it through.
- The compressive forces from the rolls reduce the material's thickness.
- Due to volume constancy, the reduction in thickness causes an **increase in length (elongation)** and a slight increase in width (spreading).

Two-High Rolling Mill

- The simplest and most common type of rolling mill.
- Consists of two heavy rolls placed one above the other.
- **Non-Reversing Two-High Mill:** Rolls rotate in one direction only. The workpiece cannot be passed back without returning it manually.
- **Reversing Two-High Mill:** The direction of roll rotation can be reversed. The workpiece can be passed back and forth between the rolls to gradually reduce thickness.

Three-High Rolling Mill

- Consists of three rolls stacked vertically.
- The top and bottom rolls rotate in the same direction, while the middle roll rotates in the opposite direction.
- The workpiece passes in one direction between the bottom and middle rolls, and then is elevated to pass back in the opposite direction between the middle and top rolls.
- **Advantage:** Eliminates the need for reversing the drive motors, saving time and energy.

Four-High Rolling Mill

- Uses two smaller-diameter **work rolls** in contact with the metal, supported by two much larger **backup rolls**.
- **Why small work rolls?** Smaller rolls require less force and power to achieve the same thickness reduction because the contact area is smaller.
- **Why backup rolls?** The high rolling pressure would cause small work rolls to bend, leading to uneven thickness. The massive backup rolls prevent this bending.
- Widely used for rolling wider sheets and plates.

Cluster Mill (Sendzimir Mill)

- An extension of the four-high mill concept.
- Uses extremely small work rolls supported by a complex arrangement of multiple backup rolls (a cluster).
- Used to roll extremely hard materials (like stainless steel, titanium) to very thin gauges (foils).
- The extensive backup system provides massive rigidity, preventing any deflection of the tiny work rolls.

Summary of Lecture 31

- Forged components are prized for high strength and fatigue resistance but can suffer from defects like cold shuts, underfill, and scale pits if not properly controlled.
- Rolling is the primary process for converting bulk metals into plates, sheets, and structural shapes via compressive forces and friction.
- Various rolling mills (Two-high, Three-high, Four-high, and Cluster mills) are used depending on the required reduction, material hardness, and operational efficiency.

Introduction to Rolling

- **Rolling** is a metal forming process in which metal stock is passed through one or more pairs of rolls to reduce thickness and to make the thickness uniform.
- The concept is similar to rolling dough with a rolling pin.
- Rolling is the most extensively used metal forming process because of its high productivity and close control of final product.
- **Classification based on temperature:**
  - **Hot Rolling:** Performed above the recrystallization temperature. Used for initial breakdown of ingots into blooms, billets, or slabs.
  - **Cold Rolling:** Performed below the recrystallization temperature (usually room temperature) to improve surface finish, tight tolerances, and increase strength via strain hardening.

Working Principle of Rolling

- The metal is subjected to high compressive stresses as it is squeezed between two driven, rotating cylindrical rolls.
- **Friction** between the rolls and the metal surface is essential to bite the metal and pull it through the roll gap.
- The rolls rotate in opposite directions to draw the material in.
- The gap between the rolls is less than the initial thickness of the metal.
- The metal's velocity increases as it passes through the rolls to maintain a constant volume flow rate, leading to **forward slip** at the exit.

Two-High & Three-High Rolling Mills

Two-High Rolling Mill

- Consists of two heavy rolls placed one over the other.
- **Non-reversing:** Rolls rotate in only one direction. Metal must be returned over the top for the next pass.
- **Reversing:** The direction of rotation can be reversed after each pass, allowing the metal to be rolled back and forth.

Three-High Rolling Mill

- Consists of three rolls arranged vertically.
- The top and bottom rolls rotate in the same direction, while the middle roll rotates in the opposite direction.
- Material passes between the bottom and middle rolls in one direction, and then returns between the middle and top rolls.
- Eliminates the need to reverse the motor drive.

Four-High & Cluster Rolling Mills

Four-High Rolling Mill

- Uses two smaller **work rolls** (which contact the metal) and two larger **backup rolls** behind them.
- Small work rolls reduce the rolling force required (smaller contact area).
- Large backup rolls prevent the smaller work rolls from bending under the high rolling pressure.
- Used for rolling thin sheets and plates.

Cluster Rolling Mills

Cluster (Sendzimir) Rolling Mill

- Uses very small work rolls supported by a complex arrangement of multiple backup rolls.
- Prevents any deflection of the work rolls.
- Ideal for cold rolling of very thin sheets (foils) of high-strength materials like stainless steel or titanium.

Tandem Rolling Mill

- Consists of a series of two-high or four-high mill stands arranged in a line (in tandem).
- The metal passes continuously through each stand.
- Each stand progressively reduces the thickness of the metal.
- The speed of each successive set of rolls must be synchronized and increased to accommodate the increasing length of the metal.
- Highly efficient for mass production of continuous sheets or plates.

Applications of Rolling

- Rolling is used to produce a vast array of cross-sections and products.
- **Structural Shapes:** I-beams, L-beams (angles), U-channels, and T-sections used in construction.
- **Flat Products:** Plates (thick), sheets (thin), and foils (very thin) used in automotive bodies, aircraft, and packaging.
- **Long Products:** Bars, rods, and rails for railway tracks.
- **Thread Rolling:** A specialized rolling process used to form threads on cylindrical parts (like bolts) with high strength and good surface finish.

Defects in Rolling (Part 1)

Rolling defects occur due to improper process parameters, material imperfections, or roll deformation.

- **Waviness (Edge or Center):**
  - If the rolls deflect (bend) elastically, the edges or the center of the sheet may become thinner than the rest.
  - This unequal elongation causes the longer regions to buckle, resulting in wavy edges or a wavy center.
- **Zipper Cracks & Edge Cracks:**
  - Caused by poor material ductility at the rolling temperature.
  - Edges are subjected to high tensile stresses as the center elongates more freely, leading to cracking along the edges.

Defects in Rolling (Part 2)

- **Alligatoring:**
  - The workpiece splits along its horizontal center plane upon exiting the rolls.
  - Caused by complex internal stresses and metallurgical weaknesses in the center of the billet (e.g., impurities or piping from casting).
- **Surface Defects:**
  - **Scale inclusion:** Oxide scale formed during hot rolling gets pressed into the metal surface.
  - **Scratches/Marks:** Caused by damaged or rough work rolls.
- **Remedies:** Use of proper roll camber (crowning) to prevent waviness, strict temperature control, and maintaining clean, well-polished rolls.

- Drawing is a metal forming process used to reduce the cross-section of a wire, rod, or tube by pulling it through a single, or a series of, conical dies.
- **Key Characteristics:**
  - It is a cold working process, generally performed at room temperature.
  - The workpiece is pulled, so it experiences tensile stress, whereas the die exerts compressive stress on the metal.
  - Results in excellent surface finish, improved mechanical properties (due to strain hardening), and close dimensional tolerances.
- **Applications:** Electrical wires, cables, strings for musical instruments, fencing, and seamless tubes.

Wire Drawing vs. Tube Drawing

Wire Drawing

- Used for reducing the diameter of a solid rod or wire.
- Involves pulling the wire through a drawing die.
- Multi-stage drawing (using a series of dies) is often required for significant reduction in diameter.
- Intermediate annealing may be required to restore ductility.

Tube Drawing

- Used for reducing the diameter and wall thickness of a seamless tube.
- Typically uses a mandrel inside the tube to support the internal wall during the drawing process.
- **Types:** Tube Sinking (no mandrel), Plug drawing (fixed or floating plug), and Mandrel drawing.

Defects in Drawing Processes

- **Center Burst (Chevron Cracking):** Internal cracks that develop due to high die angle, low reduction per pass, or impurities in the metal.
- **Seams:** Longitudinal scratches or folds in the material, often inherited from the original billet or caused by a damaged die.
- **Residual Stresses:** Non-uniform deformation across the cross-section can lead to residual stresses, causing warping or stress corrosion cracking.
- **Surface Scratches and Die Marks:** Caused by poor lubrication, improper die polishing, or particulate matter trapped in the die.

Introduction to Extrusion

- Extrusion is a bulk deformation process where a billet of material is forced to flow through a die of a desired cross-section.
- Analogous to squeezing toothpaste out of a tube.
- Can be performed as **Hot Extrusion** (for metals with high yield strength like steel, requires less force) or **Cold Extrusion** (for softer metals like aluminum or lead, yields better finish).
- **Advantages:**
  - Can produce complex, asymmetric cross-sections continuously.
  - Good surface finish and high production rate.
  - Enhances the mechanical properties of the material due to severe plastic deformation under compression.

Direct (Forward) Extrusion

- The ram pushes the billet through the die in the **same direction** as the ram's movement.
- High friction exists between the billet surface and the container wall, as the entire billet moves within the container.
- Requires a significantly higher force compared to indirect extrusion.
- A dummy block is usually placed between the ram and the billet to protect the ram from high temperatures and pressures.

Applications: Solid and hollow shapes, rods, structural profiles, and window frames.

Indirect (Backward) Extrusion

- The die is mounted on a hollow ram and is forced against the stationary billet.
- The extruded part flows in the **opposite direction** to the movement of the ram.
- **Advantage:** Zero friction between the billet and the container wall (since the billet does not move relative to the container), thus requiring 25-30% less force.
- **Limitation:** The hollow ram limits the length of the extruded part and reduces the structural rigidity of the ram.

Impact Extrusion

- A specialized form of cold extrusion used to produce short, thin-walled, hollow shapes.
- A punch strikes a slug of metal at high velocity, forcing it to flow upward around the punch (backward) or downward through the die (forward).
- Often used for softer metals like aluminum, lead, tin, or copper.
- **Advantages:** Extremely fast production rates, economical for high-volume production.
- **Applications:** Collapsible toothpaste tubes, beverage cans, battery cases, and aerosol cans.

Summary of Drawing vs. Extrusion

Parameter	**Drawing**	**Extrusion**
Force Applied	Pulling force (Tension)	Pushing force (Compression)
Material Flow	Through a converging die	Through a die opening
Process State	Usually Cold Working	Usually Hot Working (can be cold)
Products	Wires, tubes, rods	Complex solid and hollow profiles
Stress on Die	Compressive	Highly Compressive

What is Rolling?

- **Rolling** is a metal forming process in which metal stock is passed through one or more pairs of rolls to reduce thickness, make the thickness uniform, and impart a desired mechanical property.
- It is analogous to the rolling of dough with a rolling pin.
- Rolling is the most widely used metalworking process because of its high production capability, efficiency, and close control of the final product.
- The metal is subjected to high compressive stresses as a result of the friction between the rolls and the metal surface.

Hot Rolling vs. Cold Rolling

Hot Rolling

- Performed at temperatures above the recrystallization temperature of the metal.
- Used for massive deformation (e.g., converting large cast ingots into blooms, billets, or slabs).
- Results in a uniform, stress-free grain structure but leaves a scaled, rough surface finish.

Cold Rolling

Cold Rolling

- Performed below the recrystallization temperature (typically at room temperature).
- Used for final finishing stages to obtain accurate dimensions, excellent surface finish, and enhanced strength (due to strain hardening).
- Common products include thin sheets, strips, and foils.

Working Principle

- In the rolling process, the workpiece is subjected to compressive forces generated by two rotating cylindrical rolls.
- The rolls rotate in opposite directions to grip the metal and draw it through the gap between them.
- The gap between the rolls is set to be smaller than the initial thickness of the workpiece, causing a reduction in thickness.
- Friction between the rolls and the metal surface is absolutely essential to "bite" the metal and pull it into the roll gap.
- As the thickness decreases, the length of the workpiece increases proportionately to maintain constant volume.

- **Draft (d):** The difference between the initial thickness (h_0) and final thickness (h_f) of the workpiece.

$$d = h_0 - h_f$$

- **Roll Gap:** The minimum distance between the two rolls, which determines the final thickness h_f.
- **Angle of Bite (α):** The angle subtended by the deformation zone at the center of the roll. It is the maximum angle at which the metal can be drawn into the rolls without slipping.
- For the metal to be successfully bitten by the rolls, the coefficient of friction (μ) must be greater than or equal to the tangent of the angle of bite ($\mu \geq \tan \alpha$).

Mechanics of Rolling: Velocity and Slip

- As the workpiece passes through the rolls, its thickness decreases while its length and velocity increase.
- Due to the principle of volume continuity, the exit velocity of the metal (v_f) must be greater than its entry velocity (v_0).
- The surface velocity of the rotating rolls (v_r) remains constant throughout the contact zone.
- Therefore, at the entry point, the rolls are moving faster than the metal, causing the metal to slip backward (**Backward Slip**).
- At the exit point, the metal is moving faster than the rolls, causing it to slip forward (**Forward Slip**).

The Neutral Point (No-Slip Point)

- Between the entry and exit points, there is a specific location where the velocity of the metal is exactly equal to the surface velocity of the rolls ($v_{metal} = v_r$).
- This location is called the **Neutral Point** or **No-Slip Point**.
- **Role of Friction:**
  - From the entry point to the neutral point, friction acts in the direction of metal flow (pulling the metal in).
  - From the neutral point to the exit, friction acts in the opposite direction, opposing the metal flow.
- The balance of these frictional forces is what makes the continuous rolling process possible.

Lateral Spread in Rolling

- **Spread:** The slight increase in the width of the workpiece as it passes through the rolls.
- While the primary deformation is an increase in length, a small portion of the metal flows laterally, causing the width to increase.
- Spread increases under the following conditions:
  - High draft (large reduction in thickness).
  - Smaller roll diameter.
  - Low friction between the rolls and the metal.
  - Narrower initial width of the workpiece.
- In precision operations like plate rolling, spread must be strictly accounted for to ensure dimensional accuracy.

Roll Force and Bending

- The **Roll Force** is the perpendicular force that the rolls exert on the workpiece to compress it plastically.
- High roll force can cause the rolls to bendelastically (camber), resulting in a rolled plate that is thicker in the center than at the edges.
- **Methods to reduce roll force:**
  - Using smaller diameter rolls (reduces contact area).
  - Taking smaller drafts (reductions) per pass.
  - Performing the operation at higher temperatures (hot rolling).
  - Using suitable lubricants to reduce friction.

Summary of Rolling Mechanics

- Rolling relies on a delicate balance of compressive forces and friction to draw metal through rolls, reducing its thickness and increasing its length.
- The process involves a complex velocity profile, transitioning from backward slip at entry to forward slip at exit, separated by a neutral point.
- Proper control of draft, roll diameter, and friction is essential to optimize roll force and minimize defects.
- Understanding rolling mechanics is crucial for designing rolling mills and achieving high-quality structural and flat metal products.

Introduction to Rolling Mills

- A rolling mill is a complex machine used to perform the rolling operation, consisting of rolls, bearings, a housing for containing these parts, and a drive for applying power to the rolls and controlling the speed.
- The basic objective is to reduce the thickness of the metal workpiece or to alter its shape using compressive forces applied by a set of rolls.
- Rolling mills are classified based on the number and arrangement of rolls.
- Selecting the appropriate type of mill depends on the initial and final thickness, material properties, and required production rate.

Two-High and Three-High Rolling Mills

Two-High Rolling Mill

- Consists of two opposing rolls rotating in opposite directions.
- **Non-reversing:** Rolls rotate in one direction only; the material must be returned to the entrance side manually or by a conveyor.
- **Reversing:** The direction of roll rotation can be reversed, allowing the metal to be passed back and forth without moving it to the entrance side.

Three-High Rolling Mills

Three-High Rolling Mill

- Consists of three rolls arranged vertically in a single stand.
- The workpiece is passed in one direction between the lower and middle rolls, and then passed back between the middle and upper rolls.
- Eliminates the need to reverse the drive mechanism, improving efficiency.

Four-High and Cluster Rolling Mills

Four-High Rolling Mill

- Uses two smaller **work rolls** in contact with the workpiece, supported by two larger **backup rolls**.
- Smaller work rolls reduce the roll force required and minimize the contact area.
- Backup rolls prevent the smaller work rolls from bending under the high rolling forces.
- Extensively used for rolling wide metal sheets and plates.

Cluster Rolling Mills

Cluster Rolling Mill (Sendzimir Mill)

- Uses very small work rolls supported by a complex arrangement of multiple backup rolls.
- Exceptionally rigid structure, allowing the rolling of very thin sheets (foil) of high-strength materials (e.g., stainless steel, titanium).

Continuous (Tandem) Rolling Mills

- Consists of a series of rolling stands arranged in a straight line.
- The workpiece passes continuously through each stand, undergoing incremental reductions in thickness.
- The speed of each subsequent stand must be carefully synchronized to be faster than the previous one to accommodate the increased length of the material (due to volume constancy).
- Highly productive and widely used for mass production of sheet metal, wire, and structural shapes.

Applications of Rolling

Rolling is one of the most widely used manufacturing processes.

- **Primary Rolling:** Converting cast ingots into blooms, billets, or slabs (hot rolling).
- **Shape Rolling:** Producing structural shapes like I-beams, L-beams, U-channels, and railway rails.
- **Sheet and Strip Rolling:** Producing flat sheets for automotive body panels, appliances, and roofing.
- **Foil Rolling:** Producing ultra-thin foils, such as aluminum foil for packaging.
- **Thread Rolling:** A cold forming process to produce threads on cylindrical parts (e.g., bolts, screws) with high fatigue strength.

Defects in Rolling Processes

- **Wavy Edges:** Caused by roll bending. The edges of the sheet become thinner and elongate more than the center, causing them to buckle.
- **Zipper Cracks (Center Cracking):** Caused by low material ductility or excessive rolling forces, leading to cracks along the center of the strip.
- **Edge Cracking:** Occurs when the edges of the workpiece become constrained or chilled (in hot rolling), causing them to tear under tension.
- **Alligatoring:** The workpiece splits along the horizontal mid-plane upon exiting the rolls, often due to non-uniform deformation or pre-existing defects in the cast ingot.

Summary

- Rolling mills vary significantly in design (Two-high, Three-high, Four-high, Cluster, and Tandem) to handle different materials and thickness requirements.
- The use of backup rolls is crucial for maintaining uniform thickness in wide sheets.
- Rolling is versatile, capable of producing flat sheets, structural profiles, and even threaded parts.
- Careful control of roll profile, speed, and lubrication is necessary to prevent defects like wavy edges and alligatoring.

Introduction to Safety in Metal Forming

- Metal forming involves heavy machinery, high forces, and often high temperatures.
- Ensuring workplace safety is critical to prevent accidents and injuries.
- **Key hazard areas:**
    - High temperatures (Hot working, Forging)
    - Heavy loads and moving machine parts (Presses, Hammers)
    - Sharp edges (Sheared metal, Flash)
    - Noise and vibration

Common Hazards

- **Mechanical Hazards:** Entanglement, crushing, or severing from moving parts like press rams, rollers, and gears.
- **Thermal Hazards:** Burns from hot workpieces, furnaces, and flying sparks or scale.
- **Ergonomic Hazards:** Repetitive motions, lifting heavy dies and billets.
- **Environmental Hazards:** Exposure to fumes, lubricants, and high noise levels.

Safety Measures and Machine Guards

- **Machine Guards:** Physical barriers that prevent operators from reaching into the danger zone (e.g., point of operation).
- **Two-Hand Controls:** Requires the operator to use both hands to actuate the press, ensuring hands are away from the die area.
- **Light Curtains:** Opto-electronic devices that stop the machine if the light beam is broken by the operator's hand.
- **Lockout/Tagout (LOTO):** Procedures to ensure machines are safely shut off during maintenance.

Personal Protective Equipment (PPE)

Operators must wear appropriate PPE to minimize risk:

- **Safety Glasses / Face Shields:** Protection from flying sparks, scale, and debris.
- **Heat-Resistant Gloves:** To handle hot billets and prevent burns.
- **Steel-Toe Boots:** Protection against dropped heavy dies or materials.
- **Ear Protection:** Earplugs or earmuffs to prevent hearing loss from noisy forging hammers.
- **Aprons / Heat-Resistant Clothing:** Protection from radiant heat and sparks.

Introduction to Cost Estimation

- **Cost estimation** is the process of predicting the expenses required to manufacture a product.
- In forging, estimating the raw material cost is crucial as it forms a major portion of the total cost.
- The weight of the raw material required is always **greater** than the weight of the final forged component due to various material losses.

Various Losses in Forging

To calculate the gross weight of the material required, we must account for several losses:

1. **Scale Loss:** Material lost due to surface oxidation when heating the metal. (Usually 5-7% of net weight).
2. **Flash Loss:** Excess material squeezed out between the dies to ensure complete filling of the die cavity.
3. **Tong-Hold Loss:** Extra length provided at one end of the billet for gripping it with tongs during forging.
4. **Sprue / Shear Loss:** Material wasted when cutting the required billet length from a long bar.

Weight Calculations

Net Weight

The weight of the final finished forged component.

$Net\ Weight = Volume\ of\ component \times Density\ of\ material$

Gross Weight (Material Required)

The total weight of the raw material required to make the component.

$Gross\ Weight = Net\ Weight + Scale\ Loss + Flash\ Loss + Tong\text{-}Hold\ Loss + Shear\ Loss$

Material Cost = Gross Weight × Cost per kg of raw material

Basic Numerical Example

Problem: Estimate the raw material weight and cost to forge a component with a net weight of 2.5 kg. The following losses occur:

- Scale loss = 5% of net weight
- Flash loss = 10% of net weight
- Tong-hold loss = 0.15 kg
- Shear loss = 0.05 kg

The cost of raw material is Rs. 80 per kg.

Solution to Numerical Example

- **Net Weight** $= 2.5$ kg
- **Scale Loss** $= 0.05 \times 2.5 = 0.125$ kg
- **Flash Loss** $= 0.10 \times 2.5 = 0.25$ kg
- **Tong-Hold Loss** $= 0.15$ kg
- **Shear Loss** $= 0.05$ kg

Total Losses $= 0.125 + 0.25 + 0.15 + 0.05 = 0.575$ kg

Gross Weight $=$ Net Weight $+$ Total Losses
Gross Weight $= 2.5 + 0.575 = 3.075$ kg

Material Cost $=$ Gross Weight $\times$ Rate
Material Cost $= 3.075 \times 80 =$ Rs. 246

Summary

- Safety in metal forming requires proper machine guards, PPE, and adherence to safety protocols like LOTO.
- Forging cost estimation must account for material losses such as scale, flash, shear, and tong-hold losses.
- Accurate estimation ensures profitable and efficient manufacturing operations.

What is Rolling?

- **Rolling** is a metal forming process in which metal stock is passed through one or more pairs of rolls to reduce thickness and make the thickness uniform.
- The concept is similar to rolling dough with a rolling pin.
- It is the most extensively used metal forming process because of its high production rate and close control of final product.
- Can be performed as **Hot Rolling** (most common for initial breakdown of ingots) or **Cold Rolling** (for fine surface finish and mechanical properties).

Working Principle of Rolling

- The metal is drawn into the gap between two rotating rolls by means of friction.
- The compressive forces applied by the rolls reduce the thickness of the material.
- **Draft (d):** The difference between the initial thickness (t_0) and the final thickness (t_f).
  $d = t_0 - t_f$
- **Slip:** As the metal passes through the rolls, its velocity increases. The metal exits faster than the roll surface speed, creating *forward slip*.

Classification of Rolling Mills

Rolling mills are classified based on the number and arrangement of rolls:

1. Two-High Rolling Mill
2. Three-High Rolling Mill
3. Four-High Rolling Mill
4. Cluster Rolling Mill
5. Tandem Rolling Mill

Two-High and Three-High Mills

Two-High Rolling Mill

- Consists of two heavy rolls placed one over the other.
- **Non-reversing:** Rolls rotate in the same direction; material is fed from one side only.
- **Reversing:** Roll rotation direction can be reversed, allowing the material to pass back and forth.

Three-High Rolling Mill

- Consists of three rolls arranged vertically.
- The top and bottom rolls rotate in one direction, while the middle roll rotates in the opposite direction.
- Allows continuous passing of the metal back and forth without stopping or reversing the mill drive.

Four-High and Cluster Mills

Four-High Rolling Mill

- Has two smaller working rolls in contact with the workpiece, and two much larger backing rolls behind them.
- Smaller work rolls reduce the roll force required.
- Backing rolls prevent the smaller work rolls from bending under the high rolling pressure.

Cluster Rolling Mill

- Employs a single pair of very small work rolls, supported by multiple backing rolls.
- Extremely rigid, used for rolling high-strength materials (like stainless steel or titanium) and for rolling very thin foils.

Tandem Rolling Mill

- Consists of multiple rolling stands (often 3 to 6) arranged in a straight line.
- The metal strip passes continuously from one stand to the next.
- Each stand progressively reduces the thickness.
- The speed of each subsequent stand must be carefully synchronized and increased to accommodate the increasing length and velocity of the strip.
- Extremely efficient for high-volume, continuous production.

Applications of Rolling

- **Flat Rolling:** Produces plates (thickness $>$ 6 mm), sheets (thickness $<$ 6 mm), and foils (very thin). Used in shipbuilding, bridges, automotive bodies, and aircraft.
- **Shape / Profile Rolling:** Rolls have specially machined grooves to produce structural shapes like I-beams, L-beams, U-channels, and railway rails.
- **Thread Rolling:** Used to form threads on cylindrical parts (like bolts) by rolling them between threaded dies. (Produces stronger threads than machining).
- **Ring Rolling:** Used to produce seamless rings for bearings, turbines, and aerospace components.

Defects in Rolled Products

Common defects that occur during rolling operations:

- **Wavy Edges:** Caused by roll bending. The edges of the strip are elongated more than the center, causing them to buckle.
- **Zipper Cracks (Center Cracks):** Cracks down the center of the strip, resulting from low material ductility and excess stress in the center.
- **Edge Cracks:** Cracks along the edges of the strip, often caused by limited ductility at the edges during deformation.
- **Alligatoring:** The splitting of the workpiece along its horizontal midplane as it exits the rolls. Caused by non-uniform deformation and metallurgical weaknesses.

Introduction to Rolling

- **Rolling** is a metal forming process in which the thickness of a workpiece is reduced by compressive forces exerted by two opposing rolls.
- The rolls rotate to pull the material into the gap between them and simultaneously squeeze it.
- It is the most widely used metal forming process due to its high productivity and close control of final product dimensions.
- Rolling can be carried out hot (hot rolling) or cold (cold rolling) depending on the required properties and thickness.

Working Principle of Rolling

- The basic rolling process involves passing the metal between two heavy cylindrical rollers.
- The gap between the rollers is smaller than the initial thickness of the workpiece.
- **Friction** between the rolls and the metal surface is essential to draw the metal into the roll gap.
- As the metal passes through the gap, its thickness decreases while its length and (slightly) its width increase to maintain constant volume.
- The velocity of the metal increases as it passes through the rolls (exit velocity is greater than entry velocity).

Types of Rolling Mills (1/2)

Based on the arrangement and number of rolls, rolling mills are classified into several types:

1. **Two-High Rolling Mill:** Consists of two heavy rolls placed one over the other. The rolls can rotate in opposite directions. It is the simplest and most common type.
2. **Three-High Rolling Mill:** Consists of three rolls arranged vertically. The metal is passed in one direction between the lower and middle rolls, and in the reverse direction between the middle and upper rolls, eliminating the need to reverse roll rotation.
3. **Four-High Rolling Mill:** Uses two smaller diameter *work rolls* in contact with the metal, supported by two larger *backup rolls*. The backup rolls prevent the work rolls from bending under high pressure.

Types of Rolling Mills (2/2)

4. **Cluster (Sendzimir) Mill:** Uses very small diameter work rolls supported by multiple backup rolls in a cluster arrangement. It is highly rigid and used for rolling very thin sheets and high-strength alloys.
5. **Tandem Mill:** Consists of a series of two-high or four-high rolling stands arranged continuously. The metal passes continuously from one stand to the next, with each stand reducing the thickness further. High productivity, commonly used for mass production.

Applications of Rolling

- **Structural Shapes:** Production of I-beams, L-beams, U-channels, and rails for construction and railways.
- **Plates and Sheets:** Manufacturing steel plates for shipbuilding, bridges, and boilers.
- **Automotive Body Panels:** Cold-rolled steel sheets are extensively used for car bodies.
- **Foil Production:** Aluminum foil for packaging is produced by continuous cold rolling in cluster mills.
- **Seamless Rings and Tubes:** Ring rolling is used to manufacture seamless rings for bearings, jet engine parts, and pipes.

Defects in Rolling

Several defects can occur during rolling due to improper parameters, uneven cooling, or material impurities:

- **Wavy Edges:** Caused when the edges of the sheet are elongated more than the center. This usually happens if the rolls bend, making the edges thinner than the center.
- **Zipper Cracks:** Small cracks in the center of the sheet, often due to poor material ductility or excessive bending of rolls.
- **Edge Cracks:** Cracks appearing at the edges, caused by restricted lateral spread or low material ductility.
- **Alligatoring:** The workpiece splits along its horizontal centerline at the exit, opening up like an alligator's mouth. It is caused by non-uniform deformation across the thickness.

Summary of Rolling

- Rolling relies on compressive forces and friction to reduce workpiece thickness.
- Mill types (Two-high, Four-high, Cluster) are chosen based on the required reduction, material strength, and final product thickness.
- Hot rolling is used for initial breakdown of cast ingots; cold rolling is used for final sizing, surface finish, and strength enhancement.
- Understanding roll deflection and material flow is crucial to preventing defects like wavy edges and alligatoring.

Introduction to Extrusion

- Extrusion is a compressive deformation process in which a block of metal is squeezed through an orifice or die opening to obtain a reduction in diameter and increase in length of the metal block.
- The process is similar to squeezing toothpaste out of a tube.
- It is widely used for producing long, straight, metal products of uniform cross-section, such as bars, solid and hollow sections, tubes, wires, etc.
- Extrusion can be performed either hot or cold depending on the ductility of the material.

Types of Extrusion

Extrusion processes are broadly classified into the following types based on the direction of metal flow:

1. **Direct Extrusion** (Forward Extrusion)
2. **Indirect Extrusion** (Backward Extrusion)
3. **Hydrostatic Extrusion**
4. **Impact Extrusion**

Direct Extrusion (Forward Extrusion)

- In direct extrusion, a heated metal billet is placed in a container.
- A ram pushes the metal billet, forcing it to flow out through a die opening at the other end.
- The direction of metal flow is the same as the direction of ram movement.
- A dummy block is usually placed between the ram and the billet to protect the ram from heat and wear.
- High friction exists between the billet surface and the container wall, requiring higher extrusion pressure.

Indirect Extrusion (Backward Extrusion)

- In indirect extrusion, the die is mounted on a hollow ram.
- As the hollow ram moves into the container, the metal is forced to flow backward through the die opening, in the direction opposite to the ram movement.
- Since there is no relative motion between the billet and the container wall, friction is completely eliminated.
- This results in lower extrusion pressure (about 25-30% less) compared to direct extrusion.
- However, the process is limited by the structural rigidity of the hollow ram.

Hydrostatic Extrusion

- In hydrostatic extrusion, the billet is surrounded by a fluid medium inside the container.
- The ram pressurizes the fluid, which in turn applies hydrostatic pressure on the billet, forcing it through the die.
- **Advantages:**
  - Fluid eliminates friction between the billet and the container wall.
  - The hydrostatic pressure increases the ductility of the material, enabling the extrusion of brittle materials.
- **Disadvantages:** Complex equipment and fluid leakage issues at high pressures.

Impact Extrusion

- Impact extrusion is usually performed as a cold working process to produce thin-walled hollow components like toothpaste tubes, battery cases, etc.
- A flat slug of metal is placed in a die cavity.
- A punch strikes the slug with a high-velocity impact, forcing the metal to flow up around the punch (backward) or down through the die (forward).
- It is a high-speed process suitable for soft metals like aluminum, lead, and tin.

Defects in Extrusion

Common defects that may occur during the extrusion process include:

- **Surface Cracking:** Occurs due to high extrusion temperature, high friction, or high extrusion speed, leading to high surface stresses.
- **Pipe Defect (Tailpipe or Fishtailing):** Formation of a funnel-shaped void at the end of the billet, drawing surface oxides into the center of the extruded product.
- **Internal Cracking (Chevron Cracking):** Formation of V-shaped internal cracks at the center of the extruded part, caused by state of hydrostatic tension at the centerline in the deformation zone.

Introduction to Wire Drawing

- Wire drawing is a cold forming process used to reduce the cross-section of a wire or rod by pulling it through a conical die.
- The term "drawing" refers to the pulling action (tensile force) applied to the wire.
- Unlike extrusion where the material is pushed, in drawing, the material is pulled.
- It is extensively used to produce wires of very small diameters for electrical cables, springs, and musical instruments.

Wire Drawing Setup

- A typical wire drawing setup consists of a pay-off reel (source of wire), a drawing die, and a draw block (capstan) which provides the pulling force.
- To start the process, the tip of the wire is swaged or pointed to feed it through the die opening.
- The pointed end is gripped and pulled by the draw block.
- Lubrication (e.g., soap, oil) is essential at the die-wire interface to reduce friction, wear, and drawing force.

Summary: Extrusion vs. Drawing

Feature	Extrusion	Drawing
Force Application	Compressive (Pushing)	Tensile (Pulling)
Material Flow	Pushed through die	Pulled through die
Product Shape	Complex profiles, tubes	Wires, rods, thin tubes
Temperature	Hot or Cold	Usually Cold

Objectives

- Understand the fundamental principles of wire and tube drawing.
- Analyze the mechanics and forces involved in the drawing process.
- Identify various drawing methods and equipment.
- Discuss typical defects, their causes, and remedies in drawing processes.

Introduction to Drawing Processes

- **Drawing** is a bulk metal forming process in which the cross-section of a long rod, wire, or tube is reduced by pulling it through a die.
- Unlike extrusion where the material is pushed, in drawing it is **pulled**.
- **Wire drawing** involves smaller diameters, whereas **bar drawing** involves larger cross-sections.
- The process is typically performed at room temperature (cold working), which improves the material's mechanical properties through strain hardening.

Principle of Wire Drawing

- A pointed end of a rod is inserted through the die opening and grasped by a pulling mechanism (draw block).
- The metal deforms plastically as it passes through the converging section of the die.
- The major stresses are compressive (due to the die walls) and tensile (due to the pulling force).
- **Volume constancy** applies: length increases as the cross-sectional area decreases.

Wire Drawing Equipment and Dies

- **Draw Bench**: Used for large bars; involves a straight-line pull.
- **Bull Block (Capstan)**: Used for drawing long lengths of wire; wire is coiled continuously.
- **Die Zones**:
  1. **Entry zone**: Funnel-shaped to guide the wire and retain lubricant.
  2. **Approach angle**: Where the actual reduction in diameter occurs.
  3. **Bearing surface (land)**: Sets the final diameter.
  4. **Back relief**: Prevents scratching as the wire exits.

Mechanics of Drawing

- The draw stress (σ_d) must be less than the yield strength of the exiting material to prevent it from breaking.
- **Ideal Work Method**:

$$\sigma_d = Y_{avg} \ln \left(\frac{A_0}{A_f} \right)$$

where Y_{avg} is the average flow stress, A_0 is initial area, and A_f is final area.

- **Friction and Redundant Work** also increase the required draw force.
- Optimal die angle exists where the sum of friction work and redundant work is minimized.

Tube Drawing Processes

- Tube drawing is used to reduce the diameter and wall thickness of seamless tubes.
- It improves surface finish and dimensional accuracy.
- **Types of Tube Drawing**:
  1. **Tube Sinking**: Drawn without an internal mandrel. Inner surface becomes irregular.
  2. **Fixed Mandrel**: Mandrel is fixed to a long rod. Controls inside diameter accurately.
  3. **Floating Mandrel**: Mandrel finds its own equilibrium position. Used for long tubes.
  4. **Moving Mandrel**: A long cylindrical rod moves with the tube through the die.

Lubrication in Drawing

- Proper lubrication is critical to reduce friction, minimize tool wear, and improve surface finish.
- **Wet Drawing**: The dies and wire are completely immersed in a liquid lubricant (common in fine wire drawing).
- **Dry Drawing**: The wire passes through a box of dry lubricant (e.g., soap powder) before entering the die.
- **Coating**: Surface preparation like phosphate coating or copper coating is sometimes applied to hold the lubricant.

Defects in Wire and Tube Drawing

- **Center Burst (Chevron Cracking)**: Internal cracks caused by alternating tensile and compressive stresses, often due to high die angles or low reductions.
- **Seams**: Longitudinal scratches or folds, originating from the cast ingot or poor die surface.
- **Residual Stresses**: Non-uniform deformation leads to residual stresses, which can cause warping or stress corrosion cracking.
- **Die Wear**: Leads to loss of dimensional accuracy and poor surface finish.

Summary

- Drawing is a critical metal forming process relying on tensile pulling forces and compressive die stresses.
- Equipment ranges from straight draw benches to continuous bull blocks.
- Die geometry (especially die angle) and proper lubrication heavily influence the process efficiency.
- Understanding mechanics helps in predicting forces and preventing defects like center bursts.

Introduction to Plastics

- **Plastics** are synthetic or semi-synthetic materials that use polymers as a main ingredient.
- Their plasticity makes it possible for plastics to be moulded, extruded or pressed into solid objects of various shapes.
- They are lightweight, durable, cost-effective, and have excellent thermal and electrical insulation properties.
- Broadly classified into two categories based on their thermal behavior:
  - **Thermoplastics**
  - **Thermosetting plastics**

Thermoplastics vs. Thermosetting Plastics

Thermoplastics	**Thermosetting Plastics**
Soften on heating and harden on cooling, repeatedly.	Once moulded and hardened, they cannot be softened by heating.
Easily recyclable and reshapeable.	Generally cannot be recycled easily.
Weaker intermolecular forces.	Strong cross-linked intermolecular forces.
Examples: PVC, Polystyrene, Polyethylene, Teflon.	*Examples:* Bakelite, Melamine, Epoxy resins.

Plastic Moulding Processes

- Moulding is the process of shaping liquid or pliable raw material using a rigid frame called a mould or matrix.
- When creating plastic products, several different processes can be employed depending on the required shape, material, and production volume.
- **Common plastic moulding processes include:**
  1. Injection Moulding
  2. Extrusion
  3. Blow Moulding
  4. Compression Moulding
  5. Transfer Moulding

1. Injection Moulding

- **Principle:** Granular plastic is fed by gravity from a hopper into a heated barrel. It is melted and forced by a plunger or rotating screw into a heated mould.
- The melt solidifies in the mould cavity to form the required shape.
- **Key Components:**
  - Hopper, Heater, Screw/Plunger, Mould.
- **Applications:** Used for manufacturing complex, net-shaped plastic parts such as bottle caps, automotive dashboards, toys, and electronic housings.
- **Advantages:** High production rate, low labor costs, minimal scrap losses.

2. Extrusion

- **Principle:** Used to create objects of a fixed cross-sectional profile. The plastic material is melted and formed into a continuous profile.
- Raw material (polymer) is melted and pushed through a die of the desired cross-section.
- **Process steps:**
    - Feeding into hopper
    - Heating and melting in the barrel
    - Forcing through the die
    - Cooling (usually in a water bath)
- **Applications:** Pipes, tubing, weather stripping, wire insulation, and plastic sheets.

3. Blow Moulding

- **Principle:** A manufacturing process by which hollow plastic parts are formed.
- The process begins with melting down the plastic and forming it into a parison (or preform).
- The parison is a tube-like piece of plastic with a hole in one end through which compressed air can pass.
- It is clamped into a mould and air is blown into it, pushing the plastic out to match the mould.
- **Applications:** Plastic bottles, containers, fuel tanks.

4. Compression Moulding

- **Principle:** A method of moulding in which the moulding material, generally preheated, is first placed in an open, heated mould cavity.
- The mould is closed with a top force or plug member, pressure is applied to force the material into contact with all mould areas.
- Heat and pressure are maintained until the moulding material has cured.
- Frequently used for thermosetting polymers.
- **Applications:** Electrical switches, handles for cooking utensils, automotive parts.
- **Advantages:** Lower mould costs, minimal material waste, good for large, fairly intricate parts.

Summary of Plastic Moulding Processes

- The selection of a plastic moulding process depends on:
  - The type of plastic used (thermoplastic vs. thermosetting).
  - The desired shape (hollow, continuous cross-section, complex 3D shape).
  - Production volume and tooling costs.
- **Injection Moulding:** High volume, complex solid parts.
- **Extrusion:** Continuous lengths, constant cross-section.
- **Blow Moulding:** Hollow containers and bottles.
- **Compression Moulding:** Thermosetting plastics, simple and large parts.

Introduction to Plastic Moulding

- Plastic moulding is a process of shaping raw plastic material (resins or polymers) into a desired shape.
- It involves heating the plastic until it becomes pliable or liquid, and then forcing it into a mould cavity.
- Once the plastic cools and solidifies, it takes the shape of the mould.
- Widely used for mass production of plastic components due to high efficiency and dimensional accuracy.

Injection Moulding

- **Principle:** Granular plastic is melted and injected under high pressure into a closed mould cavity, where it cools and solidifies to form the product.
- Highly versatile and the most common method for producing plastic parts.
- Suitable for both thermoplastics and thermosetting plastics, though predominantly used for thermoplastics.

Construction of Injection Moulding Machine

- **Hopper:** Holds the raw plastic granules (pellets) and feeds them into the heating cylinder.
- **Heating Cylinder (Barrel):** Contains a reciprocating screw or a plunger; surrounded by band heaters to melt the plastic.
- **Reciprocating Screw:** Conveys, compresses, melts, and injects the plastic.
- **Nozzle:** The transition part connecting the cylinder to the mould.
- **Mould:** Consists of two halves (stationary and moving) with a cavity of the desired shape.
- **Clamping Unit:** Holds the two halves of the mould together against the injection pressure.

Working of Injection Moulding

1. **Clamping:** The mould halves are closed tightly by the clamping unit.
2. **Feeding & Melting:** Plastic pellets from the hopper enter the barrel. The rotating screw melts the plastic through friction and external heaters.
3. **Injection:** The screw moves forward like a plunger, injecting the molten plastic through the nozzle into the mould cavity under high pressure.
4. **Cooling:** The molten plastic cools and solidifies inside the mould. Water channels in the mould help accelerate cooling.
5. **Ejection:** The mould opens, and ejector pins push the finished solid plastic part out.

Injection Moulding: Advantages & Applications

Advantages:

- High production rate and efficiency.
- Complex shapes with fine details can be produced.
- Very little material waste (runners and sprues can often be recycled).
- Excellent surface finish and dimensional accuracy.

Applications:

- Household items (buckets, mugs, containers).
- Automotive parts (dashboards, bumpers).
- Electronic housings, toys, medical devices, and bottle caps.

Blow Moulding

- **Principle:** A heated hollow tube of plastic (called a parison) is inflated inside a closed mould until it takes the shape of the mould cavity.
- Exclusively used for making hollow plastic parts.
- Primarily used for thermoplastic materials like HDPE, PET, and PP.

Working of Blow Moulding

1. **Parison Creation:** A hollow tube of molten plastic (parison) is extruded downwards from an extruder die.
2. **Clamping:** Two halves of a split mould close around the parison, pinching off the bottom to seal it.
3. **Blowing:** Compressed air is blown into the parison through a blow pin at the top. The plastic expands outwards and presses against the cold mould walls.
4. **Cooling:** The plastic cools and solidifies into the shape of the mould cavity.
5. **Ejection:** The mould opens, the part is ejected, and excess plastic (flash) is trimmed away.

Blow Moulding: Advantages & Applications

Advantages:

- Ideal for producing seamless hollow shapes.
- Lower tool and die costs compared to injection moulding.
- Fast production rates.
- Can produce parts with narrow openings and wide bodies.

Applications:

- Plastic bottles for water, soft drinks, and milk.
- Containers for chemicals, shampoos, and oils.
- Hollow toys, fuel tanks, and drums.

Summary

- **Injection Moulding:** Used for solid parts; molten plastic is injected into a closed mould under pressure. Known for high accuracy and complex shapes.
- **Blow Moulding:** Used for hollow parts; a hot plastic tube (parison) is inflated inside a mould to take its shape. Ideal for bottles and containers.
- Both processes are highly automated and suitable for mass production in the plastic manufacturing industry.

Extrusion Moulding

- **Principle:** Extrusion is a continuous process used to produce parts with a uniform cross-section (e.g., pipes, tubes, sheets, films).
- Plastic granules or pellets are fed into a heated barrel.
- A rotating screw pushes the molten plastic through a die that shapes the material into its final form.
- The extruded product is then cooled, usually in a water bath, and cut into desired lengths.

Extrusion Moulding: Construction & Working

- **Main Components:**
  - **Hopper:** Feeds the raw plastic pellets.
  - **Heated Barrel:** Melts the plastic material.
  - **Rotating Screw:** Conveys and mixes the molten plastic.
  - **Die:** Imparts the desired cross-sectional shape.
- **Working:**
  - The rotating screw moves the plastic forward.
  - Friction and heater bands melt the material.
  - The molten plastic is forced through the die opening, adopting its shape.
  - It is then cooled continuously.

Extrusion Moulding: Applications

- **Advantages:** High production volumes, low cost per part, continuous operation, and capability to produce complex cross-sections.
- **Limitations:** Limited to uniform cross-sections, variations in thickness can be challenging to control.
- **Applications:**
  - PVC pipes and tubing.
  - Plastic films and sheets.
  - Weatherstripping and window frames.
  - Wire insulation and cable jacketing.

Rotational Moulding (Rotomoulding)

- **Principle:** A process used to create hollow, seamless plastic parts of large sizes.
- Powdered plastic is placed into a hollow mould.
- The mould is heated while being rotated simultaneously around two perpendicular axes.
- The plastic melts and coats the inner surface of the mould evenly.

Rotational Moulding: Working Cycle

1. **Loading:** A predetermined amount of polymer powder is loaded into the mould cavity.
2. **Heating & Rotation:** The mould is placed in an oven and biaxially rotated. The heat melts the powder, making it stick to the mould walls.
3. **Cooling:** The mould is moved to a cooling station where air or water is applied to cool the mould while it continues to rotate.
4. **Unloading:** Once solidified, the mould is opened, and the finished hollow part is removed.

Rotational Moulding: Applications

- **Advantages:** Can produce large hollow parts without seams, uniform wall thickness, low tooling costs, and minimal material waste.
- **Limitations:** Slow production cycle, limited to specific types of plastics (mostly polyethylene), and high energy consumption.
- **Applications:**
  - Large water tanks and storage bins.
  - Kayaks and canoes.
  - Playground equipment.
  - Road barriers and traffic cones.

Compression Moulding

- **Principle:** Mostly used for thermosetting plastics, where a pre-measured amount of moulding material (charge) is placed in a heated mould cavity.
- The mould is closed, and pressure is applied to force the material to fill the cavity.
- Heat and pressure are maintained until the plastic material cures (cross-links) and sets permanently.

Compression Moulding: Working

- **Steps:**
  1. The lower half of the mould is heated and loaded with the charge (powder or pre-compressed pellet).
  2. The upper half of the mould is brought down to close the mould.
  3. High pressure and heat are applied, causing the plastic to melt, flow, and fill the cavity.
  4. Curing time is allowed for the thermosetting plastic to harden.
  5. The mould is opened, and the part is ejected.
- **Note:** Unlike thermoplastics, thermosets undergo a chemical change and cannot be remelted.

Compression Moulding: Applications

- **Advantages:** Low tooling costs, good surface finish, suitable for large and heavy parts, and little material waste compared to injection moulding.
- **Limitations:** Slow production rate due to curing time, difficulty in moulding complex shapes with undercuts, and unsuitability for fragile inserts.
- **Applications:**
  - Electrical switch gears, sockets, and plugs.
  - Automotive parts (e.g., distributor caps).
  - Cookware handles and knobs (Bakelite).
  - Dinnerware (Melamine).

Summary of Moulding Processes

Process	Key Characteristic	Typical Products
Extrusion	Continuous length, uniform cross-section	Pipes, tubes, films
Rotational	Large, hollow, seamless parts	Water tanks, kayaks
Compression	Heat & pressure for thermosetting plastics	Electrical switches, handles

Introduction to Plastic Moulding

- Plastic moulding is the process of shaping plastic using a rigid frame or mold.
- The process typically involves heating the plastic material until it becomes pliable and then forcing it into a mold cavity.
- Once the material cools and solidifies, it takes the shape of the mold.
- Used for producing a wide variety of parts, from simple household items to complex engineering components.

Classification of Plastic Moulding Processes

- Common plastic moulding processes include:
  1. Injection Moulding
  2. Extrusion
  3. Blow Moulding
  4. Compression Moulding
  5. Transfer Moulding
  6. Thermoforming
- The choice of process depends on the type of plastic (thermoplastic or thermosetting), desired shape, production volume, and cost.

Injection Moulding

- One of the most widely used processes for high-volume production of plastic parts.
- **Process:** Granular plastic is fed from a hopper into a heated barrel. It is melted and injected under high pressure into a closed mold cavity.
- The part cools and solidifies within the mold before being ejected.
- **Advantages:** High production rates, excellent repeatability, low labor costs, and ability to mold complex shapes.
- **Applications:** Automotive parts, toys, consumer electronics casings, and bottle caps.

Extrusion Process

- Used to create objects of a fixed cross-sectional profile.
- **Process:** Plastic granules are melted and continuously forced through a die to shape the profile.
- The extruded product is then cooled, typically in a water bath, and cut to the desired length.
- **Advantages:** Continuous production, low tool cost, and excellent for long shapes.
- **Applications:** Pipes, tubing, weatherstripping, window frames, and plastic sheeting.

Blow Moulding

- Used for manufacturing hollow plastic parts.
- **Process:**
  1. A heated plastic tube (parison) is extruded.
  2. The mold closes around the parison.
  3. Air is blown into the parison, expanding it against the mold walls.
  4. The part is cooled and ejected.
- **Advantages:** Fast production of hollow parts, relatively low mold costs.
- **Applications:** Bottles, containers, fuel tanks, and drums.

Compression Moulding

- Commonly used for thermosetting plastics.
- **Process:** A pre-measured amount of molding material (charge) is placed directly into a heated mold cavity.
- The mold is closed under pressure, forcing the material into all areas of the cavity.
- Heat and pressure are maintained until the material cures (cross-links).
- **Advantages:** Low waste, suitable for large and intricate parts, low residual stress.
- **Applications:** Electrical switches, appliance knobs, automotive parts, and dinnerware.

Transfer Moulding

- Similar to compression moulding but with a slight variation in how the material is introduced.
- **Process:** The plastic charge is heated in a separate chamber (pot) until it becomes fluid.
- It is then forced through a sprue and runners into the closed mold cavity.
- **Advantages:** Faster cure times than compression moulding, allows for more complex shapes and intricate inserts.
- **Applications:** Electronic components, integrated circuits encapsulation, and complex electrical connectors.

Summary

- Plastic moulding processes are essential for modern manufacturing.
- Injection moulding is best for complex, high-volume thermoplastic parts.
- Extrusion is ideal for continuous profiles.
- Blow moulding is used for hollow containers.
- Compression and transfer moulding are primarily for thermosetting plastics.
- Selecting the right process is critical for quality and cost-effectiveness.

Selection of Moulding Process

- Selecting the correct plastic moulding process is crucial for manufacturing efficiency, cost-effectiveness, and product quality.
- Key factors influencing the selection include:
  - Type of plastic material (Thermoplastic vs. Thermosetting).
  - Complexity of the part geometry.
  - Production volume and rate required.
  - Tooling and equipment costs.
  - Dimensional accuracy and surface finish requirements.

Process Selection based on Product Type

- **Injection Moulding:** Used for complex, 3D solid parts with high precision. Examples: Gears, toys, electronic enclosures, automotive dashboards.
- **Blow Moulding:** Best for hollow, thin-walled products. Examples: Water bottles, containers, drums, fuel tanks.
- **Extrusion:** Ideal for continuous lengths with a constant cross-section. Examples: Pipes, tubes, weatherstripping, plastic sheets.
- **Compression Moulding:** Preferred for thermosetting plastics and large, relatively simple parts. Examples: Electrical switches, automotive body panels, dinnerware.
- **Rotational Moulding:** Used for large, hollow parts without seams. Examples: Water storage tanks, large playground equipment, kayaks.

Safety Precautions in Plastic Processing

- Plastic processing involves high temperatures, pressures, and potentially hazardous materials.
- **General Safety Guidelines:**
  - Always wear appropriate Personal Protective Equipment (PPE) such as heat-resistant gloves, safety glasses, and safety shoes.
  - Ensure proper ventilation in the working area to remove toxic fumes and vapors emitted during plastic melting.
  - Keep the workspace clean and free of spilled plastic pellets to prevent slip and fall hazards.
  - Understand and follow the Material Safety Data Sheet (MSDS) guidelines for each plastic type being processed.

Machine and Operational Safety

- **Machine Guards:** Never bypass, disable, or remove safety guards on injection moulding, extrusion, or blow moulding machines.
- **Burn Hazards:** Avoid touching heated barrel zones, molds, and newly extruded or injected hot plastic parts.
- **High Pressure:** Be aware of the high hydraulic and injection pressures; maintain a safe distance during the active machine cycle.
- **Emergency Stops:** Familiarize yourself with the location and operation of emergency stop buttons on all equipment.
- **Lockout/Tagout (LOTO):** Always perform proper LOTO procedures before performing maintenance, mold changes, or clearing jams in the machine.

Summary of Unit 4

- Various plastic materials (thermoplastics and thermosetting) are identified using SPI codes and have specific applications based on their properties.
- Key moulding processes include injection, blow, extrusion, rotational, and compression moulding.
- Injection moulding is highly versatile, and understanding its mold components is essential for effective process control.
- Selecting the correct process depends primarily on the product shape, material type, and production scale.
- Strict adherence to safety precautions is mandatory to prevent thermal burns, mechanical injuries, and exposure to harmful fumes.