ME6302	MANUFACTURING TECHNOLOGY – I	L T P C 3 0 0 3

OBJECTIVES:

To introduce the concepts of basic manufacturing processes and fabrication techniques, such as metal casting, metal joining, metal forming and manufacture of plastic components.

UNIT I METAL CASTING PROCESSES 9

Sand Casting: Sand Mould – Type of patterns - Pattern Materials – Pattern allowances –Moulding sand Properties and testing – Cores –Types and applications – Moulding machines– Types and applications; **Melting furnaces**: Blast and Cupola Furnaces; **Principle of special casting processes:** Shell - investment – Ceramic mould – Pressure die casting - Centrifugal Casting - CO_2 process – Stir casting; **Defects in Sand casting**

UNIT II JOINING PROCESSES 9

Operating principle, basic equipment, merits and applications of : Fusion welding processes : Gas welding - Types – Flame characteristics; Manual metal arc welding – Gas Tungsten arc welding - Gas metal arc welding – Submerged arc welding – Electro slag welding; **Operating principle and applications of** : Resistance welding - Plasma arc welding – Thermit welding – Electron beam welding – Friction welding and Friction Stir Welding; Brazing and soldering; **Weld defects:** types, causes and cure.

UNIT III METAL FORMING PROCESSES 9

Hot working and cold working of metals – Forging processes – Open, impression and closed die forging – forging operations. Rolling of metals– Types of Rolling – Flat strip rolling – shape rolling operations – Defects in rolled parts. Principle of rod and wire drawing – Tube drawing – Principles of Extrusion – Types – Hot and Cold extrusion.

UNIT IV SHEET METAL PROCESSES 9

Sheet metal characteristics – shearing, bending and drawing operations – Stretch forming operations – Formability of sheet metal – Test methods –special forming processes-Working principle and applications – Hydro forming – Rubber pad forming – Metal spinning– Introduction of Explosive forming, magnetic pulse forming, peen forming, Super plastic forming – Micro forming.

UNIT V MANUFACTURE OF PLASTIC COMPONENTS 9

Types and characteristics of plastics – Moulding of thermoplastics – working principles and typical applications – injection moulding – Plunger and screw machines – Compression moulding, Transfer Moulding – Typical industrial applications – introduction to blow moulding –Rotational moulding – Film blowing – Extrusion – Thermoforming – Bonding of Thermoplastics.

TOTAL: 45 PERIODS

OUTCOMES:

Upon completion of this course, the students can able to apply the different manufacturing process and use this in industry for component production.

TEXT BOOKS:

1. Hajra Chouldhary S.K and Hajra Choudhury. AK., "Elements of workshop Technology", volume I and II, Media promoters and Publishers Private Limited, Mumbai, 1997
2. Kalpakjian. S, "Manufacturing Engineering and Technology", Pearson Education India Edition, 2006

REFERENCES:

1. Gowri P. Hariharan, A.Suresh Babu, "Manufacturing Technology I", Pearson Education, 2008
2. Roy. A. Lindberg, "Processes and Materials of Manufacture", PHI / Pearson education, 2006
3. Paul Degarma E, Black J.T and Ronald A. Kosher, "Materials and Processes, in Manufacturing" Eight Edition, Prentice – Hall of India, 1997.
4. Sharma, P.C., "A Text book of production Technology", S.Chand and Co. Ltd., 2004.
5. Rao, P.N. "Manufacturing Technology Foundry, Forming and Welding", 2nd Edition, TMH-2003; 2003

STUCOR APP

UNIT 1

INTRODUCTION:

Manufacturing

1. To make or process (a raw material) into a finished product, especially by means of a large-scale industrial operation.
2. To make or process (a product), especially with the use of industrial machines.
3. To create, produce, or turn out in a mechanical manner.
4. To make or process goods, especially in large quantities and by means of industrial machines.
5. The making or producing of something.

Manufacturing in its broadest sense, is the process of converting raw material into products. It encompasses the design and manufacturing of goods using various production methods and techniques.

Science, Engineering and Technology

Science is the reasoned investigation or study of phenomena, aimed at discovering enduring principles by employing formal techniques such as the scientific method.

Engineering is the goal-oriented process of designing and making tools and systems using results and techniques from science.

The development of technology may draw upon many fields of knowledge, including scientific, engineering, mathematical, linguistic, and historical knowledge, to achieve some practical result.

Technologies *are not usually exclusively products of science, because they have to satisfy requirements such as utility, usability and safety.*

Source of Words:

Manufacturing – derived from Latin
Maufactus – made by hand
Manufacture appearing in 1567
Manufacturing – 1683

Syllabus Overview

Generally it's a complex activity involving people who have a broad range of disciplines and skills, together with a wide variety of machinery, equipment & tools with various levels of automation & controls, including computer, robots & material handling equipments.

CASTING: Introduction

Virtually nothing moves, turns, rolls, or flies without the benefit of cast metal products.

The metal casting industry plays a key role in all the major sectors of our economy. There are castings in locomotives, cars trucks, aircraft, office buildings, factories, schools, and homes.

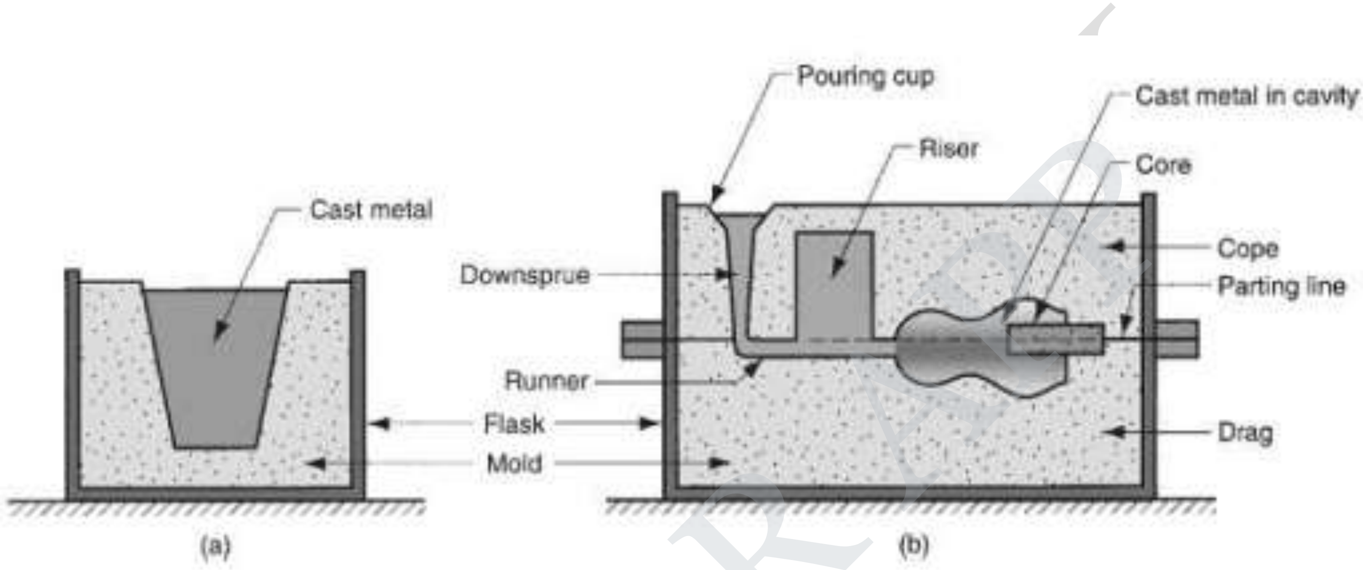


FIGURE Two forms of mold: (a) open mold, simply a container in the shape of the desired part; and (b) closed mold, in which the mold geometry is more complex and requires a gating system (passageway) leading into the cavity.

Casting means pouring molten metal into a mould with a cavity of the shape to be made, and allowing it to solidify. When solidified, the desired metal object is taken out from the mould either by breaking the mould or taking the mould apart.

The solidified object is called the casting. By this process, intricate parts can be given strength and rigidity frequently not obtainable by any other manufacturing process.

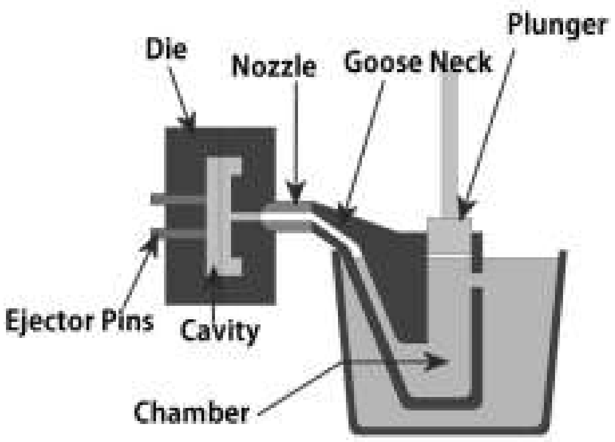
The mould, into which the metal is poured, is made of some heat resisting material. Sand is most often used as it resists the high temperature of the molten metal.

Casting processes divide into two broad categories

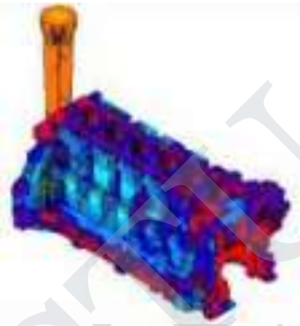
- Expendable-mold casting (Sand Casting)
- Permanent-mold casting (Die Casting)

CASTING: Facts

- ✓ One of the earliest metal shaping methods known to human being.
- ✓ *It is the Process in which molten metal flows by gravity or other force into a mold where it solidifies in the shape of the mold cavity.*
- ✓ Commonly, the term casting also applies to the part made in the process.
- ✓ The process can be applied on metals, ceramics and plastics.
- ✓ The term casting is commonly used for metals.
- ✓ Examples of castings Machine Frames, Engine Blocks and more ... *(Page 5)*
- ✓ The term molding is used for plastics.
- ✓ Examples of molds – cake-pan, an ice-cube-tray or the
- ✓ Types of castings – sand casting and die casting
- ✓ Sand casting – pouring molten metal into a sand mold, breaking up the mold to remove the casting. Sand casting requires a pattern – a full sized model of the part.
- ✓ Die casting is a permanent-mold-casting – molten metal is injected into the mold cavity under high pressure. Molds for die casting are named as dies.
- ✓ Casting is usually performed in a foundry.
- ✓ Foundry: Factory equipped for making molds, melting and handling molten metal, performing the casting process, and cleaning the finished casting.
- ✓ Workers who perform casting are called foundrymen.
- ✓ Simple Steps in casting:
    1. Prepare mould (using pattern) /die
    2. Melting and pouring molten metal into a mould/die.
    3. Let it solidify (Solidification and cooling)
    4. Removal, Cleaning, Finishing and Inspection processes



Example of Permanent mold casting

Landing gear Uplock support for the Boeing 767 long range aircraft  Aluminum	Diesel Locomotive Traction Motor Rotor Disc  Steel
Intermediate Lever Arm in the BMW Engine Valve Train  Steel	Hydraulic Accumulator Cylinder for Navy Submarines  Duplex Stainless Steel
Aluminum Cylinder Block for General Motors Truck/SUV Engines  Aluminum	Track Shoe for the NASA Crawler-Transporter  Steel
F-5 Fighter Plane Crossbleed Valve  Stainless Steel	Snubber Arm for Mining Shovel Dipper Door  Cr-Ni-Mo Steel

For more details refer<< http://sfsa.org/tutorials/index.html>>

CASTING: Advantages

- ✓ Casting can be used to create complex part geometries, including both external and internal shapes.
- ✓ Some casting processes are capable of producing parts to *net shape*. (No further manufacturing operations are required to achieve the required geometry and dimensions of the parts.)
- ✓ Other casting processes are *near net shape*, for which some additional shape processing is required (usually machining) in order to achieve accurate dimensions and details.
- ✓ Casting can be used to produce very large parts. Castings weighing more than 100 tons have been made.
- ✓ The casting process can be performed on any metal that can be heated to the liquid state.
- ✓ Some casting methods are quite suited to mass production.

CASTING: Disadvantages

Different disadvantages for different casting methods. These include

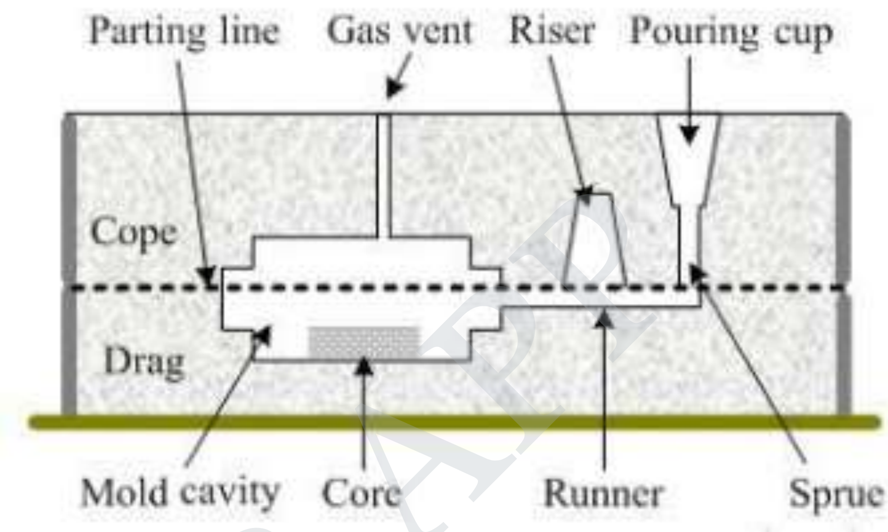
- ✓ limitations on mechanical properties
- ✓ porosity
- ✓ poor dimensional accuracy and surface finish for some casting processes,
- ✓ safety hazards to humans when processing hot molten metals,
- ✓ Environmental problems.

CASTING: Applications

- ✓ Parts made by casting processes range in size from small components weighing only a few ounces up to very large products weighing tons.
- ✓ The list of parts includes dental crowns, jewelry, statues, wood-burning stoves, engine blocks and heads for automotive vehicles, machine frames, railway wheels, frying pans, pipes, and pump housings.
- ✓ All varieties of metals can be cast, ferrous and nonferrous.

CASTING TERMS – for a Sand Casting

1. Flask: A metal or wood frame, without fixed top or bottom, in which the mold is formed. Depending upon the position of the flask in the molding structure, it is referred to by various names such as drag – lower molding flask; cope – upper molding flask, cheek – intermediate molding flask used in three piece molding.



2. Pattern: It is the replica of the final object to be made. The mold cavity is made with the help of pattern.
3. Parting line: This is the dividing line between the two molding flasks that makes up the mold.
4. Molding sand: Sand, which binds strongly without losing its permeability to air or gases. It is a mixture of silica sand, clay, and moisture in appropriate proportions.
5. Facing sand: The small amount of carbonaceous material sprinkled on the inner surface of the mold cavity to give a better surface finish to the castings.
6. Core: A separate part of the mold, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.
7. Core prints: In a casting if we want to have a hole/cavity then this is done by core. This core is placed in the mould on the impressions made in the sand. These projections are core prints.
8. Pouring basin: A small funnel shaped cavity at the top of the mold into which the molten metal is poured.
9. Sprue: The passage through which the molten metal, from the pouring basin, reaches the mold cavity. In many cases it controls the flow of metal into the mold.
10. Runner: The channel through which the molten metal is carried from the sprue to the gate.

11. Gate: A channel through which the molten metal enters the mold cavity.
12. Chaplets: Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force.
13. Riser: A riser is a reservoir in the mold that serves as a source of liquid metal for the casting to compensate for shrinkage during solidification. Also known as “feed head”.
14. Vent: Small opening in the mold to facilitate escape of air and gases.

Quick Review

Process	Advantages	Disadvantages	Examples
Sand Casting	Many metals, Sizes, Shapes, Cheap	Poor finish & Tolerance	Engine blocks, Cylinder Heads
Die Casting	Excellent Dimensional accuracy, High production rate	Costly dies, Small parts, non-ferrous metals	Gear, Camera bodies, Car wheels

Metals processed by casting

- ✓ Sand casting – 60%
- ✓ Investment casting – 7%
- ✓ Die casting – 9%
- ✓ Permanent mold casting – 11%
- ✓ Centrifugal casting – 7%
- ✓ Shell mold casting – 6%

Sand Mould (Sand Casting)

- ✓ The cavity in the sand mold is formed by packing sand around a pattern, then separating the mold into two halves and removing the pattern.
- ✓ The mold must also contain gating and riser system.
- ✓ If casting is to have internal surfaces, a core must be included in mold.
- ✓ A new sand mold must be made for each part produced.

Properties of sand moulds

- ✓ It must be strong enough to withstand the temperature and weight of the molten metal.
- ✓ It must resist the erosive action of the flowing hot metal.
- ✓ It should generate minimum amount of gases as a result of the temperature of the molten metal.
- ✓ It should have good venting capacity to allow the generated gases to completely escape from it.

Types of sand moulds

✓ Green Sand Moulds

Prepared from silica grains, clay and moisture. Metal is poured immediately and the castings taken out. Most commonly used for mass production.

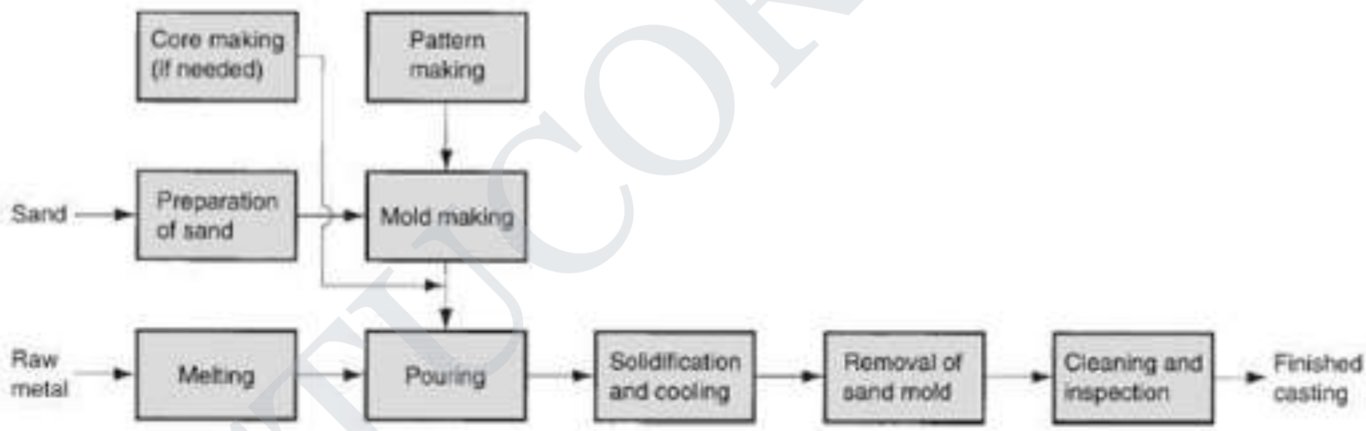
✓ Dry Sand Moulds

Completely dried by keeping in an oven between 150 to 350 C for 8 to 48 hours. Have higher strength. Used for medium to large castings. Better surface finish and dimensional accuracy.

✓ Skin Dried Moulds

Skin is normally dried to a depth of 15 to 25 mm by torches. Can be done in pit moulding. Immediate pouring is needed.

SAND CASTING STEPS



Steps in the production sequence in sand casting. The steps include not only the casting operation but also pattern making and mold making.

There are five basic steps in making sand castings:

1. Patternmaking
2. Core making
3. Molding
4. Melting and pouring
5. Cleaning

PATTERN MAKING

The pattern is a physical model of the casting used to make the mold. The mold is made by packing some readily formed aggregate material, such as molding sand, around the pattern. When the pattern is withdrawn, its imprint provides the mold cavity, which is ultimately filled with metal to become the casting. If the casting is to be hollow, as in the case of pipe fittings, additional patterns, referred to as cores, are used to form these cavities.

CORE MAKING

Cores are forms, usually made of sand, which are placed into a mold cavity to form the interior surfaces of castings. Thus the void space between the core and mold-cavity surface is what eventually becomes the casting.

MOLDING

Molding consists of all operations necessary to prepare a mold for receiving molten metal. Molding usually involves placing a molding aggregate around a pattern held with a supporting frame, withdrawing the pattern to leave the mold cavity, setting the cores in the mold cavity and finishing and closing the mold.

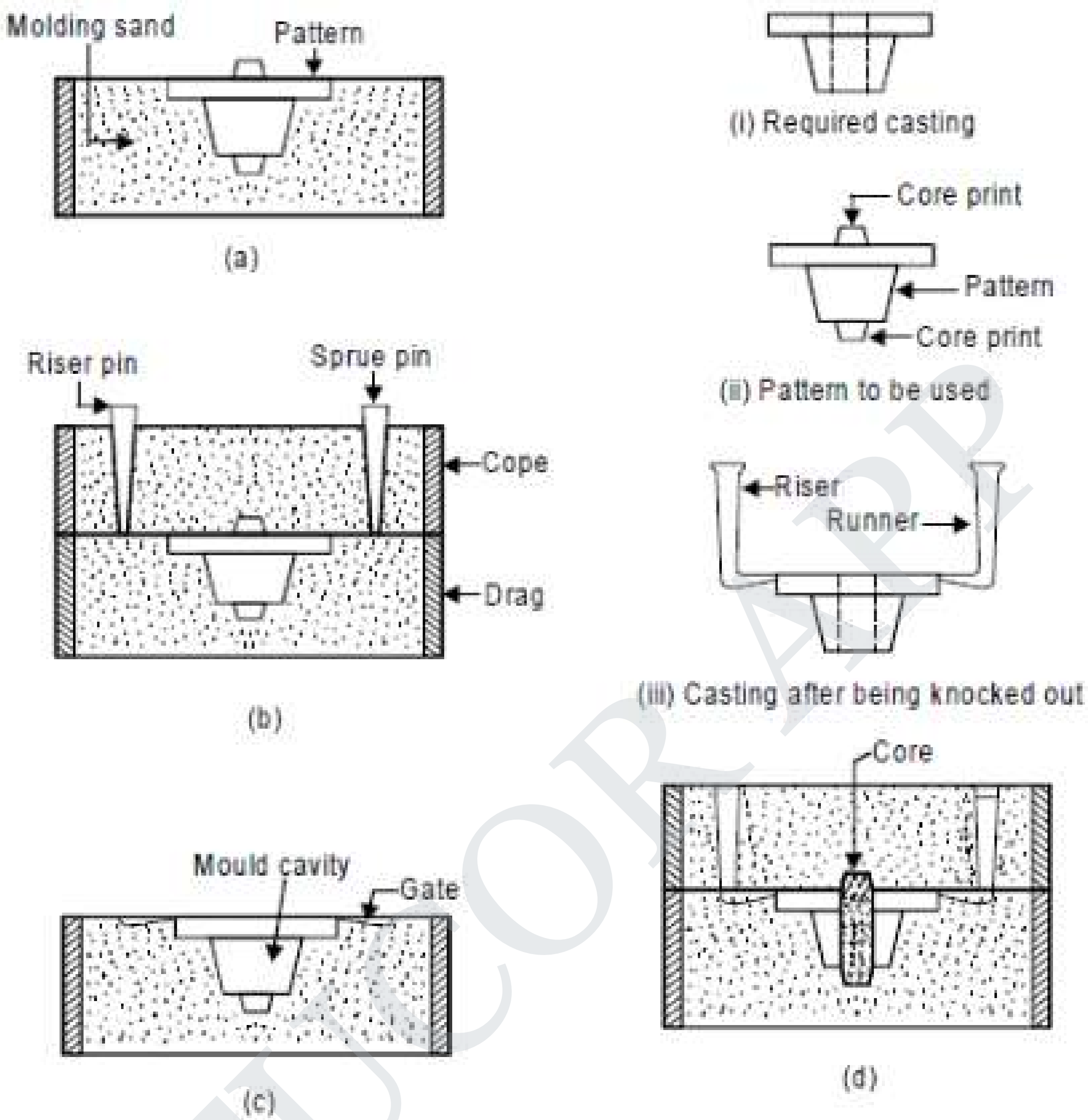
MELTING AND POURING

The preparation of molten metal for casting is referred to simply as melting. Melting is usually done in a specifically designated area of the foundry, and the molten metal is transferred to the pouring area where the molds are filled.

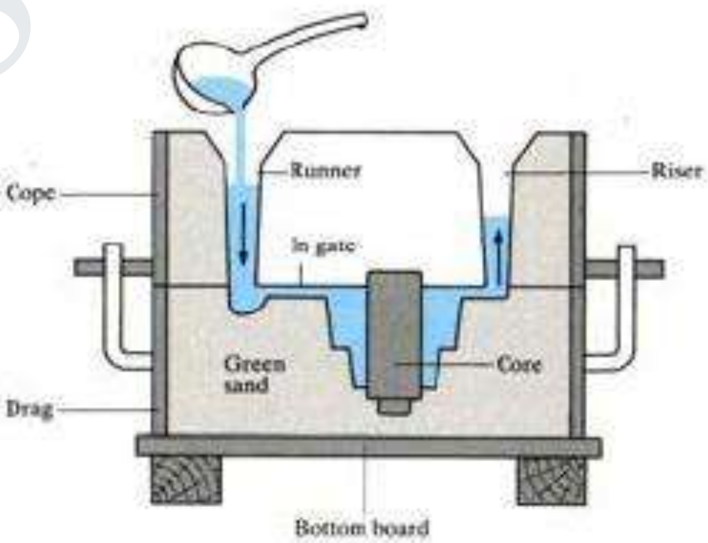
CLEANING

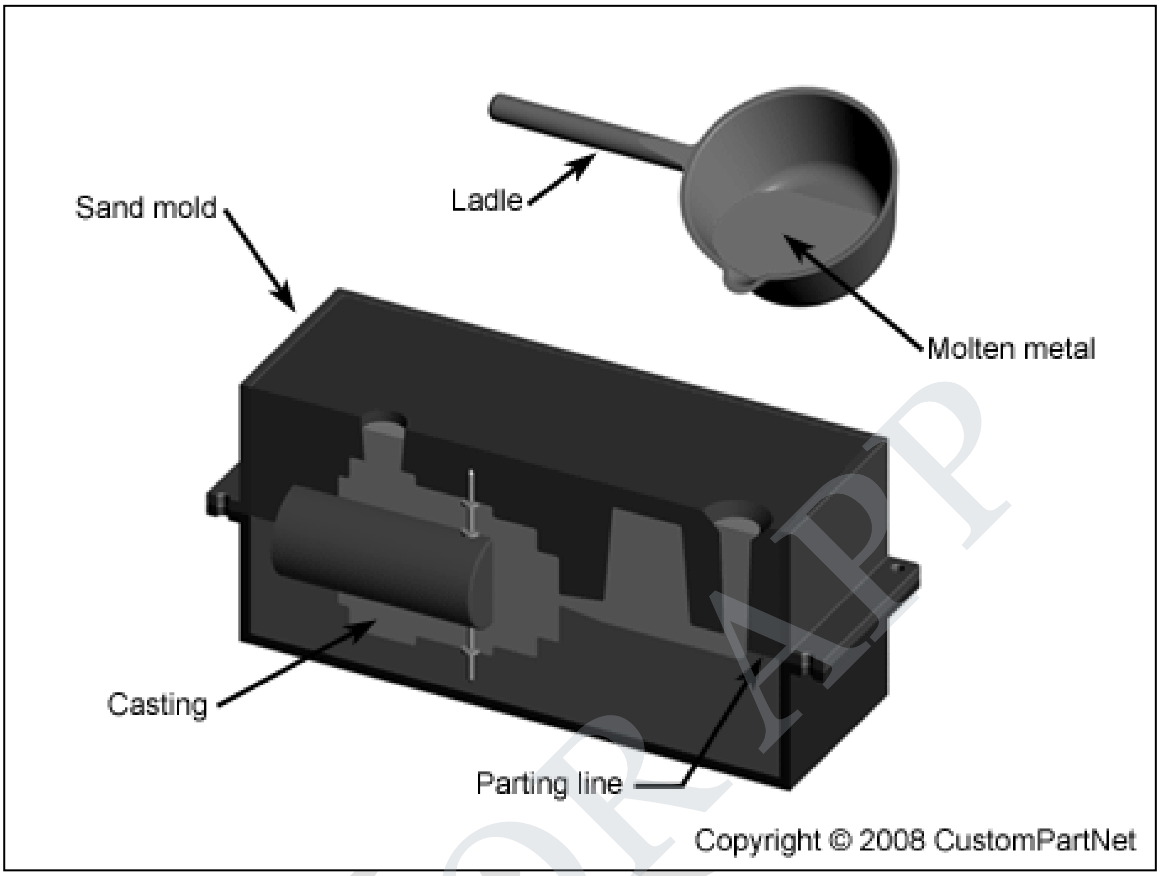
Cleaning refers to all operations necessary to the removal of sand, scale, and excess metal from the casting. Burned-on sand and scale are removed to improved the surface appearance of the casting. Excess metal, in the form of fins, wires, parting line fins, and gates, is removed. Inspection of the casting for defects and general quality is performed.

STAGES IN THE PRODUCTION OF THE MOULD



Example of making a mold





SECTIONAL VIEW OF A CASTING MOULD

PATTERN and MOULD

A Pattern is

- ✓ A replica of the final product and is used for preparing mould cavity
- ✓ Made of wood or metal or plastics

Mould cavity

- ✓ Which contains molten metal is essentially a negative of the final product

Mould material

- ✓ Should posses refractory characteristics and withstand the pouring temperature

Few Facts:

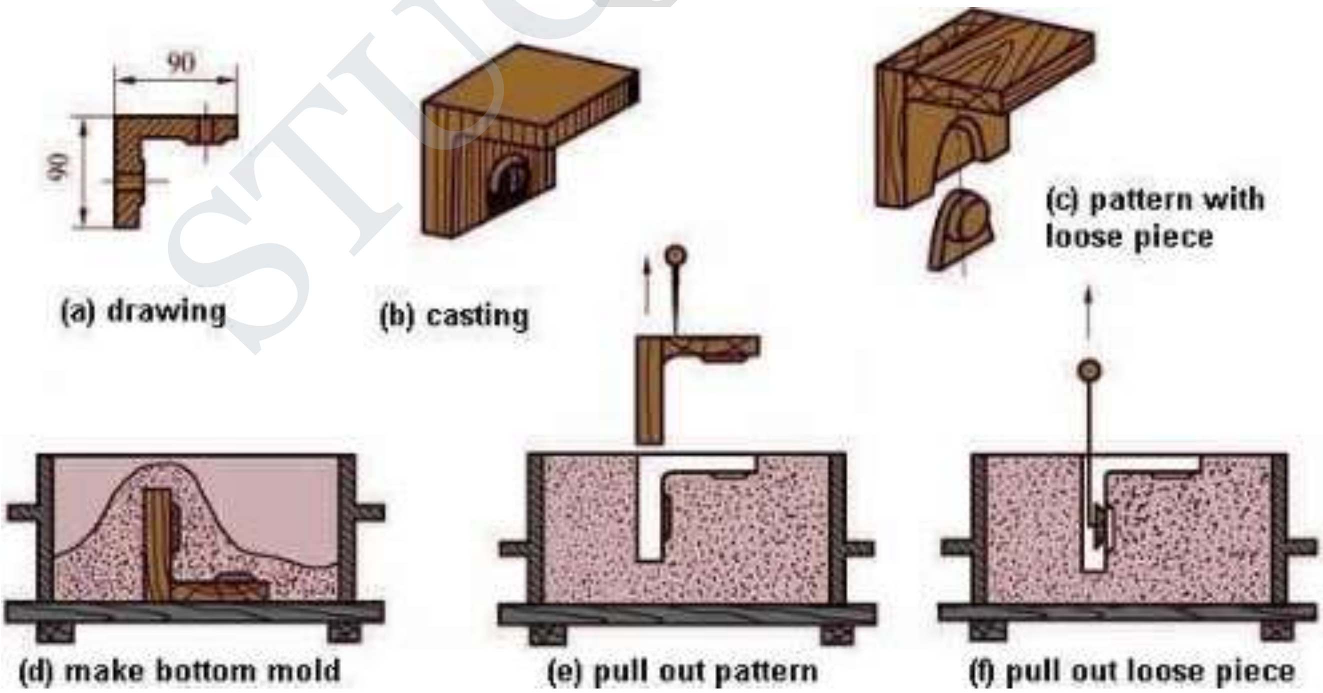
- ✓ When the mould is used for single casting, it is made of sand and known as expendable mould.
- ✓ When the mould is used repeatedly for number of castings and is made of metal or graphite are called permanent mould
- ✓ For making holes or hollow cavities inside a casting, cores made of sand are used.

PATTERNS (Page 14)

- ✓ A replica of the object to be made by the casting process, with some modifications.
- ✓ The pattern is the principal tool during the casting process. It is the replica of the object to be made by the casting process, with some modifications.
- ✓ The main modifications are the addition of pattern allowances, and the provision of core prints. If the casting is to be hollow, additional patterns called cores are used to create these cavities in the finished product.
- ✓ The quality of the casting produced depends upon the material of the pattern, its design, and construction.
- ✓ The costs of the pattern and the related equipment are reflected in the cost of the casting. The use of an expensive pattern is justified when the quantity of castings required is substantial.

Functions of the Pattern

1. A pattern prepares a mold cavity for the purpose of making a casting.
2. A pattern may contain projections known as core prints if the casting requires a core and need to be made hollow.
3. Runner, gates, and risers used for feeding molten metal in the mold cavity may form a part of the pattern.
4. Patterns properly made and having finished and smooth surfaces reduce casting defects.
5. A properly constructed pattern minimizes the overall cost of the castings.


90
90
(a) drawing
(b) casting
(c) pattern with
loose piece
(d) make bottom mold
(e) pull out pattern
(f) pull out loose piece

Types of patterns

1. Solid/Single piece pattern
2. Split/Two piece pattern
3. Three/Multi piece pattern
4. Match plate pattern
5. Loose piece pattern
6. Cope and Drag pattern
7. Follow board pattern
8. Gated pattern
9. Sweep pattern
10. Skeleton pattern
11. Segmental/Split pattern

The following factors affect the choice of a pattern.

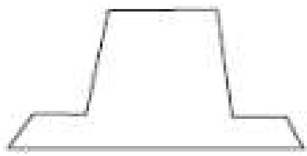
(i) Number of Castings to be produced.
(ii) Size and complexity of the shape and size of casting
(iii) Type of molding and castings method to be used.
(iv) Machining operation
(v) Characteristics of castings

TYPES OF PATTERN:

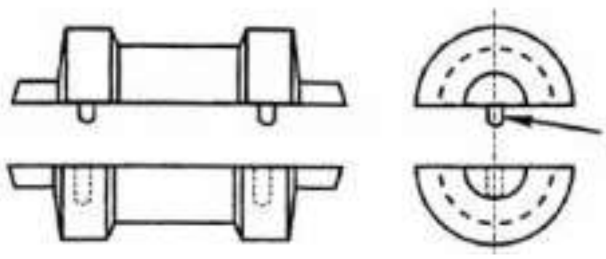
Patterns can be of different types depending on the shape and size of the part to be manufactured. Given below are some of the commonly used pattern types.

1. A *solid pattern* is the most simple of all and is used to make simple shapes.

✓ As the name itself suggests, a solid pattern is a single solid piece without joints, partings lines or loose pieces.


Single piee pattern

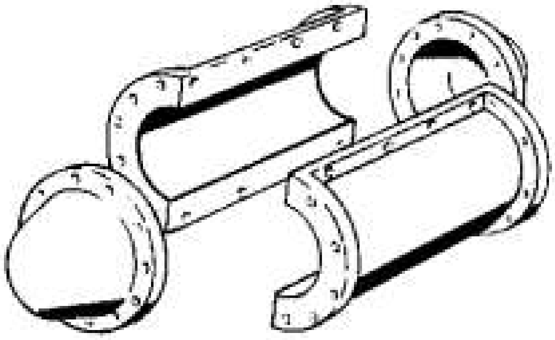
2. When solid pattern is difficult for withdrawal from the mold cavity, then solid pattern is split in two parts.



✓ *Split pattern* is made in two pieces which are joined at the parting line by means of dowel pins.

✓ The splitting at the parting line is done to facilitate the withdrawal of the pattern.

3. Some patterns are of complicated kind in shape and hence cannot be made in one or two pieces because of difficulty in withdrawing the pattern.



- ✓ Therefore these patterns are made in either *three pieces or in multi-pieces.* Multi molding flasks are needed to make mold from these patterns.

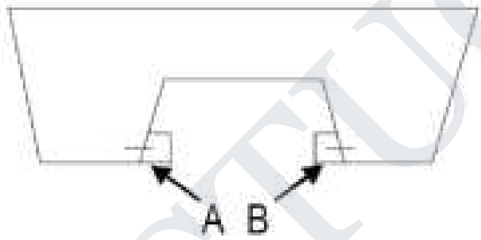
4. *Match plate pattern* is made in two halves and is on mounted on the opposite sides of a plate (wooden or metallic), known as match plate.

- ✓ The gates and runners are also mounted on the match plate, so that very little hand work is required.

Match plate pattern

- ✓ This pattern is used in machine molding which results in higher productivity.
- ✓ This type of pattern is used for a large number of castings.
- ✓ Piston rings of I.C. engines are produced by this process.

5. *Loose-piece Pattern* is used when pattern is difficult/not possible for withdrawal from the mould.

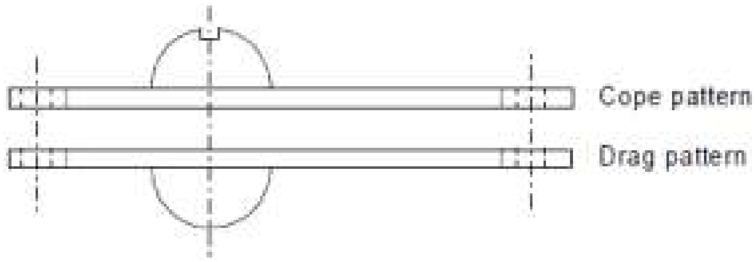


Loose piece pattern

- ✓ Loose pieces are provided on the pattern and they are the part of pattern.
- ✓ The main pattern is removed first leaving the loose piece portion of the pattern in the mould.
- ✓ Finally the loose piece is withdrawal separately leaving the intricate mould.

6. A *cope and drag pattern* is a split pattern having the cope and drag portions each mounted on separate match plates.

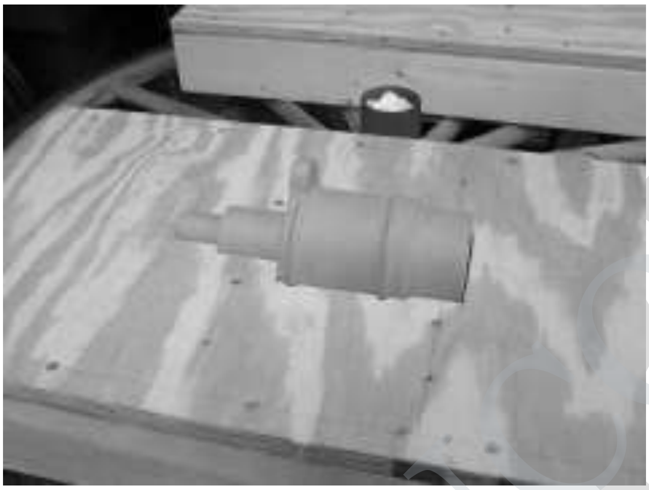
- ✓ These patterns are used when in the production of large castings; the complete moulds are too heavy and unwieldy to be handled by a single worker.

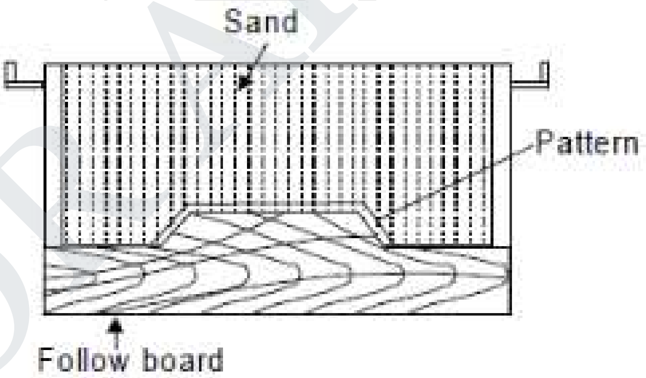


Cope and drag pattern

7. A *follow board* is a wooden board used to support a pattern during moulding. It acts as a seat for the pattern.

- ✓ Single piece patterns which have an odd shape or very thin wall require a follow board.
- ✓ In the case of odd shape, the hollow board is provided with a cavity corresponding to the shape of the pattern in which the pattern is seated for moulding.
- ✓ In the case of very thin wall, the follow- board carries a projection confirming to the inside shape of the thin walled pattern to support it during moulding.
- ✓ If such a support is not provided, the pattern may sag or get broken due to less wall thickness during ramming.

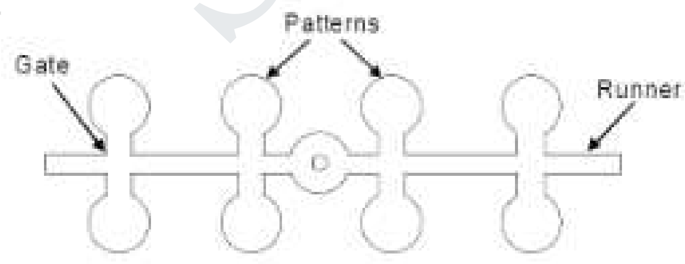




Follow board pattern

8. *Gated Pattern:* In the mass production of castings, multi cavity moulds are used.

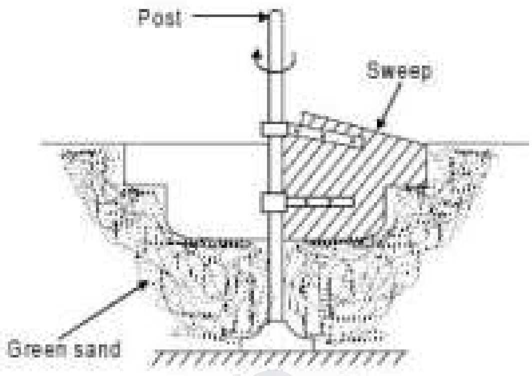
- ✓ Such moulds are formed by joining a number of patterns and gates and providing a common runner for the molten metal.



Gated pattern

- ✓ These patterns are made of metals.
- ✓ Because of their higher cost, these patterns are used for producing small castings in mass production systems and on molding machines.

9. *Sweep patterns* are used for forming large circular moulds of symmetric profile by revolving a sweep (Section of board) attached to a spindle.



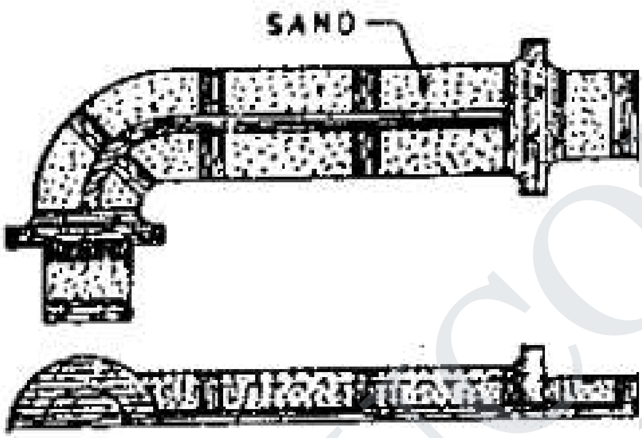
Sweep pattern

✓ In several cases it could be economical to save the money and efforts of making the full pattern because of symmetry.

✓ This type of pattern is used when a casting of large size is to be produced in a short time.

✓ Large kettles of C.I. are made by sweep patterns.

10. When only a small number of large and heavy castings are to be made, it is not economical to make a solid pattern.



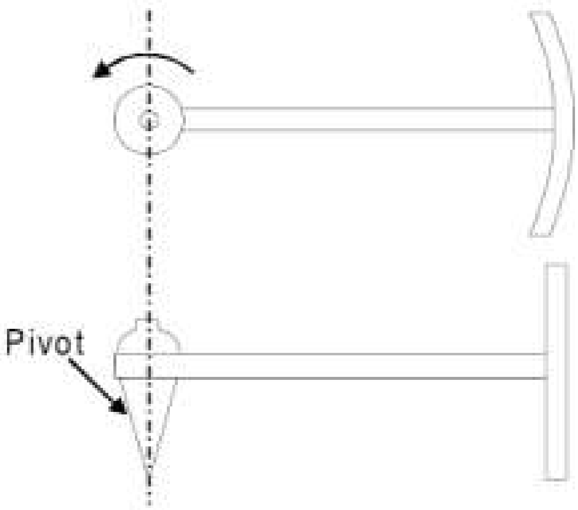
✓ In such cases, however, a *skeleton pattern* may be used.

✓ This is a ribbed construction of wood which forms an outline of the pattern to be made.

✓ This frame work is filled with loam sand and rammed. The surplus and is removed by strickle board.

✓ For round shapes, the pattern is made in two halves which are joined with glue or by means of screws etc.

11. *Segmental Patterns* are used for circular castings, (for example wheel rim, gear blank etc) avoiding the use of solid pattern of exact size.



Segmental or part pattern

✓ In principle they work like a sweep, but the difference is that a sweep is given a continuous revolving motion to generate the desired shape, where as segmental pattern is a portion of the solid pattern itself and the mould is prepared in parts by it.

✓ The movement of segmental pattern

is guided by the use of a central pivot.

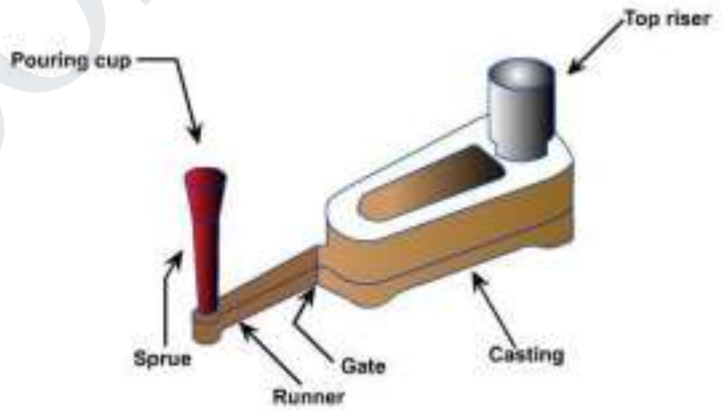
- ✓ Segmental pattern is mounted on a central pivot and after preparing the part mould in one position, the segment is moved to the next position.
- ✓ The operation is repeated till the complete mould is ready.

PATTERN MATERIALS:

Patterns may be constructed from the following materials. Each material has its own advantages, limitations, and field of application.

To be suitable for use, the pattern material should be:

1. Easily worked, shaped and joined
2. Light in weight
3. Strong, hard and durable
4. Resistant to wear and abrasion
5. Resistant to corrosion, and to chemical reactions
6. Dimensionally stable and unaffected by variations in temperature and humidity
7. Available at low cost



A typical pattern attached with gating and risering system

Some materials used for making patterns are: wood, metals and alloys, plaster of Paris, plastics and resins, and wax.

Wood:

Teak wood, rose wood, white pine are used. Laminated wooden sheets used for getting accuracy, surface finish and long life.

Advantages: Light in weight, Economical and easily available, easy to *to convert in required shape and sizes*, easily smoothened by varnishes and paints, can be preserved for a long time.

Limitations: Absorbs water from sand and changes its shape, non uniform structure, high wear and tear, Not used for mass production.

Metals and its alloys:

It is used when pattern are made in mass production with more accuracy.

It overcomes almost all the shortcomings of wood. There are some limitations also in the use of metals.

Limitation:

- In comparison to wood it is costlier.
- In this case machining is required which will increase the cost of pattern.
- It is heavier as compared to wooden pattern.
- It is affected by atmospheric corrosion due to which treatment is a must which increase the cost.

a. CAST IRON:

It is economical. It can be casted to any shape having good machinability, resistance to abrasion, gives better surface finish, it is very heavy.

b. BRASS:

Used for making patterns of smaller sizes. It has more strength, more resistance to corrosion can be machined very easily, suitable for good surface finish, can be casted into any shape. It is heavier than cast iron.

c. ALUMINIUM:

Pattern of bigger sizes are made by this metal. Since the weight is less and it is economical. It can be casted and machined easily for better finish. It is not as stronger as other metals.

Plaster:

Plaster of paris can be casted very easily to any shape.

It has a very high compressive strength and can be used to make patterns of smaller sizes with close dimension control.

It has the property that it expands on solidification.

In case proper plaster is selected the effect of shrinkage is automatically neutralized.

Plastics and resins

Plastic is used for making a pattern due to the properties lighter in weight

More strength with lesser wear, gives better finish and low shrinkage during melting also mot much costlier.

Plastic that are used for pattern making are thermosetting resins and phenolic resins.

Wax:

It primarily used in investment castings.

Good surface finish and high dimensional accuracy, cost very less, only used for making small patterns.

Commonly used waxes are paraffin wax, shellac wax and microcrystalline wax.

PATTERN ALLOWANCE:

- ✓ Pattern allowance is a vital feature as it affects the dimensional characteristics of the casting.
- ✓ when the pattern is produced, certain allowances must be given on the sizes specified in the finished component drawing so that a casting with the particular specification can be made.
- ✓ The selection of correct allowances greatly helps to reduce machining costs and avoid rejections.
- ✓ The allowances usually considered on patterns and core boxes are as follows:

1. Shrinkage/Contraction allowance
2. Draft or taper allowance
3. Machining or finish allowance
4. Distortion or camber allowance
5. Rapping allowance

Shrinkage/Contraction Allowance

All most all cast metals shrink or contract volumetrically on cooling. The metal shrinkage is of two types:

i. Liquid Shrinkage: it refers to the reduction in volume when the metal changes from liquid state to solid state at the solidus temperature. To account for this shrinkage; riser, which feed the liquid metal to the casting, are provided in the mold.

ii. Solid Shrinkage: it refers to the reduction in volume caused when metal loses temperature in solid state. To account for this, shrinkage allowance is provided on the patterns.

The rate of contraction with temperature is dependent on the material. For example steel contracts to a higher degree compared to aluminum.

To compensate the solid shrinkage, a shrink rule must be used in laying out the measurements for the pattern.

A shrink rule for cast iron is 1/8 inch longer per foot than a standard rule. If a gear blank of 4 inch in diameter was planned to produce out of cast iron, the shrink rule in measuring it 4 inch would actually measure 4 -1/24 inch, thus compensating for the shrinkage. The various rate of contraction of various materials are given in Table below.

Rate of Contraction of Various Metals

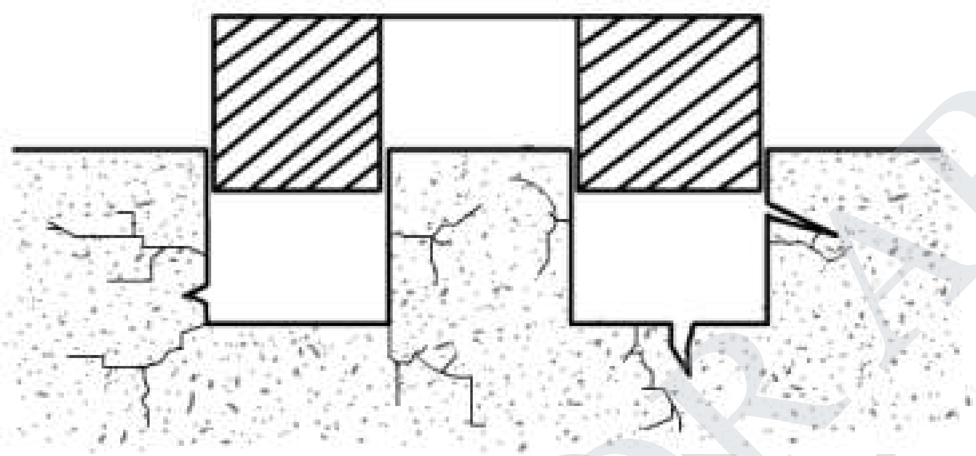
Material	Dimension	Shrinkage allowance (inch/ft)
Grey Cast Iron	Up to 2 feet	0.125
	2 feet to 4 feet	0.105
	over 4 feet	0.083
Cast Steel	Up to 2 feet	0.251
	2 feet to 6 feet	0.191
	over 6 feet	0.155
Aluminum	Up to 4 feet	0.155
	4 feet to 6 feet	0.143
	over 6 feet	0.125
Magnesium	Up to 4 feet	0.173
	Over 4 feet	0.155

Draft or Taper Allowance

By draft is meant the taper provided by the pattern maker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the sand mold and without excessive rapping by the molder.

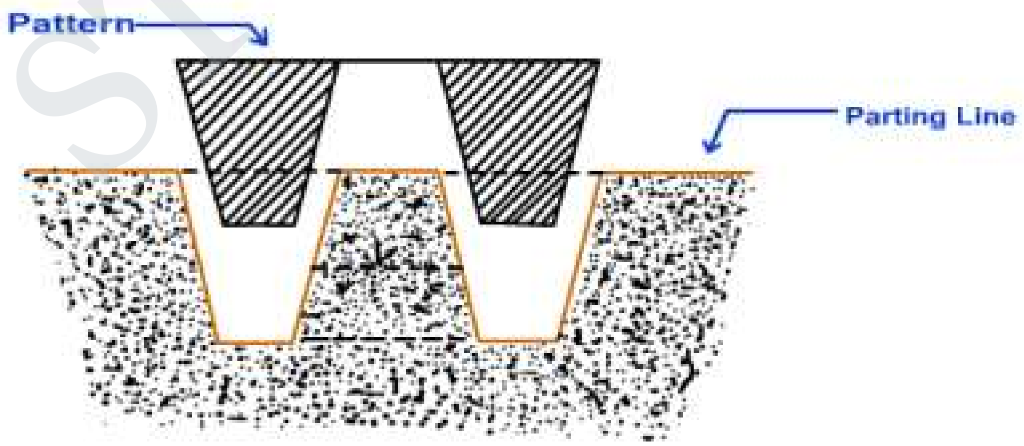
In the following figure, till the pattern is completely lifted out, its sides will remain in contact with the walls of the mold, thus tending to break it.

Pattern Having No Draft on Vertical Edges



In the following figure, the moment the pattern lifting commences, all of its surfaces are well away from the sand surface. Thus the pattern can be removed without damaging the mold cavity.

Pattern Having Draft on Vertical Edges



Draft allowance varies with the complexity of the sand job. But in general inner details of the pattern require higher draft than outer surfaces.

The amount of draft depends upon the length of the vertical side of the pattern to be extracted; the intricacy of the pattern; the method of molding; and pattern material.

Table : Draft Allowances of Various Metals

Pattern material	Height of the given surface (inch)	Draft angle (External surface)	Draft angle (Internal surface)
	1	3.00	3.00
	1 to 2	1.50	2.50
Wood	2 to 4	1.00	1.50
	4 to 8	0.75	1.00
	8 to 32	0.50	1.00
	1	1.50	3.00
	1 to 2	1.00	2.00
Metal and plastic	2 to 4	0.75	1.00
	4 to 8	0.50	1.00
	8 to 32	0.50	0.75

Machining or Finish Allowance

The finish and accuracy achieved in sand casting are generally poor and therefore when the casting is functionally required to be of good surface finish or dimensionally accurate, it is generally achieved by subsequent machining.
Machining or finish allowances are therefore added in the pattern dimension.
The amount of machining allowance to be provided for is affected by the method of molding and casting used viz. hand molding or machine molding, sand casting or metal mold casting.
The amount of machining allowance is also affected by the size and shape of the casting; the casting orientation; the metal; and the degree of accuracy and finish required.

Table : Machining Allowances of Various Metals

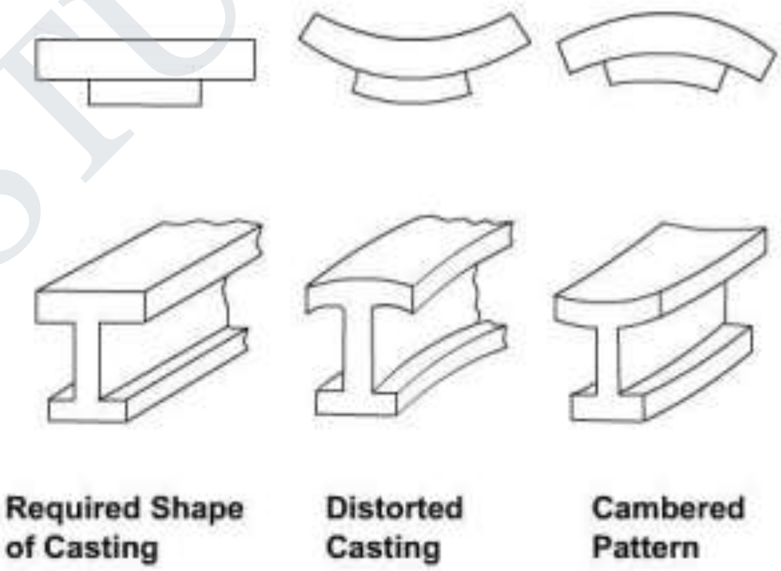
Metal	Dimension (inch)	Allowance (inch)
	Up to 12	0.12
Cast iron	12 to 20	0.20
	20 to 40	0.25
	Up to 6	0.12
Cast steel	6 to 20	0.25
	20 to 40	0.30
	Up to 8	0.09
Non ferrous	8 to 12	0.12
	12 to 40	0.16

Distortion/Camber Allowance

This is provided on patterns whose castings tend to distort on cooling.

The pattern itself is distorted suitably to yield a proper shaped casting.

Required for flat, long, 'U' and 'V' shaped castings.



Shake/Rapping Allowance

To withdraw the pattern from the rammed sand easily without damaging the mould walls of mould cavity pattern is Shaked/ rapped.

During this process the mould cavity is enlarged. To compensate this pattern size is reduced.

Important for large sized and precision castings;

Amount of allowance depends on Extent of rapping, Degree of compaction of sand, size of mould; most of this are difficult to evaluate.

Corner and fillets allowance:

The intersection of surfaces in castings must be smooth and form no sharp angles. For this, the external and internal corners of patterns are suitably rounded.

Fillets facilitate the removal of the pattern from the mould, prevent the formation of cracks and shrink holes in the casting.

MOULDING SAND

- ✓ It is the freshly prepared refractory material used for making the mould cavity.
- ✓ It is a mixture of silica, clay and moisture in appropriate proportions to get the desired results and it surrounds the pattern while making the mould.

MOULDING SAND COMPOSITION:

1. Sand 2. Binder 3. Additive

SAND

- ✓ Silica (SiO_2) or silica mixed with other minerals
- ✓ Good refractory properties - capacity to endure high temperature
- ✓ Small grain size yields on the cast part
- ✓ Large grain size is more permeable allowing gases to escape during pouring
- ✓ Irregular grain shapes strengthen molds due to interlocking, compared to round grains; Disadvantage: interlocking tends to reduce permeability.

BINDER

- *It used to bring the property of cohesiveness to the sand. It binds the sand grains and gives strength to moulding sand.*
- Organic binders:

  Mainly used for core making.
  They are cereal, resins, pitch, drying oils, molasses etc.
- Inorganic binders:

  Clay binder most common type of organic binder.

  It is natural earthy material.

  Clay is formed by weathering and decomposition of rocks.

  Common used type of clays are fire clay, kaolinite, bentonite, the last two are popular because they have high thermo chemical stability.

ADDITIVES

- It improves the molding sand strength, refractoriness and permeability.
- It gives good surface finish to casting and eliminates casting defects.
- Sea coal:

  Fine powdered bituminous coal, used to obtain smoother and cleaner surfaces of casting, mainly used to make ferrous castings.
- Saw dust:

It improves permeability and deformability of moulds.(expansion defects)

- Coal dust:

  It is basically used for providing better surface finish to the castings. When it comes into contact with the molten metal, it would provide a gaseous envelope to keep the molten metal from fusing with the sand thus providing a good surface finish.
- Cereals:

Finely ground corn flour or cornstarch. It increases green and dry strength of the moulding sand.

TYPES OF MOULDING SAND:

- Nature moulding sand; Artificial/Synthetic moulding sand (expensive); Sources;
- Desired strength and bonding properties of this sand are developed by additive materials. (Which controls Permeability, Dry strength and so on)

GREEN SAND:

It consists of silica sand with 18 – 30% of clay and 4 – 8% of water. Green sand retains the shape given to it. 'Green Sand' implies damp or undried sand, as the mould made from this sand is used immediately to pour the molten metal; Not a green coloured sand; Collected from natural resources. It has the advantage of Maintaining the moisture content for a long time.

DRY SAND:

Green sand that has been dried or baked after the mould preparation is called dry sand. Dry sand yields porosity absent castings, as there is no moisture. Suitable for large- sized castings. (Heavier than 500kg)

LOAM SAND:

When Clay and silica are mixed in equal proportions with little or no special additives, it is called loam sand. It is used for loam moulding.

BACKING/SYSTEM SAND;

It is what constitutes most of the refractory material found in the mould. This is made up of used and burnt sand. Normally Moulding sand of requisite quality is pored on the pattern to a thickness of 30 to 50 mm. Rest of the mould box is filled with the back up sand

PARTING SAND:

Used on the parting surface of the flasks to separate without clinging. This permits easy withdrawal of the pattern after ramming. It's free from clay and is dry.

FACING SAND:

This sand is used next to the pattern to obtain cleaner and smoother casting surfaces. Generally, sea coal or coal dust is mixed with the system sand to improve the mouldability and surface finish. The sea coal being carbonaceous, will slowly burn due to the heat from the molten metal and give off small amounts of gases. This creates a small gas pressure.

CORE SAND:

Sand used for making cores is called Core sand; Should be stronger than the moulding sand; To make core sand, Core oil, which is composed of linseed oil, resin and other binding materials, is mixed with silica sand.

PROPERTIES OF MOULDING MATERIALS(SAND):

Moulding materials should posses certain properties to produce good moulds and castings.

COHESIVENESS OR STRENGTH:

- ✓ Ability of sand particles to stick together determines the cohesiveness or strength of sand.
- ✓ Moulding sand is combined with a suitable binder, to develop adequate cohesion among its grains.
- ✓ To be able to form and stay as mould.
- ✓ Should be capable of withstanding the compressive & erosive force exerted by liquid metal while filling the mould cavity.
- ✓ Low strength moulding sands can result in defective castings.
- ✓ Moisture and clay content determines the strength of moulding sand.
- ✓ Green strength, Dry strength, Hot strength.

CHEMICAL RESISTIVITY:

- ✓ Sand used for moulding should be inert and should not react chemically with the metal/alloy being poured into it.
- ✓ Special care has to be taken while preparing moulding sand for casting reactive metals like magnesium and titanium alloys.

PERMEABILITY:

- ✓ The property of the sand to allow easy flow of gases and vapours through it is called permeability.
- ✓ Liquid metals poured into mould cause evolution of gases due to their reaction with moulding sand ingredients such as binders, additives and water.
- ✓ One cc of water added to moulding sand can evolve 1600 cc of steam in few seconds while liquid metal is filled in the mould.
- ✓ Unless the moulding sand has sufficient porosity to allow these gases and vapours to escape, the gases tend to get entrapped in the casting during solidification.
- ✓ This results in casting defects such as blow holes.

FLOWABILITY:

- The capacity of moulding sand to flow to different corners and intricate details on pattern without much special effort is called as flowability.
- It is an important requirement of moulding sand and more significant for machine moulding.

ADHESIVENESS:

- The sand particles adhere to the mould box surface by the property called adhesiveness.
- This property helps the sand to retain the mould cavity and stay in the box. (During the process while changing the positions of cope and drag)

REFRACTORINESS:

- Sand must not fuse when it comes in contact with molten metal.
- As the sand should withstand the liquid metal temperature while it is poured, the moulding sand should have sufficient refractoriness.
- For example, sand used for steel castings should have to withstand pouring temperatures of above 1500 c.
- Without sufficient refractoriness, the sand partially fuses with the liquid metal giving rise to very rough sand-fused casting surface and causing rejection.

COLLAPSIBILITY:

- After solidification of the molten metal, the casting is required to be removed from the mould.
- If the moulding sand is easily collapsible, free contraction of the metal as well as easy removal of the casting is possible.
- If the sand is not collapsible, it will strongly adhere to the casting, becoming very hard to separate after the metal is solidified and resulting in high cost of fettling and finishing.

REUSABILITY:

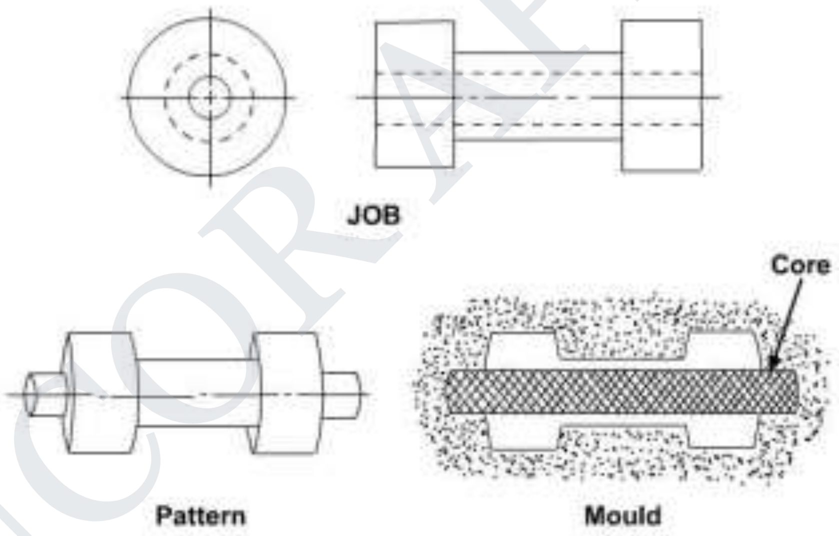
- Moulding sand from broken mould should be reused to make other moulds.
- This property keeps down the cost per mould.

CORES

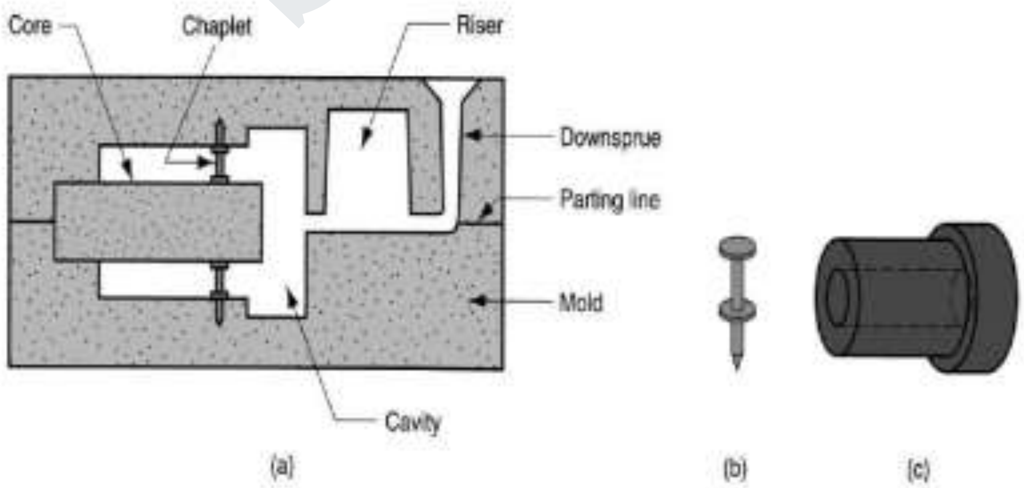
- ✓ A core is a body of sand which is used to make a cavity or a hole in a casting.
- ✓ It shape is similar to the required cavity in the casting to be made.
- ✓ It is also used to make recesses, projections, undercuts and internal cavities.

Core Prints

- ✓ Where coring is required, provision should be made to support the core inside the mold cavity.
- ✓ Core prints are used to serve this purpose.
- ✓ The core print is an added projection on the pattern and it forms a seat in the mold on which the sand core rests during pouring of the mold.
- ✓ The core print must be of adequate size and shape so that it can support the weight of the core during the casting operation.



Chaplets: Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force.



A Typical Job, its Pattern and the Mold Cavity

CORE BOXES

- ✓ It is used to produce cores, made up of wood or metal.

TYPE OF CORE BOXES:

- ✓ Half core box

  Used to make one half of the symmetrical core piece
  After baking, two core pieces will be pasted to form full core.
- ✓ Dump or slap core box

  Used for making a full core.
  Used for making slab or rectangular, trapezoidal cores.
- ✓ Split core box

  It has two similar half boxes.
  Box assembled in correct position by dowels before filling sand
  Two boxes separated after ramming the sand
  Used for making cylindrical core.
- ✓ Strickle core box

  It is used to make an irregular shape core.
  Dump core box is filled up with core sand then required core shape of strickle board is pressed and swiped to form a profile.
- ✓ Gang core box

  Used for producing many number of cores to be produced identical at a time.

CORE OVENS

- ✓ Core ovens used for heating the cores to obtain required hardness.

Types of Core ovens

- ✓ Batch type oven

  Small or medium cores are baked
  Fired with coal, oil or gas.
  It has several drawers. Each drawer loaded with a batch of cores.
  Core heated batch by batch.
- ✓ Continuous type ovens

  Heating is done continuously in this oven.
  Cores are loaded on a conveyor at one side of oven and moves inside the oven then unloaded at other end.
  Heating time controlled by speed of the conveyor movement.
  Heating is done by electrical means or by burners.

Oven best suited for mass production and small cores of approximately same size.
Oven may be vertical or horizontal.

- Dielectric baking ovens

It is also continuous oven and quickest method of heating cores in ovens.
Core is placed between two electrodes and high frequency alternating current is supplied to electrodes.
Heating time required- Small core 30 seconds, large core 3 minutes.
Core baking removes moisture, oxides from oil and polymerizes the binder, so core made hard.

CORE MAKING METHOD

- Core are made manually or with machines
- Only core box methods are used for making cores.
- Various methods employed for the manufacture of core depend on

a) Shape and size of core b) types of binder used

CORE MAKING

Hand core making method:

It consist following sequence of operations

1. Core sand preparation:

- Core is made of clay-free silica sand, which is mixed homogeneously with suitable binders, water, and other ingredients to produce a core mix.

2. Core Making:

- The core mix is packed into core box that contains a cavity of the desired shape.
- The core is then removed from the core box.
- Cores can be made manually or using machines.
- Large cores reinforced with rods for strength.

3. Core Baking:

- Cores are heated in core baking ovens at temperature range 2000 c to 3500 c.
- During heating, moisture is removed.

- ✓ The binder hardens and gives strength.
- ✓ Proper baking is essential for a core to work satisfactorily.
- ✓ Under-baked cores release gases and may cause many defects.
- ✓ Over-baked cores may collapse too early and ay break before the solidification of the metal.

4. Finishing:

- ✓ cores are cleaned and sized.
- ✓ It involves three process. 1.trimming 2.brushing 3.sizing

5. Coating:

- ✓ It gives smooth surface to the castings and prevent metal leaking into core.
- ✓ Coating material is powdered graphite or silica or mica.
- ✓ Coating is applied either by dipping or spraying.

Hot core box method:

- ✓ It eliminates baking process by using quickset synthetic resins, bonded core sands, formaldehyde, urea formaldehyde, phenolic alcohols and furan base binders.
- ✓ To speed up the curing process, catalyst nitric oxide is added.
- ✓ Metal core box is heated by electrical heater and core sand is forced by blower machine.

Synthetic resin based cold curing method:

- ✓ This sand not requires further heat treatment after obtaining from ovens to get required strength and hardness.
- ✓ Same earlier method binder and catalyst are used.
- ✓ Mixed sand is poured into core boxes and held for some time then removed from the box and stand in the air for 30 to 120 min.
- ✓ Strength of core is lesser than hot box method. So it's used for moderately complex and simple configuration.

Cold curing CO_2 process:

- ✓ Used to make good quality castings in large numbers.
- ✓ Pure dry silica sand is mixed with sodium silicate liquid to use as binder.

- ✓ Mixing is done by Muller. Moisture not exceed 3%,additives like saw dust 1.5%,asbestos powder 5% and graphite powder added with this core sand to get more deformable and collapsible.
- ✓ Core sand mix is filled in core box and then CO_2 gas is passes through core for 30 seconds at a pressure of 140 KN/m^2. It forms sodium carbonate and silica jell.
- ✓ Silica jell binds the sand grains and gives hardness and strength.
- ✓ Baking not necessary, good strength and hardness, cores can handled and stored for long time, saves time and cost of heating.

TYPES OF CORES

According to state of core

i) Green sand core
- Sand core is formed by the pattern itself when it is being rammed
- Core is made of the same sand as the moulding sand.
- It is weak and only used for light castings.

ii) Dry sand core
- Made separately and then positioned in the mould
- It is most commonly used.

According to position of the core in the mould:

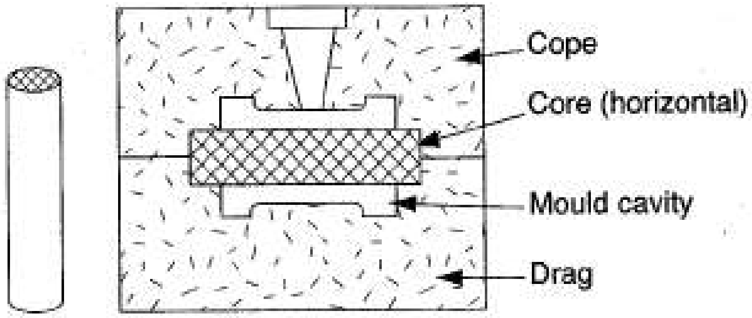
1) Horizontal core
- Core is placed horizontally in the mould
- Cores are usually cylindrical shape. It may have any other shape depending upon the shape of cavity required.
- Core is supported in core seats at both the ends.

2) Vertical core
- Core is positioned vertically in the mould
- Two ends of core rest on core seats in cope and drag,
- Major portion rest in drag box.

3) Balancing core
- Core is supported and balanced from its end only
- Requires long core seats in cope and drag so that core does not sag of fall into the mould.
- Used when the blind holes along a horizontal axis are to be produced.

4) Hanging core
- Cores are supported at the top and hung into the mould and no support from bottom

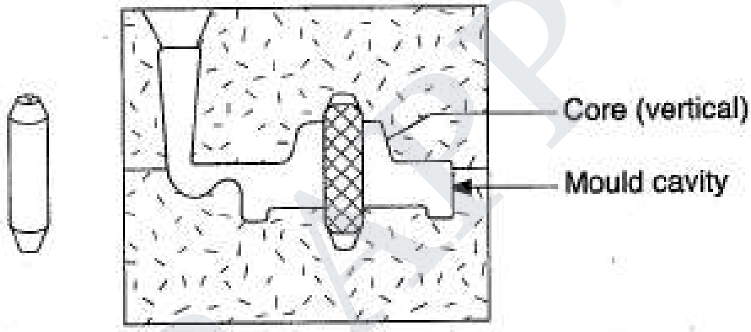
- supported by seat made in top portion of drag.
- used when cored casting is to be completely molded in the drag with the help of single piece solid pattern.



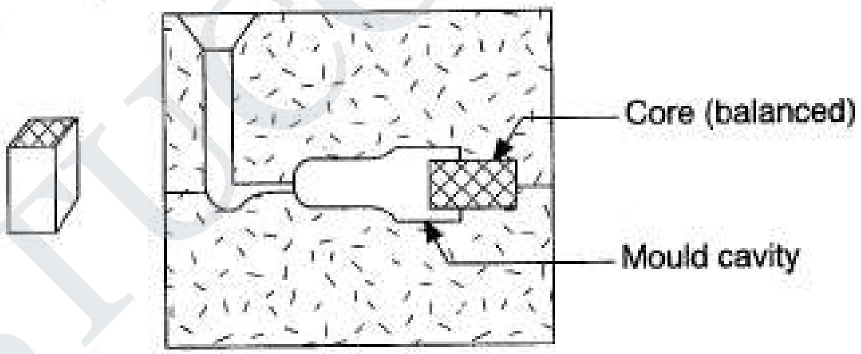
(a) Horizontal core

5) Drop core

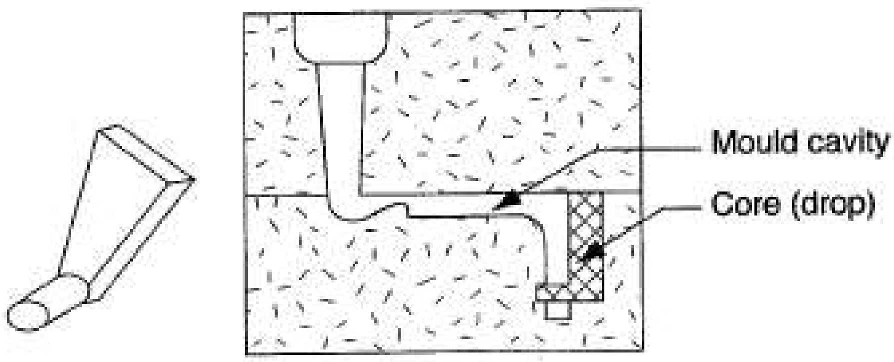
- used when a hole is not in line with the parting surface is to be produced at a lower level.
- Hole may be above or below the parting line of the mould.
- Depending on the use it may be called tail core, chair core or saddle core.



(b) Vertical core



(c) Balanced core



(d) Drop core

METHODS OF SAND TESTING:

1. Moisture content test

a) Loss of weight after evaporation

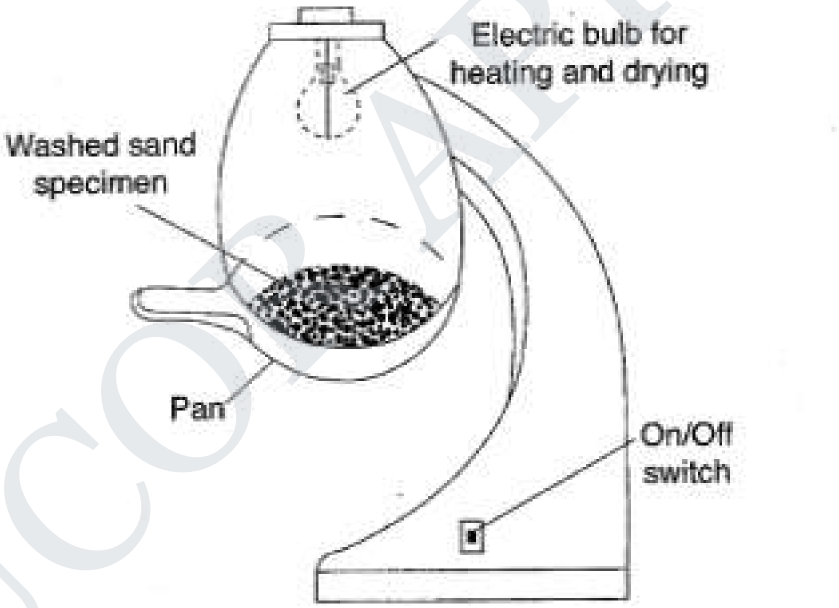
Percentage of moisture content = $(W_1 - W_2)/W_1 \times 100$

b) Moisture teller method

2. Clay content test

- Quantity of sand sample, distilled water and 1% sodium hydroxide solution are put in the mixing device.

- Mixture stirred nearly about 5 minutes and allowed to settle down for 10 min at the bottom. The dirty water is removed from the top.



Dryer for removing moisture from sand sample

- Again distilled water and 1% NaOH solution are added with sand settle down at bottom of the mixing device. Then it is stirred well and dirty water is removed off.

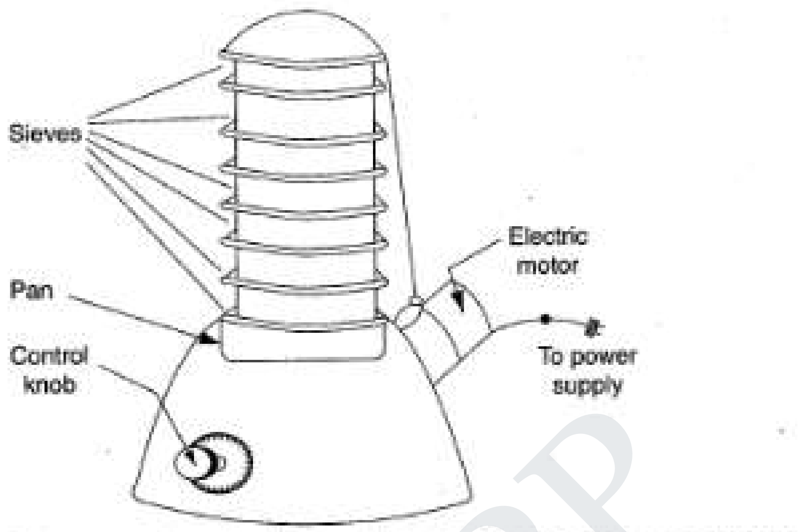
- The above procedure repeated again until the water at the top of the sand becomes clean. This water is drained completely and sand is dried well.

- The dried sand is reweighed. The loss of weight indicated the clay content.

3. Grain fineness test

- It is carried out on completely dry and clay free sand.

- Apparatus has a set of known values of graded sieves. Top most sieves are coarsest one and finest sieve at the bottom most.



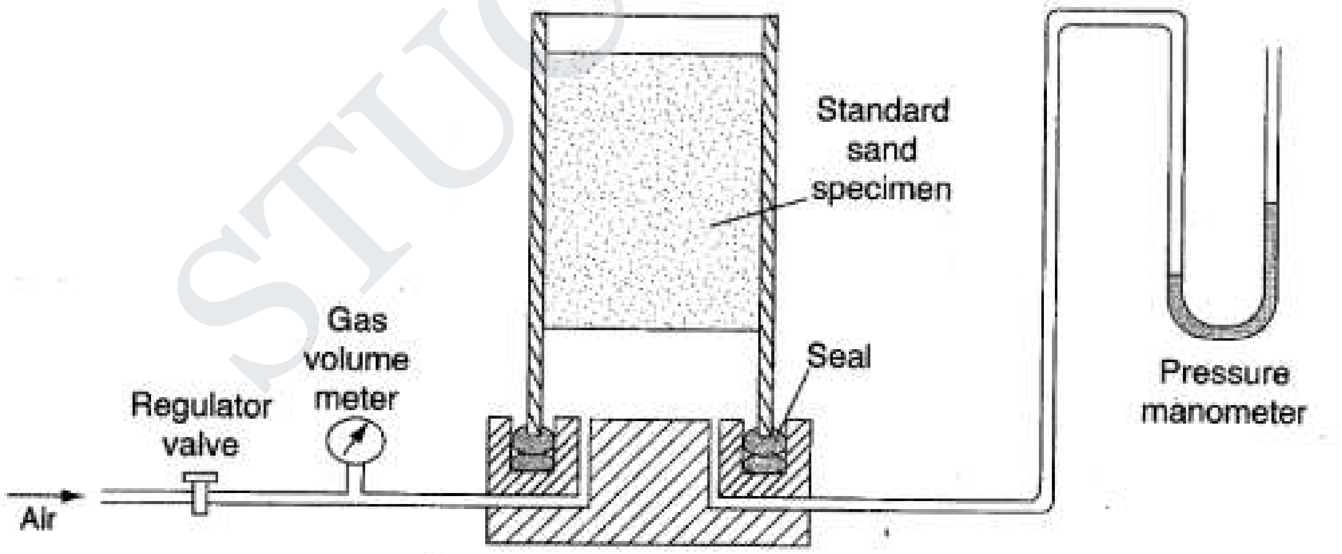
Test apparatus for determining sand grain fineness number

$$\text{AFS fineness number} = \sum P_i N_i / \sum P_i$$

4. Permeability test

- Permeability is defined as the amount of air which will pass through the standard specimen of the sand under a given applied pressure over a particular period of time.

- permeability depends on grain size, shape of grains, clay content or binder content, grain distribution, ramming capacity and water content.

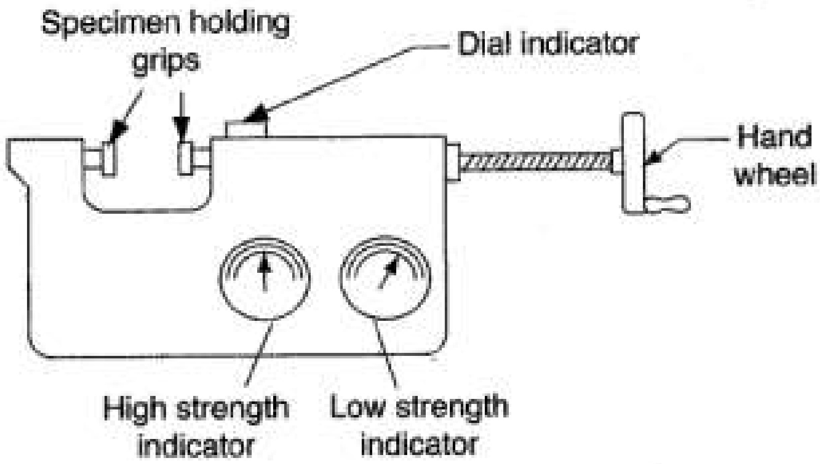


Test apparatus for determining permeability of moulding sand

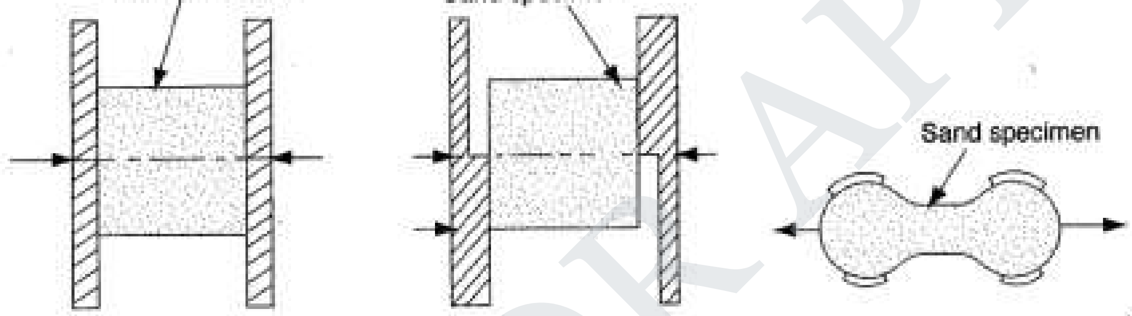
5. Strength test

- Its mainly carried out to measure the holding power or bonding power of green sand or dry sand; specimen of sand: 50 mm dia x 50 mm dia.

- Various tests are carried out such as a) compressive strength test (50 to 150 kPa) b) Shear strength c) tensile strength d) bending strength



Universal sand strength testing machine



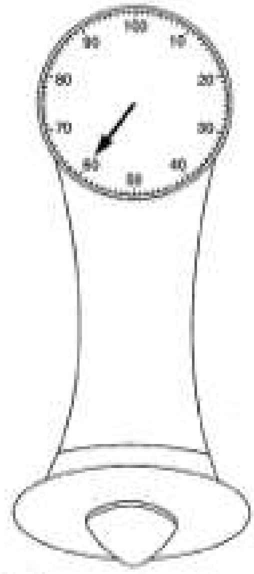
(a) Compressive strength test arrangement

(b) Shear strength test arrangement

(c) Tensile strength test arrangement

6. Deformation and toughness test

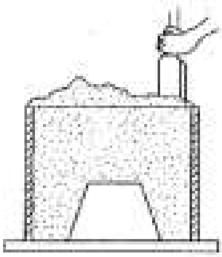
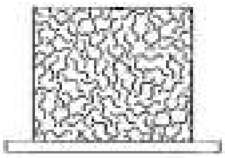
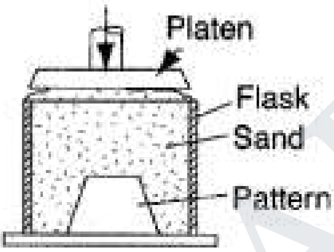
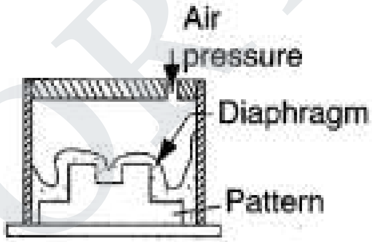
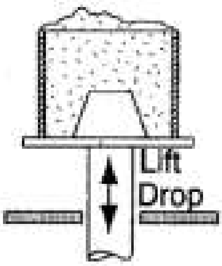
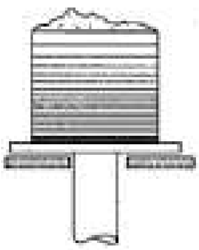
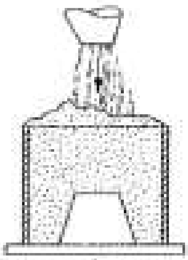
- Deformation is defined as the plasticity of sand that can be tested by reducing length of specimen applying compressive force on it.
- Higher deformation indicates the better capacity of the mould; it can withstand hydrostatic pressure as well as volumetric contraction of the moulding sand.
- Deformation of compressive strength indicates toughness. It means that ability of sand to withstand rough handling and strain when the pattern is with drawn.



Moulding sand hardness test

7. Mould hardness test

- Surface hardness indicates the ramming density of the actual sand mould.
- Hardness of the moulding sand is tested in an indentation hardness tester.- Steel ball of mass 0.9 kg

Process and main characteristics	Sketch	Hardness Isofirms
a. Hand ramming - Variable hardness - Laborius and slow - Manual labour required - Initial cost low		
b. Squeezing - Top layers more compacted than lower layers - Best for shallow flasks and small patterns		
c. Flexible diaphragm squeezing - Uniform compactness along pattern contour - Best for contoured patterns		Uniform packing of sand around contour of pattern
d. Jolt ramming - Top layers less compacted than lower layers - Noisy - Best for horizontal surfaces		
e. Sand slinger - Uniform ramming - Initial cost high - Fast operation		

Schematic of different mould making processes, their main characteristics and hardness isofirms of mould made by each process

Classification of casting Processes

Casting processes can be classified into following FOUR categories:

1. Conventional Molding Processes
    a. Green Sand Molding
    b. Dry Sand Molding
    c. Flask less Molding
2. Chemical Sand Molding Processes
    a. Shell Molding
    b. Sodium Silicate Molding
    c. No-Bake Molding
3. Permanent Mold Processes
    a. Gravity Die casting
    b. Low and High Pressure Die Casting
4. Special Casting Processes
    a. Lost Wax Process
    b. Ceramic (Shell) Molding
    c. Evaporative Pattern Casting
    d. Vacuum Sealed Molding
    e. Centrifugal Casting

Melting Practices

- ✓ A number of furnaces can be used for melting the metal, to be used, to make a metal casting.
- ✓ The choice of furnace depends on the type of metal to be melted.

    Crucible furnaces
    Cupola furnace
    Open hearth/Reverberatory furnace
    Electrical Arc furnace
    Induction furnace

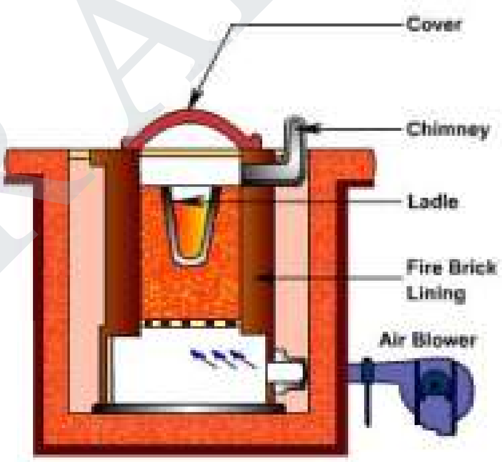
Crucible Furnace

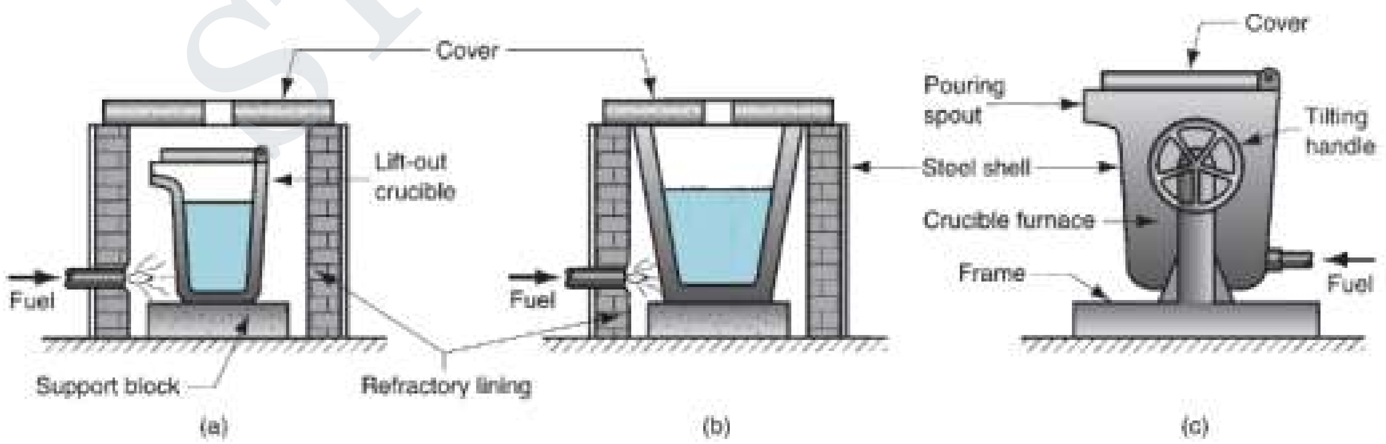
- ✓ Crucible furnaces are small capacity typically used for small melting applications.
- ✓ This furnace, also called as pit furnace; built in a pit and utilizes burning of gas with a blast of air as the source of heat.
- ✓ Crucible furnace is suitable for the batch type foundries where the metal requirement is intermittent.
- ✓ The metal is placed in a crucible which is made of clay and graphite.

- ✓ The energy is applied indirectly to the metal by heating the crucible by coke, oil or gas.
- ✓ The heating of crucible is done by coke, oil or gas.
- ✓
- ✓ The melting of alloy takes place in a pot-like structure, called crucible.
- ✓ The crucible, with the metal charge in it, is placed in the furnace. The hot blast of air from the firebox heats the crucible and melts the metal charge contained in it.
- ✓ When the metal reaches the right temperature (as seen by lifting the cover of pit), the blast is cut off. The crucible is taken out and used as a ladle to pour the molten metal in moulds.

Coke-Fired Crucible Furnace:

Primarily used for non-ferrous metals
Furnace is of a cylindrical shape
Also known as pit furnace
Preparation involves: first to make a deep bed of coke in the furnace
Burn the coke till it attains the state of maximum combustion
Insert the crucible in the coke bed
Remove the crucible when the melt reaches to desired temperature





Three types of crucible furnaces: (a) lift-out crucible, (b) stationary pot, and (c) tilting-pot furnace.

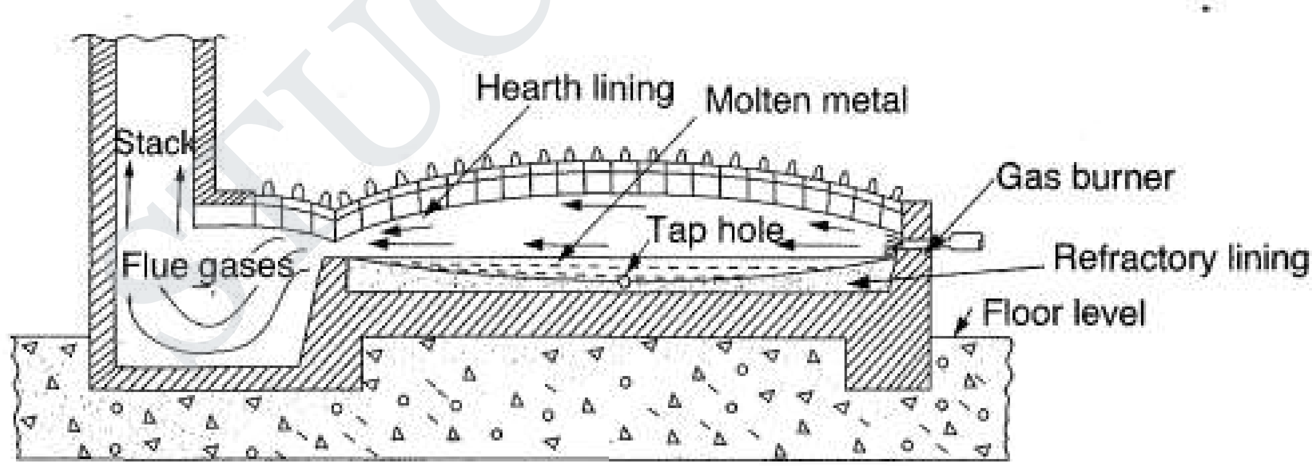
Oil-Fired Furnace.

Primarily used for non-ferrous metals
Furnace is of a cylindrical shape
Advantages include: no wastage of fuel
Less contamination of the metal
Absorption of water vapor is least as the metal melts inside the closed metallic furnace

- ✓ Crucible furnaces are mostly used for melting of relatively small quantities of low melting point non-ferrous metals and alloys.
- ✓ Control of temperature and chemistry of molten metal, is poor.
- ✓ The main advantages of these furnaces are that their fabrication, operation and maintenance are easy and the capital cost is low.

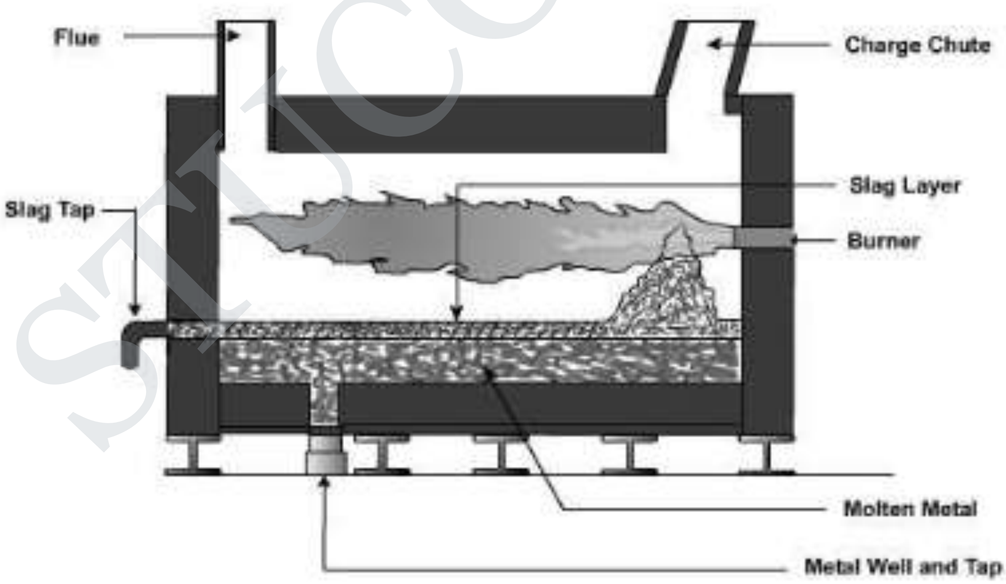
Open hearth/Reverberatory furnace

- ✓ This furnace is a squat, rectangular brick structure having a shallow hearth that holds the metal charge.
- ✓ There is a combustion chamber where powdered coal, gas, or oil is burned.
- ✓ The hot gases from the burning fuel are directed to the hearth where they heat and melt the metal charge.



- ✓ They also heat the lining of the hearth which, in turn, makes the heat reverberate and helps melt the metal before they leave the furnace through the chimney.
- ✓ The open-hearth furnace is commonly used for melting of non-ferrous metals and steel in batch quantities.
- ✓ It also finds use for holding of cast iron that has been melted previously in a cupola furnace.

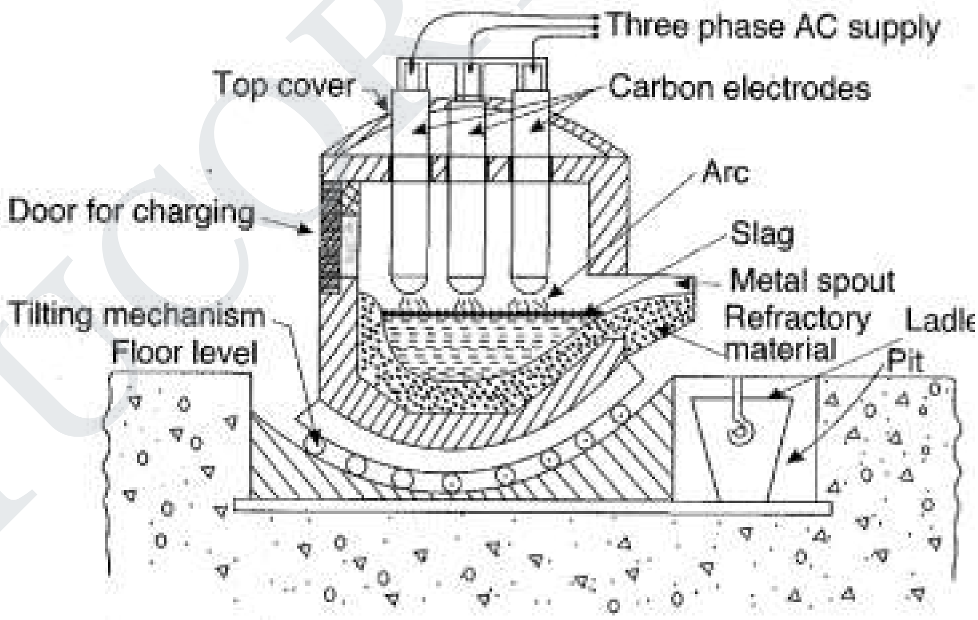
- ✓ The capacity of open hearth furnace is much larger than the crucible furnace. It is also less popular than electric arc furnace.
- ✓ A furnace or kiln in which the material under treatment is heated indirectly by means of a flame deflected downward from the roof.
- ✓ Reverberatory furnaces are used in copper, tin, and nickel production, in the production of certain concretes and cements, and in aluminum.
- ✓ Reverberatory furnaces heat the metal to melting temperatures with direct fired wall-mounted burners.
- ✓ The primary mode of heat transfer is through radiation from the refractory brick walls to the metal, but convective heat transfer also provides additional heating from the burner to the metal.
- ✓ The advantages provided by reverberatory melters is the high volume processing rate, and low operating and maintenance costs.
- ✓ The disadvantages of the reverberatory melters are the high metal oxidation rates, low efficiencies, and large floor space requirements.



Schematic of a Open hearth Furnace

Electric arc furnace

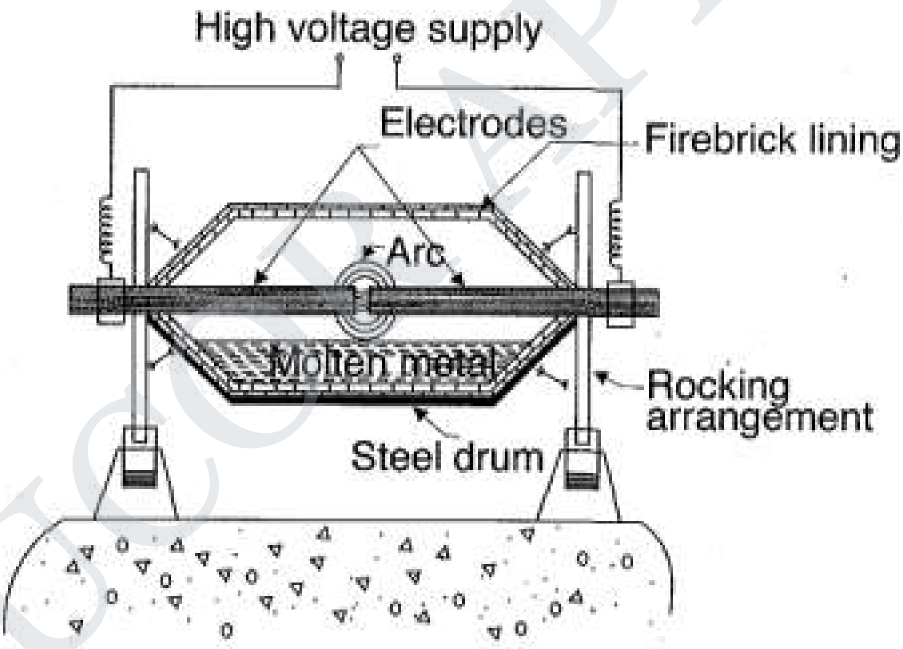
- ✓ An arc furnace is used to melt ferrous alloys, especially steel. The popularity of arc furnaces is because of their
  - (i) High melting rates,
  - (ii) High pouring temperature,
  - (iii) Ability to produce high quality of metal of almost any desired composition, and
  - (iv) Ability to hold the molten metal at constant temperature for longer periods of time.
- ✓ The furnace roof is swung aside and the metal charge is introduced.
- ✓ The roof is replaced, followed by lowering the three carbon electrodes (of about 700 mm in diameter and 1.5 to 2 m in length), and finally the power supply is switched on.
- ✓ A continuous electric arc is formed between the carbon electrodes and the metal charge.
- ✓ The path of the heating current is generally through one electrode, across an arc, through the metal charge, and back through another arc to another electrode.



- ✓ The height of electrodes in the furnace can be adjusted, depending upon the amount of metal present.
- ✓ The metal melts in about two hours. The power supply is then switched-off, the electrodes are raised, and the furnace is tilted to get the molten metal in a ladle.
- ✓ A direct arc furnace has a thermal efficiency as high as 70%.
- ✓ Temperatures as high as 1900°C can be generated;Sizes up to 100 tonnes.

In Indirect electric arc furnace, the electric arc is struck between two graphite electrodes and the metal charge does not form a part of the electric circuit.

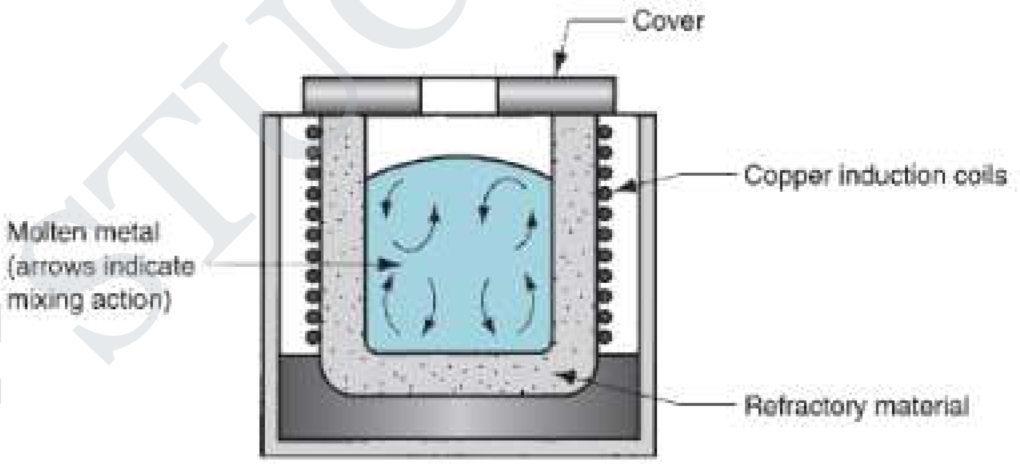
- ✓ The furnace rocks back and forth so that the metal charge comes in contact with the hot refractory lining and picks up heat for melting.
- ✓ In addition, the radiations from the arc and the hot refractory lining of the furnace help the metal charge in melting.
- ✓ While the furnace rocks, metal charge constituents get mixed up thoroughly, melting is fastened, molten metal gets stirred up, and over-heating of the refractory lining is avoided, which eventually leads to its extended life.
- ✓ The angle of rocking of furnace is adjusted in such a manner that the liquid metal level remains below the pouring spout.



- ✓ When the metal has completely melted, the furnace is tilted in order to allow the liquid metal to flow out of the tap hole.
- ✓ The temperatures and the thermal efficiency obtained in indirect arc furnace are lower than those obtained in a direct arc furnace.
- ✓ This furnace is generally used for melting of copper and its alloys, cast iron and steel.
- ✓ Both direct and indirect arc furnaces suffer from the disadvantages that their (i) noise pollution is high, and
  (ii) operating costs (in terms of costs of electrodes, refractories, and electric power) are high.

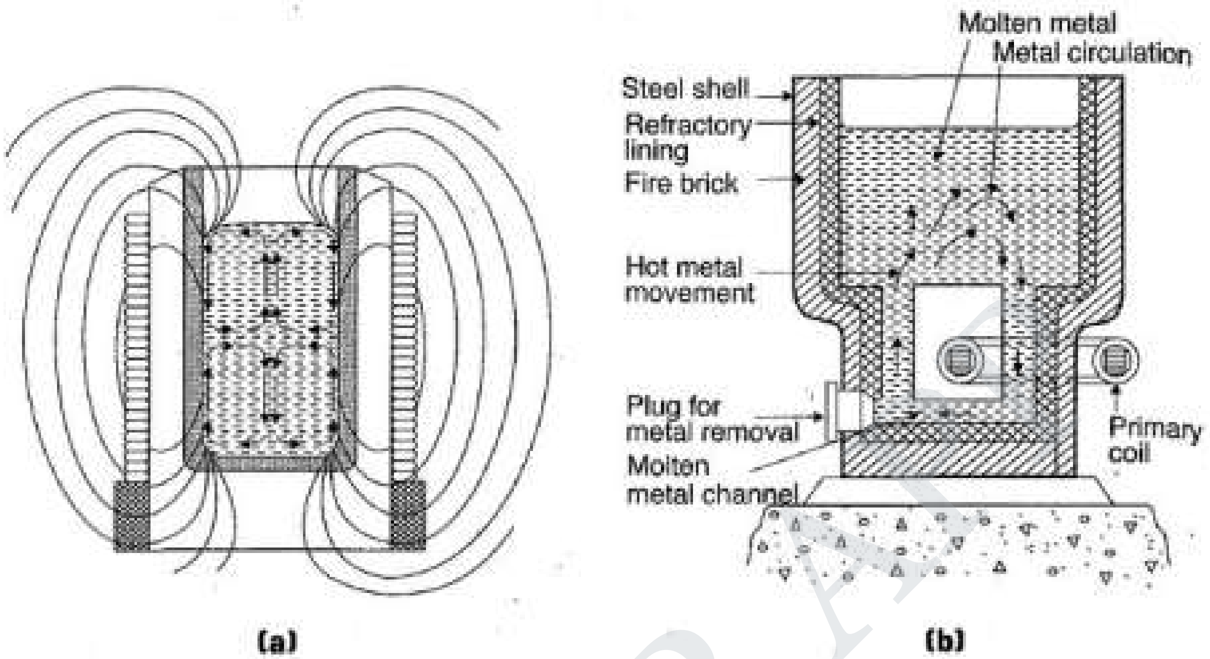
Induction furnace

- ✓ Induction heating is a heating method.
- ✓ This type of furnace is becoming very popular because of
  (i) Very high melting rates, (ii) less pollution.
- ✓ There are two basic types of electric induction furnaces:
  - High-frequency (or coreless) induction furnace
  - Low-frequency (or channel-type) induction furnace.
- ✓ The high frequency unit comprises a crucible around which a water cooled coil of copper tubing is wound. High-frequency (up to 10 Kc/s) electrical current is passed through the coil to generate an alternating magnetic field.
- ✓ The changing magnetic field induces secondary currents in the metal charge inside the crucible, thus heating and melting the metal rapidly.
- ✓ The furnace offers good control of temperature and composition of molten metal.
- ✓ As there is no contamination from the source of heat, the furnace has the capability of producing very pure metal.
- ✓ Though almost all common alloys can be melted with this furnace, it is especially useful where relatively small quantities of special alloys of any type are needed.



- ✓ The heating by the induction method occurs when an electrically conductive material is placed in a varying magnetic field.
- ✓ Induction heating is a rapid form of heating in which a current is induced directly into the part being heated.
- ✓ Induction heating is a non-contact form of heating.
- ✓ The heating system in an induction furnace includes:
  1. Induction heating power supply,

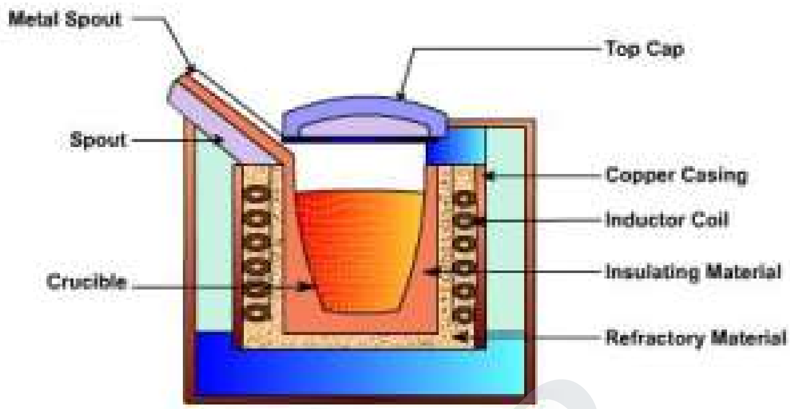
2. Induction heating coil,
3. Water-cooling source, which cools the coil and several internal components inside the power supply.



Schematic of induction furnaces (a) Coreless induction furnace showing lines of magnetic force; and (b) Low frequency induction furnace

- ✓ The induction heating power supply sends alternating current through the induction coil, which generates a magnetic field.
- ✓ Induction furnaces work on the principle of a transformer.
- ✓ An alternative electromagnetic field induces eddy currents in the metal which converts the electric energy to heat without any physical contact between the induction coil and the work piece.
- ✓ The furnace contains a crucible surrounded by a water cooled copper coil.
- ✓ The coil is called primary coil to which a high frequency current is supplied.
- ✓ By induction secondary currents, called eddy currents are produced in the crucible.
- ✓ High temperature can be obtained by this method.
- ✓ Cored furnaces are used almost exclusively as holding furnaces. In cored furnace the electromagnetic field heats the metal between two coils.
- ✓ Coreless furnaces heat the metal via an external primary coil.

Advantages of Induction Furnace



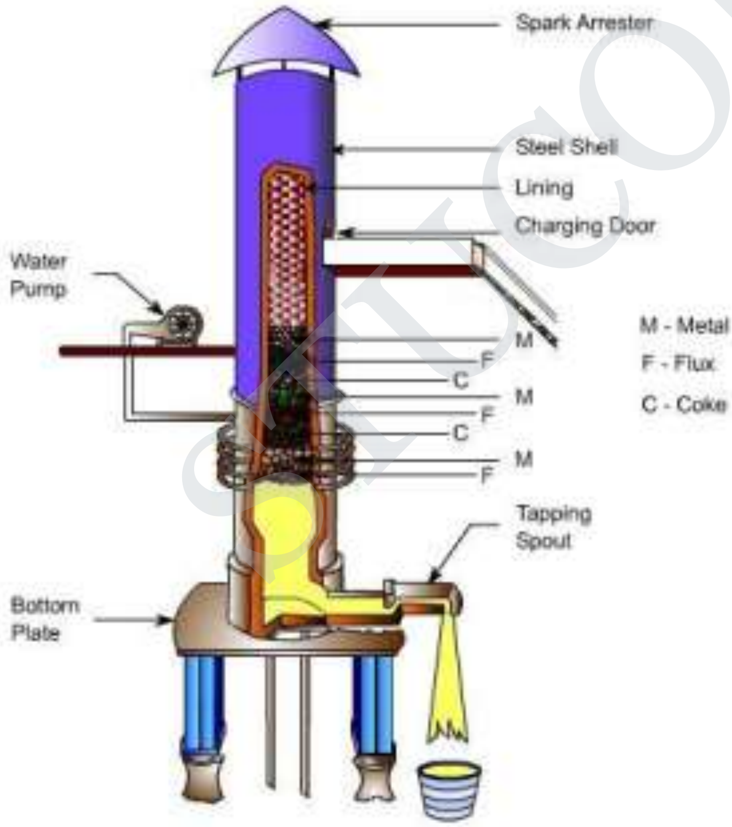
Induction heating is a clean form of heating
High rate of melting or high melting efficiency
Alloyed steels can be melted without any loss of alloying elements
Controllable and localized heating

Disadvantages of Induction Furnace

High capital cost of the equipment
High operating cost

Cupola Furnace

✓ Cupola furnaces are tall, cylindrical furnaces used to melt iron and ferrous alloys in foundry operations.



✓ Alternating layers of metal and ferrous alloys, coke, and limestone are fed into the furnace from the top.

✓ Furnace's cylindrical shaft lined with refractory and the alternating layers of coke and metal scrap.

✓ The molten metal flows out of a spout at the bottom of the cupola.

Description of Cupola

The cupola consists of a vertical cylindrical steel sheet and lined inside with acid refractory bricks. The lining is generally thicker in the lower portion of the cupola as the temperature is higher.

There is a charging door through which coke, pig iron, steel scrap and flux is charged.

The blast is blown through the tuyeres.

These tuyeres are arranged in one or more row around the periphery of cupola.

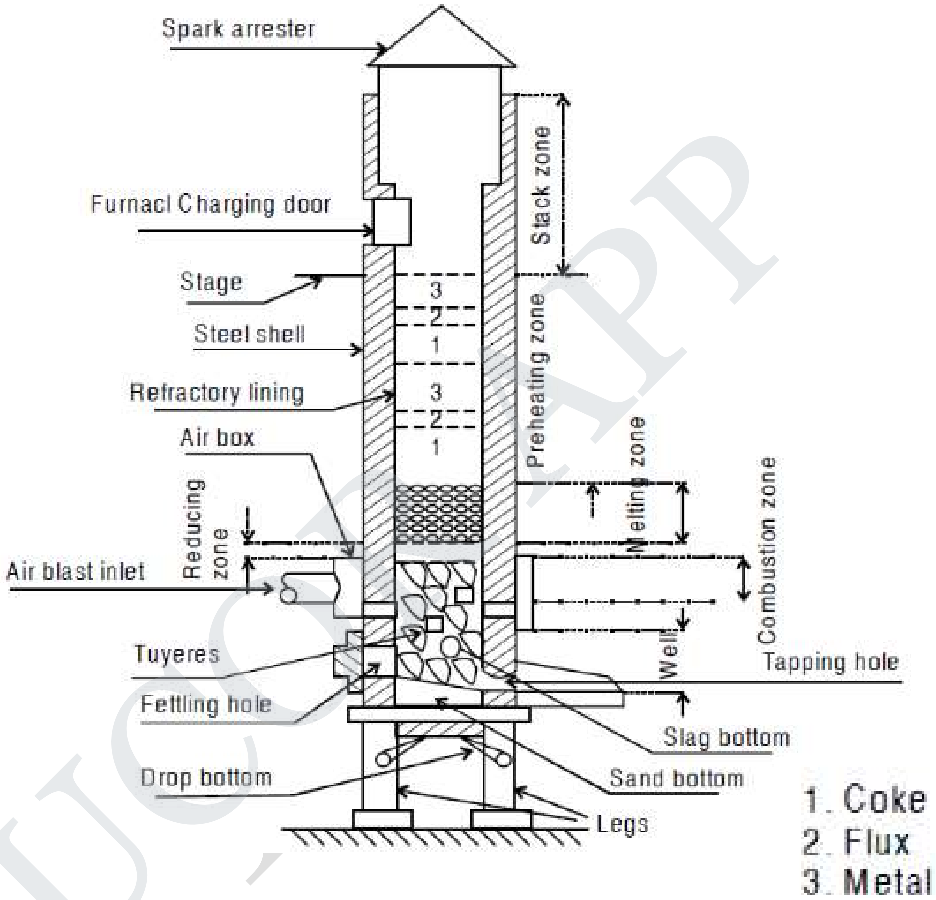
Hot gases which ascends from the bottom (combustion zone) preheats the iron in the preheating zone

Cupolas are provided with a drop bottom door through which debris, consisting of coke, slag etc. can be discharged at the en d of the melt.

A slag hole is provided to remove the slag from the melt.

Through the tap hole molten metal is poured into the ladle.

At the top conical cap called the spark arrest is provided to prevent the spark emerging to outside.



Operation of Cupola

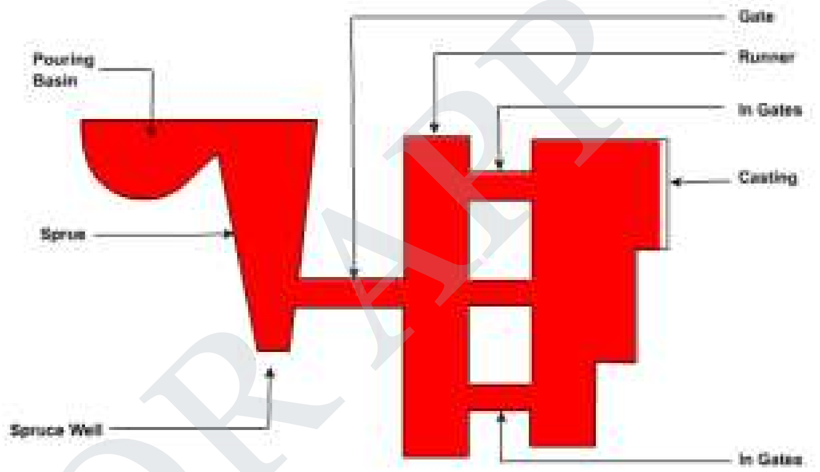
- ✓ The cupola is charged with wood at the bottom. On the top of the wood a bed of coke is built.
- ✓ Alternating layers of metal and ferrous alloys, coke, and limestone are fed into the furnace from the top.
- ✓ The purpose of adding flux is to eliminate the impurities and to protect the metal from oxidation.
- ✓ Air blast is opened for the complete combustion of coke.
- ✓ When sufficient metal has been melted that slag hole is first opened to remove the slag.
- ✓ Tap hole is then opened to collect the metal in the ladle.

Gating System

- ✓ The assembly of channels which facilitates the molten metal to enter into the mold cavity is called the gating system.
- ✓ Alternatively, the gating system refers to all passage ways through which molten metal passes to enter into the mold cavity.
- ✓ The nomenclature of gating system depends upon the function of different channels which they perform.

Pouring basin/cup
Down gates/ sprue
Cross gates or runners
Ingates or gates

- ✓ The metal flows down from the pouring basin or pouring cup into the down gate or sprue and passes through the cross gate or channels and ingates or gates before entering into the mold cavity.



Goals of Gating System

To minimize turbulence to avoid trapping gasses into the mold
To get enough metal into the mold cavity before the metal starts to solidify
To avoid shrinkage
Establish the best possible temperature gradient in the solidifying casting so that the shrinkage if occurs must be in the gating system not in the required cast part.
Incorporates a system for trapping the non-metallic inclusions

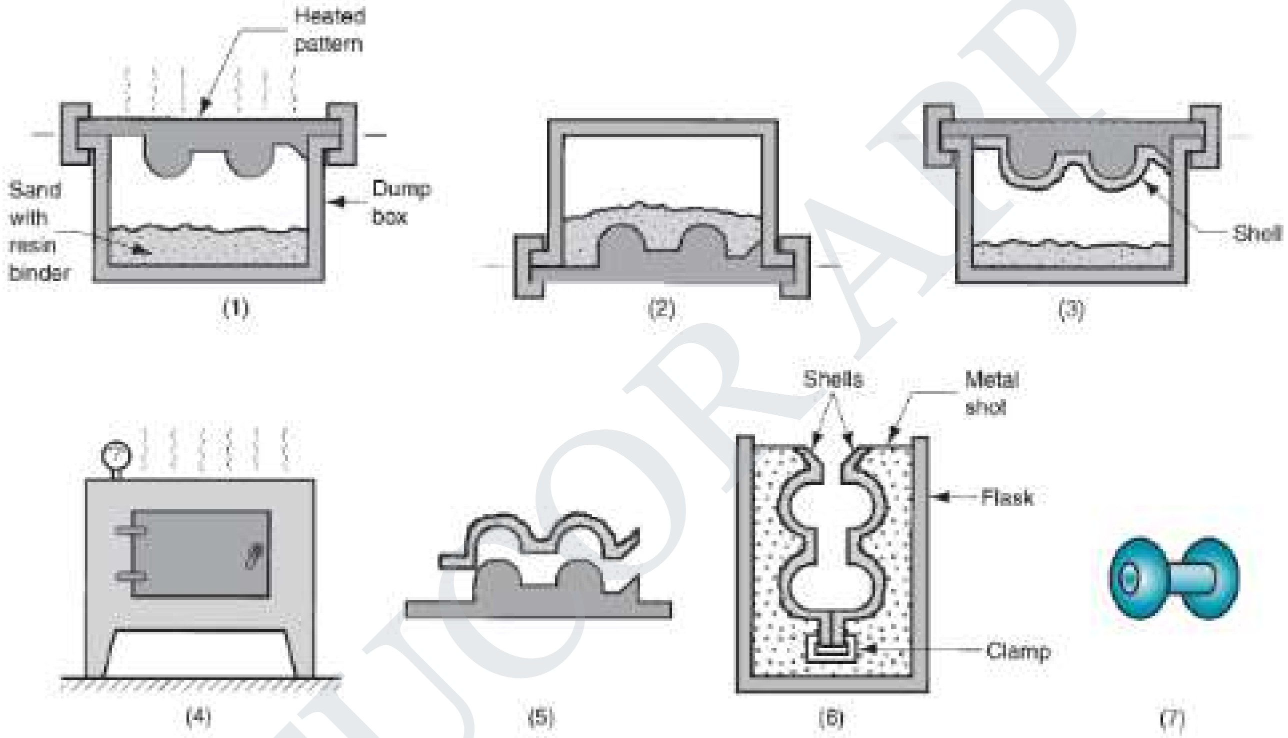
Fettling

Complete process of cleaning of castings

- ✓ Sand core removal
- ✓ Gates and Risers removal
- ✓ Removal of fins and flash
- ✓ Rough surface removal
- ✓ Cleaning the sand particles
- ✓ Cleaning the casting surface
- ✓ Repairing of defects, if any

Shell Molding Process

- ✓ A metal pattern, attached to a pattern plate, usually made of cast iron is uniformly heated in an oven to nearly 200 °C-300 °C.
- ✓ The pattern-pattern plate assembly is taken out from the oven and sprayed with a lubricant. (For easy removal of shell, patterns are sprayed with silicone dissolved in acetone, and also provided with some ejector pins).
- ✓ It is then clamped onto the top of a container (called dump box). The dump box contains resin-coated sand. (Dry silica sand & thermosetting resins).
- ✓ The dump box is rotated through 180° so that the coated sand falls on the hot pattern.



Steps in shell molding: (1) a match-plate or cope-and-drag metal pattern is heated and placed over a box containing sand mixed with thermosetting resin; (2) box is inverted so that sand and resin fall onto the hot pattern, causing a layer of the mixture to partially cure on the surface to form a hard shell; (3) box is repositioned so that loose, uncured particles drop away; (4) sand shell is heated in oven for several minutes to complete curing; (5) shell mold is stripped from the pattern; (6) two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is accomplished.

- ✓ By giving enough contact time, a partially cured layer (shell) of about 5 to 10 mm thickness is allowed to be formed around the pattern. The box is now rotated to its original position.
- ✓ The unused sand falls back to the bottom of the box while the shell (often called biscuit) remains sticking to the pattern.
- ✓ The pattern plate is de-clamped from the dump box. For the purpose of curing the resin completely, pattern-pattern plate assembly is put in an oven at 350 °C- 400 °C for 1 to 5 minutes, depending upon the thickness of the shell.

Over-curing may cause the mould to develop cracks or even break, whereas under-curing results in low strength shells and may even cause blow holes in the casting.

- ✓ The pattern plate is removed from the oven and shell is carefully stripped from the pattern using ejector devices.
- ✓ The shell is ready for use or for storage (for later use).
- ✓ In most cases, the shell mould is prepared by using two half-shells, which are glued, clamped, or wired together.
- ✓ The shell mould is now ready for pouring. Alternatively, for larger moulds, the shells are placed in a container and given outside support of cast iron shots or moulding sand.

Advantages

1. The amount of sand used is only one-twentieth of the sand used in sand casting.
2. Can be easily adapted to mass production using automatic equipments that will require minimum of skilled labour.
3. Shell moulds can be kept for a long time because cured resins do not absorb moisture. This allows a more flexible production schedule to be followed.
4. Shell moulds have relatively smooth walls, offering low resistance to flow of molten metal and producing castings with sharper comers, thinner sections, and smaller projections than are possible to achieve in green-sand moulding.
5. Shell moulds have relatively smooth walls and, therefore, castings with a very smooth surface can be obtained. (In the order of 3 to 5 microns is common.)
6. Use of cores is eliminated by forming internal cavities in the shell mould itself.
7. Almost all metals can be cast by this process.
8. Complex shapes can be produced by employing relatively less labour.
9. Castings are more accurate and have closer tolerances. In most cases, tolerance values range between ± 0.20 to.± 0.35 mm.
10. High quality of casting produced leads to saving on cleaning, machining and other finishing operation costs.

Disadvantages

1. Shell sand has lower permeability than the sand used in green-sand moulding as much finer sand is used in shell moulding. Further, the decomposition of the shell-sand binder produces a high volume of gas; trapped gas can cause serious problems in ferrous castings.
2. The size of casting is generally a limitation. However, castings up to 500 kg have been shell moulded nowadays.
3. Cost of pattern, resin, and other equipment is high. Generally, this process is economical only if more than 15,000 castings are to be produced.

Applications

Applications include casting of small mechanical parts requiring high precision such as gear blanks, chain seat brackets, crank shafts (small), automobile transmission parts, cylinder and cylinder head for air cooled IC engines, etc.

INVESTMENT CASTING

1. Pattern making:

- ✓ A metal die, usually of aluminium, having the cavity shape corresponding to the shape of the pattern is taken and molten wax is injected into it.
- ✓ When the wax solidifies, the die is opened and the pattern is removed.
- ✓ For economic considerations, it is a usual practice to make a gated pattern by assembling several wax patterns in a tree-like structure onto a central runner or sprue.
- ✓ Heated tool called spatula is used for assembling wax gates and sprue to the wax patterns.

2. Pattern investment:

- ✓ The multi-pattern assembly is covered in a permeable container.
- ✓ A fine ceramic based slurry known as investment is poured into the container.
- ✓ While the whole assembly is given low frequency vibrations. (The name of the casting process is derived from this process).
- ✓ Fineness of slurry is important as it determines the surface finish of the final castings.
- ✓ One way is to a How drying of the investment around the gated pattern in the container itself.
- ✓ Alternatively, the gated pattern with a thin coating of investment on it is take Fell out and after drying of this initial coating, the pattern is re-coated many times with a coarse refractory powder until a coating thickness of 5-10 mm has been built up over the entire wax pattern assembly.

3. Pattern melting and removal:

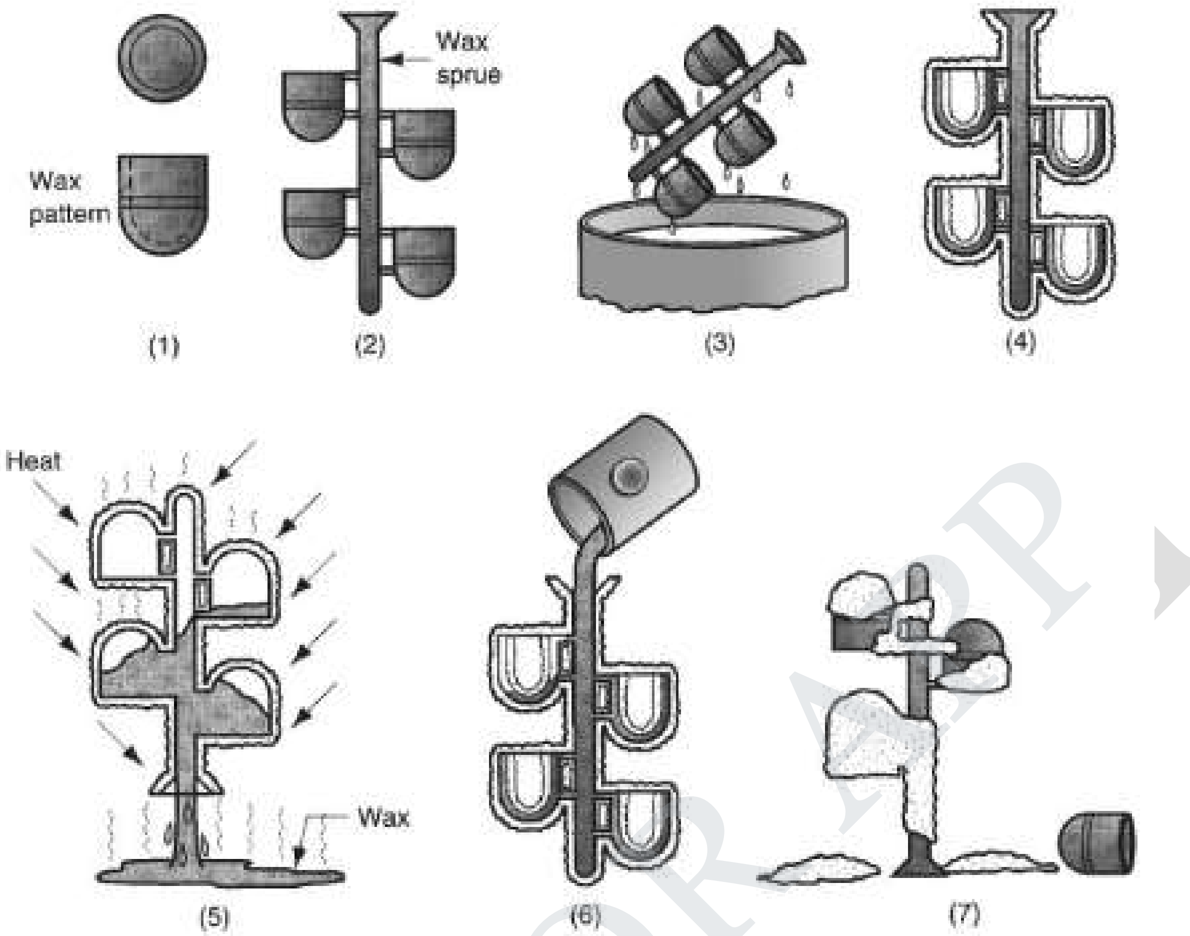
- ✓ After the investment has set around the pattern tree and dried, it is heated; for a temperature of 100°C-I5O°C by holding it in an inverted position for the wax pattern-tree to melt and run out (de-waxing).

4. Investment hardening:

- ✓ The mould of investment material is fully hardened by placing it for about 2 hours in an oven at a temperature of 700°C- 1000°C, depending on the metal to be cast.
- ✓ This also burns off any residual wax in the mould cavities.

5. Metal pouring and fettling of castings:

- ✓ As soon as the mould is removed from the oven, the molten metal is poured into it.
- ✓ When solidified, the cast tree of the components is retrieved by breaking the mould made of the brittle investment material.
- ✓ Each component is then carefully cut from the tree and fettled.



Steps in investment casting: (1) wax patterns are produced; (2) several patterns are attached to a sprue to form a pattern tree; (3) the pattern tree is coated with a thin layer of refractory material; (4) the full mold is formed by covering the coated tree with sufficient refractory material to make it rigid; (5) the mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity; (6) the mold is preheated to a high temperature, which ensures that all contaminants are eliminated from the mold; it also permits the liquid metal to flow more easily into the detailed cavity; the molten metal is poured; it solidifies; and (7) the mold is broken away from the finished casting. Parts are separated from the sprue.

The investment casting process uses a pattern which is usually made of low melting point wax (or it can also be made of plastic, such as polystyrene). A mould is prepared around the pattern and the pattern material is then melted out by heating before pouring the molten metal. The process is also called the lost wax casting process or the precision casting process.

Advantages

1. Most ferrous and non-ferrous metals can be cast.

This process is particularly suitable for casting of alloys that are expensive, hard, difficult-to-machine, and have high melting point and high strength.

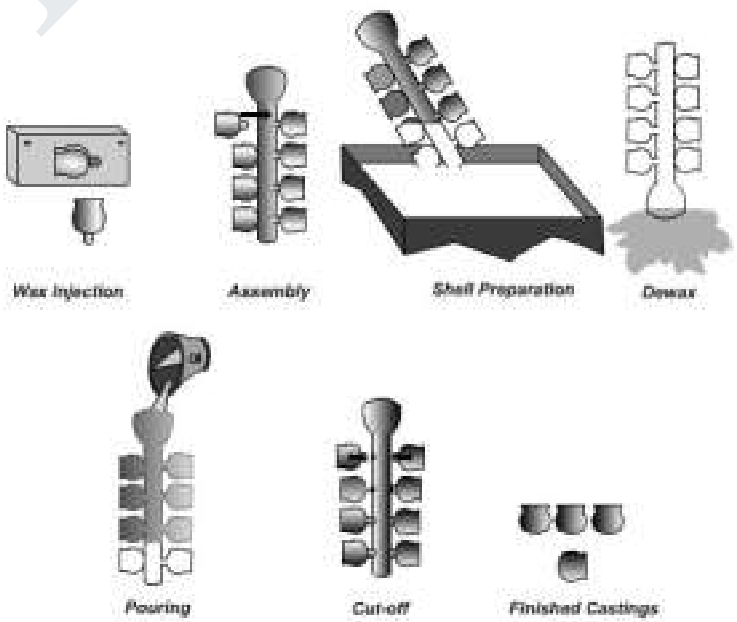
2. It is possible to produce intricate shaped parts weighing from 1g to 10 kg.
3. It is possible to produce parts as big as 1.5 m in diameter with as thin walls as 1 mm.
4. The parts produced have good surface finish with matte appearance and close dimensional tolerances of the order of ±5microns.
5. The parts produced do not normally need any further machining or finishing operations.
6. This process is adaptable to automated mass production.

Disadvantages

1. The moulds can only be used once.
2. The process is comparatively slow.
3. The costs incurred due to the investment material and needed skill of labour are high.
4. The process is generally limited to small size and light weight castings.

Applications

- ✓ The process is particularly advantageous for making small precision parts of intricate shapes.
- ✓ Typical parts made from this process are mechanical components such as gears, cams, valves, turbine blades, turbo-supercharge buckets and vanes of jet propelled engines.



CERAMIC MOULDING

1. Pattern making: The pattern may be made of wood, thermo-setting plastic, brass, or aluminium alloy.

2. Slurry making: A mixture of fine-grained zircon (ZrSi04); aluminium oxide, and fused silica is prepared.

- ✓ Bonding agents are mixed thoroughly to the mixture to form homogeneous slurry.

3. Mould making: The pattern is placed in a flask. Some parting agent such as an oil or grease is applied over the pattern surface.

- ✓ The slurry is poured over the pattern. Enough number of coatings of slurry is applied so that the mould (also called ceramic facing) is about 5 mm thick. After initial setting in the air, the ceramic facing is removed from the pattern and placed in an oven for drying and baking.
- ✓ The mould-halves are clamped firmly as soon as they are taken out from the oven so that metal can be poured while the mould is hot.
- ✓ In the Shaw process, the assembled ceramic facings are placed in a flask. The empty space around the assembled facings is filled with fire clay as back-up material to give support and strength to the mould.

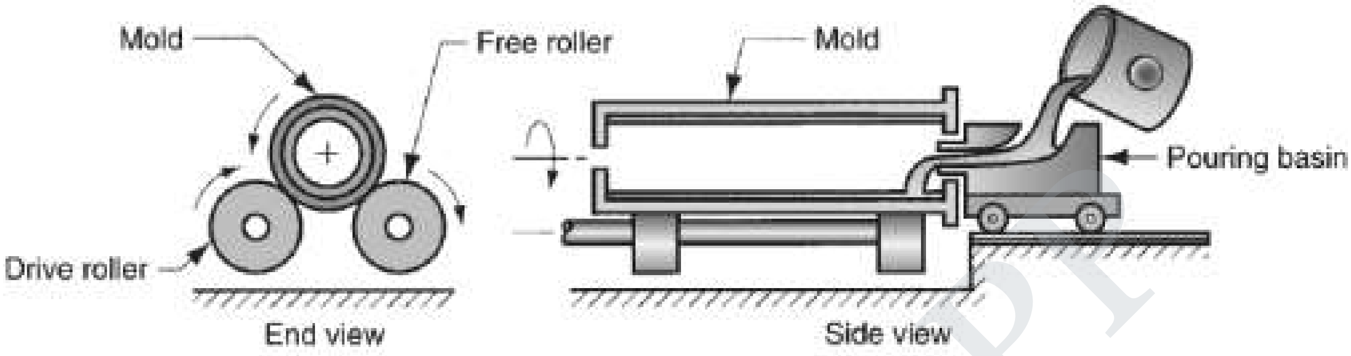
4. Casting: Molten metal is poured in the hot mould cavity.

- ✓ Stainless steels, tool steels and other ferrous alloys can be cast as the refractory moulding materials have high-temperature resistance.
- ✓ It is possible to produce intricate shaped castings in a wide range of sizes weighing up to 500 kg.
- ✓ The castings produced have good dimensional accuracy and surface finish. The main limitation of this process is that it is relatively expensive. Typical parts made by this process are dies for metal working, dies for making plastic and rubber components, impellers, and components of tanks and gas engines.

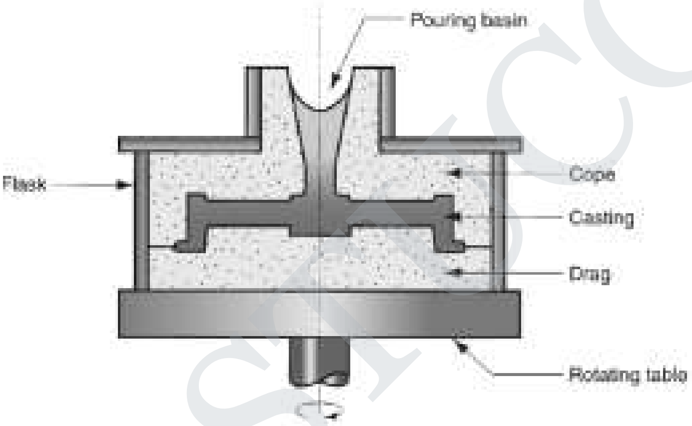
The ceramic moulding process is similar to the plaster moulding process, with the difference that ceramic moulding uses a refractory material for the mould, thereby making the moulds suitable for casting ferrous and other high-temperature alloys. Commonly used mould materials a slurry consisting of fine grained zircon ($ZrSiO_4$), aluminium oxide, and fused silica to which some bonding agents are added.

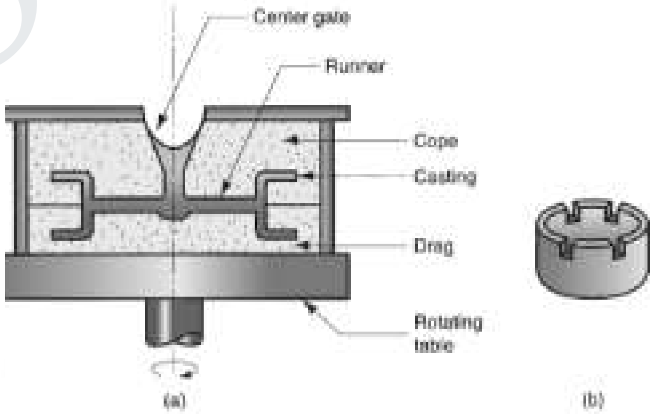
Centrifugal Casting

✓ The centrifugal force acts to throw the molten metal against the mould wall, where it is allowed to remain until it cools and solidifies.



Centrifugal Casting





Semi Centrifugal Casting

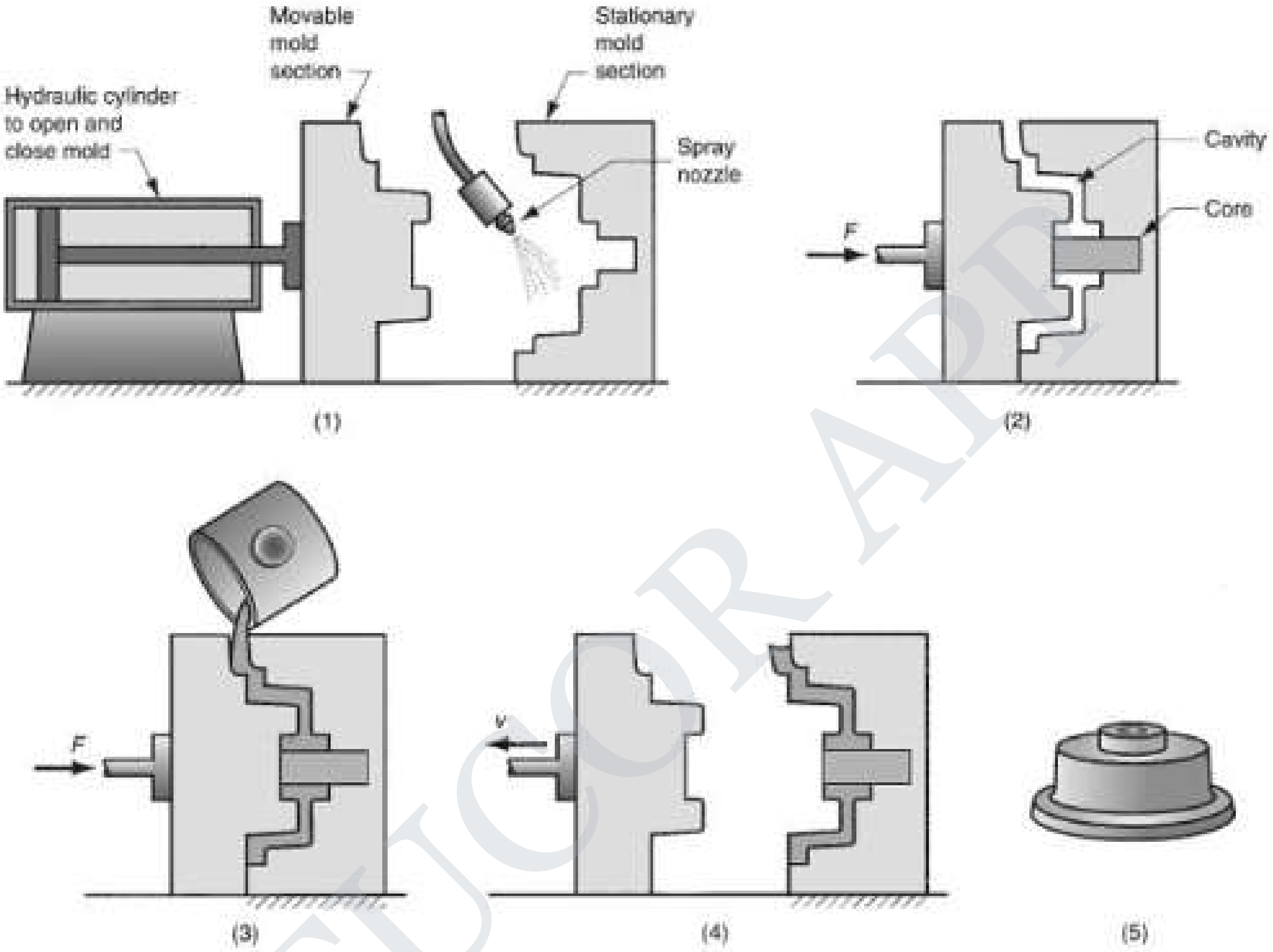
Centrifuging

Advantages

1. Directional solidification.
2. Less percentage of defective castings and, therefore, high casting yield.
3. Castings with thin sections or fine outside surface details can be readily produced.
4. Castings are sound and dense grain structure with physical properties comparable with those of forgings.
5. Virtually free of porosity.
6. Castings need less fettling and cleaning of surface.

Permanent-mold Casting

- ✓ Die casting process uses a re-usable mould, i.e., metallic die and, therefore, it is also known by the term permanent mould process.
- ✓ The gating and riser systems are machined into the die itself



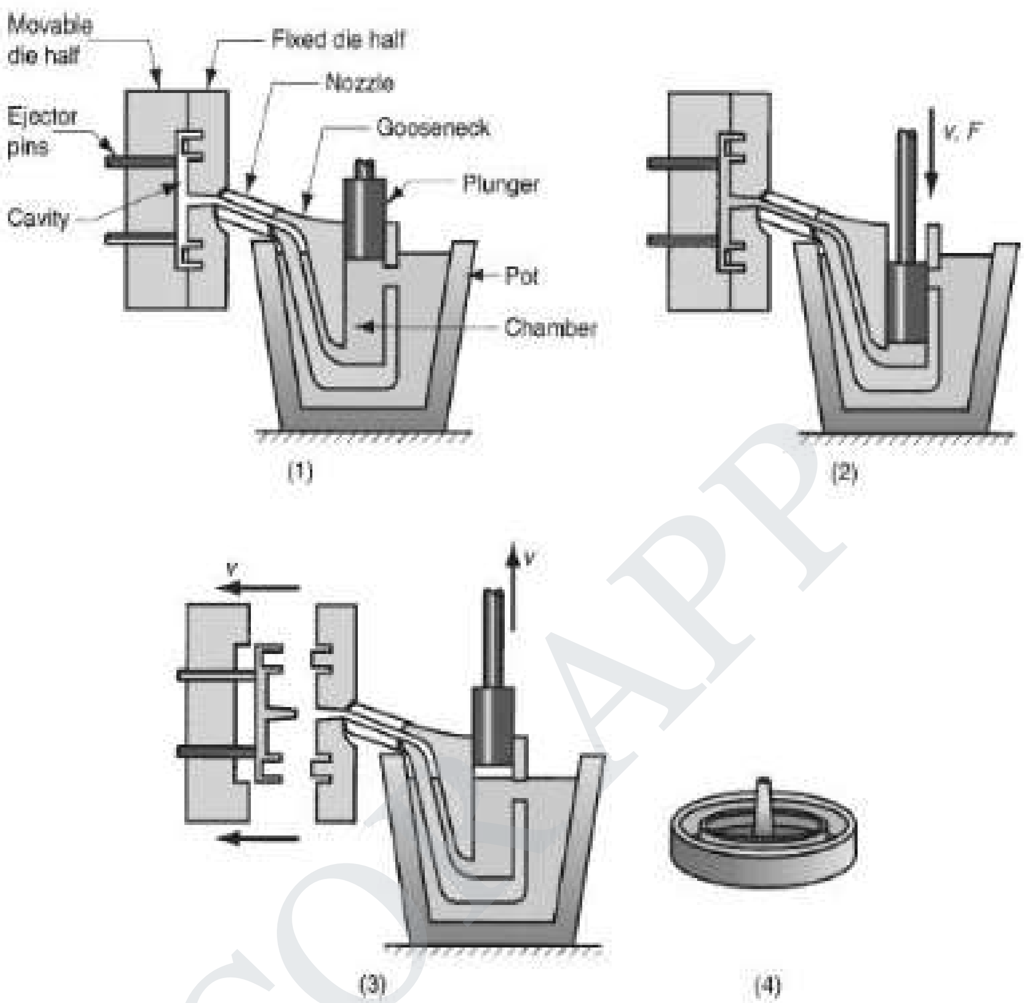
Steps in permanent-mold casting: (1) mold is preheated and coated; (2) cores (if used) are inserted, and mold is closed; (3) molten metal is poured into the mold; and (4) mold is opened. Finished part is shown in (5).

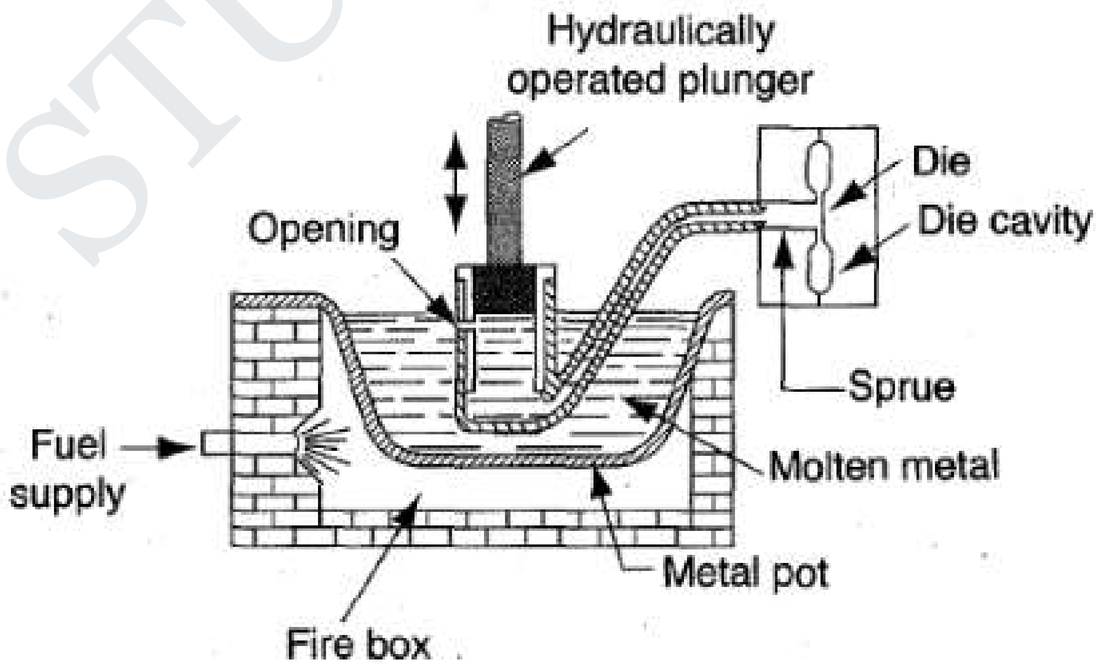
Classifications

- ✓ Slush casting
- ✓ Low-pressure casting
- ✓ Vacuum permanent-mold casting
- ✓ Pressure Die Casting
    - o Hot chamber casting
    - o Cold chamber casting

Hot chamber casting

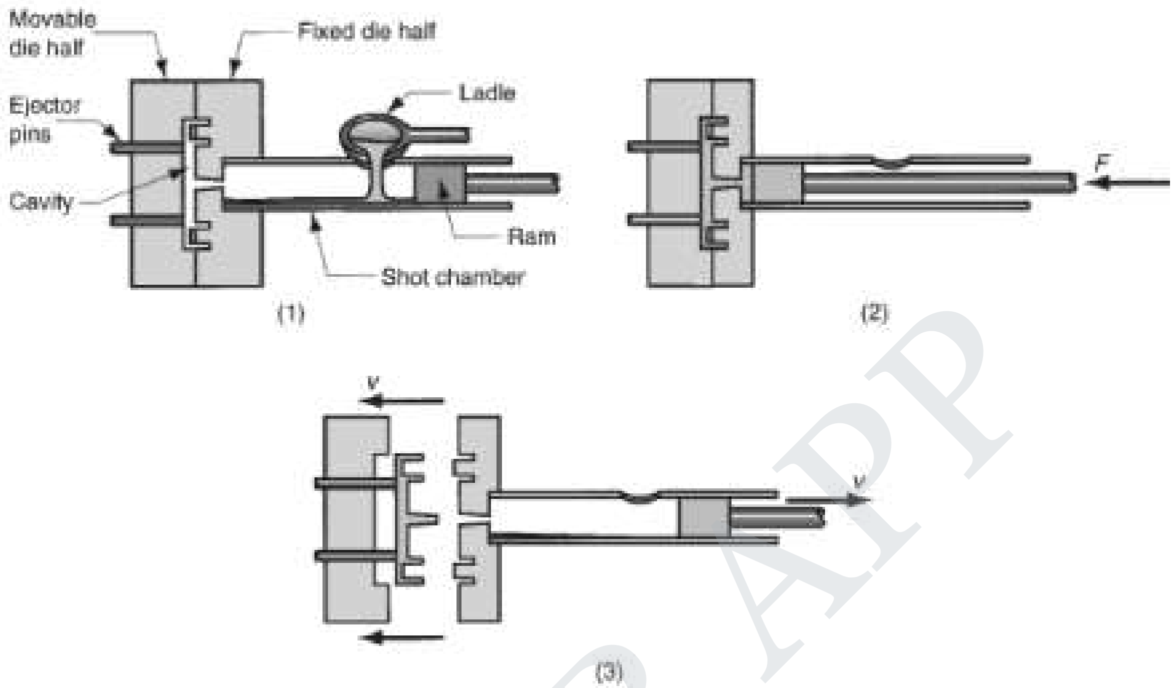
- ✓ Typical injection pressures are 7 to 35 MPa
- ✓ 500 parts per hour
- ✓ Metals include zinc, tin, lead, and sometimes magnesium





Cold chamber casting

- ✓ 14 to 140 MPa
- ✓ For casting aluminum, brass, and magnesium alloys.
- ✓ Also for Low-melting-point alloys tool steel, mold steel



Facts: Die Casting

- ✓ Die Materials: Tungsten and molybdenum with good refractory qualities are also being used
- ✓ Ejector pins are required to remove the part from the die when it opens, as in our diagrams. These pins push the part away from the mold surface so that it can be removed.
- ✓ Lubricants must also be sprayed into the cavities to prevent sticking.
- ✓ No natural porosity and the molten metal rapidly flows into the die during injection, venting holes and passageways must be built into the dies at the parting line to evacuate the air and gases in the cavity.
- ✓ Formation of flash is common in die casting, in which the liquid metal under high pressure squeezes into the small space between the die halves at the parting line or into the clearances around the cores and ejector pins.

Advantages

1. High production rate is possible
2. Thin sections and complex shapes can be obtained
3. High precision of the cast components.
4. Much closer dimensional tolerances (3 mm/m is common).
5. Improved surface finish (of the order of 1 micron).
6. Greater soundness and compactness of casting. (Fewer defective castings.)
7. Better mechanical properties of the casting due to the fine-grained skin formed during the solidification process.
8. Requires less work training; therefore, low labour cost per casting.
9. Requires less floor space compared to other processes for the same production rate.
10. Process can be easily automated.

Limitations

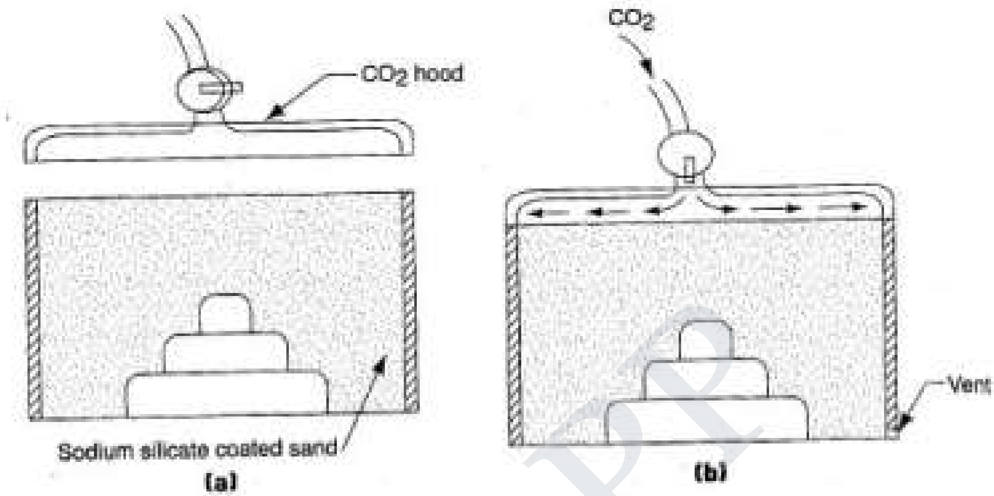
1. Cost of dies and equipments is high.
2. Maximum size of casting is limited due to limited machine capacity.
3. Entrapment of air in the die cavity while injecting the molten metal is a serious problem.
4. Die life decreases with an increase in the molten metal temperature.
5. Metallic parts having a larger coefficient of contraction need to be removed quickly from the die; otherwise, casting removal from the die becomes difficult.
6. Maintenance and supervisory staff need to be skilled, though special skills are not required from machine operators.

Applications

- ✓ Non-ferrous alloys which have base metals as zinc, aluminium, copper, magnesium, lead, and tin can be cast by this process.
- ✓ Typical applications are for casting of hand tools, appliances, automotive components, motor frames and housings, plumbing fixtures, household utensils, building hardware, and toys.

CO_2 Process (Sodium Silicate Molding Process)

- ✓ The dry silica sand is thoroughly mixed with 20% to 40% Sodium silicate, an organic binder which is a viscous fluid.
- ✓ The sand particles get coated with a thin film of the binder. The silica mix is packed around the pattern in a flask in the usual manner.



- ✓ For molds, the sand mixture can be compacted manually, jolted or squeezed around the pattern in the flask.
- ✓ After compaction, CO_2 gas of 1.4 - 1.5 bar is passed through the core or mold.
- ✓ The CO_2 chemically reacts with the sodium silicate to cure, or harden, the binder. This cured binder then holds the refractory in place around the pattern.
- ✓ After curing, the pattern is withdrawn from the mold.
- ✓ The sand mixture remains soft and mouldable until it is exposed to CO_2 gas, when it hardens in a fraction of a minute.

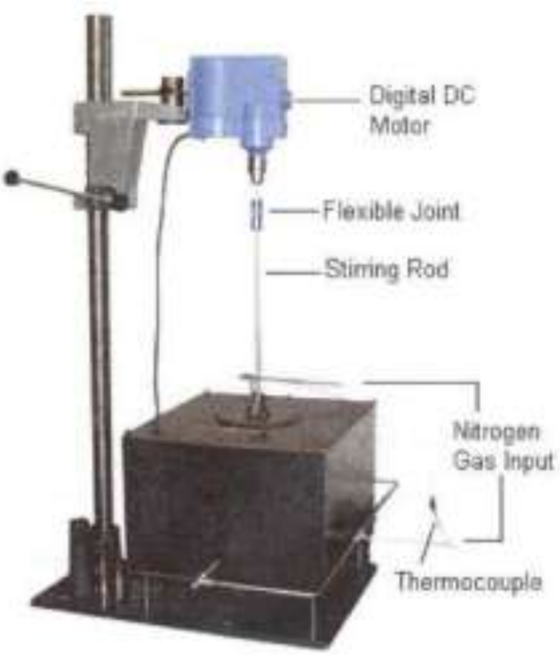
$$Na_2SiO_3 + CO_2 \rightarrow Na_2CO_3 + SiO_2 \text{ (colloidal)}$$

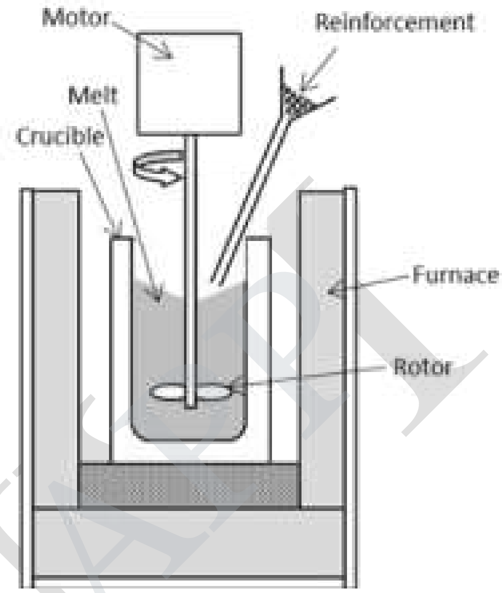
- ✓ The sodium silicate process is one of the most environmentally acceptable of the chemical processes available.
- ✓ The major disadvantage of the process is that the binder is very hygroscopic and readily absorbs water, which causes porosity in the castings.
- ✓ Also, because the binder creates such a hard, rigid mold wall, shakeout and collapsibility characteristics can slow down production.

Some of the advantages of the process are:

- ✓ A hard, rigid core and mold are typical of the process, which gives the casting good dimensional tolerances;
- ✓ Good casting surface finishes are readily obtainable.

Stir casting





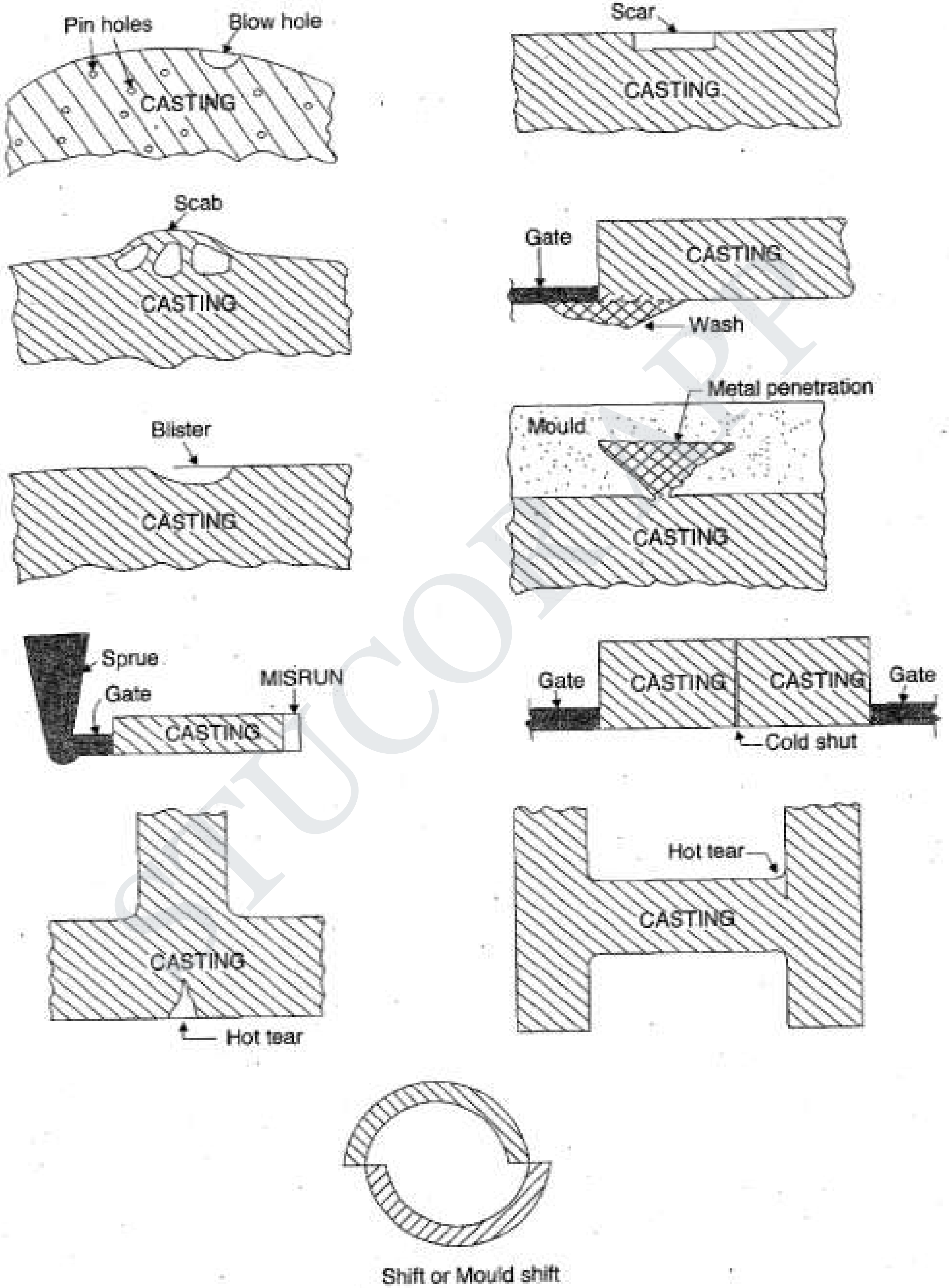
Inspection and Testing Of Castings

Destructive Testing Techniques

Non-destructive Testing (NDT) Techniques

- ✓ Optical or visual inspection
- ✓ Dimensional inspection
- ✓ X-ray and gamma-ray inspection
- ✓ Magnetic-particle inspection
- ✓ Fluorescent penetrant inspection
- ✓ Ultrasonic inspection
- ✓ Acoustic emission inspection
- ✓ Eddy current testing
- ✓ Pressure testing

SAND CASTING DEFECTS



SAND CASTING DEFECTS

- ✓ Several types of defects may occur in castings, considerably reducing the total output of castings besides increasing the cost of their production.
- ✓ Defective castings offer problems to the foundry industry.
- ✓ A defect may be the result of a single clearly defined cause or of a combination of factors.

1. Blowholes and Pinholes

- ✓ Blowholes generally appear as smooth walled, round voids or cavities opened to the casting surface.
- ✓ Blowholes are caused due to the entrapped bubbles of gas with smooth walls, excessive moisture in the moulding sand, low permeability of sand, hard ramming of sand or gas producing ingredients in the mould.
- ✓ They may occur in clusters or there may be one large smooth depression.

2. Shrinkage defects

- ✓ When the metals solidify, there is a volumetric shrinkage, and if adequate feeding does not compensate for the shrinkage, voids will occur inside the casting.
- ✓ This defect can be prevented by adequate feeding of the molten metal and designing a gating system to enable directional solidification.

3. Hot tears

- ✓ Hot tears are internal or external cracks or discontinuities on the casting surface.
- ✓ These are caused by hindered contraction occurring immediately after the metal has solidified.
- ✓ Immediately after the solidification, metal will have low strength, and if the solid shrinkage after casting causes sufficiently high stresses, the metal will fail with the resulting hot tear.
- ✓ They may be produced when the casting is poorly designed and abrupt sectional changes take place or no proper corner radii are provided.
- ✓ Hot tears can also be due to hard ramming and too much shrinkage of metal during solidification.

4. Misruns, cold shuts and pour short

- ✓ A misrun casting is one that remains incomplete due to the failure of metal to fill the entire mould cavity.
- ✓ This can happen when the dimensions of a casting is very less or the metal temperature is too cold, so that the entire section is not filled before the metal solidifies. This defect is called a misrun.
- ✓ When two streams of metal, which are too cold, meet inside the mould cavity and do not fuse together, the defect is known as cold shut.
- ✓ In cold shut, a discontinuity is formed due to the imperfect fusion of two layers of metal in the mould cavity and the defect may appear like a crack or seam with smooth rounded edges.
- ✓ When the metal cavity is not completely filled because of insufficient metal, the defect is called pour short.

5. Inclusions

- ✓ Any separate undesirable foreign material present within the metal of a casting is known as inclusion.
- ✓ An inclusion may be oxides, slag, dirt, etc., which enters the mould cavity along with the molten metal during pouring.
- ✓ To avoid inclusions, molten metal should be skimmed of before pouring into the mould cavity and all loose sand should be blown off before closing the moulds.

Gas Defects:

Blow holes and open blows

Pin hole porosity

Blisters and Scars

Scab

Shrinkage Cavities

Moulding material defects:

Fins

Metal penetration or wash

Fusion

Runouts and Bust out

Rat tails and buckles

Swell – metallostatic forces

Drops

Rough surface finish

Hard spots

Pouring metal defects:

Mis-runs and cold shuts

Pour short

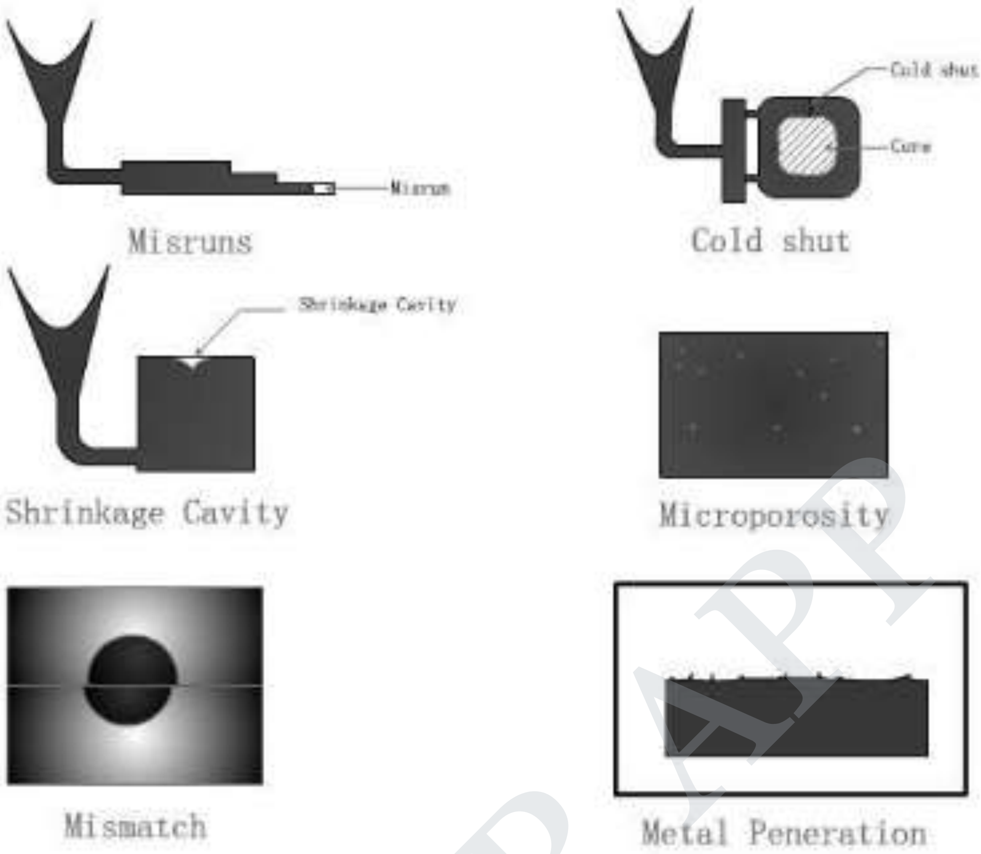
Slag inclusions

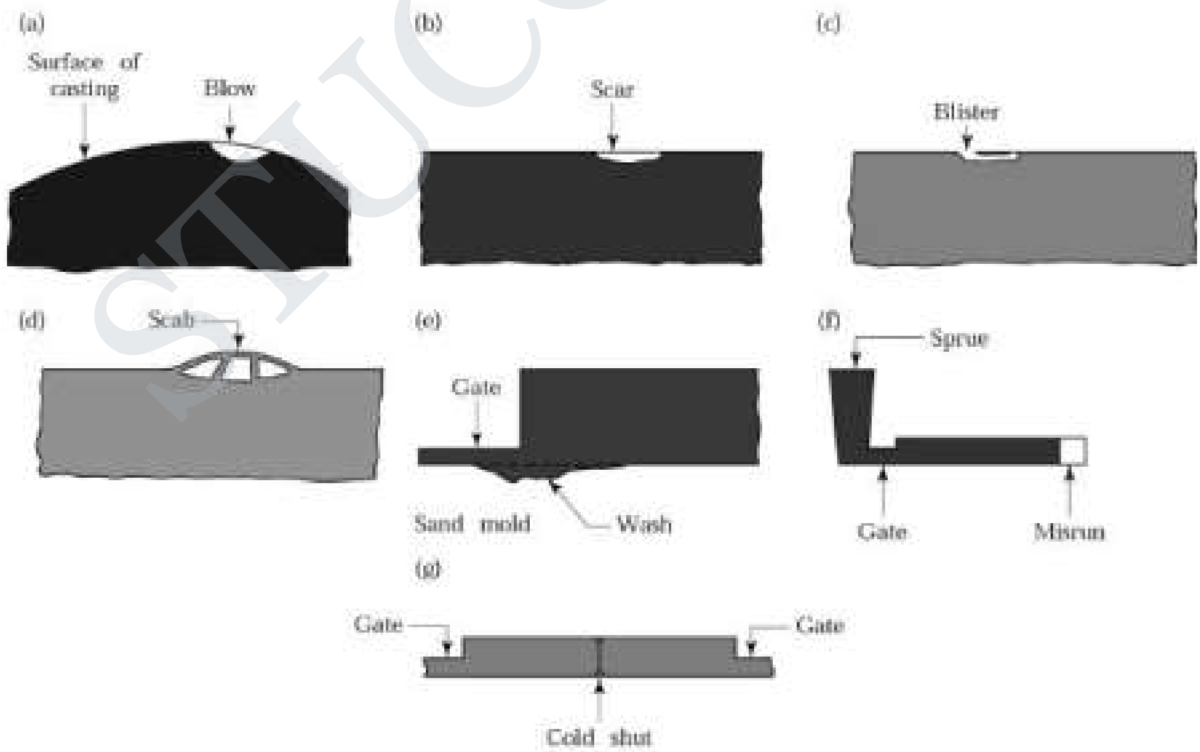
Metallurgical defects:

Hot tears

Hot spots – GCI – Hard WCI

Cold cracks


Misrun
Misruns
Cold shut
Core
Cold shut
Shrinkage Cavity
Shrinkage Cavity
Microporosity
Mismatch
Metal Peneration


(a)
Surface of casting
Blow
(b)
Scar
(c)
Blister
(d)
Scab
(e)
Gate
Sand mold
Wash
(f)
Sprue
Gate
Misrun
(g)
Gate
Gate
Cold shut

UNIT II JOINING PROCESSES 9

Operating principle, basic equipment, merits and applications of: Fusion welding processes: Gas welding - Types – Flame characteristics; Manual metal arc welding – Gas Tungsten arc welding - Gas metal arc welding – Submerged arc welding – Electro slag welding; Operating principle and applications of: Resistance welding - Plasma arc welding – Thermit welding – Electron beam welding – Friction welding and Friction Stir Welding; Brazing and soldering; Weld defects: types, causes and cure.

Introduction:

- ✓ Welding which is the process of joining two metallic components for the desired purpose, can be defined as the process of joining two similar or dissimilar metallic components with the application of heat, with or without the application of pressure and with or without the use of filler metal. Heat may be obtained by chemical reaction, electric arc, electrical resistance, frictional heat, sound and light energy.
- ✓ If no filter metal is used during welding then it is termed as 'Autogenous Welding Process'.
- ✓ During 'Bronze Age' parts were joined by forge welding to produce tools, weapons and ornaments etc, however, present day welding processes have been developed within a period of about a century.
- ✓ First application of welding with carbon electrode was developed in 1885 while metal arc welding with bare electrode was patented in 1890.
- ✓ However, these developments were more of experimental value and applicable only for repair welding but proved to be the important base for present day manual metal arc (MMAW) welding and other arc welding processes.

- ✓ In the mean time resistance butt welding was invented in USA in the year 1886. Other resistance welding processes such as spot and flash welding with manual application of load were developed around 1905.
- ✓ With the production of cheap oxygen in 1902, oxy – acetylene welding became feasible in Europe in 1903.
- ✓ When the coated electrodes were developed in 1907, the manual metal arc welding process becomes viable for production/fabrication of components and assemblies in the industries on large scale.
- ✓ All welded 'Liberty' ships failure in 1942, gave a big jolt to application of welding. However, it had drawn attention to fracture problem in welded structures.

Applications

Pressure Vessels:

One of the first major uses of welding was in the fabrication of pressure vessels. Welding made considerable increases in the operating temperatures and pressures possible as compared to riveted pressure vessels.

Bridges:

Early use of welding in bridge construction took place in Australia . This was due to problems in transporting complete riveted spans or heavy riveting machines necessary for fabrication on site to remote areas. The first all welded bridge was erected in UK in 1934. Since then all welded bridges are erected very commonly and successfully.

Ship Building :

Ships were produced earlier by riveting. Over ten million rivets were used in 'Queen Mary' ship which required skills and massive organization for riveting but welding would have allowed the semiskilled/ unskilled labor and the principle of pre-fabrication. Welding found its place in ship building around 1920 and presently all welded ships are widely used. Similarly submarines are also produced by welding.

Building Structures:

Arc welding is used for construction of steel building leading to considerable savings in steel and money. In addition to building, huge structures such as steel towers etc also require welding for fabrication.

Aircraft and Spacecraft:

Similar to ships, aircrafts were produced by riveting in early days but with the introduction of jet engines welding is widely used for aircraft structure and for joining of skin sheet to body.

Space vehicles which have to encounter frictional heat as well as low temperatures require outer skin and other parts of special materials. These materials are welded with full success achieving safety and reliability.

Railways:

Railways use welding extensively for fabrication of coaches and wagons, wheel tyres laying of new railway tracks by mobile flash butt welding machines and repair of cracked/damaged tracks by thermit welding.

Automobiles:

Production of automobile components like chassis, body and its structure, fuel tanks and joining of door hinges require welding.

Electrical Industry:

Starting from generation to distribution and utilization of electrical energy, welding plays important role. Components of both hydro and steam power generation system, such as penstocks, water control gates, condensers, electrical transmission towers and distribution system equipment are fabricated by welding. Turbine blades and cooling fins are also joined by welding.

Electronic Industry:

Electronic industry uses welding to limited extent such as for joining leads of special transistors but other joining processes such as brazing and soldering are widely being used. Soldering is used for joining electronic components to printed circuit boards. Robotic soldering is very common for joining of parts to printed circuit boards of computers, television, communication equipment and other control equipment etc.

Nuclear Installations:

Spheres for nuclear reactor, pipe line bends joining two pipes carrying heavy water and other components require welding for safe and reliable operations.

Defence Industry:

Defence industry requires welding for joining of many components of war equipment. Tank bodies fabrication, joining of turret mounting to main body of tanks are typical examples of applications of welding.

Micro-Joining:

It employs the processes such as micro-plasma, ultrasonic, laser and electron beam welding, for joining of thin wire to wire, foil to foil and foil to wire, such as producing junctions of thermocouples, strain gauges to wire leads etc.

General Applications:

Welding is vastly being used for construction of transport tankers for transporting oil, water, milk and fabrication of welded tubes and pipes, chains, LPG cylinders and other items. Steel furniture, gates, doors and door frames, body and other parts of white goods items such as refrigerators, washing machines, microwave ovens and many other items of general applications are fabricated by welding.

Apart from above applications welding are also used for joining of pipes, during laying of crude oil and gas pipelines, construction of tankers for their storage and transportation. Offshore structures, dockyards, loading and unloading cranes are also produced by welding.

Classification of Welding Processes:

Welding processes can be classified based on following criteria;

1. Welding with or without filler material.
2. Source of energy of welding.
3. Arc and Non-arc welding.
4. Fusion and Pressure welding.

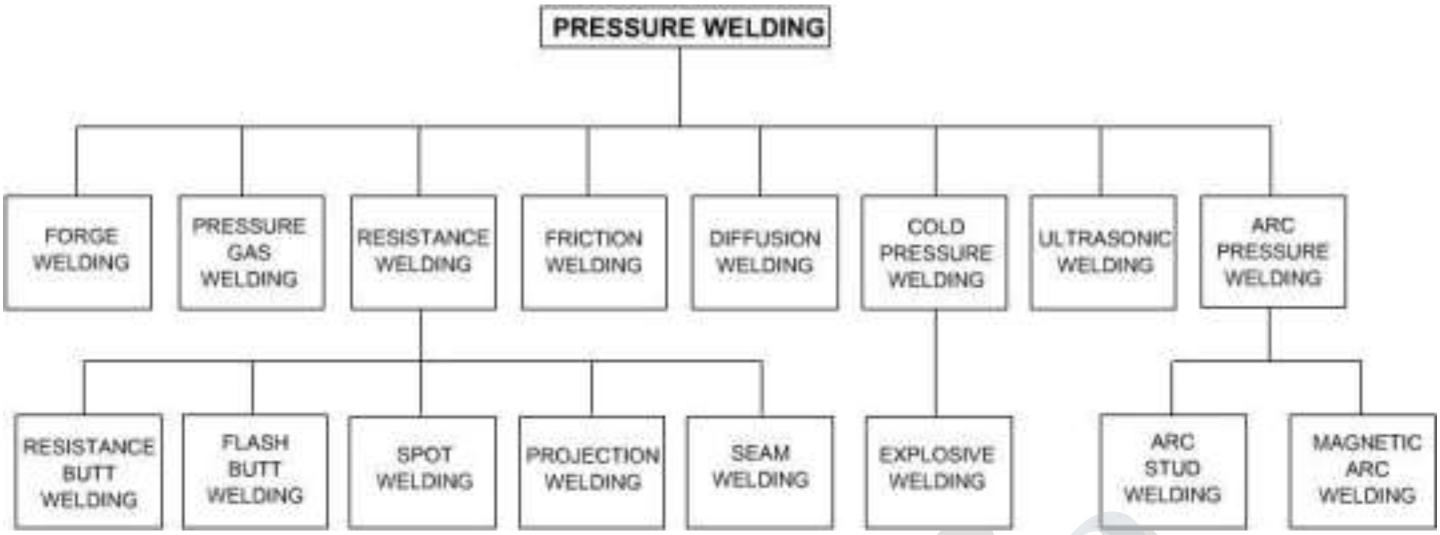


Figure 1: Classification of Pressure Welding Processes

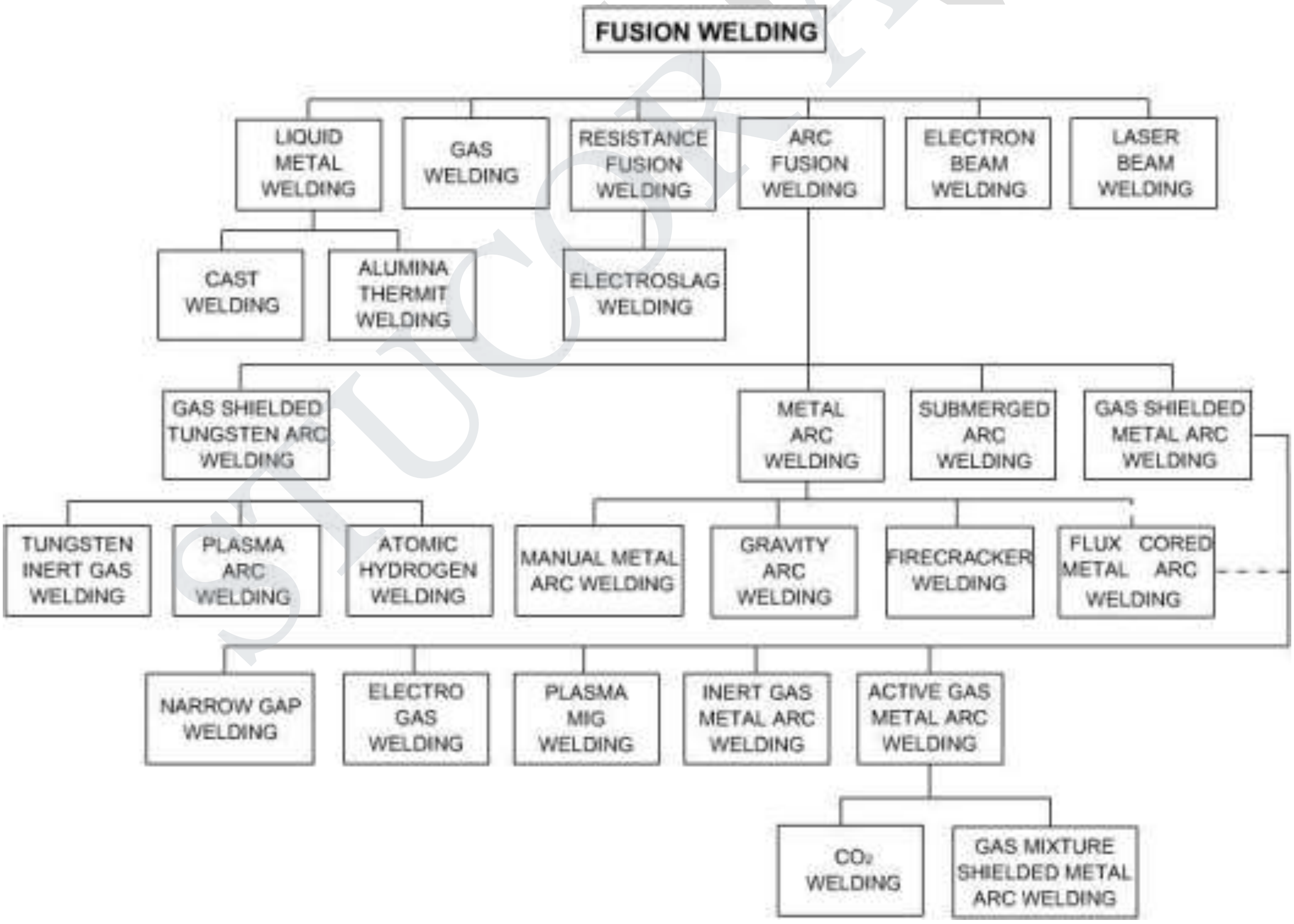


Figure 2: Classification of Fusion Welding Processes

TERMINOLOGICAL ELEMENTS OF WELDING PROCESS

The terminological elements of welding process used with common welding joints such as base metal, fusion zone, weld face, root face, root opening toe and root are depicted in Fig.

Edge preparations For welding the edges of joining surfaces of metals are prepared first. Different edge preparations may be used for welding butt joints, which are given in Fig

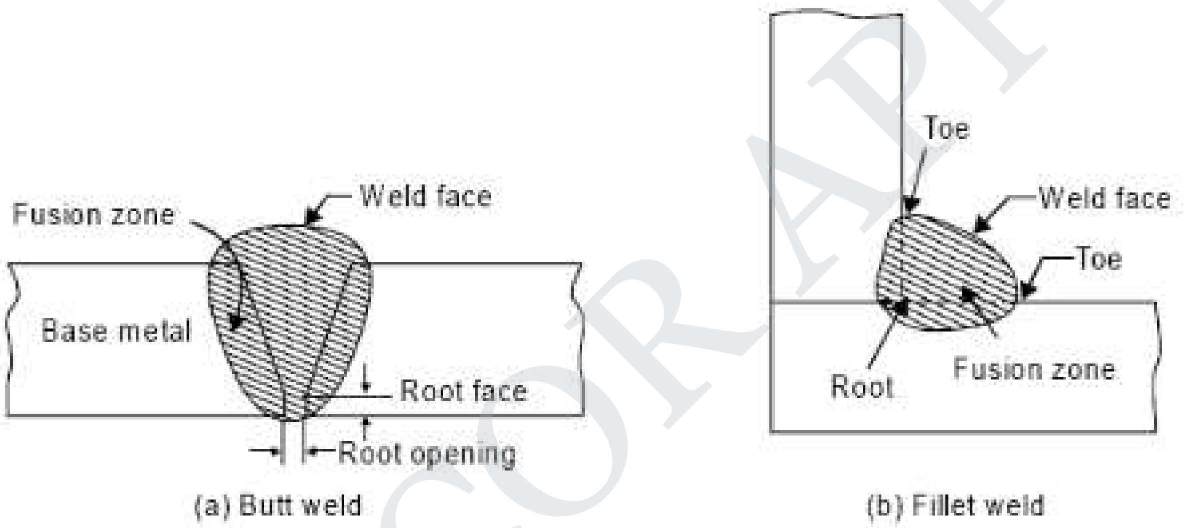


Fig. Terminological elements of welding process

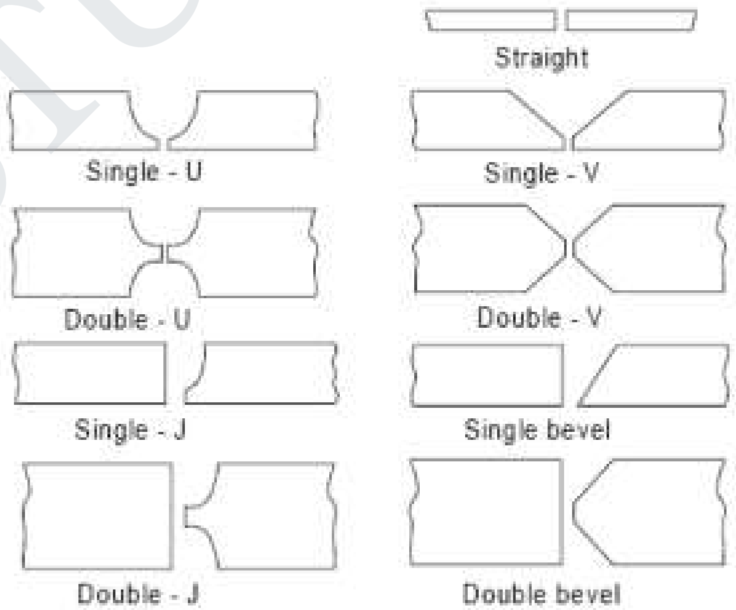


Fig. Butt welding joints edge preparations

Welding joints

Some common welding joints are shown in Fig. Welding joints are of generally of two major kinds namely lap joint and butt joint.

The main types are described as under.

Lap weld joint

Single-Lap Joint

This joint, made by overlapping the edges of the plate, is not recommended for mostwork. The single lap has very little resistance to bending. It can be used satisfactorily forjoining two cylinders that fit inside one another.

Double-Lap Joint

This is stronger than the single-lap joint but has the disadvantage that it requires twice as much welding.

Butt weld joint

Single-Vee Butt Weld

It is used for plates up to 15.8 mm thick. The angle of the vee depends upon the technique being used, the plates being spaced approximately 3.2 mm.

Double-Vee Butt Weld

It is used for plates over 13 mm thick when the welding can be performed on both sides of the plate. The top vee angle is either 60° or 80°, while the bottom angle is 80°, depending on the technique being used.

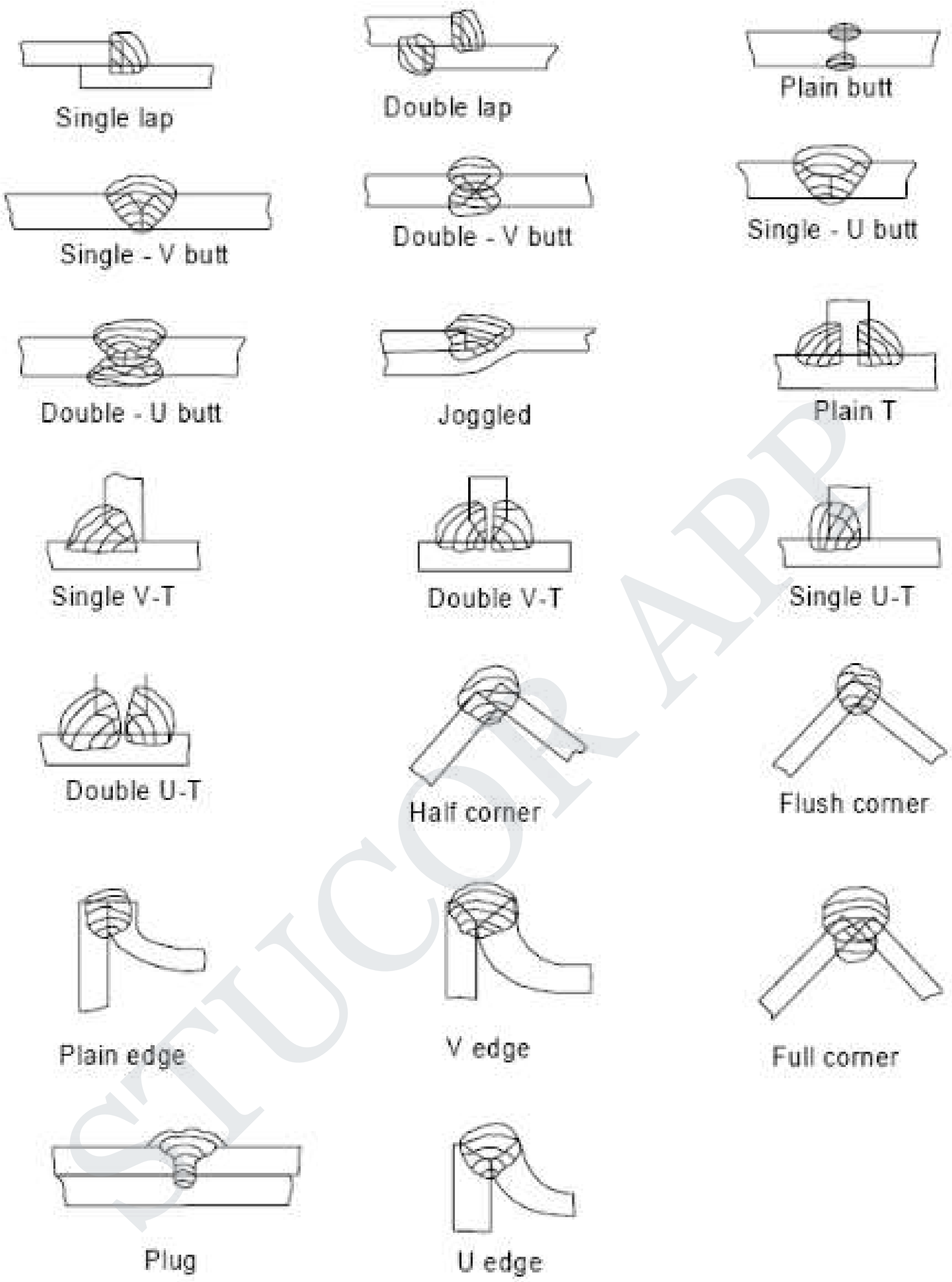


Fig. Types of welding joints

Welding Positions

As shown in Fig., there are four types of welding positions, which are given as:

1. Flat or down hand position
2. Horizontal position
3. Vertical position
4. Overhead position

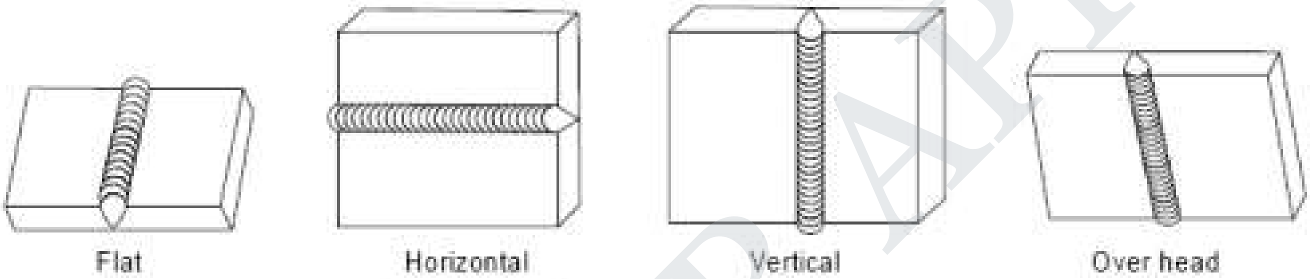


Fig. Kinds of welding positions

Flat or Downhand Welding Position

The flat position or down hand position is one in which the welding is performed from the upper side of the joint and the face of the weld is approximately horizontal. This is the simplest and the most convenient position for welding. Using this technique, excellent welded joints at a fast speed with minimum risk of fatigue to the welders can be obtained.

Horizontal Welding Position

In horizontal position, the plane of the workpiece is vertical and the deposited weld head is horizontal. The metal deposition rate in horizontal welding is next to that achieved in flat or down hand welding position. This position of welding is most commonly used in welding vessels and reservoirs.

Veritical Welding Position

In vertical position, the plane of the workpiece is vertical and the weld is deposited upon a vertical surface. It is difficult to produce satisfactory welds in this position due to the effect of the force of gravity on the molten metal. The welder must constantly control the metal so that it does not run or drop from the weld. Vertical welding may be of two types viz., vertical-up and vertical-down. Vertical-up welding is preferred when strength is the major consideration. The vertical-down welding is used for a sealing operation and for welding sheet metal.

Overhead Welding Position

The overhead position is probably even more difficult to weld than the vertical position.

Here the pull of gravity against the molten metal is much greater. The force of the flame against the weld serves to counteract the pull of gravity. In overhead position, the plane of the workpiece is horizontal. But the welding is carried out from the underside. The electrode is held with its welding end upward. It is a good practice to use very short arc and basic coated electrodes for overhead welding.

ADVANTAGES AND DISADVANTAGES OF WELDING

Advantages

1. Welding is more economical and is much faster process as compared to other processes (riveting, bolting, casting etc.)

2. Welding, if properly controlled results permanent joints having strength equal or sometimes more than base metal.

3. Large number of metals and alloys both similar and dissimilar can be joined by welding.

4. General welding equipment is not very costly.

5. Portable welding equipments can be easily made available.

6. Welding permits considerable freedom in design.

7. Welding can join welding jobs through spots, as continuous pressure tight seams, end-to-end and in a number of other configurations.

8. Welding can also be mechanized.

Disadvantages

1. It results in residual stresses and distortion of the workpieces.
2. Welded joint needs stress relieving and heat treatment.
3. Welding gives out harmful radiations (light), fumes and spatter.
4. Jigs, and fixtures may also be needed to hold and position the parts to be welded.
5. Edges preparation of the welding jobs are required before welding
6. Skilled welder is required for production of good welding
7. Heat during welding produces metallurgical changes as the structure of the welded joint is not same as that of the parent metal.

CLASSIFICATION OF WELDING AND ALLIED PROCESSES

There is different welding; brazing and soldering methods are being used in industries today.

(A) Welding Processes

1. Oxy-Fuel Gas Welding Processes
    1 Air-acetylene welding
    2 Oxy-acetylene welding
    3 Oxy-hydrogen welding
    4 Pressure gas welding
2. Arc Welding Processes
    1. Carbon Arc Welding
    2. Shielded Metal Arc Welding
    3. Submerged Arc Welding
    4. Gas Tungsten Arc Welding
    5. Gas Metal Arc Welding
    6. Plasma Arc Welding
    7. Atomic Hydrogen Welding
    8. Electro-slag Welding
    9. Stud Arc Welding
    10. Electro-gas Welding
3. Resistance Welding
    1. Spot Welding
    2. Seam Welding
    3. Projection Welding
    4. Resistance Butt Welding
    5. Flash Butt Welding
    6. Percussion Welding
    7. High Frequency Resistance Welding
    8. High Frequency Induction Welding

4. Solid-State Welding Processes
    1. Forge Welding
    2. Cold Pressure Welding
    3. Friction Welding
    4. Explosive Welding
    5. Diffusion Welding
    6. Cold Pressure Welding
    7. Thermo-compression Welding
5. Thermit Welding Processes
    1. Thermit Welding
    2. Pressure Thermit Welding
6. Radiant Energy Welding Processes
    1. Laser Welding
    2. Electron Beam Welding

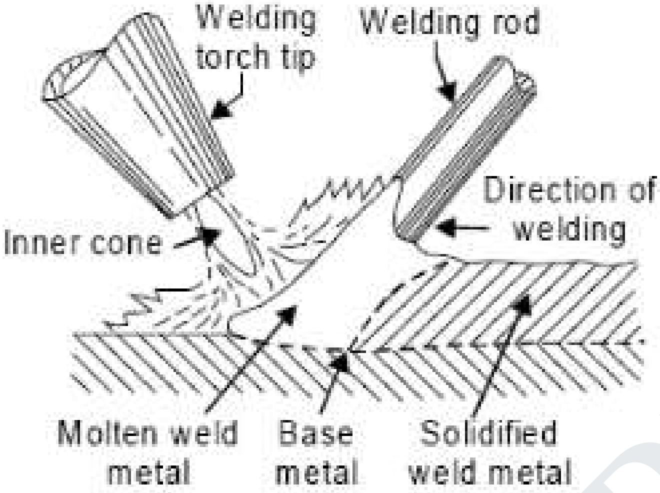
(B) Allied Processes

1. Metal Joining or Metal Depositing Processes
    1. Soldering
    2. Brazing
    3. Braze Welding
    4. Adhesive Bonding
    5. Metal Spraying
    6. Surfacing
2. Thermal Cuting Processes
    1. Gas Cutting
    2. Arc Cutting

GAS WELDING PROCESSES

- ✓ A fusion welding process which joins metals, using the heat of combustion of an oxygen /air and fuel gas (i.e. acetylene, hydrogen propane or butane) mixture is usually referred as 'gas welding'.
- ✓ The intense heat (flame) thus produced melts and fuses together the edges of the parts to be welded, generally with the addition of a filler metal. Operation of gas welding is shown in Fig.
- ✓ The fuel gas generally employed is acetylene; however gases other than acetylene can also be used though with lower flame temperature.
- ✓ Oxy-acetylene flame is the most versatile and hottest of all the flames produced by the combination of oxygen and other fuel gases.

- ✓ Other gases such as Hydrogen, Propane, Butane, Natural gas etc., may be used for some welding and brazing applications.



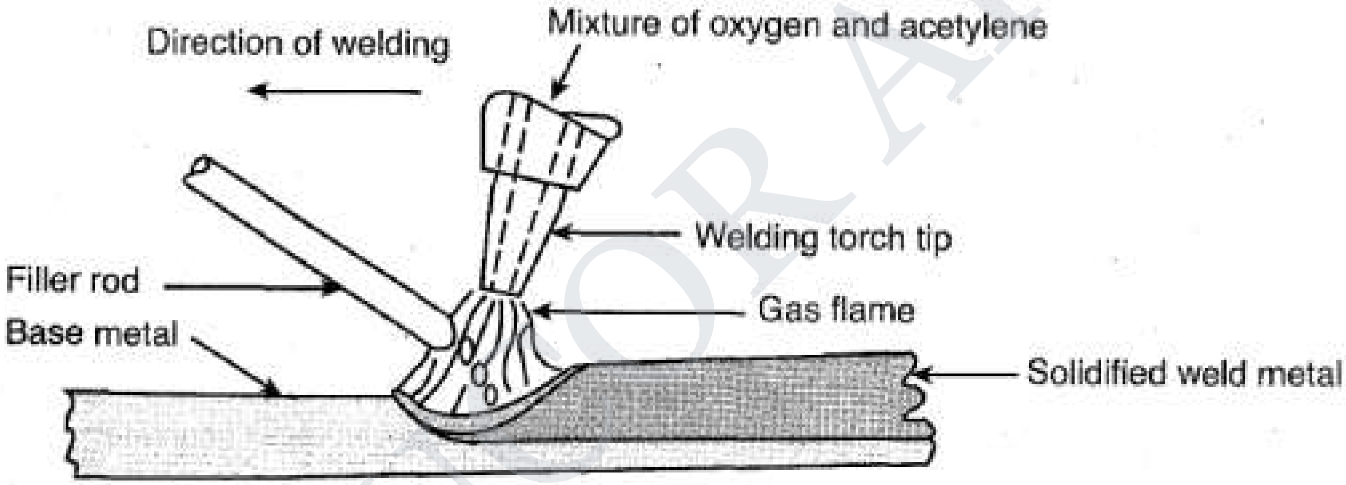


Figure 16.1 Schematic of oxy-acetylene welding process

Oxy-Acetylene Welding

- ✓ In this process, acetylene is mixed with oxygen in correct proportions in the welding torch and ignited.
- ✓ The flame resulting at the tip of the torch is sufficiently hot to melt and join the parent metal.
- ✓ The oxy-acetylene flame reaches a temperature of about 3300°C and thus can melt most of the ferrous and non-ferrous metals in common use.
- ✓ A filler metal rod or welding rod is generally added to the molten metal pool to build up the seam slightly for greater strength.

Types of Welding Flames

- ✓ In oxy-acetylene welding, flame is the most important means to control the welding joint and the welding process.
- ✓ The correct type of flame is essential for the production of satisfactory welds.
- ✓ The flame must be of the proper size, shape and condition in order to operate with maximum efficiency.
- ✓ There are three basic types of oxy-acetylene flames.

1. Neutral welding flame (Acetylene and oxygen in equal proportions).
2. Oxidizing welding flame (excess of oxygen).
3. Carburizing welding flame or reducing (excess of acetylene).

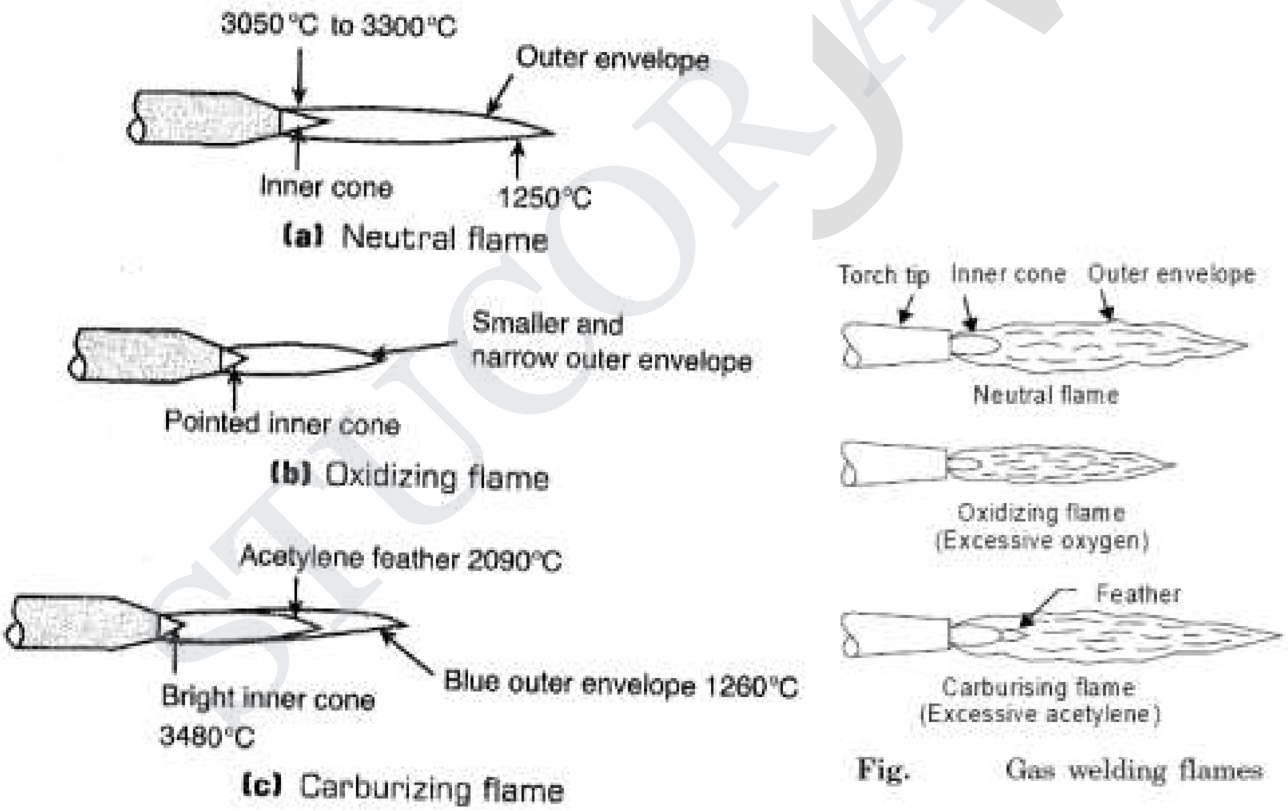


Fig. Gas welding flames

Neutral Welding Flame

- ✓ A neutral flame results when approximately equal volumes of oxygen and acetylene are mixed in the welding torch and burnt at the torch tip.
- ✓ The temperature of the neutral flame is of the order of about 5900°F (3260°C).

- ✓ It has a clear, well defined inner cone, indicating that the combustion is complete.
- ✓ The inner cone is light blue in color. It is surrounded by an outer flame envelope, produced by the combination of oxygen in the air and superheated carbon monoxide and hydrogen gases from the inner cone. This envelope is usually a much darker blue than the inner cone.
- ✓ A neutral flame is named so because it affects no chemical change on the molten metal and, therefore will not oxidize or carburize the metal.
- ✓ The neutral flame is commonly used for the welding of mild steel, stainless steel, cast Iron, copper, and aluminium.

Oxidising Welding flame

- ✓ The oxidizing flame has an excess of oxygen over the acetylene. An oxidizing flame can be recognized by the small cone, which is shorter, much bluer in color and more pointed than that of the neutral flame.
- ✓ The outer flame envelope is much shorter and tends to fan out at the end. Such a flame makes a loud roaring sound. It is the hottest flame (temperature as high as 6300°F) produced by any oxy-fuel gas source.
- ✓ But the excess oxygen especially at high temperatures tends to combine with many metals to form hard, brittle, low strength oxides.
- ✓ Moreover, an excess of oxygen causes the weld bead and the surrounding area to have a scummy or dirty appearance. For these reasons, an oxidizing flame is of limited use in welding.
- ✓ It is not used in the welding of steel. A slightly oxidizing flame is helpful when welding (i) Copper-base metals (ii) Zinc-base metals and (iii) A few types of ferrous metals such as manganese steel and cast iron. The oxidizing atmosphere in these cases, create a basemetal oxide that protects the base metal.

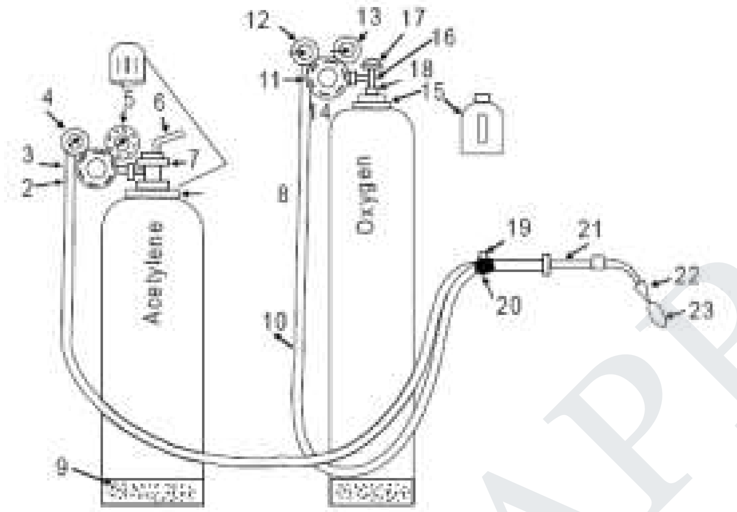
Carburising or Reducing Welding Flame

- ✓ The carburizing or reducing flame has excess of acetylene and can be recognized by acetylene feather, which exists between the inner cone and the outer envelope.

- ✓ The outer flame envelope is longer than that of the neutral flame and is usually much brighter in color.
- ✓ With iron and steel, carburizing flame produces very hard, brittle substance known as iron carbide.
- ✓ A reducing flame may be distinguished from carburizing flame by the fact that a carburizing flame contains more acetylene than a reducing flame.
- ✓ A reducing flame has an approximate temperature of 3038°C. A carburizing-flame is used in the welding of lead and for carburizing (surface hardening) purpose.
- ✓ A reducing flame, on the other hand, does not carburize the metal; rather it ensures the absence of the oxidizing condition.
- ✓ It is used for welding with low alloy steel rods and for welding those metals, (e.g., non-ferrous) that do not tend to absorb carbon. This flame is very well used for welding high carbon steel.

Gas Welding Equipments

An arrangement of oxy acetylene welding set up is shown in Fig. The basic tools and equipments used for oxy-acetylene welding are following:



1. Acetylene hose
2. Adjusting screw
3. Acetylene regulator
4. Regulator outlet pressure gauge
5. Cylinder pressure gauge
6. Valve wrench
7. Acetylene cylinder valve
8. Cylinder cap
9. Fusible plugs
10. Oxygen hose
11. Oxygen regulator
12. Regulator outlet pressure gauge
13. Cylinder pressure gauge
14. Cylinder cap
15. Oxygen cylinder valve
16. Oxygen cylinder valve
17. Hand wheel
18. Bursting disc
19. Acetylene valve
20. Oxygen valve
21. Welding torch
22. Torch tip
23. Flame

Fig. Oxy acetylene welding set up

- ✓ Acetylene and oxygen gas is stored in compressed gas cylinders.
- ✓ These gas cylinders differ widely in capacity, design and color code.
- ✓ However, in most of the countries, the standard size of these cylinders is 6 to 7 m^3 and is painted black for oxygen and maroon for acetylene.
- ✓ An acetylene cylinder is filled with some absorptive material, which is saturated with a chemical solvent acetone.
- ✓ Acetone has the ability to absorb a large volume of acetylene and release it as the pressure falls.
- ✓ If large quantities of acetylene gas are being consumed, it is much cheaper to generate the gas at the place of use with the help of acetylene gas generators.
- ✓ Acetylene gas is generated by carbide-to-water method.

- Oxygen gas cylinders are usually equipped with about 40 litres of oxygen at a pressure of about 154 Kgf/cm^2 at 21°C.
- To provide against dangerously excessive pressure, such could occur if the cylinders were exposed to fire, every valve has a safety device to release the oxygen before there is any danger of rupturing the cylinders.
- Fragile discs and fusible plugs are usually provided in the cylinders valves in case it is subjected to danger.

Gas pressure regulators

- Gas pressure regulators are employed for regulating the supply of acetylene and oxygen gas from cylinders.
- A pressure regulator is connected between the cylinder and hose leading to welding torch.
- The cylinder and hose connections have left-handed threads on the acetylene regulator while these are right handed on the oxygen regulator.
- A pressure regulator is fitted with two pressure gauges, one for indication of the gas pressure in the cylinder and the other for indication of the reduced pressure at which the gas is going out.

Welding torch

- It is a tool for mixing oxygen and acetylene in correct proportion and burning the mixture at the end of a tip.
- Gas flow to the torch is controlled with the help of two needle valves in the handle of the torch.
- There are two basic types of gas welding torches:

(1) Positive pressure (also known as medium or equal pressure), and

(2) Low pressure or injector type

The positive pressure type welding torch is the more common of the two types of oxyacetylene torches.

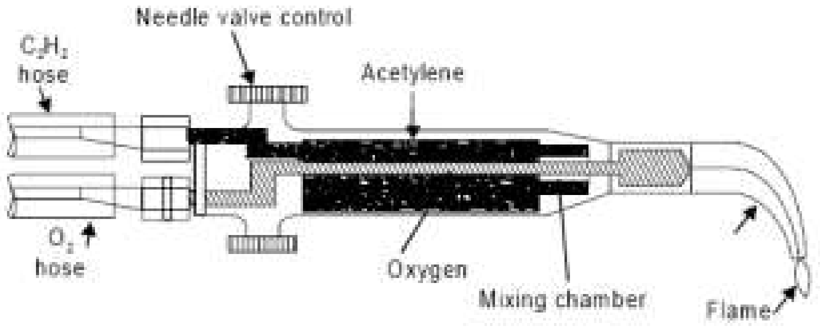


Fig. Welding torch

Torch tips

- ✓ It is the portion of the welding apparatus through which the gases pass just prior to their ignition and burning.
- ✓ A great variety of interchangeable welding tips differing in size, shape and construction are available commercially.
- ✓ The tip sizes are identified by the diameter of the opening. The diameter of the tip opening used for welding depends upon the type of metal to be welded.

Hose pipes

- ✓ The hose pipes are used for the supply of gases from the pressure regulators.
- ✓ The most common method of hose pipe fitting both oxygen and acetylene gas is the reinforced rubber hose pipe.
- ✓ Green is the standard color for oxygen hose, red for acetylene, and black hose for other industrially available welding gases.

Goggles

- ✓ These are fitted with colored lenses and are used to protect the eyes from harmful heat and ultraviolet and infrared rays.

Gloves

- ✓ These are required to protect the hands from any injury due to the heat of welding process.

Spark-lighter

- ✓ It is used for frequent igniting the welding torch.

Filler rods

- ✓ Gas welding can be done with or without using filler rod. When welding with the filler rod, it should be held at approximately 90^0 to the welding tip.
- ✓ Filler rods have the same or nearly the same chemical composition as the base metal.
- ✓ Metallurgical properties of the weld deposit can be controlled by the optimum choice of filler rod.
- ✓ Most of the filler rods for gas welding also contain deoxidizers to control the oxygen content of weld pool.

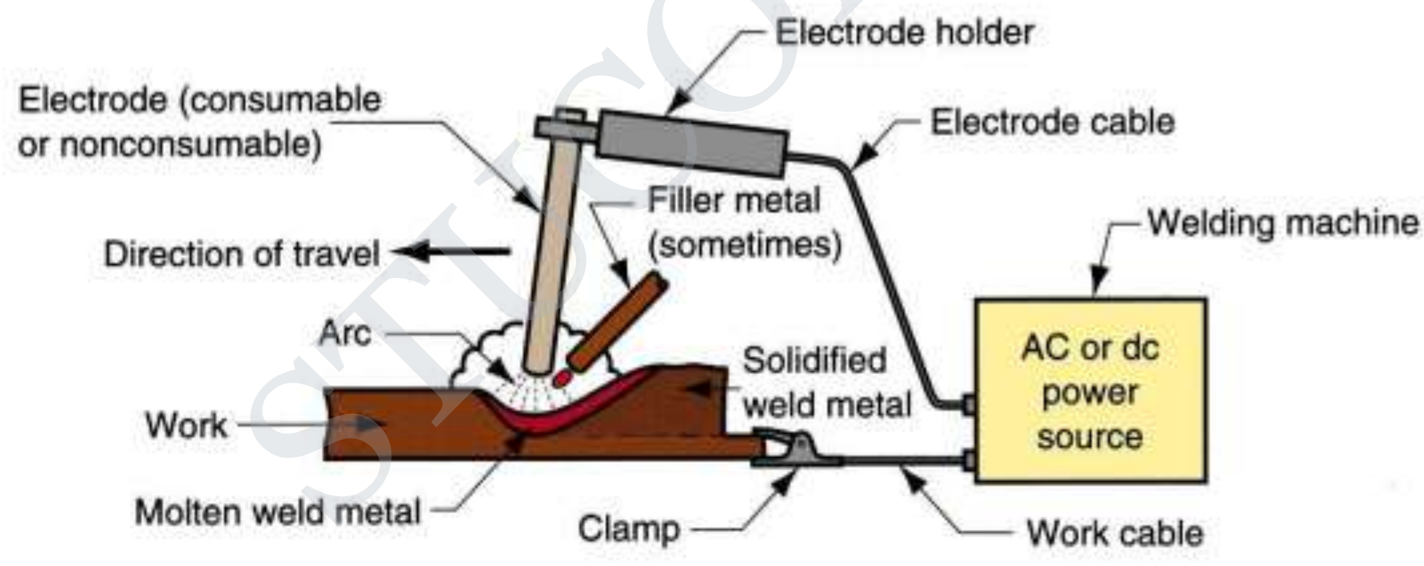
Fluxes

- ✓ Fluxes are used in gas welding to remove the oxide film and to maintain a clean surface.
- ✓ These are usually employed for gas welding of aluminium, stainless steel, cast iron, brass and silicon bronze.
- ✓ They are available in the market in the form of dry powder, paste, or thick solutions.

ARC WELDING PROCESSES

- ✓ The process, in which an electric arc between an electrode and a workpiece or between two electrodes is utilized to weld base metals, is called an arc welding process.
- ✓ Most of these processes use some shielding gas while others employ coatings or fluxes to prevent the weld pool from the surrounding atmosphere.
- ✓ The various arc welding processes are:

1. Carbon Arc Welding	6. Plasma Arc Welding
2. Shielded Metal Arc Welding	7. Atomic Hydrogen Welding
3. Submerged Arc Welding	8. Electro-slag Welding
4. Gas Tungsten Arc Welding	9. Stud Arc Welding
5. Gas Metal Arc Welding	10. Electro-gas Welding



Basic configuration of an arc welding process

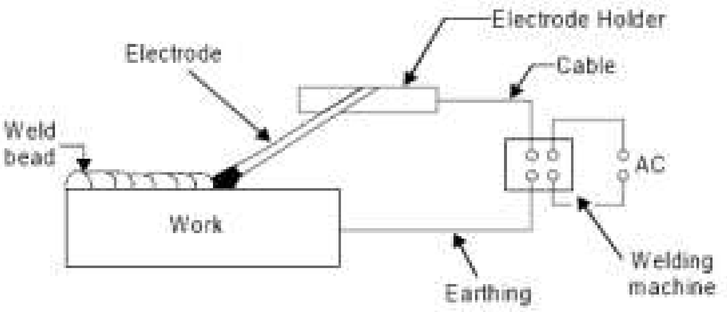
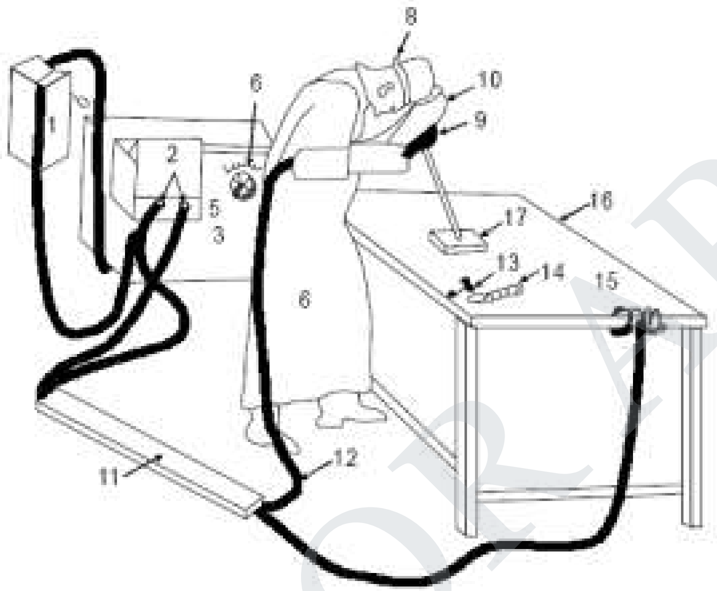


Fig. Principle of arc welding



(1) Switch box.
(2) Secondary terminals.
(3) Welding machine.
(4) Current reading scale.
(5) Current regulating hand wheel.
(6) Leather apron.
(7) Asbestos hand gloves.
(8) Protective glasses strap.
(9) Electrode holder.
(10) Hand shield.
(11) Channel for cable protection.
(12) Welding cable.
(13) Chipping hammer.
(14) Wire brush.
(15) Earth clamp.
(16) Welding table (metallic).
(17) Job.

Fig. Arc welding process setup

Arc Welding Equipment

Few of the important components of arc welding setup are described as under.

1. Arc welding power source

- ✓ Both direct current (DC) and alternating current (AC) are used for electric arc welding, each having its particular applications.
- ✓ DC welding supply is usually obtained from generators driven by electric motor or if no electricity is available by internal combustion engines.

- For AC welding supply, transformers are predominantly used for almost all arc welding where mains electricity supply is available.
- They have to step down the usual supply voltage (200-400 volts) to the normal open circuit welding voltage (50-90 volts) (50 and 250 amp).
- The following factors influence the selection of a power source:
    1. Type of electrodes to be used and metals to be welded
    2. Available power source (AC or DC)
    3. Required output
    4. Duty cycle
    5. Efficiency
    6. Initial costs and running costs
    7. Available floor space
    8. Versatility of equipment

2. Welding cables

- Welding cables are required for conduction of current from the power source through the electrode holder, the arc, the workpiece and back to the welding power source.
- These are insulated copper or aluminium cables.

3. Electrode holder

- Electrode holder is used for holding the electrode mannually and conducting current to it.
- These are usually matched to the size of the lead, which in turn matched to the amperage output of the arc welder.
- Electrode holders are available in sizes that range from 150 to 500 Amps.

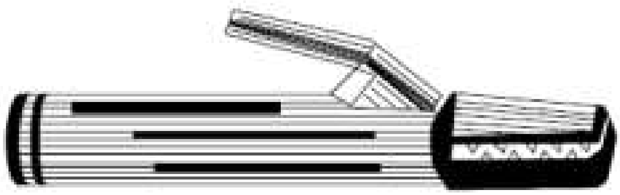


Fig. Electrode holder

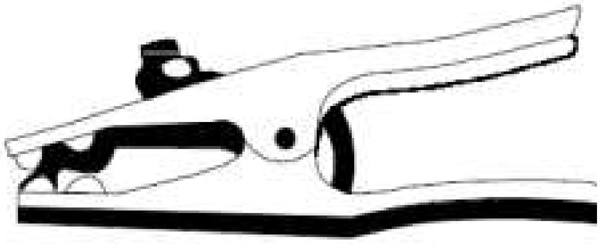


Fig. Earth clamp

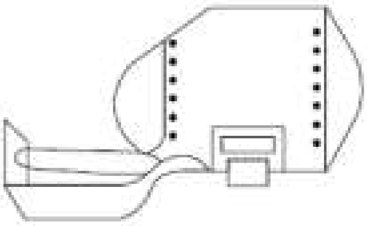


Fig. Hand screen

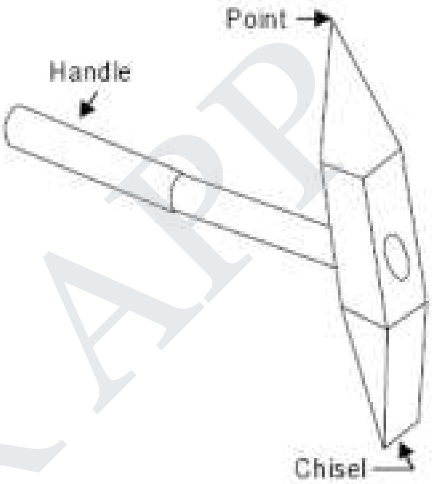


Fig. Chipping and hammer

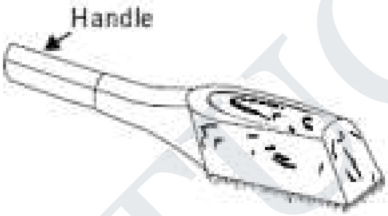


Fig. Wire brush

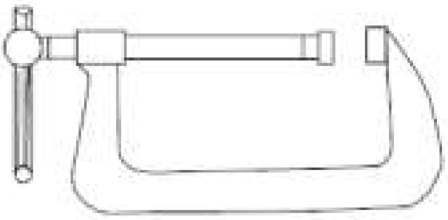


Fig. C-clamp

Fig. V-block

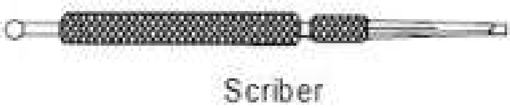


Fig. Scriber

4. Welding Electrodes

- ✓ An electrode is a piece of wire or a rod of a metal or alloy, with or without coatings.
- ✓ An arc is set up between electrode and workpiece.
- ✓ Welding electrodes are classified into following types:

    (1) Consumable Electrodes

        (a) Bare Electrodes

        (b) Coated Electrodes

    (2) Non-consumable Electrodes

        (a) Carbon or Graphite Electrodes

        (b) Tungsten Electrodes

- ✓ Consumable electrode is made of different metals and their alloys.
- ✓ The end of this electrode starts melting when arc is struck between the electrode and workpiece.
- ✓ Thus consumable electrode itself acts as a filler metal.
- ✓ Bare electrodes consist of a metal or alloy wire without any flux coating on them.
- ✓ Coated electrodes have flux coating which starts melting as soon as an electric arc is struck.
- ✓ This coating on melting performs many functions like prevention of joint from atmospheric contamination, arc stabilizers etc.
- ✓ Non-consumable electrodes are made up of high melting point materials like carbon, pure tungsten or alloy tungsten etc.
- ✓ These electrodes do not melt away during welding.
- ✓ But practically, the electrode length goes on decreasing with the passage of time, because of oxidation and vaporization of the electrode material during welding.

- ✓ The materials of non consumable electrodes are usually copper coated carbon or graphite, pure tungsten, thoriated or zirconiated tungsten.

5. Hand Screen

- ✓ Hand screen used for protection of eyes and supervision of weld bead.

6. Chipping hammer

- ✓ Chipping Hammer is used to remove the slag by striking.

7. Wire brush

- ✓ Wire brush is used to clean the surface to be weld.

8. Protective clothing

- ✓ Operator wears the protective clothing such as apron to keep away the exposure of direct heat to the body.

Carbon Arc Welding

- ✓ In this process, a pure graphite or baked carbon rod is used as a non-consumable electrode to create an electric arc between it and the workpiece.
- ✓ The electric arc produces heat and weld can be made with or without the addition of filler material.
- ✓ Carbon arc welding may be classified as

  (1) Single electrode arc welding, and

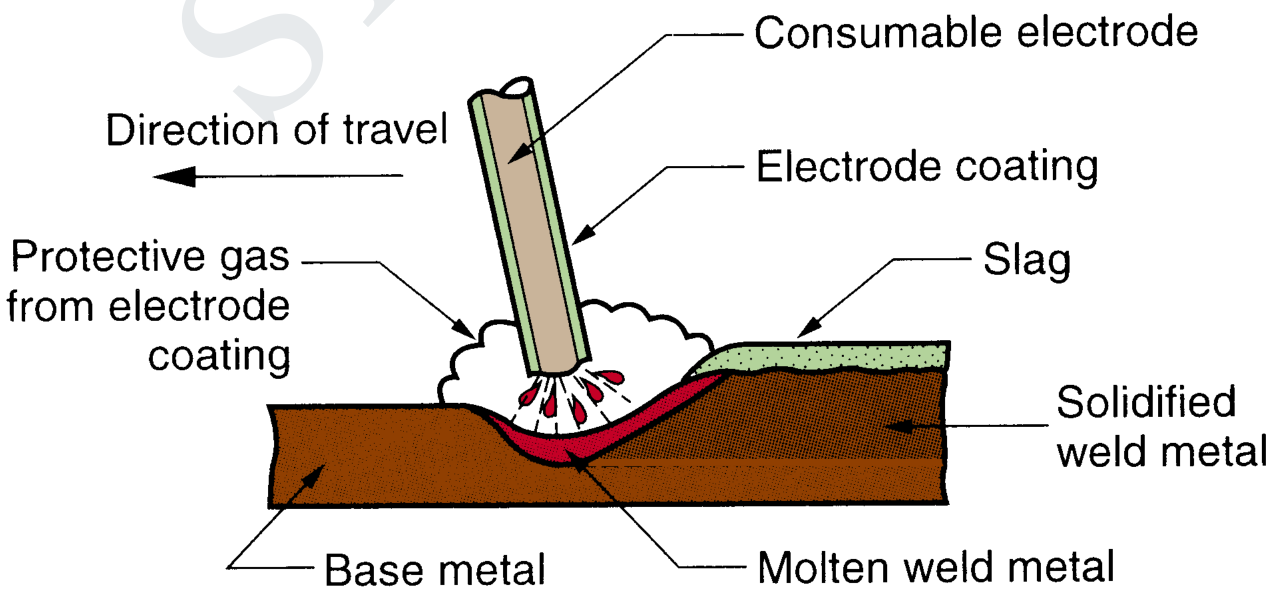
  (2) Twin carbon electrode arc welding
- ✓ In single electrode arc welding, an electric arc is struck between a carbon electrode and the workpiece.
- ✓ Welding may be carried out in air or in an inert atmosphere.
- ✓ Direct current straight polarity (DCSP) is preferred to restrict electrode disintegration and the amount of carbon going into the weld metal.

- ✓ This process is mainly used for providing heat source for brazing, braze welding, soldering and heat treating as well as for repairing iron and steel castings.
- ✓ It is also used for welding of galvanized steel and copper.
- ✓ In twin carbon arc welding the arc struck between two carbon electrodes produces heat and welds the joint.
- ✓ The arc produced between these two electrodes heats the metal to the melting temperature and welds the joint after solidification.
- ✓ The power source used is AC (Alternating Current) to keep the electrodes at the same temperature.
- ✓ Twin-electrode carbon arc welding can be used for welding in any position.
- ✓ This process is mainly used for joining copper alloys to each other or to ferrous metal.
- ✓ It can also be used for welding aluminium, nickel, zinc and lead alloys.

Shielded Metal Arc Welding (SMAW)

or Manual Metal Arc Welding

(MMAW)



- ✓ Shielded metal arc welding (SMAW) is a commonly used arc welding process manually carried by welder.
- ✓ It is an arc welding process in which heat for welding is produced through an electric arc set up between a flux coated electrode and the workpiece.
- ✓ The process uses a consumable electrode which is primarily a filler metal rod having a coating of chemicals that provide flux and shielding.
- ✓ The flux coating of electrode decomposes due to arc heat and serves many functions, like weld metal protection, arc stability etc.
- ✓ Inner core of the electrode supply the filler material for making a weld.
- ✓ Polarity is important and its selection depends on the metal to be welded, its thickness, required depth of heated zone, and the type of electrode used.
- ✓ Straight polarity (workpiece positive; electrode negative) is preferred for thin workpieces and sheet metal because it produces shallow heat penetration.
- ✓ On the other hand, reverse polarity (workpiece negative; electrode positive) produces deeper weld penetration and is preferred for thick workpieces.
- ✓ An electric arc is established by striking the tip of coated metal electrode with the metal workpiece and quickly raising it through a short distance sufficient to maintain the arc.
- ✓ Temperature greater than 5000°C.
- ✓ Clean the weld bead surface.
- ✓ The heat (or the temperature) generated in the arc depends upon the amount of input electric power. H=EIT

where H is heat (Joules or Watt-sec); E is voltage (Volts); I is current (amperes); and T is time (seconds).

✓ If the parent metal is thick it may be necessary to make two or three passes for completing the weld.

Advantages

1. Shielded Metal Arc Welding (SMAW) can be carried out in any position with highest weld quality.

2. MMAW is the simplest of all the arc welding processes.

3. This welding process finds innumerable applications, because of the availability of a wide variety of electrodes.

4. Big range of metals and their alloys can be welded easily.

5. The process can be very well employed for hard facing and metal resistance etc.

6. Joints (e.g., between nozzles and shell in a pressure vessel) which because of their position are difficult to be welded by automatic welding machines can be easily accomplished by flux shielded metal arc welding.

7. The MMAW welding equipment is portable and the cost is fairly low.

8. The SMA W process is simple and versatile.

Limitations

1. Due to flux coated electrodes, the chances of slag entrapment and other related defects are more as compared to MIG and TIG welding.

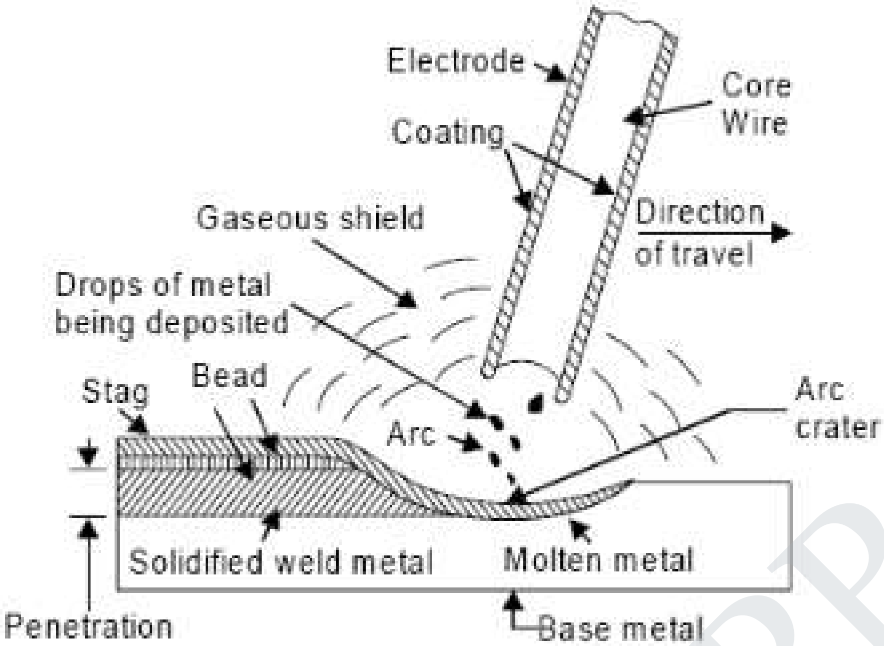


Fig. Arc welding operation

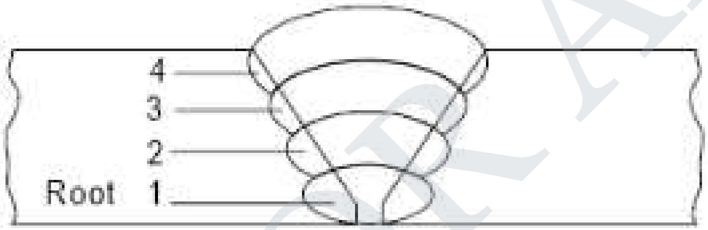


Fig. A typical multi pass bead

2. Duo to fumes and particles of slag, the arc and metal transfer is not very clear and thus welding control in this process is a bit difficult as compared to MIG welding.

3. Due to limited length of each electrode and brittle flux coating on it, mechanization is difficult.

4. In welding long joints (e.g., in pressure vessels), as one electrode finishes, the weld is to be progressed with the next electrode. Unless properly cared, a defect (like slag inclusion or insufficient penetration) may occur at the place where welding is restarted with the new electrode.

5. The process uses stick electrodes and thus it is slower as compared to MIG welding.

Applications

1. Today, almost all the commonly employed metals and their alloys can be welded by this process.

2. Shielded metal arc welding is used both as a fabrication process and for maintenance and repair jobs.

3. The process finds applications in

(a) Building and Bridge construction

(b) Automotive and aircraft industry, etc.

(c) Air receiver, tank, boiler and pressure vessel fabrication

(d) Ship building

(e) Pipes and

(f) Penstock joining

Functions of Electrode Coating Ingredients

The covering coating on the core wire consists of many materials which perform a number of functions as listed below:

1. Welding electrodes are used to join various similar and dissimilar metals as plain carbon steels, cast iron, copper, aluminium, magnesium and their alloys, stainless steels and other alloy steels.

2. Slag forming ingredients, like silicates of magnesium, aluminium, sodium, potassium, iron oxide, china clay, mica etc., produce a slag which because of its light weight forms a layer on the molten metal and protects the same from atmospheric contamination.

3. Arc stabilizing constituents like calcium carbonate, potassium silicate, titanates, magnesium silicates, etc.; add to arc stability and ease of striking the same.

4. Gas shielding ingredients, like cellulose, wood, wood flour, starch, calcium carbonate etc. form a protective gas shield around the electrode end, arc and weld pool.

5. Deoxidizing elements like ferro-manganese, and ferro-silicon, refine the molten metal.

6. It limits spatter, produces a quiet arc and easily removable slag.

7. Alloying elements like ferro alloys of manganese, molybdenum etc., may be added to impart suitable properties and strength to the weld metal and to make good the loss of some of the elements, which vaporize while welding.

8. Iron powder in the coating improves arc behavior, bead appearance helps increase metal deposition rate and arc travel speed.

9. The covering improves penetration and surface finish.

10. Core wire melts faster than the covering, thus forming a sleeve of the coating which constricts and produces an arc with high concentrated heat.

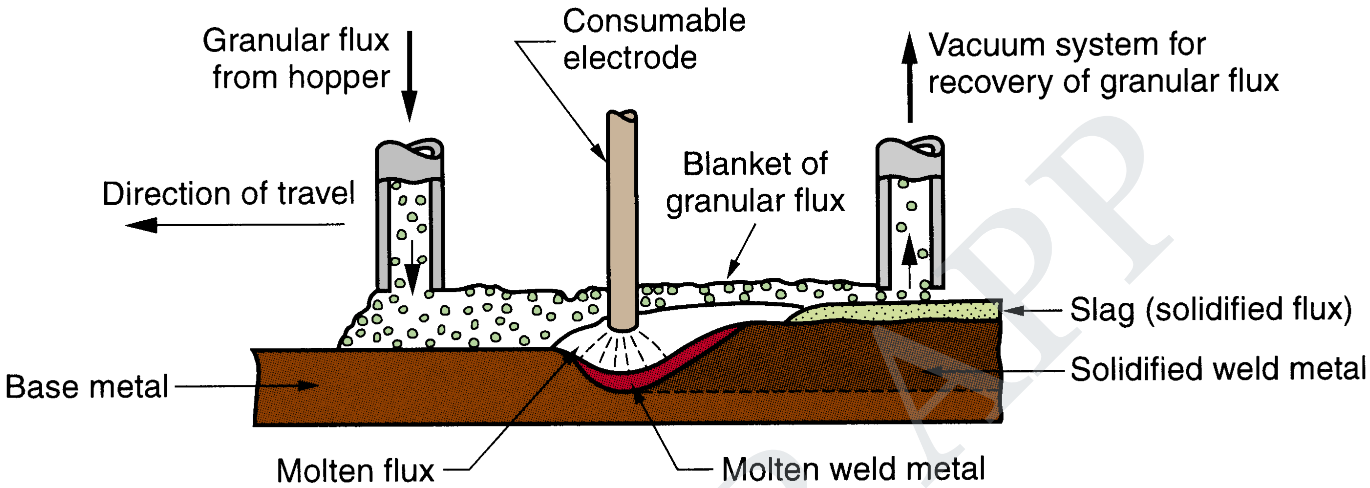
11. Coating saves the welder from the radiations otherwise emitted from a bare electrode while the current flows through it during welding.

12. Proper coating ingredients produce weld metals resistant to hot and cold cracking. Suitable coating will improve metal deposition rates.

Submerged Arc Welding

- ✓ In this welding process, a consumable bare electrode is used in combination with a flux feeder tube.
- ✓ The arc, end of the bare electrode and molten pool remain completely submerged under blanket of granular flux (lime, silica, calcium fluoride and magnesium oxide).

- ✓ The feed of electrode and tube is automatic and the welding is homogenous in structure.
- ✓ No pressure is applied for welding purposes. This process is used for welding low carbon steel, bronze, nickel and other non-ferrous materials.



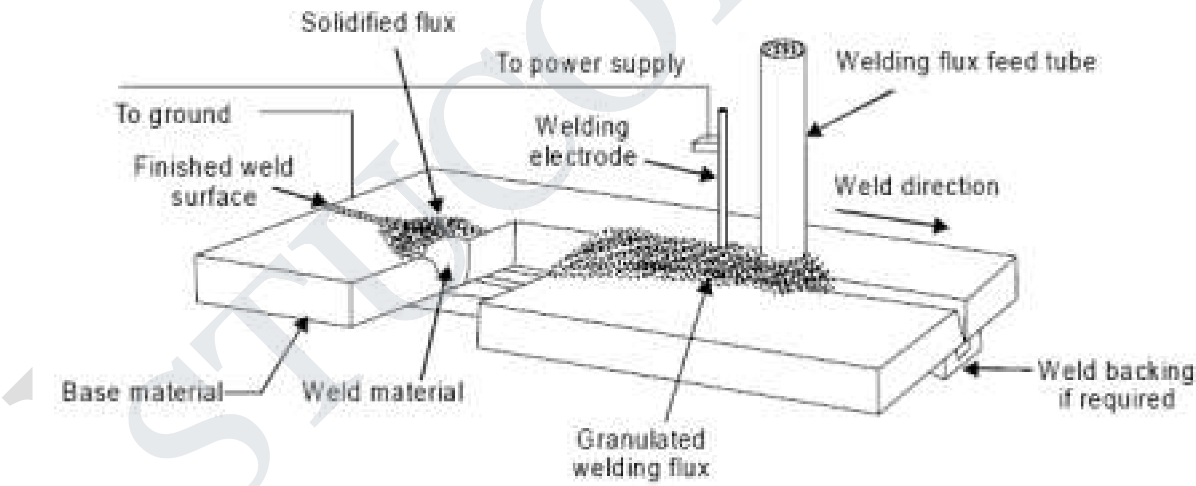


Fig. Schematic submerged arc welding process

- ✓ The molten weld metal pool is thus entirely covered under a thick layer of flux and oxidation of weld metal is prevented.
- ✓ In addition, spatter and sparks are prevented while fumes and u-v radiations are suppressed. The flux also acts as a thermal barrier, enabling faster weld pool formation.

- ✓ The flux is fed into the weld zone by gravity flow through a nozzle that delivers it ahead of the welding electrode.
- ✓ The portion of the flux closest to the arc is melted. It mixes with the molten weld metal to remove impurities, and then solidifies on the top of the weld joint to form a glass-like slag.
- ✓ The slag and unfused flux granules on the top provide good protection from the surrounding atmosphere and good thermal insulation for the weld area.
- ✓ As a result of slow cooling, a high quality weld joint is obtained. After welding, the unfused flux can be recovered, treated and then reused.
- ✓ The power source used with SAW can be either ac or dc. Both constant voltage and constant current type machines can be employed. The electric currents range between 250 amp to 2500 amp. Higher the current, higher is the burn-off rate for a given electrode wire diameter and material.
- ✓ Welding current higher than necessary should not be used as it would give out additional heat as well as filler metal into the weld joint resulting in more heat affected zone (HAZ) and unnecessary reinforcement of the weld joint.
- ✓ On the other hand, use of lesser welding current than necessary would result in lesser deposition of filler metal and hence weak joint. The joint design and edge preparation used with SAW are somewhat different from other arc welding processes because of relatively higher deposition rates and deeper penetrations involved.
- ✓ If the amount of flux is less, it would not cover, the arc completely, thus, resulting in oxidation of the weld metal as well as flashing and spattering.
- ✓ Similarly, if the amount of flux is too much, the weld gases generated during the process would not be able to flow out, resulting in porosity in the weld metal.

Advantages

- ✓ It is simple and versatile.
- ✓ It has high productivity. Weld metal deposition rates are 5 to 10 times as compared to SMAW process. Welding speed as high as 5m/min can be achieved.
- ✓ It produces very high quality of the weld. The toughness and uniformity of weld metal properties are exceptionally good.
- ✓ It can be used to weld a large variety of sheet and plates of carbon and alloy steels.
- ✓ It can be automated for greater economy.

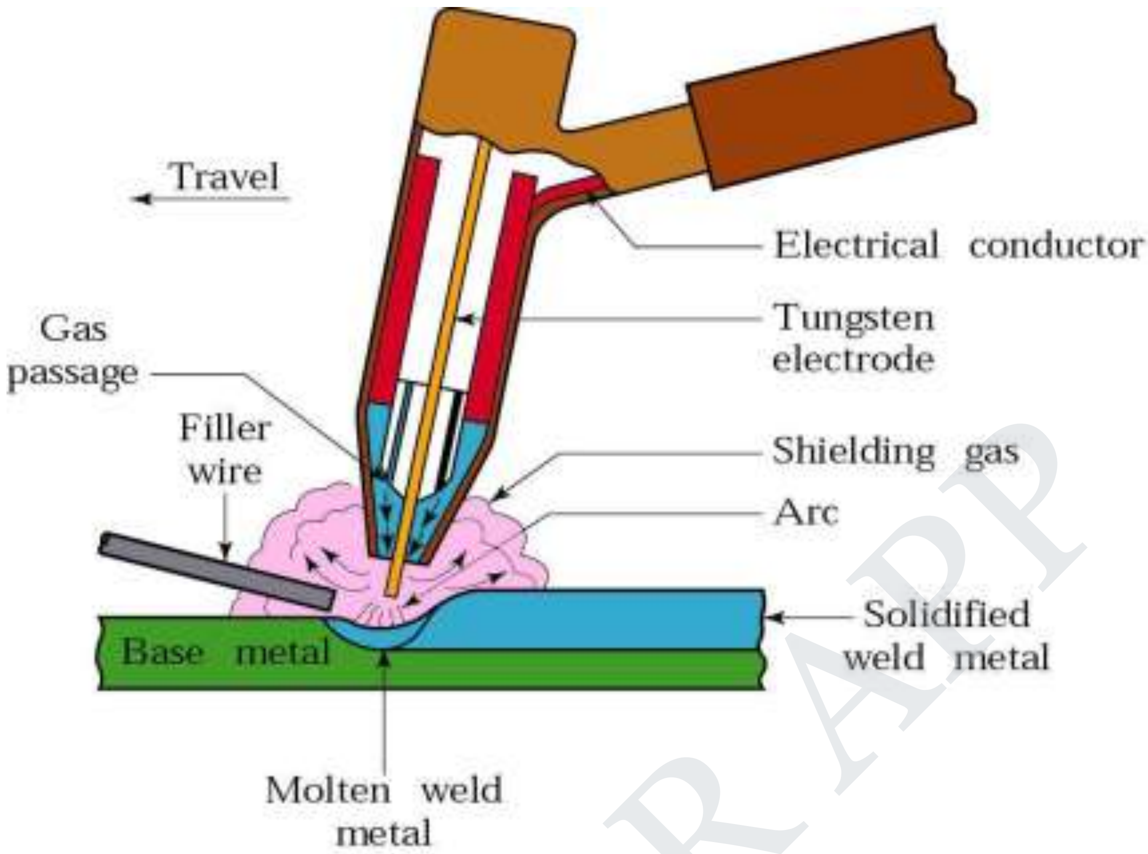
Limitations

- ✓ The process is not suitable for welding of some materials such as high carbon steels, tool steels, and most non-ferrous metals.
- ✓ The parts to be welded by SAW must always be in horizontal position. This is because granular flux is fed to the joint by gravity.
- ✓ A back-up plate is generally required beneath the joint during welding operation.

Applications

- ✓ Thick plate welding of ships and pressure vessels.
- ✓ The process is also widely used for steel fabrication of structural shapes (e.g., I-beams); longitudinal and circumferential joints of large diameter pipes.
- ✓ It is advantageous to traverse the workpiece under a stationary welding head to obtain the required relative movement between the welding head and the workpiece.
- ✓ Circumferential welds can be made on pipes in this manner. Low-carbon, low alloy, and stainless steels can be easily welded by SAW.

Gas Tungsten Arc Welding (GTAW) *or* Tungsten Inert Gas Welding(TIG)



- ✓ In this process a non-consumable tungsten electrode is used with an envelope of inert shielding gas around it.
- ✓ The shielding gas protects the tungsten electrode and the molten metal weld pool from the atmospheric contamination.
- ✓ The shielding gases generally used are argon, helium or their mixtures.

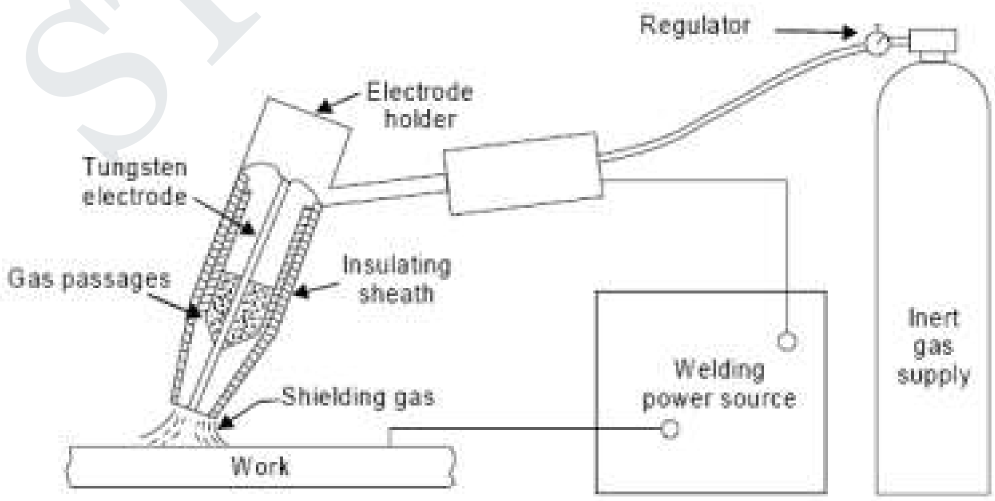


Fig. Tungsten inert gas welding setup

Electrode materials

- ✓ The electrode material may be tungsten, or tungsten alloy (thoriated tungsten or zirconiated tungsten).
- ✓ The oxides of thorium and zirconium help the electrodes to maintain its shape at the tip for a longer time and improve the ease of electron emission.
- ✓ Alloy-tungsten electrodes possess higher current carrying capacity, produce a steadier arc as compared to pure tungsten electrodes and high resistance to contamination.
- ✓ Size may vary from 0.5 mm to 10 mm.
- ✓ There is hardly any wear loss of tungsten, since its melting point is quite high (3410 C).

Electric power source

- ✓ Both AC and DC power source can be used for TIG welding.
- ✓ DC(Straight polarity) is preferred for welding of cast iron, copper, copper alloys, nickel and stainless steel, titanium.
- ✓ DC reverse polarity (DCRP) or AC is used for welding aluminium, magnesium or their alloys. DCRP removes oxide film on magnesium and aluminium and improves the weld quality.
- ✓ Welding voltage is 20 to 40 V and the weld current varies between 100 to 500 amperes.

Inert gases

1. Argon
2. Helium
3. Argon-helium mixtures
4. Argon-hydrogen mixtures

Tig Nozzle

- ✓ The nozzle or shield size (the diameter of the opening of the shroud around the electrode) to be chosen depends on the shape of the groove to be welded as well as the required gas flow rate.
- ✓ The gas flow rate depends on the position of the weld as well as its size.

- ✓ Too high a gas consumption would give rise to turbulence of the weld metal pool and consequently porous welds.
- ✓ Because of the use of shielding gases, no fluxes are required to be used in inert gas shielded arc welding.
- ✓ However for thicker sections, it may be desirable to protect the root side of the joint by providing a flux.

Advantages

- ✓ Operating costs are low.
- ✓ Very high quality of welds.
- ✓ There is no spatter (unwanted small droplets of weld metal) because the filler metal is not transferred across the arc gap. Thus, there is no post-welding grinding or finishing operation. This is an important feature when welding is done in hard-to-reach locations.
- ✓ There is no need for separate cleaning operation because welds produced are very clean.
- ✓ A variety of metals (both ferrous and non-ferrous) especially aluminum, magnesium, titanium and refractory metals can be welded. The process is particularly suitable for welding high alloyed metals where weld purity is essential.

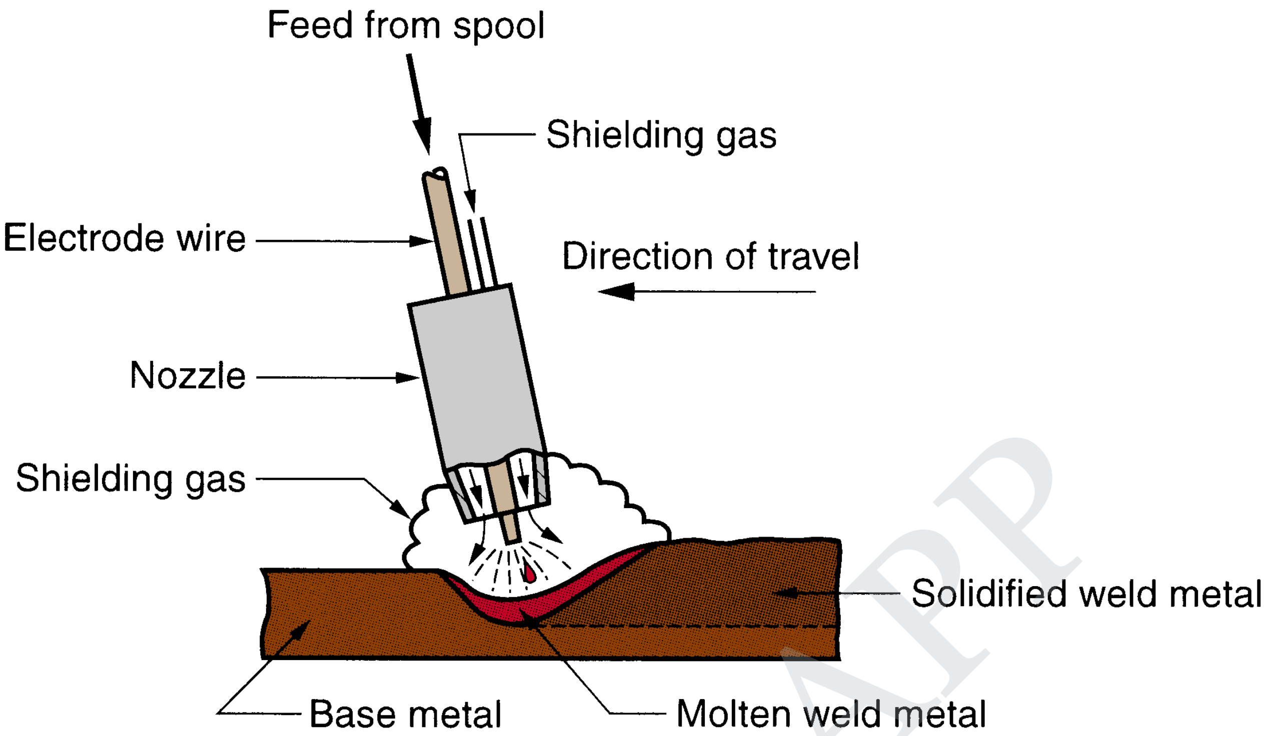
Limitations

- ✓ Tungsten electrode cannot be allowed to touch the work-metal because some tungsten may get deposited.
- ✓ Cast iron, wrought iron, and lead are difficult to weld by this process.
- ✓ For welding, of steel the process is slower and more costly than consumable electrode arc welding.

Applications

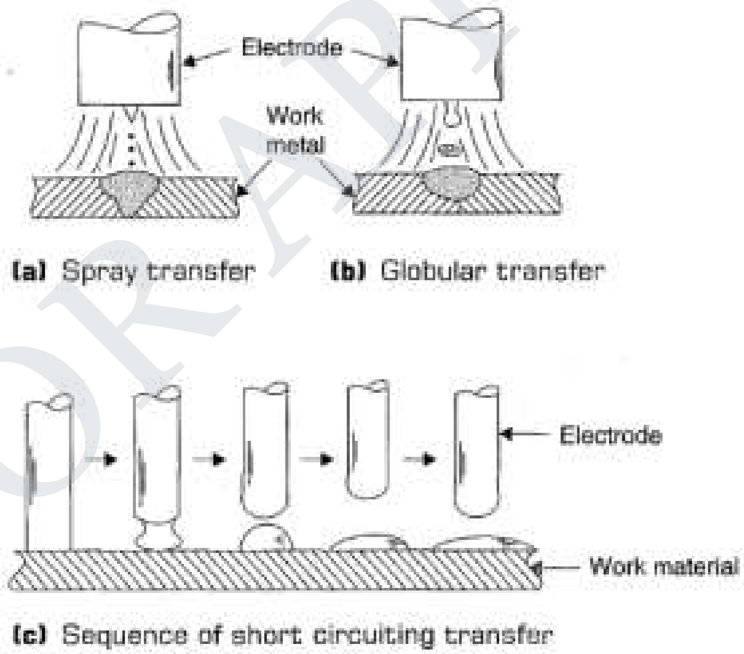
- ✓ The process is suited for high quality welding of thinner workpieces rather than for welding thicker workpieces.
- ✓ The process is generally used for welding aluminium, magnesium and stainless steel.

Gas Metal ARC Welding (GMAW) or Metal Inert Gas Welding (MIG)



- ✓ GMAW is also known by other names such as metal inert gas (MIG) welding and CO_2 welding.
- ✓ Utilizes a consumable bare wire electrode
- ✓ There are other gas shielded arc welding processes utilizing the consumable electrodes, such as flux cored arc welding (FCAW) all of which can be termed under MIG.
- ✓ Though gas tungsten arc welding (GTAW) can be used to weld all types of metals, it is more suitable for thin sheets. When thicker sheets are to be welded, the filler metal requirement makes GTAW difficult to use. In this situation, the GMAW comes handy.
- ✓ The consumable electrode is in the form of a wire reel which is fed at a constant rate, through the feed rollers.
- ✓ The welding torch is connected to the gas supply cylinder which provides the necessary inert gas.
- ✓ The electrode and the work-piece are connected to the welding power supply.
- ✓ The power supplies are always of the constant voltage type only.

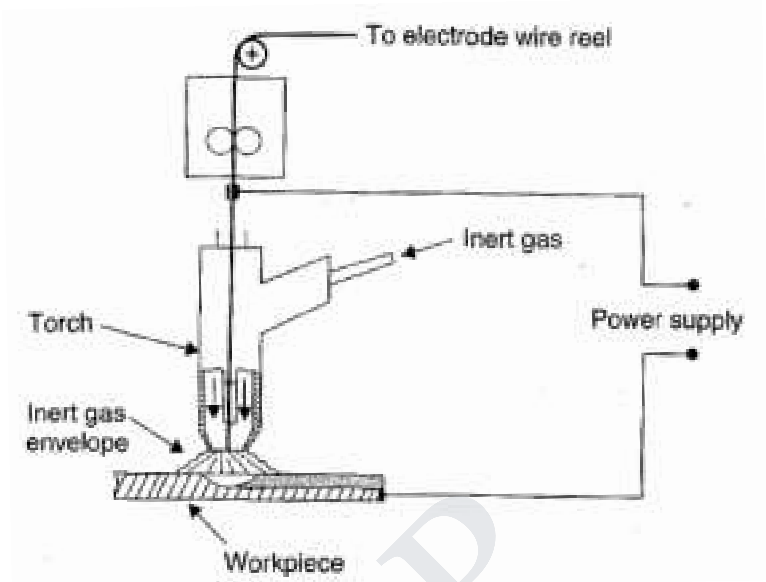
- The current from the welding machine is changed by the rate of feeding of the electrode wire.
- Normally DC arc welding machines are used for GMAW with electrode positive.
- The DCRP increases the metal deposition rate and also provides for a stable arc and smooth electrode metal transfer.
- With DCSP, the arc becomes highly unstable and also results in a large spatter.
- But special electrodes having calcium and titanium oxide mixtures as coatings are found to be good for welding steel with DCSP.
- In the GMAW process, the filler metal is transferred from the electrode to the joint.
- Depending on the current and voltage used for a given electrode, the metal transfer is done in different ways.



Advantages

- It produces very clean, smooth and sound welds at high speeds.
- No flux is required and, therefore, no slag forms over the weld. This is particularly useful for multi-pass welds as no intermediate cleaning will be required.
- The weld metal penetration is exceptionally good.
- There is no frequent change of electrodes as is the case with shielded metal arc process.
- The process can be easily adapted to an automatic operation.
- The welding unit is light and compact and, thus, can be easily adopted for robotic manipulation.
- It is an economical welding process.

Limitations

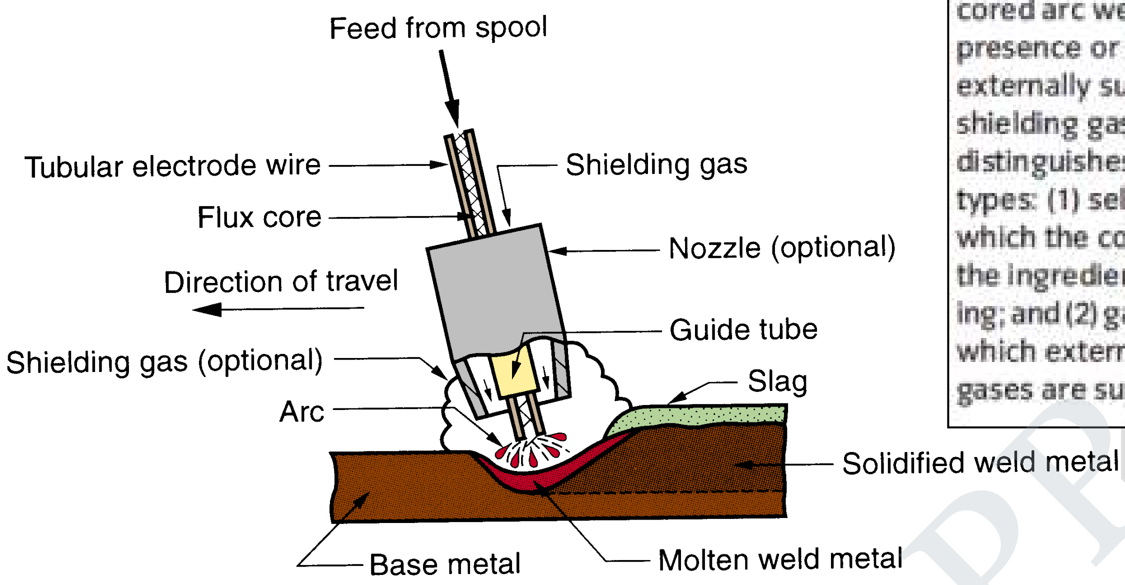


- ✓ Dross: This is a common problem when welding aluminium with GMAW. The cause of dross is the aluminium oxide or aluminium nitride present in the electrode or workpiece materials.
- ✓ The problem can be overcome by brushing the electrode and workpieces with a wire brush or treating the electrodes chemically to remove oxide on the surface.
- ✓ Providing sufficient flow of shielding gases also helps to overcome the problem to some extent.
- ✓ Porosity: The primary cause of porosity in GMAW is gas entrapment in the weld joint, which occurs when the metal solidifies before the gas escapes. The gas can come from impurities in the shielding gas or on the workpiece.
- ✓ Generally, the amount of gas entrapped is directly related to the cooling rate of the weld metal pool.
- ✓ Aluminium welds, because of their higher thermal conductivity, are especially susceptible to higher cooling rates and therefore more porosity.
- ✓ Exposure to dangerous gases and particulate matter: GMAW produces smoke containing particles of oxides. Smaller particles present a greater danger. CO_2 can be a serious health hazard if ventilation is inadequate.
- ✓ Fire risk: GMAW uses compressed gases which pose an explosion and fire risk.
- ✓ Use of safety devices: Safety devices must be used during GMAW operation because of the electric arc that produces extreme heat and UV light brightness.

Applications

- ✓ The process can be used for welding any metal.
- ✓ The process is particularly suitable for light to medium steel fabrication work when high production rates are needed.

FLUX CORED ARC WELDING (FCAW)

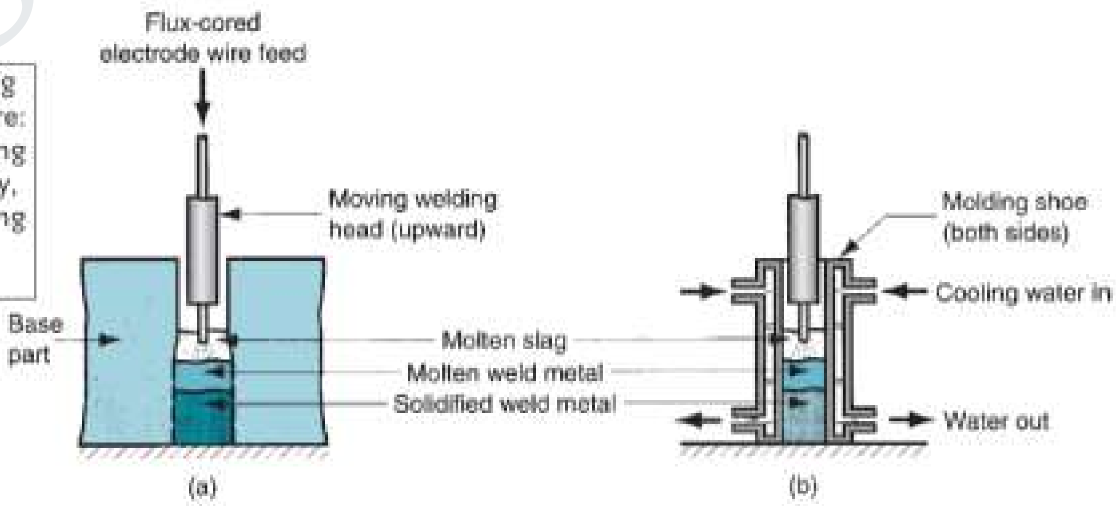


Flux-cored arc welding. The presence or absence of externally supplied shielding gas distinguishes the two types: (1) self-shielded, in which the core provides the ingredients for shielding; and (2) gas shielded, in which external shielding gases are supplied.

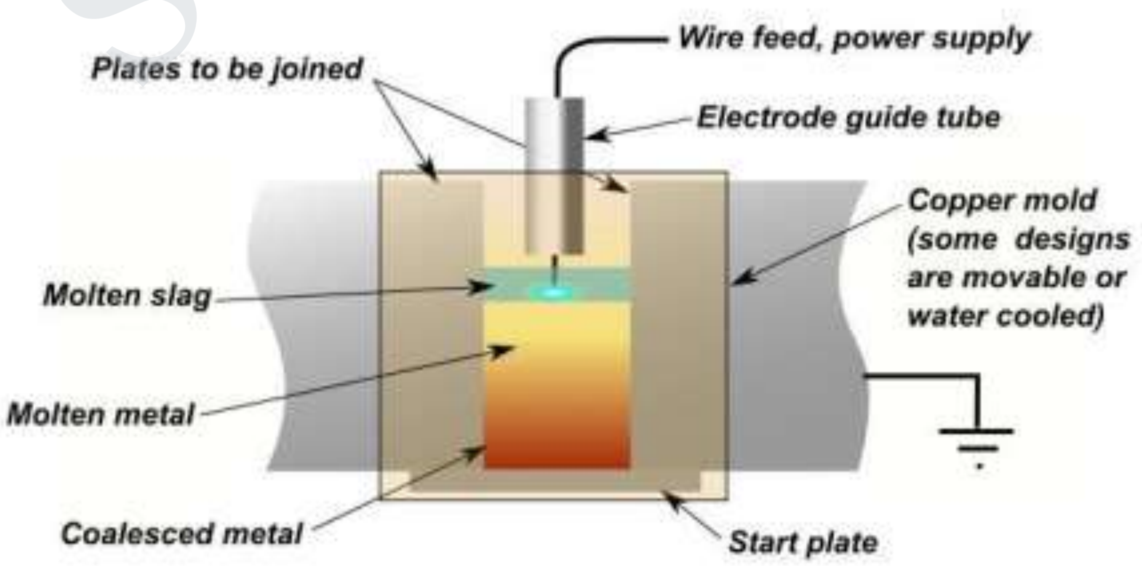
Electro-slag Welding (ESW)

- ✓ Electro-slag welding is mostly used for welding very thick components or plates (up to 40 to 500 mm thickness) where the joint to be welded is in a vertical position.
- ✓ The components to be welded are set in the required vertical position with the necessary gap between the butted edges and a backing plate is tacked at the bottom.
- ✓ Water-cooled copper shoes which can travel along the joint are initially located at the lowermost position.
- ✓ These shoes close off the space between the parts to be welded so that a V-shaped starting block is formed that prevents the slag and molten metal from spilling out of the pool.

Electrogas welding using flux-cored electrode wire: (a) front view with molding shoe removed for clarity, and (b) side view showing molding shoes on both sides.



- ✓ To start the welding operation, an arc is created between the tip of the consumable electrodes and the bottom plate and upon the introduction of granular flux into the joint, a 3-4 mm thick layer of molten slag starts floating at the top of weld metal pool.
- ✓ As the molten slag reaches the tip of the electrode the arc is extinguished and current is conducted directly from the electrode wire to the base metal through the conductive slag.
- ✓ Thereafter, the high electrical resistance of the slag causes most of the heating required for welding, i.e., for melting the wire electrode and the workpiece metal.
- ✓ As the welding progresses, single or multiple electrode wires along with flux are continuously fed into the molten slag pool confined between the copper shoes.
- ✓ The slag being lighter than the molten metal remains on top to protect the weld metal pool.
- ✓ The shoes are made to slide upwards along the joint at a speed determined by the speed at which the electrode and the work-material at the joint are melted.
- ✓ The lower part of the weld-metal bath is solidified as heat is conducted away by the copper shoes and the work material.
- ✓ The welding operation takes place at 40-50 V, and the current requirements are 500-600 amps, although higher currents are used for very thick plates.



Advantages

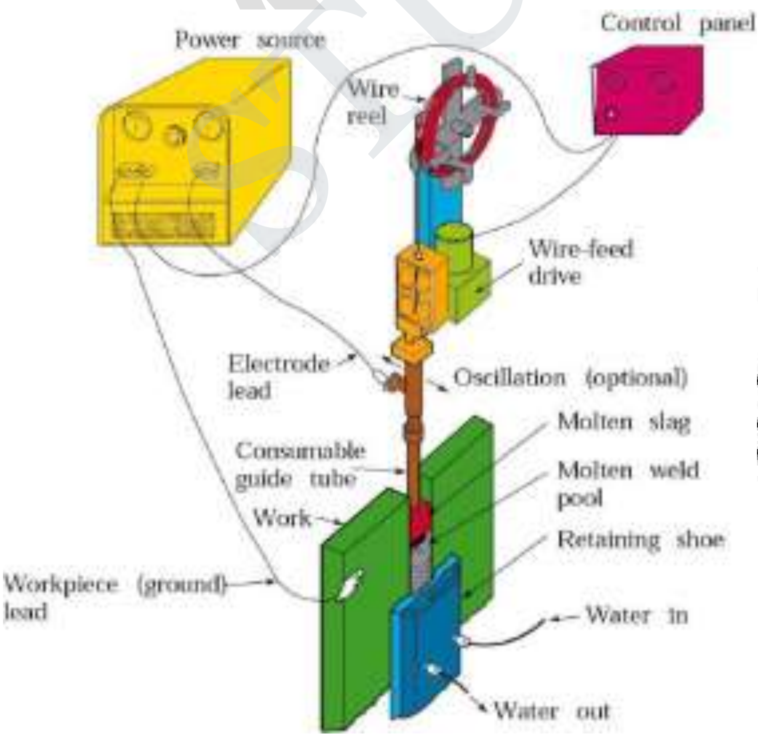
- ✓ Thick metals can be welded in a single pass.
- ✓ Almost no joint preparation is required.
- ✓ Heating is uniform; therefore, there is good stress distribution across the weld and distortion is also minimum.
- ✓ The weld quality is good as the weld metal is protected at all times from contamination.
- ✓ The weld speed is good, as much as 15-40 mm/min.
- ✓ Process is almost automatic; once started, it keeps going until the job is completed.

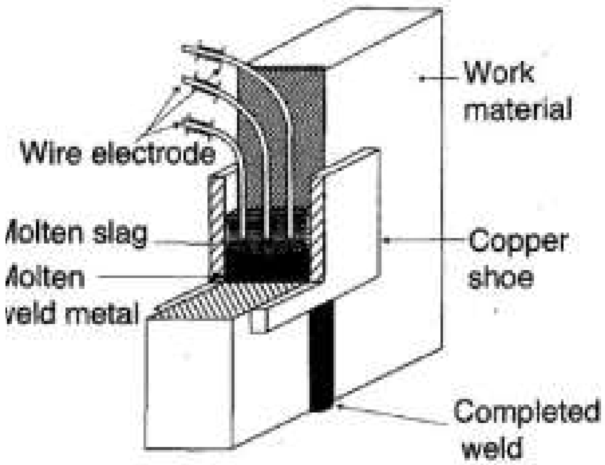
Limitations

- ✓ The scale interferes with heat transfer to the copper shoes and can prevent a good fit-up of joint, thus causing some of the weld metal to run out.
- ✓ Uneconomical for welding plates of thickness less than 20 mm.

Applications

- ✓ For welding of plates, as thick as 1 metre in one pass.
- ✓ For welding of heavy structural steel sections, such as heavy machinery and nuclear-reactor vessels.
- ✓ For welding of hot rolled carbon steels, low-alloy steels and quenched-and-tempered steels.





Safety Recommendations for ARC Welding

The beginner in the field of arc welding must go through and become familiar with these general safety recommendations which are given as under.

1. The body or the frame of the welding machine shall be efficiently earthed. Pipe lines containing gases or inflammable liquids or conduits carrying electrical conductors shall not be used for a ground return circuit All earth connections shall be mechanically strong and electrically adequate for the required current.

2. Welding arc in addition to being very is a source of infra-red and ultra-violet light also; consequently the operator must use either helmet or a hand-shield fitted with a special filter glass to protect eyes

3. Excess ultra-violet light can cause an effect similar to sunburn on the skin of the welder

4. The welder's body and clothing are protected from radiation and burns caused by sparks and flying globules of molten metal with the help of the following:

5. Gloves protect the hands of a welder.

6. Leather or asbestos apron is very useful to protect welder's clothes and his trunk and thighs while seated he is doing welding.

7. For overhead welding, some form of protection for the head is required

8. Leather skull cap or peaked cap will do the needful.

9. Leather jackets and 1ather leggings are also available as clothes for body protection.

10. Welding equipment shall be inspected periodically and maintained in safe working order at all times.

11. Arc welding machines should be of suitable quality.

12. All parts of welding set shall be suitably enclosed and protected to meet the usual service conditions.

13. Welders and workers need to be protected from welding rays, f1ying sparks, metal globules and metal spatter, hot slag particles, hot stubs, fumes and gases when welding in confined spaces, e.g., rail tank wagon, falling when welding at a height from the ground.

14. In AC arc welding machines, in transformers, the secondary circuit shall be thoroughly insulated from the primary. Input terminal shall be completely enclosed and accessible only by means of tools.

15. The primary side of the transformer shall be provided with suitable wire terminals inside the machine case.

16. Welding (secondary) terminals shall be so arranged that current carrying parts are not exposed to accidental contact.

17. In a transformer, the welding circuit should be quite separate from power circuit, so that there is no risk of the welder suffering serious shock or burns through power voltage appearing across the electric holder.

18. At or near each welding machine, a disconnecting switch shall provide.

19. Control apparatus provided with the welding machine shall enclose except for the operating wheels, levers, etc.

20. Transformer windings be suction or compressed-air cleaned periodically.

21. Before undertaking any maintenance work on welding machine disconnects them from the main supply.

22. As regards other arc welding equipments, electrode holders should be soundly connected to the welding lead

23. They should be of adequate rating for the maximum welding current to prevent them from heating up and be coming too hot to handle.

24. Electrode holder sha1l be provided with discs or shields to protect the hands of the welder from heat of the arc. Installation of all metallic of current carrying parts, including the jaws which grip the electrodes, is recommended.

25. Hot electrode holders shall not be permitted to dip in water because the retained moisture may cause an electric shock.

26. Welding cables shall be of completely insulated, flexible type. They should be capable of handling the maximum current requirements of the work in progress, taking into account the duty cycle under which the welder is working in case the cable insulation is damaged, do not operate the equipment.

27. The welding cable should be free from repair or splices up to a minimum distance of three metres from the electrode holder.

28. Fully insulated cable connectors of capacity at least equivalent to that of the cable shall be used to connect two cables together.

29. Welding cables shall be kept dry and free from grease and oil to avoid premature breakdown of insulation.

30. Arc welding machines should be properly ground (earthed).

31. Construction of arc welding machines should be such that they can operate satisfactorily even under conditions of saltish or moist air as in coastal areas, dust, smoke, fumes and gases, excessive shock or vibrations, steam and corrosive atmosphere, etc.

32. One should not work on the wiring of an arc welding machine unless qualified to do so.

33. Welding equipment used in the open and shall be protected from weather conditions. If it has been wetted it shall be thoroughly dried before being used.

34. Proper terminals should be used on the arc welding machines for the power line voltage connection.

35. Neither terminal of the welding generator shall be bonded to the frame of the welding machine.

36. Periodically clear out the accumulated dust from the welding machine with suction cleaner as this will not blow dust into other parts of the machine.

37. Over greasing may foul the commutators of DC generator.

38. Check and, if necessary, clean commutators of DC generator periodically, using fine sand paper.

39. Excessive sparking may result in a worn commutator of DC generator which may be cured by skimming in a lathe.

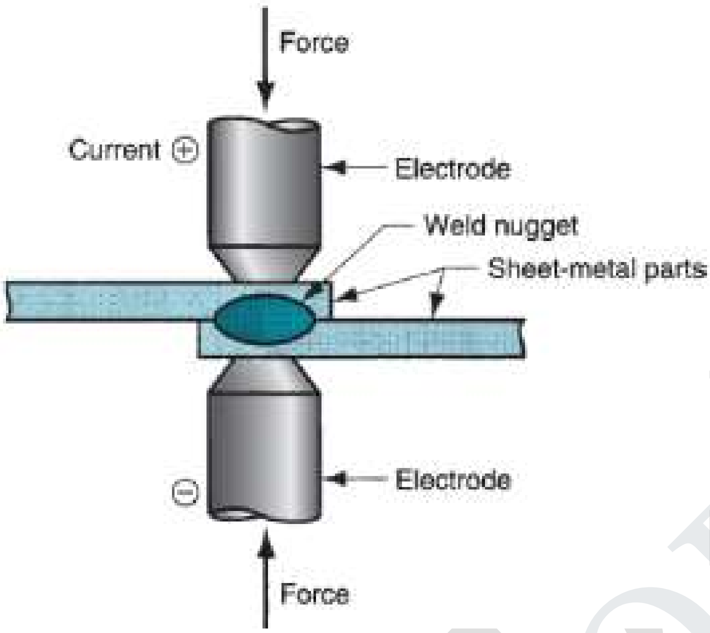
40. Brushes should move freely and have adequate spring tension. This can be tested by lifting and releasing them. Brushes should snap be firmly against the commutator of DC generator.

41. Greasing points need attention periodically.

42. Switch contacts should be cleaned periodically.

RESISTANCE WELDING

- ✓ Resistance welding (RW) is a group of fusion-welding processes that uses a combination of heat and pressure to accomplish coalescence.
- ✓ The heat being generated by electrical resistance to current flow at the junction to be welded.



- ✓ The principal components include workparts to be welded (usually sheet metal parts), two opposing electrodes, a means of applying pressure to squeeze the parts between the electrodes, and an AC power supply from which a controlled current can be applied.
- ✓ The operation results in a fused zone between the two parts, called a weld nugget in spot welding.
- ✓ By comparison to arc welding, resistance welding uses no shielding gases, flux, or filler metal; and the electrodes that conduct electrical power to the process are non consumable.
- ✓ RW is classified as fusion welding because the applied heat almost always causes melting of the faying surfaces (With exceptions).
- ✓ Some welding operations based on resistance heating use temperatures below the melting points of the base metals, so fusion does not occur.
- ✓ Few of the welding operations combine resistance heating with arc heating, and possibly with combustion of metal in the arc.
- ✓ The amount of heat generated in the workpiece Mathematically, $H = IVt = I(IR)t = I^2Rt$; Where H = heat generated in joules; I = current in Amp; R = resistance in ohms; t = time of current flow in seconds.

Types of Resistance welding

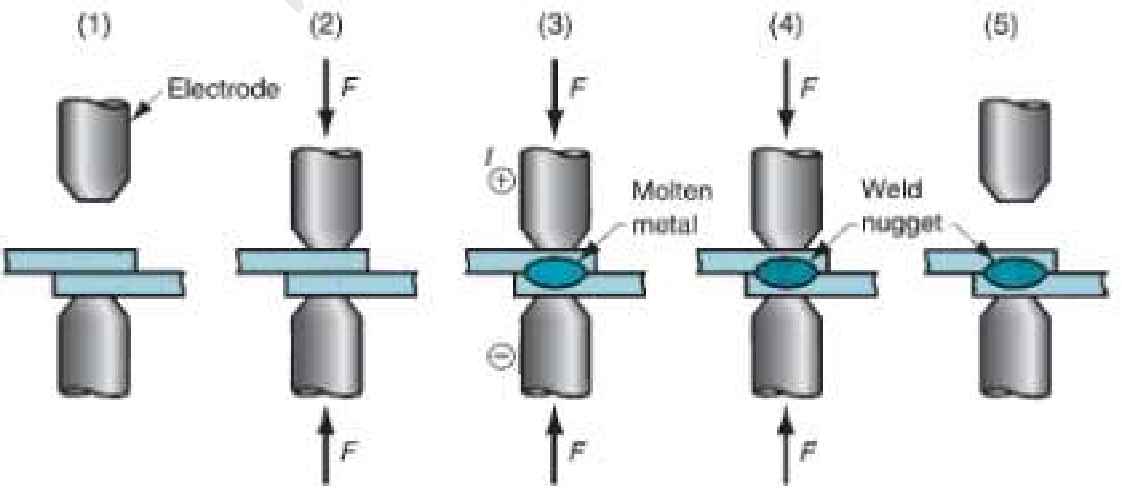
(1) Spot Welding
(2) Seam Welding
(3) Projection Welding
(4) Resistance Butt Welding
(5) Flash Butt Welding
(6) Percussion Welding
(7) High Frequency Resistance Welding
(8) High Frequency Induction Welding

Spot Welding

- ✓ Resistance spot welding is by far the predominant process in this group.
- ✓ It is widely used in mass production of automobiles, appliances, metal furniture, and other products made of sheet metal.
- ✓ A typical car body has approximately 10,000 individual spot welds, and that the annual production of automobiles throughout the world is measured in tens of millions of units; the economic importance of resistance spot welding is very high.

The total resistance in the welding circuit is the sum of:

i. Resistance of the electrodes.
ii. Contact resistance between electrodes and the workpieces.
iii. Resistance of the workpieces.
iv. Resistance between the surfaces to be joined. These surfaces are called the faying surfaces.

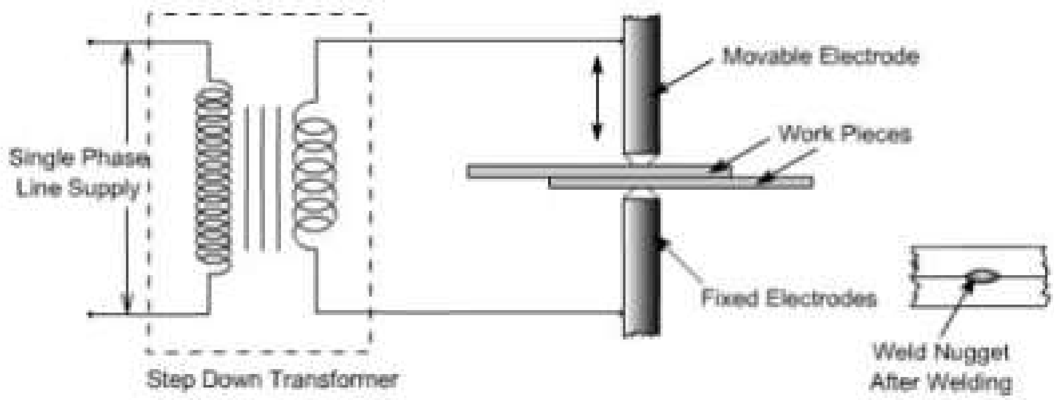


(1) parts inserted between open electrodes, (2) electrodes close and force is applied, (3) weld time—current is switched on, (4) current is turned off but force is maintained or increased (a reduced current is sometimes applied near the end of this step for stress relief in the weld region), and (5) electrodes are opened, and the welded assembly is removed.

- ✓ Resistance spot welding (RSW) is an RW process in which fusion of the faying surfaces of a lap joint is achieved at one location by opposing electrodes.
- ✓ The process is used to join sheet-metal parts of thickness 3 mm or less, using a series of spot welds, in situations where an airtight assembly is not required.
- ✓ The size and shape of the weld spot is determined by the electrode tip, the most common electrode shape being round, but hexagonal, square, and other shapes are also used.
- ✓ The resulting weld nugget is typically 5 to 10 mm in diameter, with a heat-affected zone extending slightly beyond the nugget into the base metals.
- ✓ If the weld is made properly, its strength will be comparable to that of the surrounding metal.
- ✓ Materials used for RSW electrodes consist of two main groups: (1) copper-based alloys and (2) refractory metal compositions such as copper and tungsten combinations.
- ✓ The second group is noted for superior wear resistance. As in most manufacturing processes, the tooling in spot welding gradually wears out as it is used.
- ✓ Whenever practical, the electrodes are designed with internal passageways for water cooling.
- ✓ Because of its widespread industrial use, various machines and methods are available to perform spot-welding operations.
- ✓ The equipment includes rocker-arm and press-type spot-welding machines, and portable spot-welding guns.
- ✓ It essentially consists of two electrodes, out of which one is fixed.
- ✓ The other electrode is fixed to a rocker arm (to provide mechanical advantage) for transmitting the mechanical force from a pneumatic cylinder. (This is the simplest type of arrangement.)

- ✓ The other possibility is that of a pneumatic or hydraulic cylinder being directly connected to the electrode without any rocker arm.
- ✓ For welding large assemblies such as car bodies, portable spot welding machines are used.
- ✓ Here the electrode holders and the pneumatic pressurizing system are present in the form of a portable assembly which is taken to the place, where the spot is to be made.
- ✓ The electric current, compressed air and the cooling water needed for the electrodes is supplied through cables and hoses from the main welding machine to the portable unit.
- ✓ In spot welding, a satisfactory weld is obtained when a proper current density is maintained.
- ✓ The current density depends on the contact area between the electrode and the work-piece.
- ✓ With the continuous use, if the tip becomes upset and- the contact area increases, the current density will be lowered and consequently the weld is obtained over a large area.
- ✓ This would not be able to melt the metal and hence there would be no proper fusion.
- ✓ A resistance welding schedule is the sequence of events that normally take place in each of the welds. The events are:

1. The *squeeze time* is the time required for the electrodes to align and clamp the two work-pieces together under them and provide the necessary electrical contact.
2. The *weld time* is the time of the current flow through the work-pieces till they are heated to the melting temperature.
3. *The hold time* is the time when the pressure is to be maintained on the molten metal without the electric current. During this time, the pieces are expected to be forged welded.
4. The *off time* is time during which, the pressure on the electrode is taken off so that the plates can be positioned for the next spot.



Before spot welding one must make sure that

(i) The job is clean, i.e., free from grease, dirt, paint, scale, oxide etc.

(ii) Electrode tip surface is clean, since it has to conduct the current into the work with as little loss as possible. Very fine emery cloth may be used for routine cleaning.

(iii) Water is running through the electrodes in order to

(a) Avoid them from getting overheated and thus damaged,

(b) Cool the weld.

(iv) Proper welding current has been set on the current selector switch.

(v) Proper time has been set on the weld-timer.

Spot welding electrodes

Spot welding electrodes are made of materials which have

(1) Higher electrical and thermal resistivities, and

(2) Sufficient strength to withstand high pressure at elevated temperatures.

- ✓ Copper base alloys such as copper beryllium and copper tungsten are commonly used materials for spot welding electrodes.
- ✓ For achieving the desired current density, It is important to have proper electrode shape for which three main types of spot welding electrodes are used which are pointed, domed and flat electrodes.

Applications of Spot Welding

(i) It has applications in automobile and aircraft industries

(ii) The attachment of braces, brackets, pads or clips to formed sheet-metal parts such as cases, covers or trays is another application of spot welding.

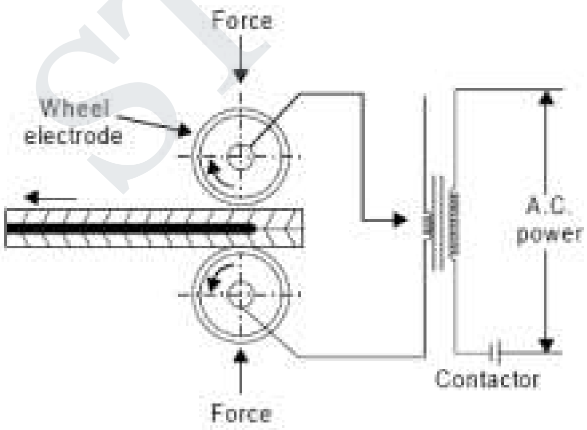
(iii) Spot welding of two 12.5 mm thick steel plates has been done satisfactorily as a replacement for riveting.

(iv) Many assemblies of two or more sheet metal stampings that do not require gas tight or liquid tight joints can be more economically joined by spot welding than by mechanical methods.

(v) Containers and boxes frequently are spot welded.

Resistance Seam Welding

- ✓ It is a continuous type of spot welding wherein spot welds overlap each other to the desired extent.
- ✓ In this process coalescence at the faying surfaces is produced by the heat obtained from the resistance to electric current (flow) through the work pieces held together under pressure by circular electrodes.



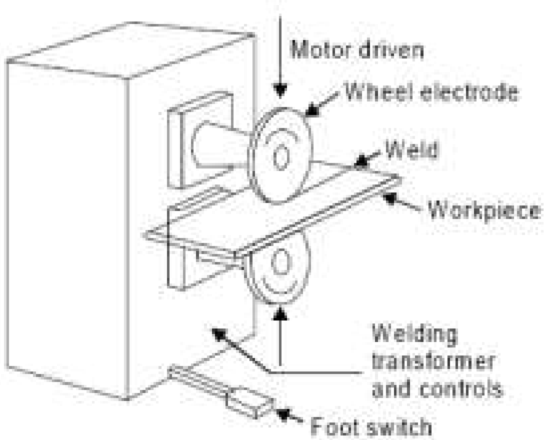


Fig. (a) Principle of seam welding process Fig. (b) Resistance seam welding process setup

- ✓ The resulting weld is a series of overlapping resistance-spots welds made progressively along a joint by rotating the circular electrodes.

- The seam welding is similar to spot welding, except that circular rolling electrodes are used to produce a continuous air-tight seam of overlapping welds.
- Overlapping continuous spot welds seams are produced by the rotating electrodes and a regularly interrupted current.

Applications

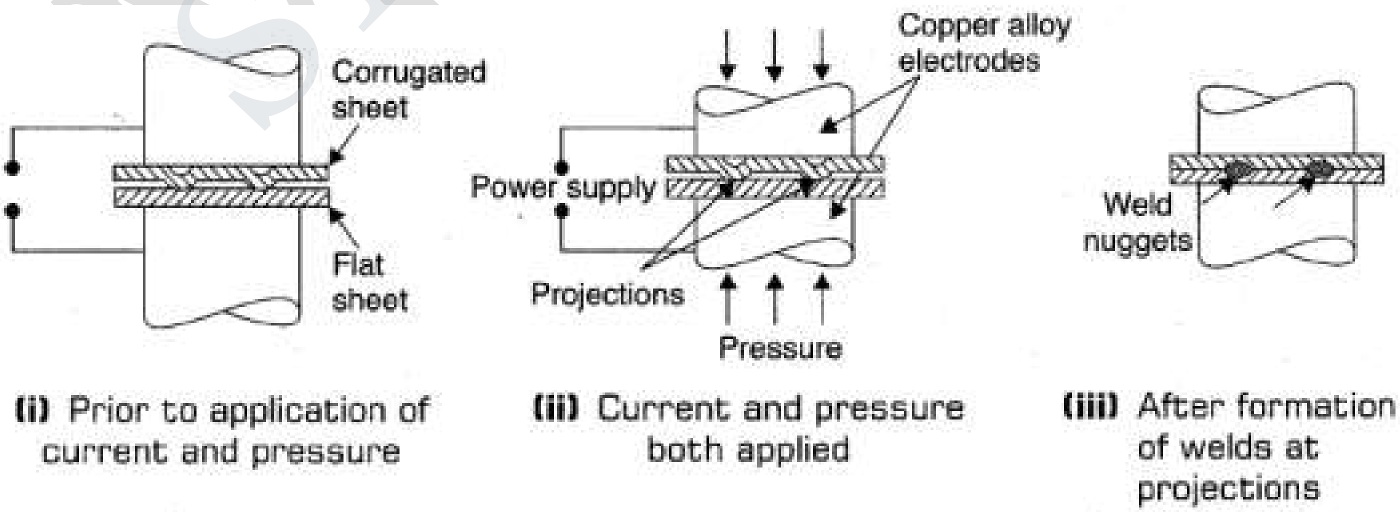
1. It is used for making leak proof joints in fuel tanks of automobiles.

2. Except for copper and high copper alloys, most other metals can be seam welded.

3. It is also used for making flange welds for use in watertight tanks.

Resistance Projection Welding

- This process is a resistance welding process in which two or more than two spot welds are made simultaneously by making raised portions or projections on predetermined locations on one of the workpiece.
- These projections act to localize the heat of the welding circuit. The pieces to be welded are held in position under pressure being maintained by electrodes.
- The projected contact spot for welding should be approximately equal to the weld metal thickness.
- The welding of a nut on the automotive chasis is an example of projection welding.



Resistance Upset Butt and Flash Butt Welding

- This welding is also used for joining metal pieces end to end but it has largely replaced the butt-welding method for weld articles small cross-sections. It can be used for thick sections also.
- Initially the current is switched on and then one end the moveable part to be welded is brought gently closer to the fixed end of the other part to localize heat at the ends and thus raises the temperature of the ends quickly to the welding heat.
- On acquiring contact of fixed end and moveable end with each other, the moveable end is then pressed against one another by applying mechanical pressure.
- Thus the molten metal and slag to be squeezed out in the form of sparks enabling the pure metal to form the joint and disallowing the heat to spread back.

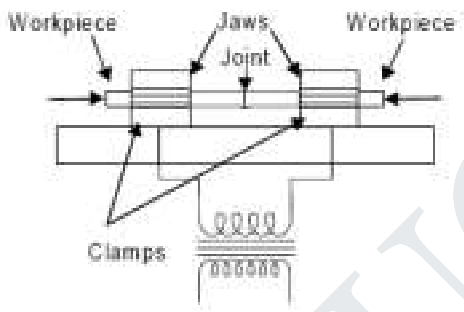


Fig. (a) Resistance upset butt welding

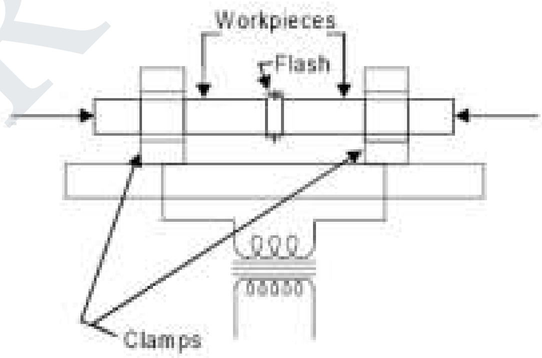


Fig. (b) Resistance flash butt welding

Merits

1. It is comparatively much faster than butt welding.

2. This method utilizes less current in comparison to butt welding as the small portion of the metal is only being heated for getting a good weld

3. Created joint by this welding is much stronger than the butt welding joint. Also the strength of the weld produced is high even more than that of the base metal.

4. The end of the metal pieces to be welded in this welding need not be squared as it is the basic requirement in butt-welding.

5. A high degree of accuracy can be easily achieved in terms of length alignment of weld.

Demerits

1. The periodic maintenance of machine and replacement of insulation is needed as flashing particles of molten metal are thrown out during welding which may enter into the slide ways and insulation of the set up.

2. Welder has to take enough care against possible fire hazard due to flashing during welding.

3. Additional stock has to be provided for compensating loss of metal during flashing and upsetting. This increases to the cost of weld.

4. Cost of removal of flash weld metal by trimming, chipping, grinding, etc. will increase to the welded product.

5. Surface of the jobs where they come in contact with the gripping surfaces, should be clean otherwise they will restrict the flow of electric current.

6. The available power, opening between the jaws of the gripping clamps and upsetting pressure of the welding set limit the size and cross sectional area of the jobs to be welded.

Applications

- ✓ All conducting forged metals can be easily be flash welded.
- ✓ A number of dissimilar metals can also be welded by controlling the welding conditions carefully.
- ✓ Metals generally welded metal by the process involves lead, tin, antimony, zinc, bismuth and their alloys, low carbon steels, stainless steel, alloy steels, tool steels, copper alloys, aluminium alloys, magnesium alloys nickel alloys, molybdenum alloys, and titanium alloys.
- ✓ This process is used in automobile industry, welding of solid and tubular structural assemblies, etc. in air-craft industry, welding of band saw blades, welding of tool steel drills, reamers and taps etc. to mild steel or alloy steel shanks, welding of pipes and tubes.

Common Advantages of Resistance Welding

(a) It is well suited for mass production. (High production rates are possible)

(b) It is economical in operation, since nothing is consumed except electrical power.

(c) Skilled welders are not required.

(d) Welds are quickly made.

(e) It is possible to weld dissimilar metals.

(f) No filler metal and flux is required.

(g)Lends itself to mechanization and automation,

(h)Operator skill level is lower than that required for arc welding

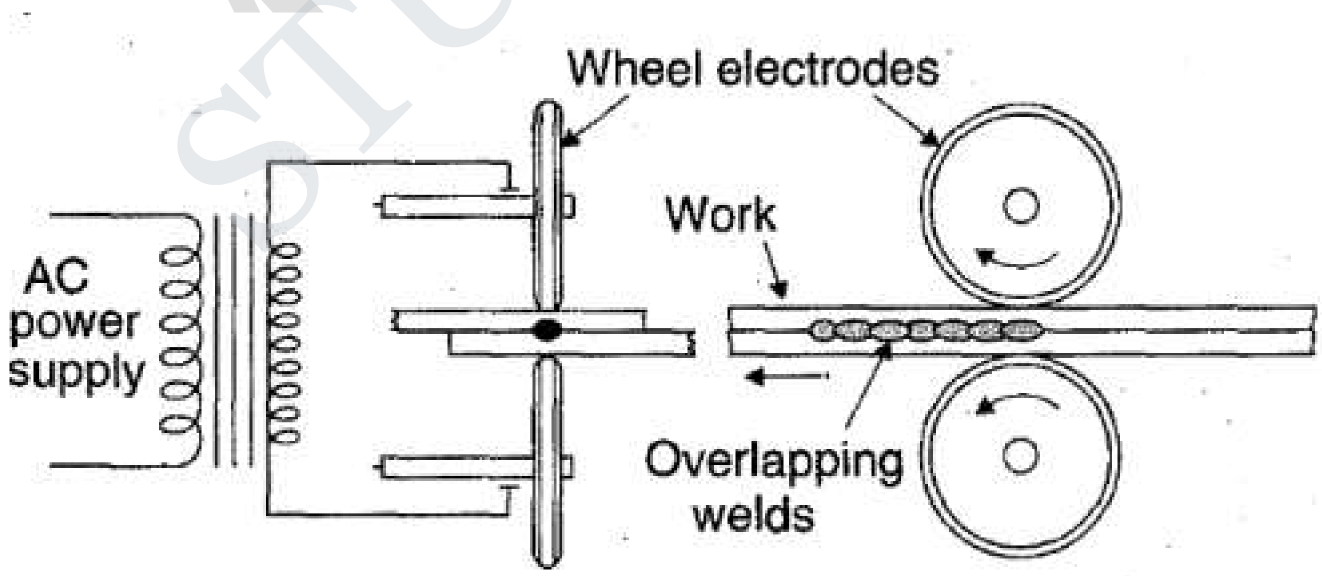
(i)Good repeatability and reliability.

Some disadvantages of resistance welding include:

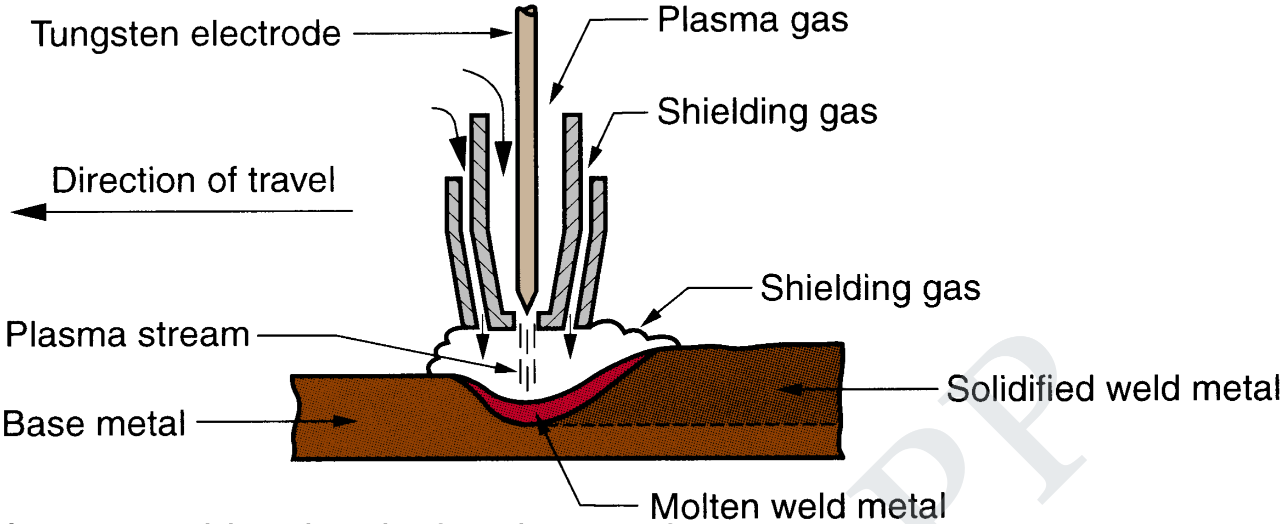
(a) High initial cost of the resistance welding equipment

(b) Certain resistance welding processes are limited to lap joints.

(c) A lap joint has an inherent service between the two metal pieces, which causes stress concentrations in applications where fatigue is present. This service may also cause trouble when corrosion is present

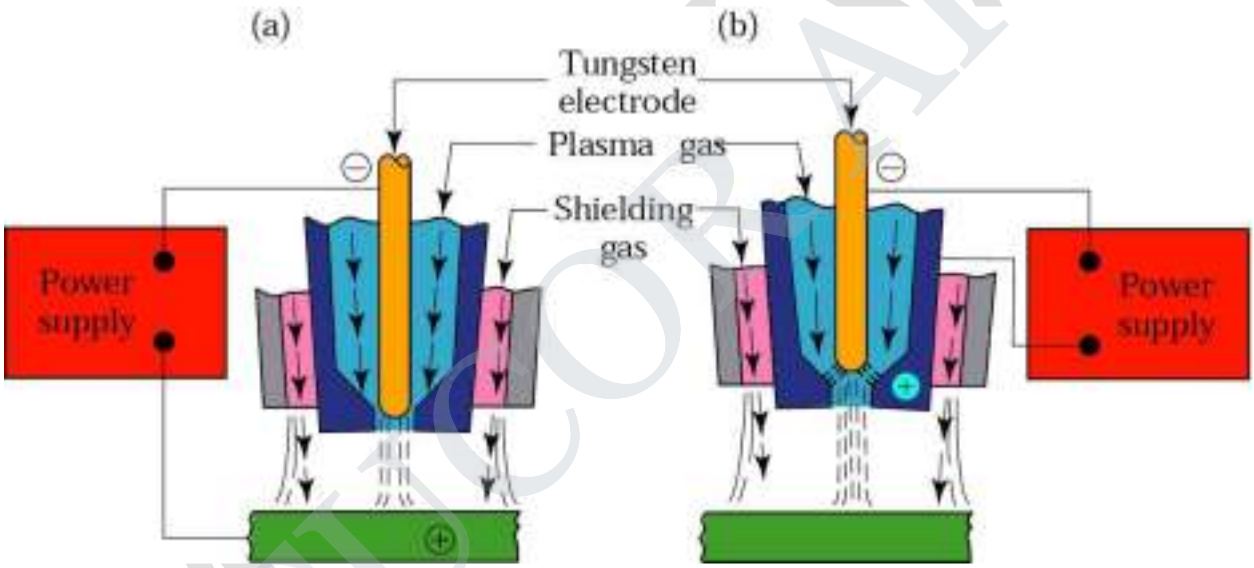


PLASMA ARC WELDING (PAW)



- Plasma, considered as the fourth state of matter.
- Plasma is a partially ionized gas produced by the, passage of gas through an electrical field which separates into free electrons, neutrons and ions.
- The energy required for this dissociation of gas is very high but as the atoms recombine, the process releases extremely high latent heat and temperatures as high as 17,000°C are generated.
- Plasma, which is electrically conducting, is always present in between the electrodes whenever an arc is formed.
- PAW and GTAW resemble in the sense that both use non-consumable tungsten electrodes and shielding gas.
- However, the construction of the welding torch is different in the two cases.
- In PAW, a tungsten electrode is contained in a specially designed nozzle that focuses a high-velocity stream of inert gas (e.g., argon or argon–hydrogen mixtures) into the region of the arc to form a high velocity, intensely hot plasma arc stream.
- There are two types of plasma torches - transferred arc type and non-transferred arc type.
- In case of non-transferred type, both electrodes are inside the torch, while in the case of transferred arc type, the arc is struck between the negatively charged electrode (which is in the torch) and the positively charged workpiece.

- ✓ The transferred arc is better since it transfers more energy at the workpiece and is less susceptible to magnetic deflection but it can be used only with conductive work materials.
- ✓ A high-velocity stream of plasma gas (argon or argon-hydrogen mixture) is introduced into the region of the arc to form a high-velocity, intensely hot plasma. For the purpose of arc shielding the gases used are argon, helium, and argon-helium mixture.
- ✓ The reason for higher temperatures in PAW compared to those in GTAW lies in the constriction of the arc which produces a plasma jet of small diameter and a very high energy density.



Two types of plasma-arc welding processes: (a) transferred, (b) nontransferred. Deep and narrow welds can be made by this process at high welding speeds.

- ✓ Argon, argon–hydrogen, and helium are also used as the arc-shielding gases.
- ✓ Temperatures in plasma arc welding reach 17,000^{0}C (30,000^{0}F) or greater, hot enough to melt any known metal.
- ✓ The reason why temperatures are so high in PAW (significantly higher than those in GTAW) derives from the construction of the arc.
- ✓ Although the typical power levels used in PAW are below those used in GTAW, the power is highly concentrated to produce a plasma jet of small diameter and very high power density.

- ✓ Plasma arc welding was introduced around 1960 but was slow to catch on.
- ✓ In recent years its use is increasing as a substitute for GTAW in applications such as automobile, subassemblies, metal cabinets, door and window frames, and home appliances.

Advantages

- ✓ Good arc stability,
- ✓ Better penetration control than most other AW processes, high travel speeds, and excellent weld quality.
- ✓ The process can be used to weld almost any metal, including tungsten.
- ✓ Difficult-to-weld metals with PAW include bronze, cast irons, lead, and magnesium

Limitations

- ✓ Include high equipment cost and larger torch size, which tends to restrict access in some joint configurations.

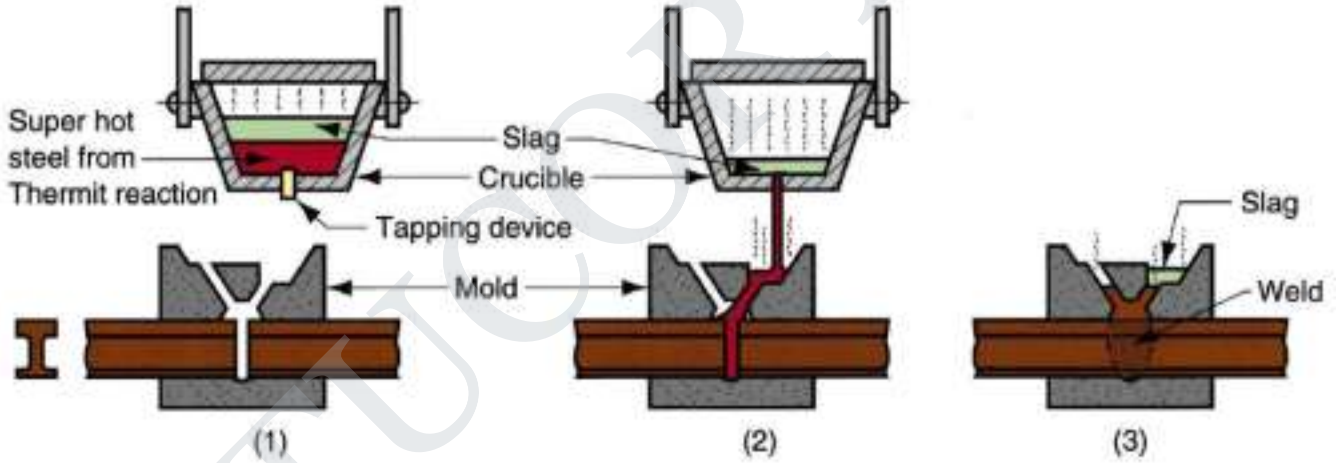
THERMIT WELDING

- ✓ It may be of forge or fusion kind of welding.
- ✓ Thermit is a trademark name for thermite, a mixture of aluminum powder and iron oxide that produces an exothermic reaction when ignited.
- ✓ It is used in incendiary bombs and for welding. As a welding process, the use of Thermit dates from around 1900.
- ✓ Thermit welding (TW) is a fusion-welding process in which the heat for coalescence is produced by superheated molten metal from the chemical reaction of Thermit.
- ✓ Finely mixed powders of aluminum and iron oxide (in a 1:3 mixture), when ignited at a temperature of around 1300 C (2300 F), produce the following chemical reaction.

$$8Al + 3Fe_3O_4 \rightarrow 9Fe + 4Al_2O_3 + heat$$

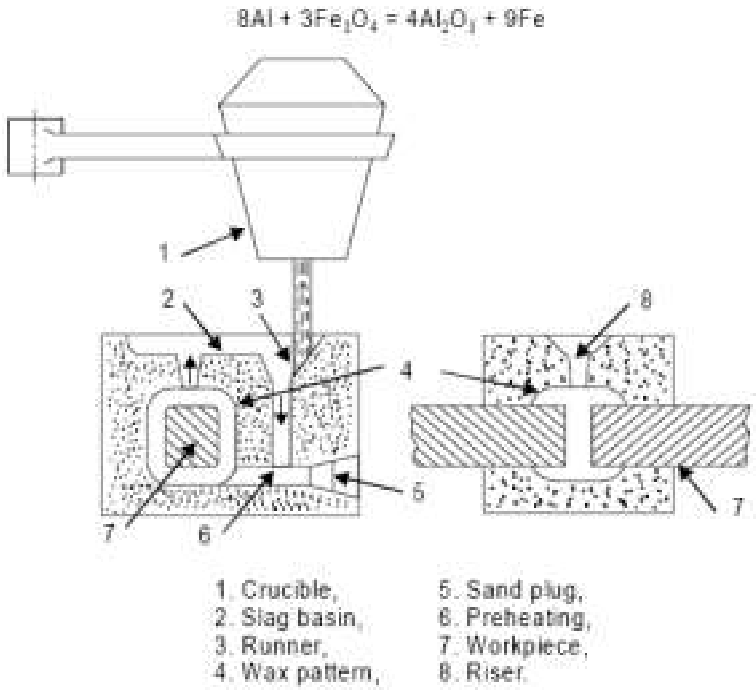
- ✓ The temperature produced in the thermit reaction is of the order of 3000°C.

- ✓ Filler metal is obtained from the liquid metal; and although the process is used for joining, it has more in common with casting than it does with welding.
- ✓ This mixture in superheat liquid state is poured around the parts to be joined.
- ✓ The joint is equipped with the refractory mold structure all around.
- ✓ After the reaction is complete (about 30 sec, irrespective of the amount of Thermit involved), the crucible is tapped and the liquid metal flows into a mold built specially to surround the weld joint.
- ✓ Because the entering metal is so hot, it melts the edges of the base parts, causing coalescence upon solidification.
- ✓ After cooling, the mold is broken away, and the gates and risers are removed by oxyacetylene torch or other method.



(1) Thermit ignited; (2) crucible tapped, superheated metal flows into mold; (3) metal solidifies to produce weld joint.

- ✓ Thermit welding is used for welding pipes, cables, conductors, shafts, and broken machinery frames, rails and repair of large gear tooth.
- ✓ Thermit welding has applications in joining of railroad, and repair of cracks in large steel castings and forgings such as ingot molds, large diameter shafts, frames for machinery, and ship rudders.
- ✓ The surface of the weld in these applications is often sufficiently smooth so that no subsequent finishing is required.



SOLID STATE WELDING PROCESSES

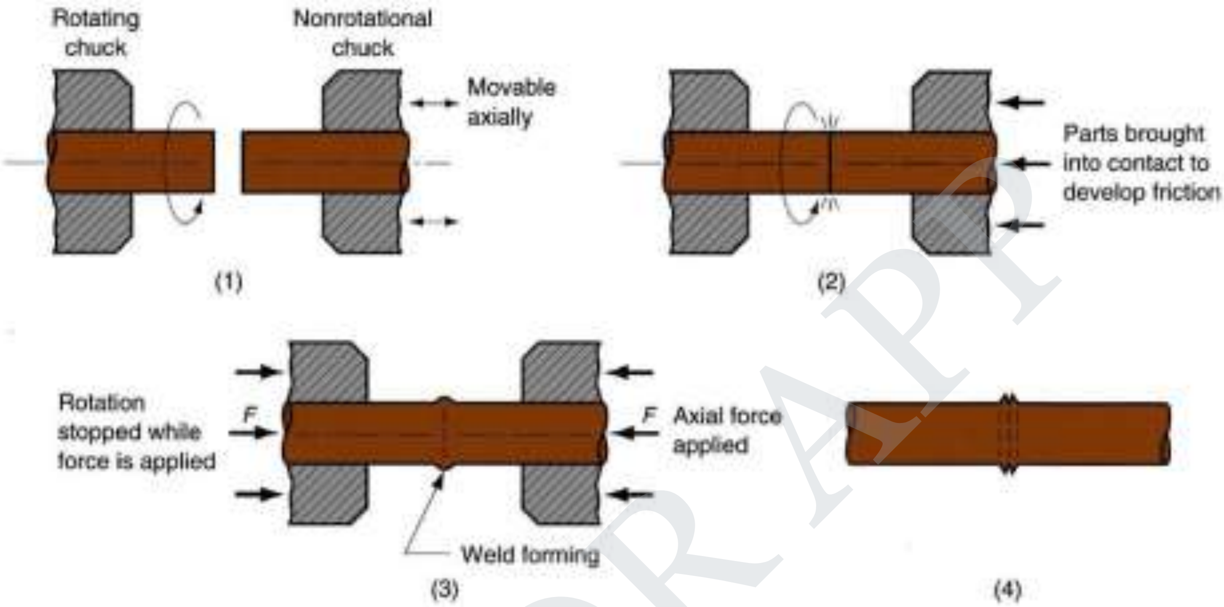
- ✓ In these processes, the base materials to be joined are heated to a temperature below or just up to the solidus temperature and then continuous pressure is applied to form the welded joint.
- ✓ No filler metal is used in solid-state welding processes.
- ✓ The various solid-state welding processes are-

(1) Forge Welding
(2) Cold Pressure Welding
(3) Friction Welding
(4) Explosive Welding
(5) Diffusion Welding
(6) Thermo-compression Welding
(7) Friction Stir Welding

Friction Welding

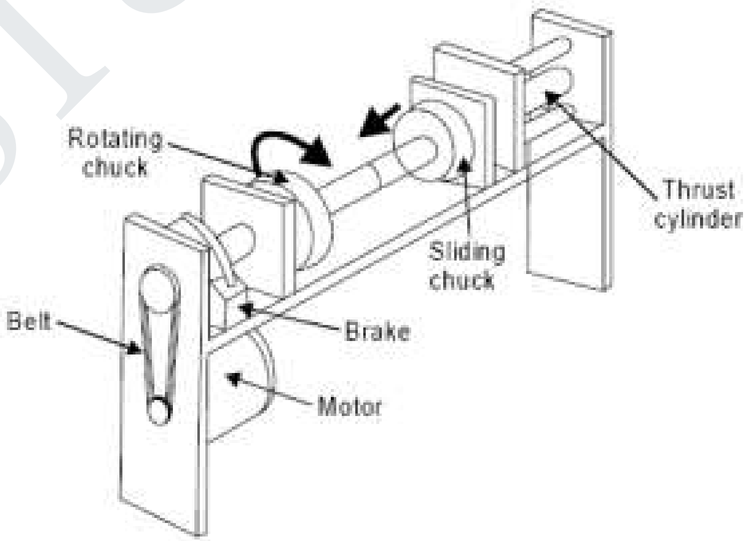
- ✓ In this process, the heat for welding is obtained from mechanically induced sliding motion between rubbing surfaces of work-pieces.
- ✓ In friction welding, one part is firmly held while the other (usually cylindrical) is rotated under simultaneous application of axial pressure.

- ✓ As these parts are brought to rub against each other under pressure, they get heated due to friction.
- ✓ When the desired forging temperature is attained, the rotation is stopped and the axial pressure is increased (upto 10 MN) to obtain forging action and hence welded joint.



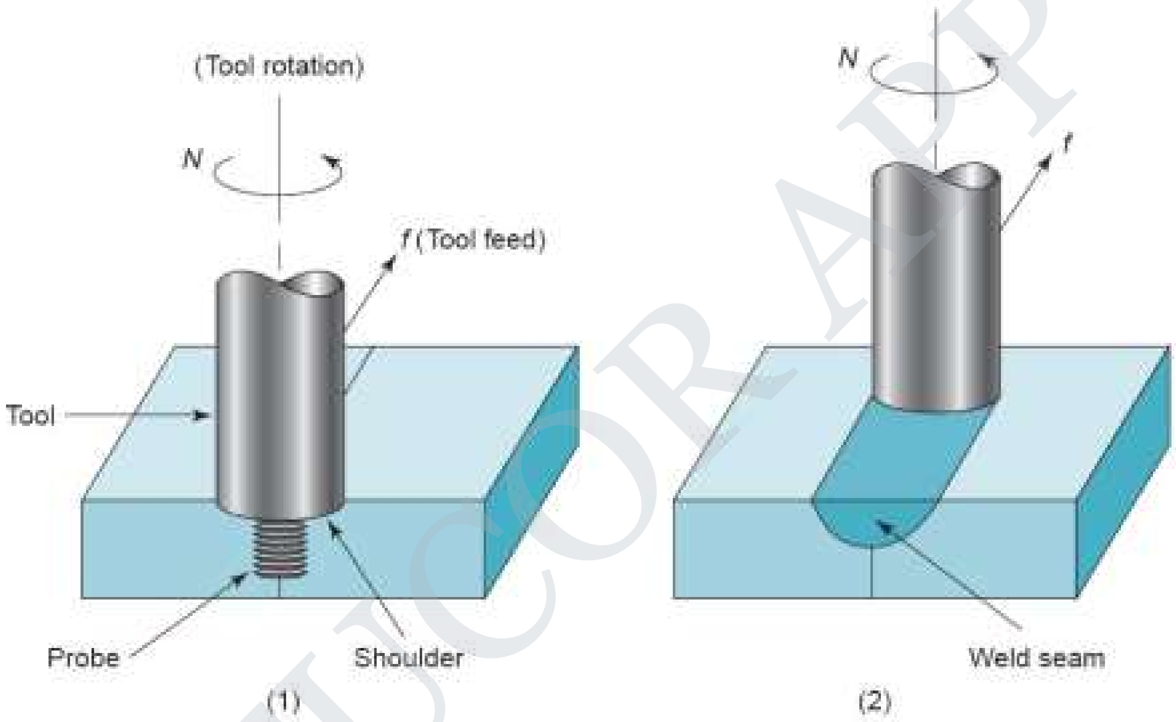
(1) Rotating part, no contact; (2) Parts brought into contact to generate friction heat; (3) Rotation stopped and axial pressure applied; and (4) Weld created(30 sec).

- ✓ Most of the metals and their dissimilar combinations such as aluminium and titanium, copper and steel, aluminium and steel etc. can be welded using friction welding.



Friction Stir Welding(FSW)

- Friction stir welding (FSW) is a solid state welding process in which a rotating tool is fed along the joint line between two work pieces, generating friction heat and mechanically stirring the metal to form the weld seam.
- The process derives its name from this stirring or mixing action.
- FSW is distinguished from conventional FRW by the fact that friction heat is generated by a separate wear-resistant tool rather than by the parts themselves.



- FSW was developed in 1991 at The Welding Institute in Cambridge, UK.
- The rotating tool is stepped, consisting of a cylindrical shoulder and a smaller probe (pin) projecting beneath it.
- During welding, the shoulder rubs against the top surfaces of the two parts, developing much of the friction heat, while the probe generates additional heat by mechanically mixing the metal along the butt surfaces.
- The probe has a geometry designed to facilitate the mixing action.
- The heat produced by the combination of friction and mixing does not melt the metal but softens it to a highly plastic condition.

- ✓ As the tool is fed forward along the joint, the leading surface of the rotating probe forces the metal around it and into its wake, developing forces that forge the metal into a weld seam.
- ✓ The shoulder serves to constrain the plasticized metal flowing around the probe.
- ✓ The welding of the material is facilitated by the severe plastic deformation in the solid state, involving dynamic recrystallization of the work material.

Advantages

- ✓ Good mechanical properties of the weld joint,
- ✓ Avoidance of toxic fumes, warping, shielding issues, and other problems associated with arc welding.
- ✓ Improved safety due to the absence of toxic fumes or the spatter of molten material.
- ✓ Low environmental impact.
- ✓ Little distortion or shrinkage, and
- ✓ Process is easy to perform.
- ✓ Process requires simple setup and less operator skill.
- ✓ Process can be easily automated on simple milling machines.
- ✓ Process can be carried out in all positions (horizontal, vertical, etc.), as there is no weld pool formation.
- ✓ Welds produced are of high quality. Welds have good appearance so that there is no need for expensive machining after welding.
- ✓ No microstructural change in the work material since the process is completed at low temperature.
- ✓ Only a threaded pin made of tool steel is enough to weld over 1000m of aluminium.

Disadvantages

- ✓ Exit hole left when tool is withdrawn.
- ✓ Large forces required for clamping of the plates for keeping them together.

- ✓ Less flexible than manual arc welding processes (difficulties with thickness variations and non-linear welds).
- ✓ Often slower traverse rate than some fusion welding techniques.

Applications

- ✓ The FSW process is used in the aerospace, automotive, railway, and shipbuilding industries.
- ✓ Typical applications are butt joints on large aluminum parts.
- ✓ Other metals, including steel, copper, and titanium, as well as polymers and composites have also been joined using FSW.

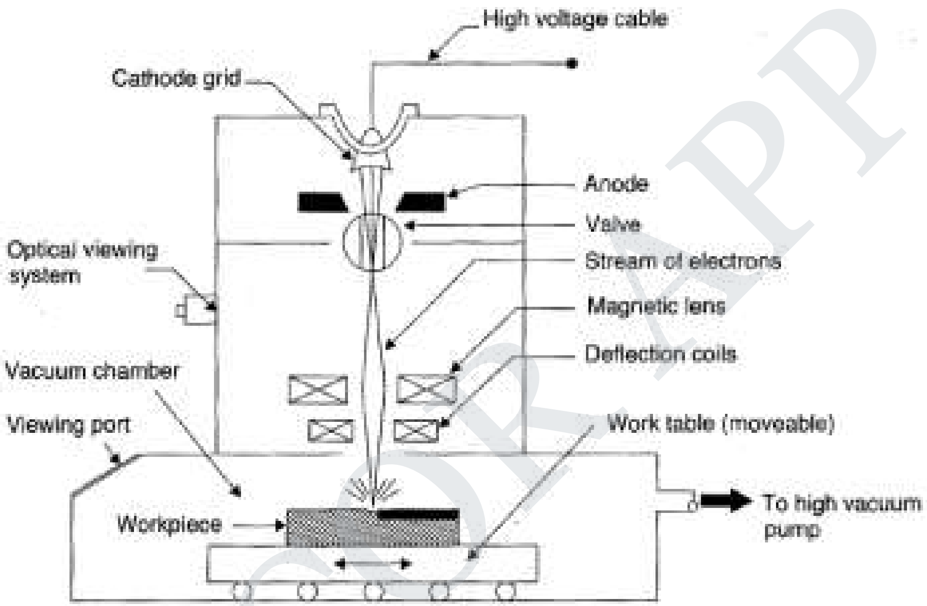
RADIANT ENERGY WELDING PROCESSES

- ✓ In radiant energy welding processes, heat is produced at the point of welding when a stream of electrons or a beam of electro-magnetic radiations strikes on the workpiece.
- ✓ This welding can be carried out in vacuum or at low pressures. Electron beam welding (EBW) and laser welding are two main types of radiant energy welding processes.

Electron Beam Welding (EBW)

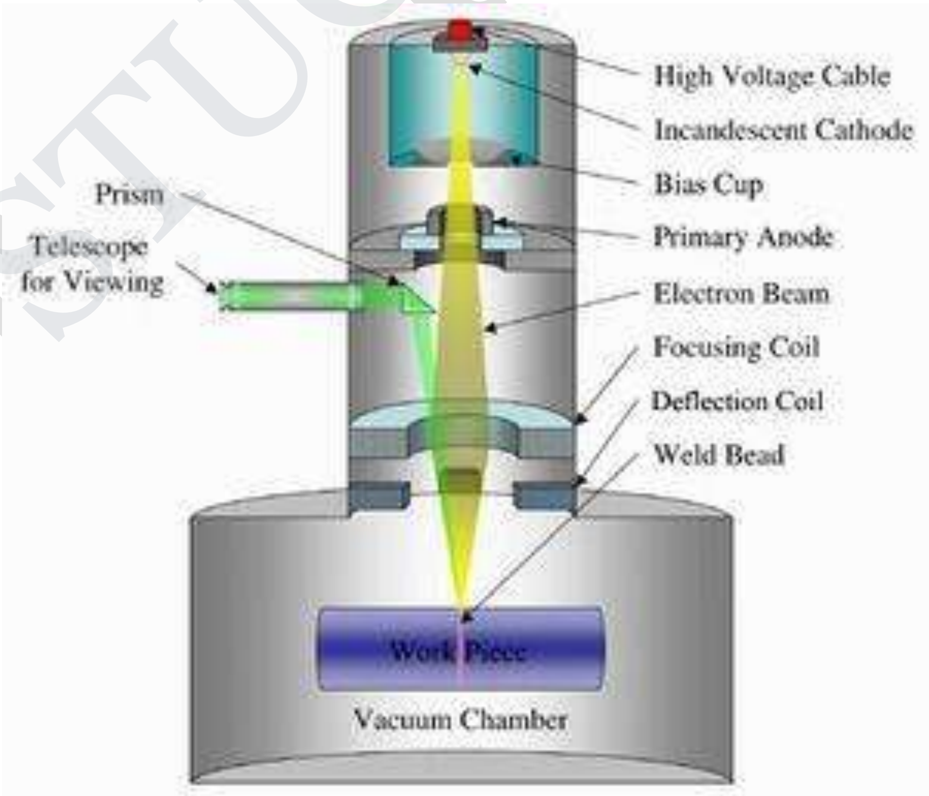
- ✓ In EBW process, the heat is generated when the electron beam impinges on work piece.
- ✓ As the high velocity electron beam strikes the surfaces to be welded, their kinetic energy changes into thermal energy and hence causes the workpiece metal to melt and fuse.
- ✓ Electron beam welding (EBW) is a fusion welding process that uses the heat resulting from impingement of a narrow focused beam of high velocity electrons on the workpiece to be welded.
- ✓ The kinetic energy of electrons is converted into heat that melts the surface in the form of a hole.
- ✓ The molten metal from this hole flows back into the joint area as the weld progresses, creating a deep and narrow weld with little or no distortion.

- ✓ A tungsten filament is heated to about 2200°C with a high-voltage (in the range 50 to 100 kV) current, causing it to emit electrons.
- ✓ This process employs an electron gun in which the cathode in form of hot filament of tungsten or tantalum is the source of a stream of electrons.
- ✓ The electrons emitted from filament by thermionic emission are accelerated to a high velocity to the anode because of the large potential difference that exists between them.



- ✓ By using a control grid, an accelerating anode and focusing coils, these electrons are accelerated in order to achieve an extremely high speed and, in the process, form a narrow beam which can be focused onto the workpiece in a circular spot about 1 mm in diameter.
- ✓ The electron beam is focused by a magnetic lens system on the workpieces to be welded.
- ✓ Normal atmosphere slows down the speed of electrons to such an extent as to render the process ineffective.
- ✓ Therefore, to be effective as a heat source for welding, the electron beam must be generated and focused in a very high vacuum (say, at a pressure of 0.01 Pa).
- ✓ In most applications, even the workpiece to be welded is enclosed in the high vacuum chamber.

- ✓ The depth of penetration of the weld depends on the electron speed which in turn is dependent upon the accelerating voltage.
- ✓ The current levels are low ranging between 50 mA to 1000 mA.
- ✓ The heat liberated is low and also is in a narrow zone, thus the heat affected zone is minimal as well as weld distortions are virtually eliminated.
- ✓ It is possible to carry out the electron beam welding in open atmosphere. For welding in vacuum, the work-piece is enclosed in a box in which the vacuum is created.
- ✓ When electron beam moves in the normal atmosphere, the electrons would be impinging with the gas molecules in the atmosphere and would thus be scattered.
- ✓ This scattering increases the spot size of the electron beam and consequently there is lower penetration.
- ✓ As the vacuum increases, the scattering effect of the electron beam decreases and hence, penetration increases. The other advantage of using vacuum is that the weld metal is not contaminated.



Advantages

- ✓ Welds are of high purity and quality, as vacuum assures both de-gasification and de-contamination.
- ✓ Welds have narrow profile with deep penetration. Fusion zone can have a depth-to-width ratio of 25:1.
- ✓ Heat affected zone is very narrow, typically 2-5% of that produced in arc welding processes.
- ✓ Distortion in the weld area is very small.
- ✓ Almost any metal in the thickness range of 0.2 mm to 100 mm can be butt or lap welded.
- ✓ Even metals such as zirconium, beryllium and tungsten, which are otherwise difficult to weld by other methods, can be welded.
- ✓ Dissimilar metals can also be welded.
- ✓ Heat-sensitive materials can be welded without any damage to the workpiece material.
- ✓ The process can be performed in any position.
- ✓ High welding speed. When parameters are precisely controlled with servo controls, welding speeds can be as high as 10 mpm.
- ✓ No requirement of shielding gas, flux, or any filler metal.
- ✓ No requirement of any pre-welding or post-welding operations since the weld is not contaminated.

Disadvantages

- ✓ The process equipment is expensive.
- ✓ There is need for stringent safety precautions in terms of expensive shielding, as the equipment emits harmful X-rays.
- ✓ There is need for extensive joint preparation and alignment.
- ✓ There is limit on the size of workpiece that can be accommodated in the vacuum chamber.
- ✓ Process productivity is low, as a lot of time is lost in re-establishing the vacuum every time a new job is to be loaded in the chamber.
- ✓ Not suitable for those applications where a wide gap filling is required.

Applications

- ✓ In which thin parts have to be welded along with the thick parts.
- ✓ In which other welding processes are unable to produce the required results. That is, where thequality of welds required is quite high.
- ✓ In which deep penetration is required.
- ✓ In automotive and electronics industries.
- ✓ In aircraft and aerospace industries.
- ✓ In defense industry for welding of reactive materials (nuclear reactor) and missile components.

WELDING DEFECTS

1. Lack of Penetration

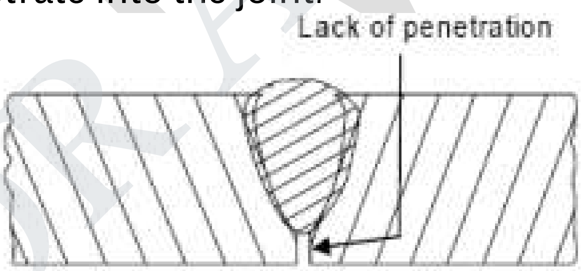
It is the failure of the filler metal to penetrate into the joint.

It is due to

(a) Inadequate de-slagging

(b) Incorrect edge penetration

(c) Incorrect welding technique.



2. Incomplete penetration and Fusion

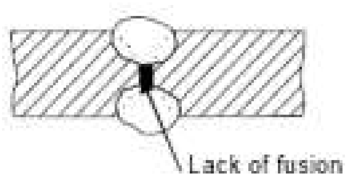
Lack of fusion is the failure of the filler metal to fuse with the parent metal.

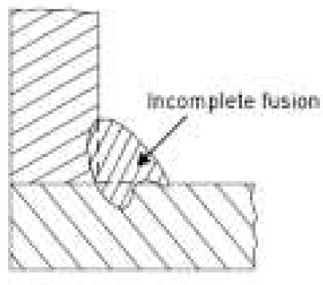
It is due to

(a) Too fast a travel

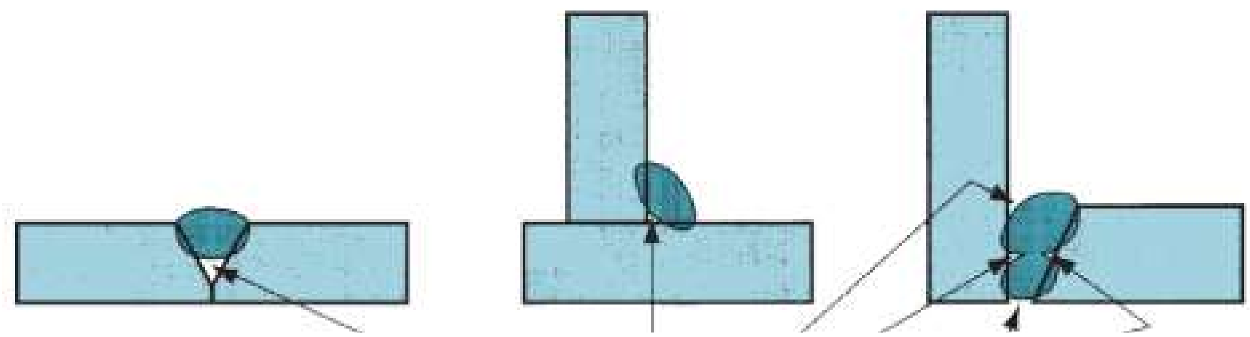
(b) Incorrect welding technique

(c) Insufficient heat





Incomplete Fusion



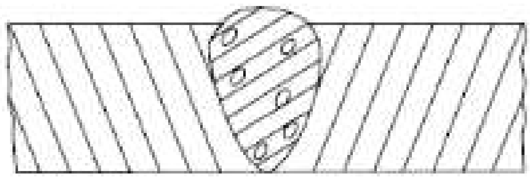
3. Porosity

It is a group of small holes throughout the weld metal. It is caused by the trapping of gas during the welding process, due to

(a) Chemicals in the metal

(b) Dampness

(c) Too rapid cooling of the weld.

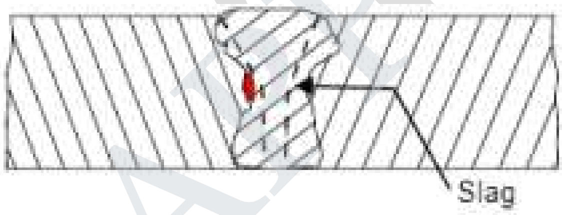


4. Slag Inclusion

It is the entrapment of slag or other impurities in the weld. It is caused by

(a) Slag from previous runs not being cleaned away,

(b) Insufficient cleaning and preparation of the base metal before welding commences.



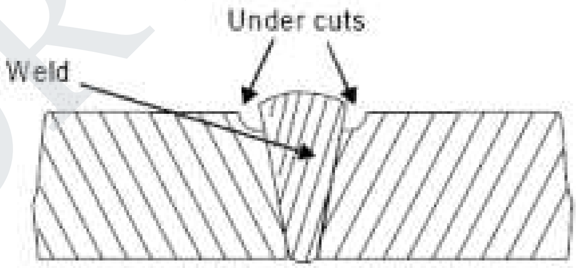
5. Undercuts

These are grooves or slots along the edges of the weld caused by

(a) Too fast a travel

(b) Bad welding technique

(c) Too great a heat build-up.

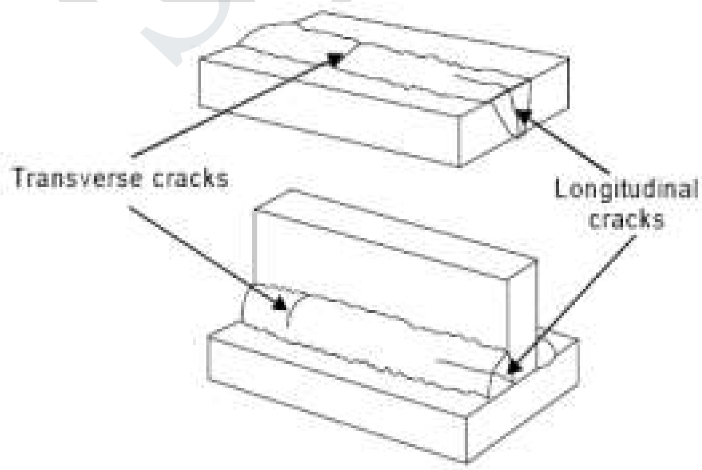


6. Cracking

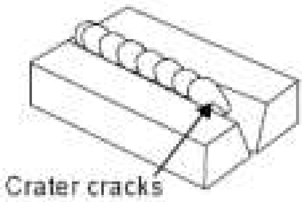
It is the formation of cracks either in the weld metal or in the parent metal. It is due to

(a) Unsuitable parent metals used in the weld

(b) Bad welding technique.



(a) Longitudinal and Transverse Crack



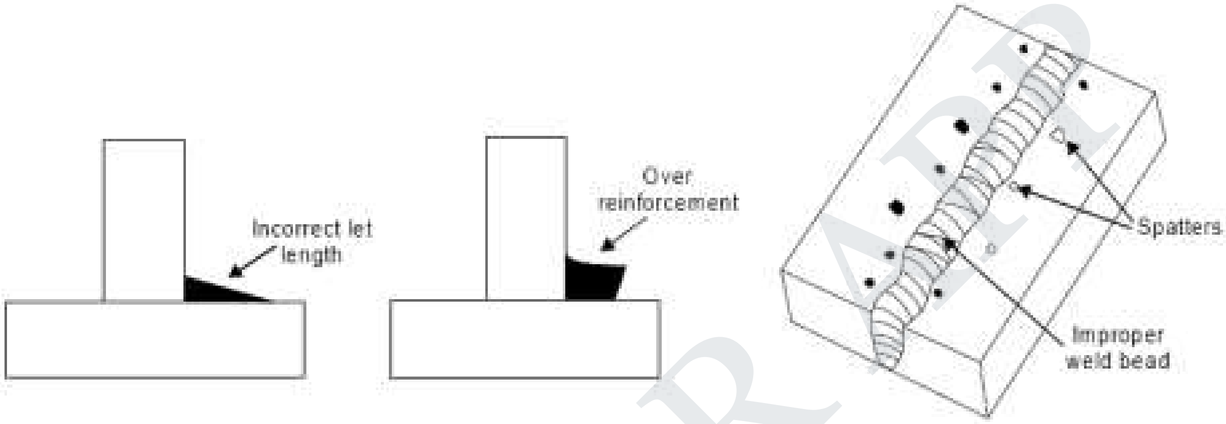
(b) Crater cracks

7. Poor Weld Bead Appearance

If the width of weld bead deposited is not uniform or straight, then the weld bead is termed as poor.

It is due to

(a) improper arc length,
(b) improper welding technique,
(c) damaged electrode coating and
(d) poor electrode and earthing connections.



Poor Weld Bead Appearance

8. Distortion

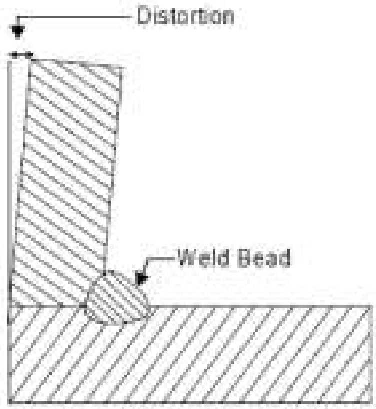
Distortion is due to

(a) high cooling rate,

(b) small diameter electrode,

(c)poor clamping and

(d) slow arc travel speed.



Distorted T Joint

9. Overlays

These consist of metal that has flowed on to the parent metal without fusing with it. The defect is due to

(a) Contamination of the surface of the parent metal

(b) Insufficient heat

10. Blowholes

These are large holes in the weld caused by

(a) Gas being trapped, due to moisture.

(b) Contamination of either the filler or parent metals.

11. Burn Through

It is the collapse of the weld pool due to

(a) Too great a heat concentration

(b) Poor edge preparation.

12. Excessive Penetration

It is where the weld metal protrudes through the root of the weld. It is caused by

(a) Incorrect edge preparation

(b) Too big a heat concentration

(c) Too slow a travel.

BRAZING

- ✓ Brazing is a joining process in which a filler metal is melted and distributed by capillary action between the faying surfaces of the metal parts being joined.
- ✓ No melting of the base metals occurs in brazing; only the filler melts.
- ✓ Filler material (spelter - 427°C) used for brazing has liquidus temperature above 450°C and below the solidus temperature of the base metal.
- ✓ The filler metal is drawn into the joint by means of capillary action (entering of fluid into tightly fitted surfaces).
- ✓ Due to the higher melting point of the filler material, the joint strength is more than in soldering.

- ✓ Almost all metals can be joined by brazing except aluminum and magnesium which cannot easily be joined by brazing.
- ✓ Dissimilar metals, such as stainless steel to cast iron can be joined by brazing.
- ✓ Because of the lower temperatures used there is less distortion in brazed joints.
- ✓ The joint can be quickly finished without much skill. Because of the simplicity of the process it is often an economical joining method with reasonable joint strength.
- ✓ The brazed joints are reasonably stronger, depending on the strength of the filler metal used.
- ✓ But the brazed joint is generally not useful for high temperature service because of the low melting temperature of the filler metal.
- ✓ The color of the filler metal in the brazed joint also, may not match with that of the base metal.
- ✓ Because the filler metal reaches the joint by capillary action, it is essential that the joint is designed properly.
- ✓ The clearance between the two parts to be joined should be critically controlled.
- ✓ Another important factor to be considered is the temperature at which the filler metal is entering the joint.
- ✓ During brazing, the base metal of the two pieces to be joined is not melted. An important requirement is that the filler metal must wet the base metal surfaces to which it is applied.
- ✓ The diffusion or alloying of the filler metal with the base metal place even though the base metal does not reach its solidus temperature.
- ✓ The surfaces to be joined must be chemically clean before brazing. However, fluxes are applied to remove oxides from the surfaces.
- ✓ Borax is the most widely used flux during the process of brazing. It will dissolve the oxides of most of the common metals.

Methods of Brazing

Torch Brazing

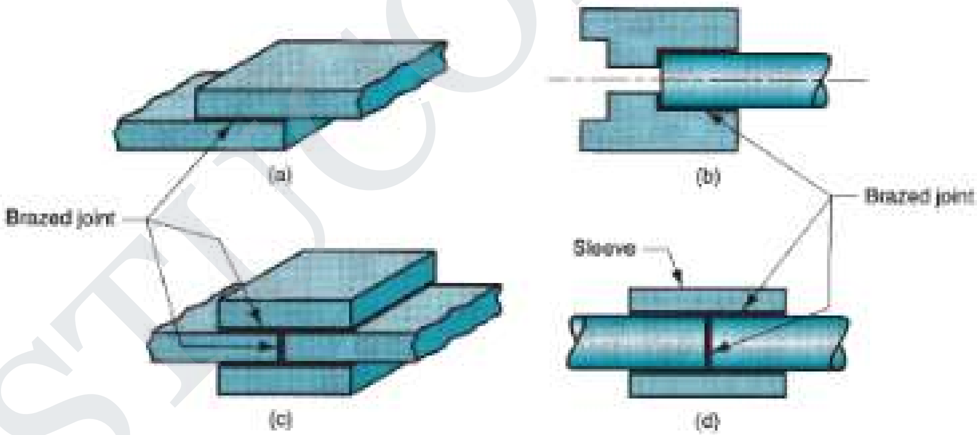
It is the most widely used brazing method. Heat is produced, generally, by burning a mixture of oxy-acetylene gas, as in the gas welding. A carbonizing flame is suitable for this purpose as it produces sufficiently high temperature needed for brazing.

Furnace Brazing

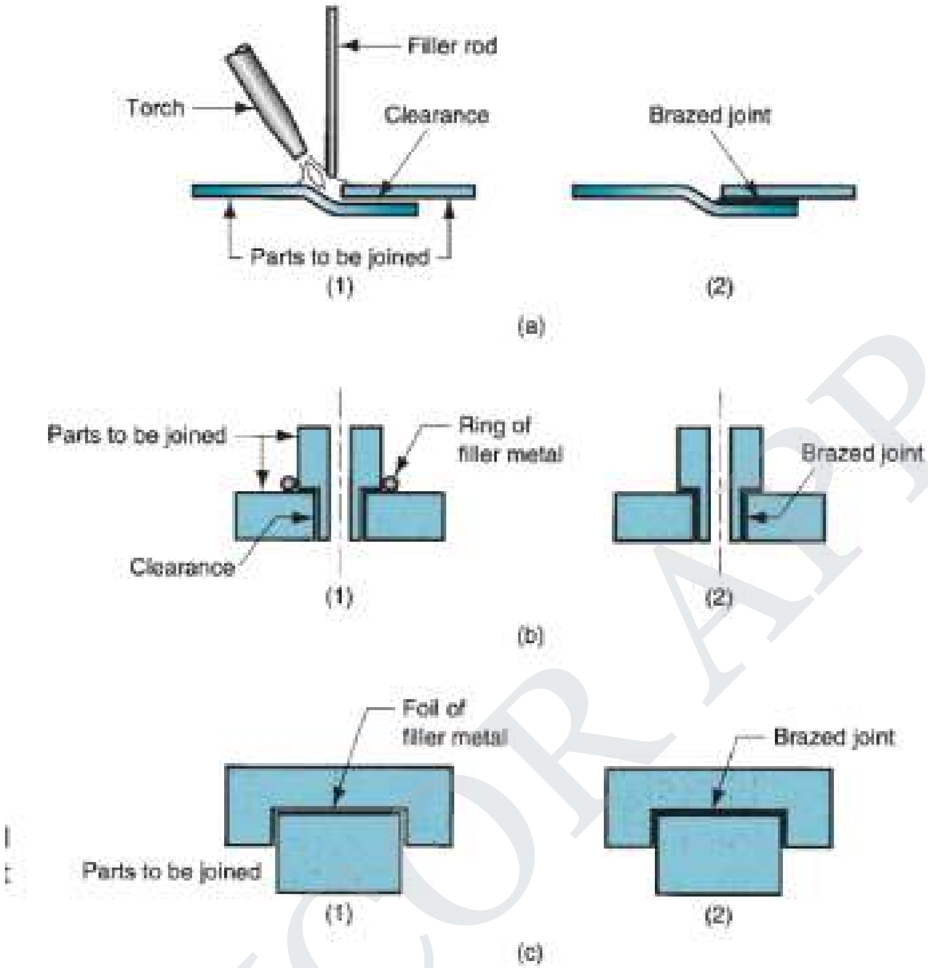
It is suitable for brazing large number of small or medium parts. Usually brazing filler metal in the granular or powder form or as strips is placed at the joint, and then the assembly is placed in the furnace and heated. Large number of small parts can be accommodated in a furnace and simultaneously brazed.

Braze Welding

In welding processes where the joint of the base metal is melted and a joint is prepared having higher joint strength, it is likely to cause metallurgical damage by way of phase transformations and oxide formation. In this process, the base metal is not melted, but the joint is obtained by means of a filler metal.



✓ Brazing has several advantages compared to welding: (1) any metals can be joined, including dissimilar metals; (2) certain brazing methods can be performed quickly and consistently, thus permitting high cycle rates and automated production; (3) some methods allow multiple joints to be brazed simultaneously; (4) brazing can be applied to join thin-walled parts that cannot be welded; (5) in general, less heat and power are required than in fusion welding; (6) problems with the heat-affected zone in the base metal near the joint are reduced; and (7) joint areas that are inaccessible by many welding processes can be brazed, since capillary action draws the molten filler metal into the joint.



- ✓ Disadvantages and limitations of brazing include (1) joint strength is generally less than that of a welded joint; (2) although strength of a good brazed joint is greater than that of the filler metal, it is likely to be less than that of the base metals; (3) high service temperatures may weaken a brazed joint; and (4) the color of the metal in the brazed joint may not match the color of the base metal parts, a possible aesthetic disadvantage.
- ✓ Brazing as a production process is widely used in a variety of industries, including automotive (e.g., joining tubes and pipes), electrical equipment (e.g., joining wires and cables), cutting tools (e.g., brazing cemented carbide inserts to shanks), and jewelry making. In addition, the chemical processing industry and plumbing and heating, contractors join metal pipes and tubes by brazing. The process is used extensively for repair and maintenance work in nearly all industries.

SOLDERING

- ✓ Soldering is a method of joining similar or dissimilar metals by heating them to a suitable temperature and by means of a filler metal, called solder, having liquidus temperuatre not exceeding 450°C and below the solidus of the base material. (solders used have a melting point between 180 to 270 °C)
- ✓ Though soldering obtains a good joint between the two plates, the strength of the joint is limited by the strength of the filler metal used.
- ✓ Solders are essentially alloys of lead and tin.
- ✓ To improve the mechanical properties and temperature resistance, solders are added to other alloying elements such as zinc, cadmium and silver in various proportions.
- ✓ Soldering is normally used for obtaining a neat leak proof joint or a low resistance electrical joint.
- ✓ The soldered joints are not suitable for high temperature service because of the low melting temperatures of the filler metals used.
- ✓ The soldering joints also need to be cleaned meticulously to provide chemically clean surfaces to obtain a proper bond.
- ✓ Solvent cleaning, acid pickling and even mechanical cleaning are applied before soldering.
- ✓ To remove the oxides from the joint surfaces and to prevent the filler metal from oxidizing, fluxes are generally used in soldering.
- ✓ The most commonly used soldering methods include Hard soldering (Filler material – silver), soft soldering(copper rod) (flame or electrically heated), dip soldering, and wave soldering.
- ✓ A soldering iron is a copper rod with a thin tip which can be used for flattening the soldering material.
- ✓ The soldering iron can be heated by keeping in a furnace or by means of an internal electrical resistance whose power rating may range from 15 W for the electronic applications to 200 W for sheet metal joining.

- ✓ This is the most convenient method of soldering but somewhat slower compared to the other methods.
- ✓ In dip soldering, a large amount of solder is melted in a tank which is closed. The parts that are to be soldered are first cleaned properly and dipped in a flux bath as per the requirement.
- ✓ These are then dipped into the molten solder pool and lifted with the soldering complete. The wave soldering is a variant of this method wherein the part to be soldered (e.g.: an electronic printed circuit board, PCB) is not dipped into the solder tank, but a wave is generated in the tank so that the solder comes up and makes a necessary joint.

Basic Operations in Soldering

For making soldered joints, following operations are required to be performed sequentially.

1. Shaping and fitting of metal parts together
2. Cleaning of surfaces
3. Flux application
4. Application of heat and solder

Solder Fluxes

The flux does not constitute a part of the soldered joint. Zinc chloride, ammonium chloride, and hydrochloric acid are the examples of fluxes commonly used in soldering.

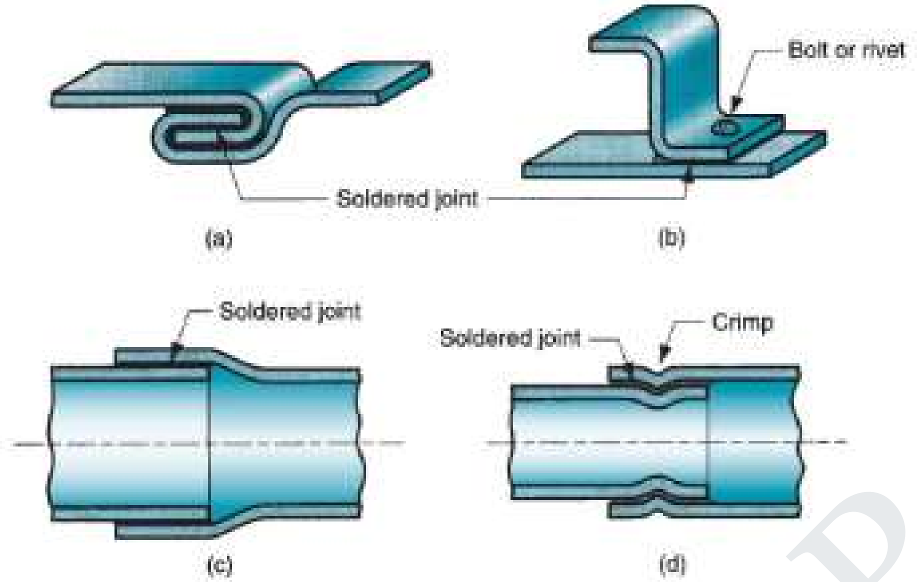
The function of fluxes in soldering is to remove oxides and other surface compounds from the surfaces to be soldered by displacing or dissolving them. Soldering fluxes may be classified into four groups-

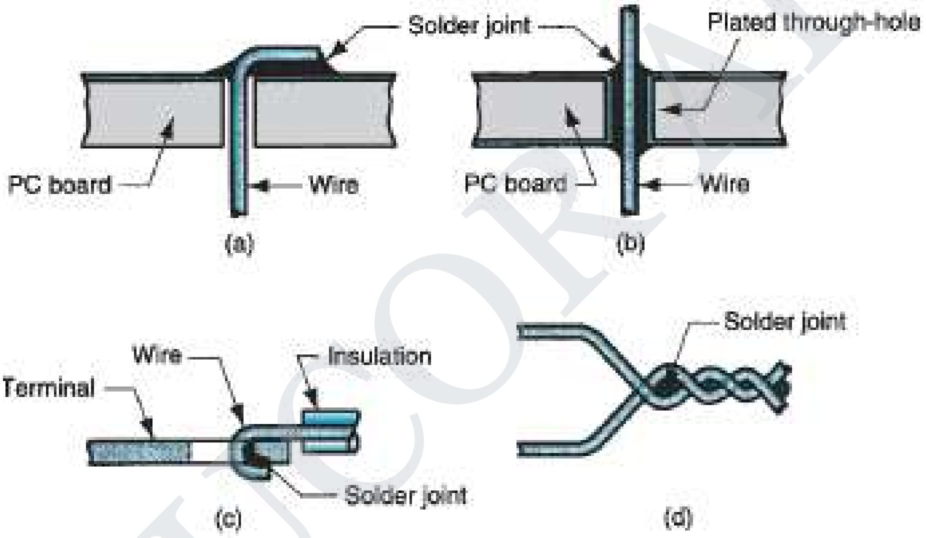
(1) Inorganic fluxes (most active)

(2) Organic fluxes (moderately active)

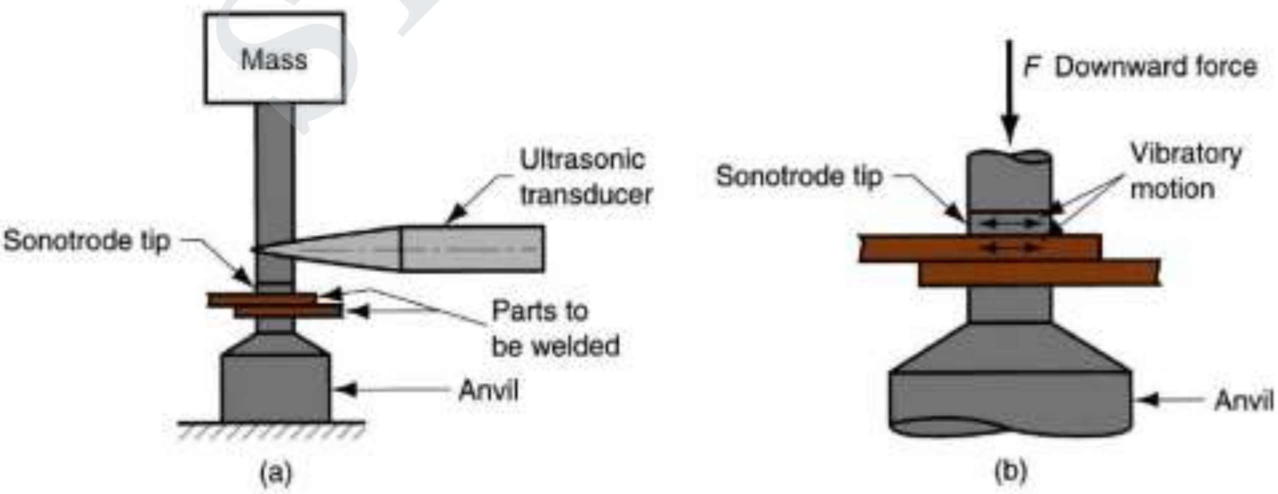
(3) Rosin fluxes (least active), and

(4) Special fluxes for specific applications





Ultrasonic welding



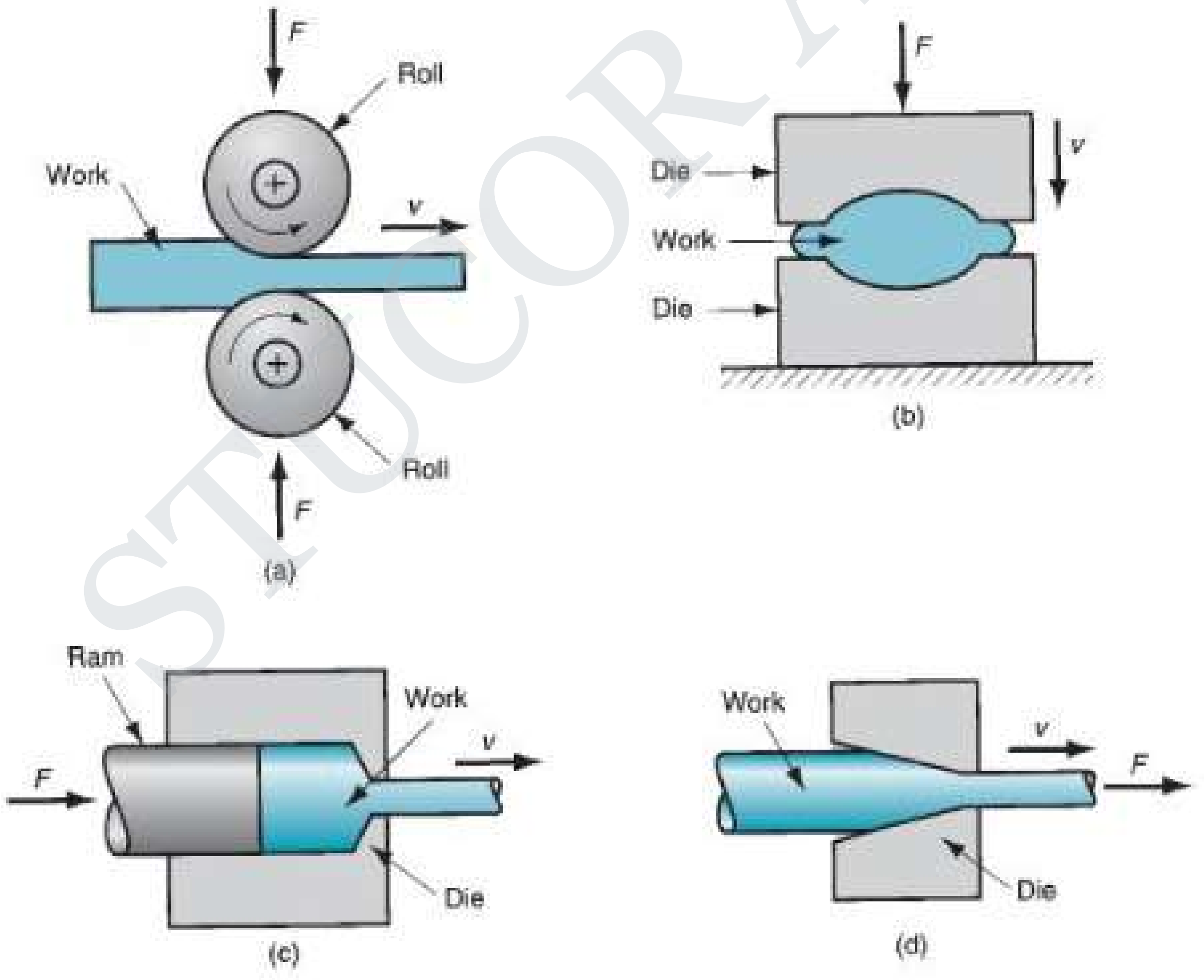
Ultrasonic welding (USW): (a) general setup for a lap joint; and (b) close-up of weld area.

UNIT III METAL FORMING PROCESSES 9

Hot working and cold working of metals – Forging processes – Open, impression and closed die forging – forging operations. Rolling of metals– Types of Rolling – Flat strip rolling – shape rolling operations – Defects in rolled parts. Principle of rod and wire drawing – Tube drawing – Principles of Extrusion – Types – Hot and Cold extrusion.

Bulk Metal Forming

- **Rolling** - compression process to reduce the thickness of a slab by a pair of rolls.
- **Forging** - compression process performing between a set of opposing dies.
- **Extrusion** - compression process squeezing metal flow a die opening.
- **Drawing** - pulling a wire or bar through a die opening.



Metal forming can be classified as

Bulk deformation processes – generally characterized by significant deformations and massive shape changes; and the surface area-to- volume of the work is relatively small.

- ✓ Forging
- ✓ Extrusion
- ✓ Rolling
- ✓ Wire and bar drawing

Sheet metalworking processes are forming and cutting operations performed on metal sheets, strips, and coils. The surface area-to-volume ratio of the starting metal is high;

Thus, this ratio is a useful means to distinguish bulk deformation from sheet metal processes

- ✓ Bending operations
- ✓ Deep or cup drawing
- ✓ Shearing processes
- ✓ Miscellaneous

Hot Working *(0.5 – 0.75T_m)*

- ✓ Plastic deformation of metal carried out at a temperature above the recrystallization temperature is called hot working.
- ✓ Under the action of heat and force, when the atoms of metal reach a certain higher energy level, the new crystals start forming. This is called recrystallization.
- ✓ When this happens, the old grain structure formed by previously carried out mechanical working no longer exists; instead, new crystals which are strain-free are formed.
- ✓ In hot working, the temperature at which the working is completed is critical since any extra heat left in the material after working will promote grain growth, leading to poor mechanical properties of the material.

Advantages

1. Power requirement: Lesser forces and, therefore, lesser power is needed for deformation
2. Material requirement: All ductile as well as some brittle materials can be formed
3. Material properties: No strain hardening and no residual stresses remain in the material
4. Amount of deformation: Greater ductility of material is available and, therefore, more deformation is possible. Bulky jobs can be worked upon
5. Product quality: Favorable grain size is obtained, leading to better mechanical properties of Materials

Disadvantages

1. Power requirement: Heat energy is needed and thus proves to be costly
2. Limited materials: Materials which become brittle at higher temperatures cannot be hot worked
3. Material loss: Scale formation causes loss of material Surface quality: Poor surface finish of material due to scale formation
4. Surface quality: Poor surface finish of material due to scale formation
5. Surface degradation: Surface of ferrous metals is decarburized and hardness at surface may be poor
6. Product quality: There is poor accuracy and dimensional control of parts
7. Reproducibility: Poor reproducibility and interchangeability of parts
8. Equipment: There is lower life of tooling and equipment
9. Problems: Handling and maintaining of hot metal is difficult and troublesome

Cold Working *(Less than $0.3T_m$)*

- ✓ Plastic deformation of metals performed generally at room temperature (i.e., below the recrystallization temperature) is known as cold working.
- ✓ In some cases, slightly elevated temperatures may be used to provide increased ductility and reduced strength.
- ✓ Cold working offers a number of distinct advantages, and for this reason various cold-working processes have become extremely important.
- ✓ Significant advances in recent years have led to their greater use, and the trend appears likely to continue.

Advantages

1. Cost: No heating is required and thus cold working is less costly
2. Surface quality: There is no scale formation on the metal. No post process cleaning of the product is required and better surface finish is obtained
3. Product quality: Better dimensional control is achieved; therefore, no secondary machining operation is generally needed
4. Product reproducibility: There is better reproducibility and interchangeability of parts
5. Product properties: Although large energy is required for deformation; part of this energy is utilized in increasing strength, fatigue, and wear properties of products
6. Material properties: Directional properties can be imparted
7. Material quality: No decarburization of the surface occurs. There is no loss of material, as also negligible contamination problems
8. Handling problems: Almost no handling problems exist with cold metal

Disadvantages

1. Limited materials: Brittle materials cannot be cold worked
2. Limited products: Big and bulky parts cannot be easily formed. Strain hardening occurs (may require intermediate annealing)

3. Limited deformation: Metals are less ductile at room temperature and, so, less deformation is possible
4. Power requirement: Higher forces are required for deformation
5. Equipment capacity: Heavier and more powerful equipment is required
6. Surface quality: Metal surfaces before deformation must be clean and scale-free
7. Product quality: Undesirable residual stresses may be present in the component

Applications

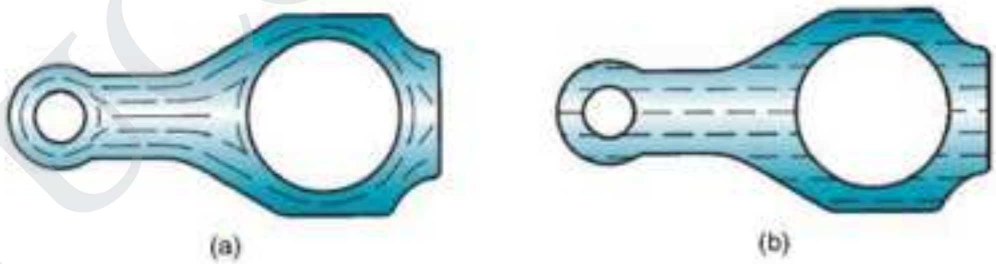
- ✓ Cold forming processes, in general, are better suited to small and medium size parts that are to be produced in large quantities:
- ✓ Large quantity of production is necessary to recover the higher cost of the required equipment and tooling.

Forging

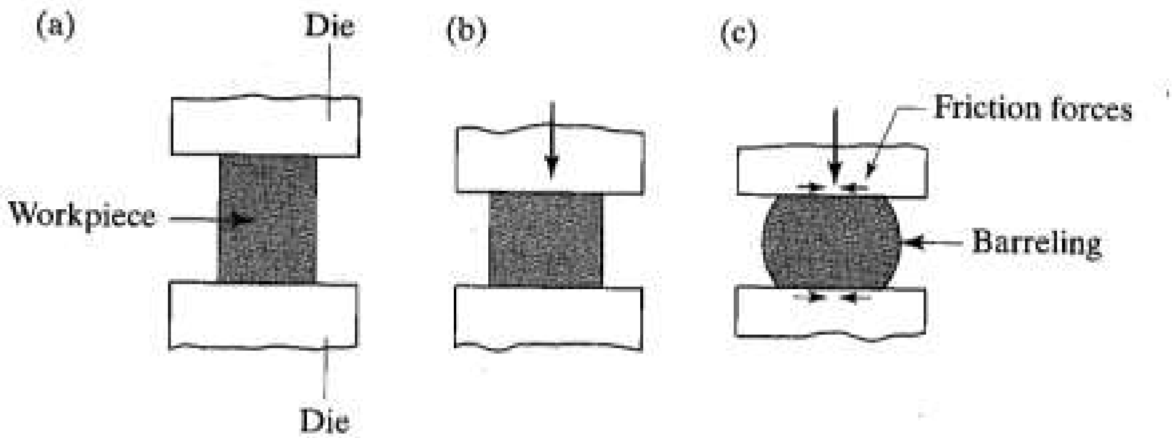
- ✓ Forging is a deformation process in which the work is compressed between two dies, using either impact or gradual pressure to form the part.
- ✓ Forging is carried out in many different ways.
- ✓ One way to classify forging is by working temperature.
- ✓ Most forging operations are performed hot or warm, owing to the significant deformation demanded by the process and the need to reduce strength and increase ductility of the work metal. However, cold forging is also very common for certain products.
- ✓ The advantage of cold forging is the increased strength that results from strain hardening of the component.
- ✓ Either impact or gradual pressure is used in forging. The distinction derives more form the type of equipment used than differences in process technology.

- ✓ A forging machine that applies an impact load is called a forging hammer, while one that applies gradual pressure is called a forging press.
- ✓ Another difference among forging operations is the degree to which the flow of the work metal is constrained by the dies.
- ✓ By this classification there are three types of forging operations like
  - (i) Open-die forging,
  - (ii) Impression or Close die forging and
  - (iii) Flashless Forging.
- ✓ Today, forging is an important industrial process used to make a variety of high-strength components for automotive, aerospace, and other applications.
- ✓ These components include engine crankshafts and connecting rods, gears, aircraft structural components, and jet engine turbine parts.
- ✓ In addition, steel and other basic metals industries use forging to establish the basic forms of large components that are subsequently machined to final shape and dimensions.

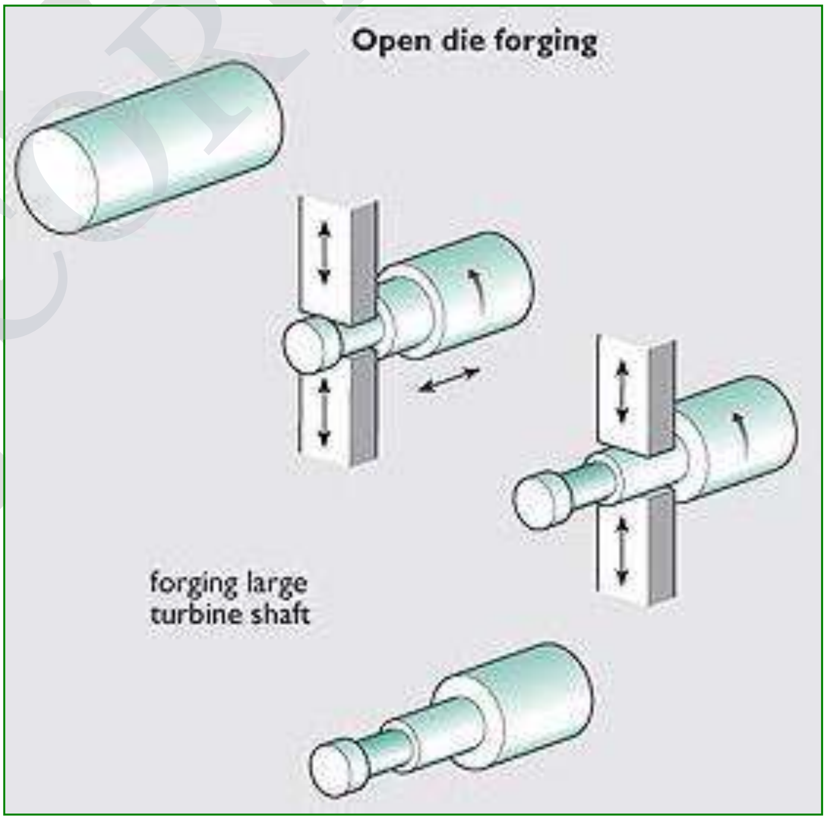
Comparison of metal grain flow in a part that is: (a) hot forged with finish machining, and (b) machined complete.



Open-Die Forging

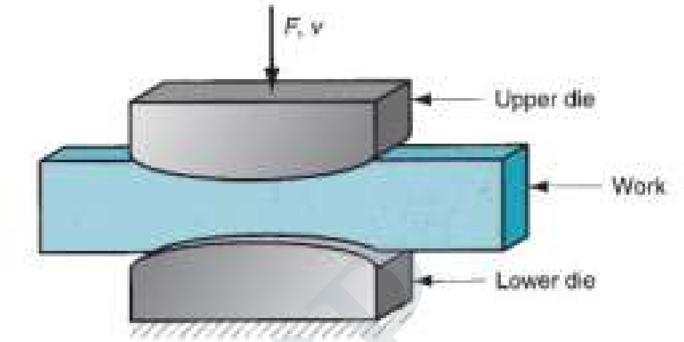


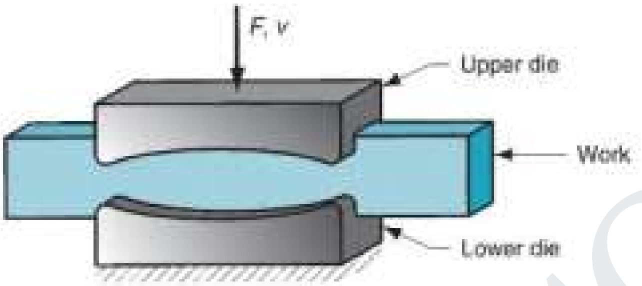
- ✓ Most forging processes begin with open die forging.
- ✓ Open die forging is hot mechanical forming between flat or shaped dies in which the metal flow is not completely restricted.
- ✓ The stock is laid on a flat anvil while the flat face of the forging hammer is struck against the stock.
- ✓ The equipment may range from the anvil and hammer to giant hydraulic presses.
- ✓ Open-die hot forging is an important industrial process.
- ✓ Shapes generated by open-die operations are simple; examples include shafts, disks, and rings.
- ✓ In some applications, the work must often be manipulated (for example, rotating in steps) to effect the desired shape change.
- ✓ The skill of the human operator is a factor in the success of these operations.
- ✓ An example of open-die forging in the steel industry is the shaping of a large, square cast ingot into a round cross section.
- ✓ Open-die forging operations produce rough forms, and subsequent operations are required to refine the parts to final geometry and dimensions.



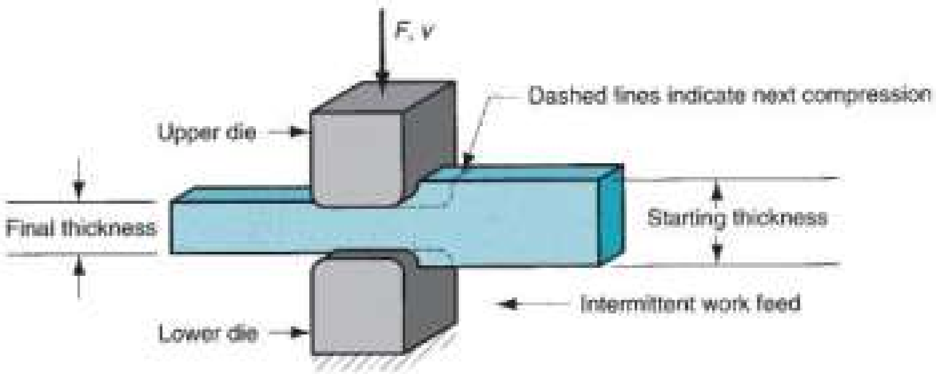
- ✓ An important contribution of open-die hot forging is that it creates favorable grain low and metallurgical structure in the metal.
- ✓ Operations classified as open-die forging or related operations include **fullering, edging, and cogging**, as shown in the next diagrams.

- ✓ **Fullering** is a forging operation performed to reduce the cross section and redistribute the metal in a workpart in preparation for subsequent shape forging.
- ✓ It is accomplished by dies with ***convex surfaces***.
- ✓ Fullering die cavities are often used designed into multicavity impression dies so that the starting bar can be rough formed before final shaping.





- ✓ **Edging** is similar to fullering, except that the dies have **concave surfaces**.
- ✓ **Cogging** operation consists of a sequence of forging compressions along the length of a workpiece to reduce cross section and increase length.
- ✓ It is used in the steel industry to produce blooms and slabs from cast ingots.
- ✓ It is accomplished using open dies with flat or slightly contoured surfaces.
- ✓ The term ***incremental forging*** is sometimes used for this process.



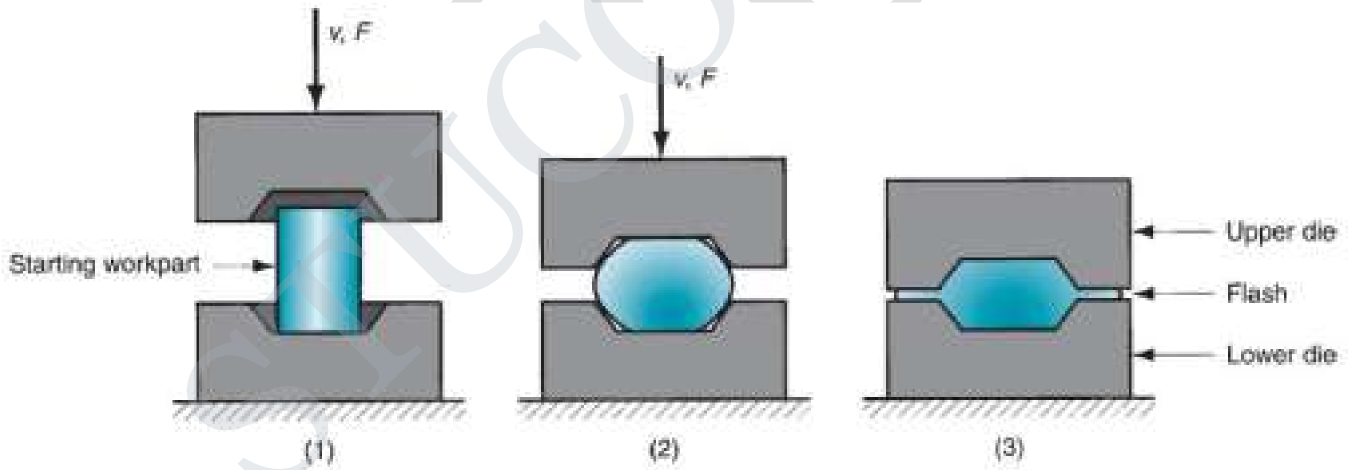
Advantages

- ✓ Simplest type of forging
- ✓ Dies are inexpensive
- ✓ Wide range of part sizes, ranging from 30-1000lbs
- ✓ Good strength qualities
- ✓ Generally good for small quantities

Limitations

- ✓ Simple shapes only
- ✓ Difficult to hold close tolerances
- ✓ Machining necessary
- ✓ Low production rate
- ✓ Poor utilization of material
- ✓ High skill required

Impression or Close Die Forging



Sequence in impression-die forging: (1) just prior to initial contact with raw workpiece, (2) partial compression, and (3) final die closure, causing flash to form in gap between die plates.

- ✓ Impression-die forging, sometimes called closed-die forging, is performed with dies that contain the inverse of the desired shape of the part.
- ✓ The raw workpiece is shown as a cylindrical part similar to that used in the previous open-die operation.
- ✓ As the die closes to its final position, flash is formed by metal that flows beyond the die cavity and into the small gap between the die plates.

- Although this flash must be cut away from the part in a subsequent trimming operation, it actually serves an important function during impression-die forging.
- As the flash begins to form in the die gap, friction resists continued flow of metal into the gap, thus constraining the bulk of the work material to remain in the die cavity.
- In hot forging, metal flow is further restricted because the thin flash cools quickly against the die plates, thereby increasing its resistance to deformation.
- Restricting metal flow in the gap causes the compression pressures on the part to increase significantly, thus forcing the material to fill the sometimes intricate details of the die cavity to ensure a high-quality product.

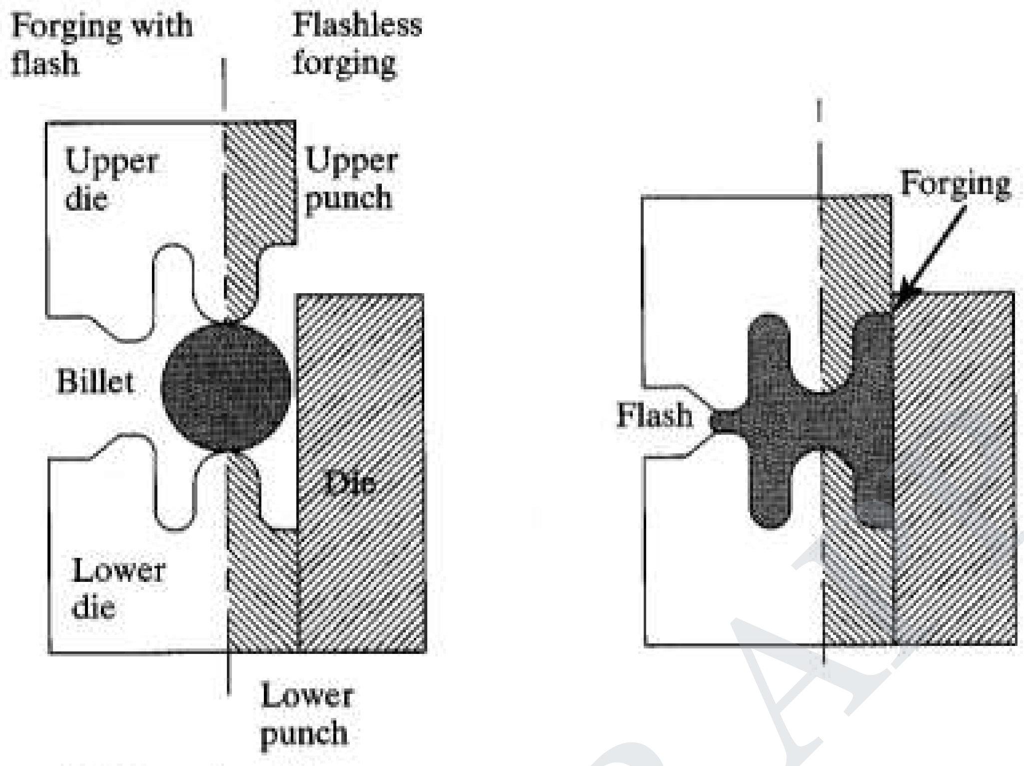
Advantages

- Good utilization of material
- Better properties than Open Die Forgings
- Dies can be made of several pieces and inserts to create more advanced parts
- Presses can go up to 50,000 ton capacities
- Good dimensional accuracy
- High production rates
- Good reproducibility

Limitations

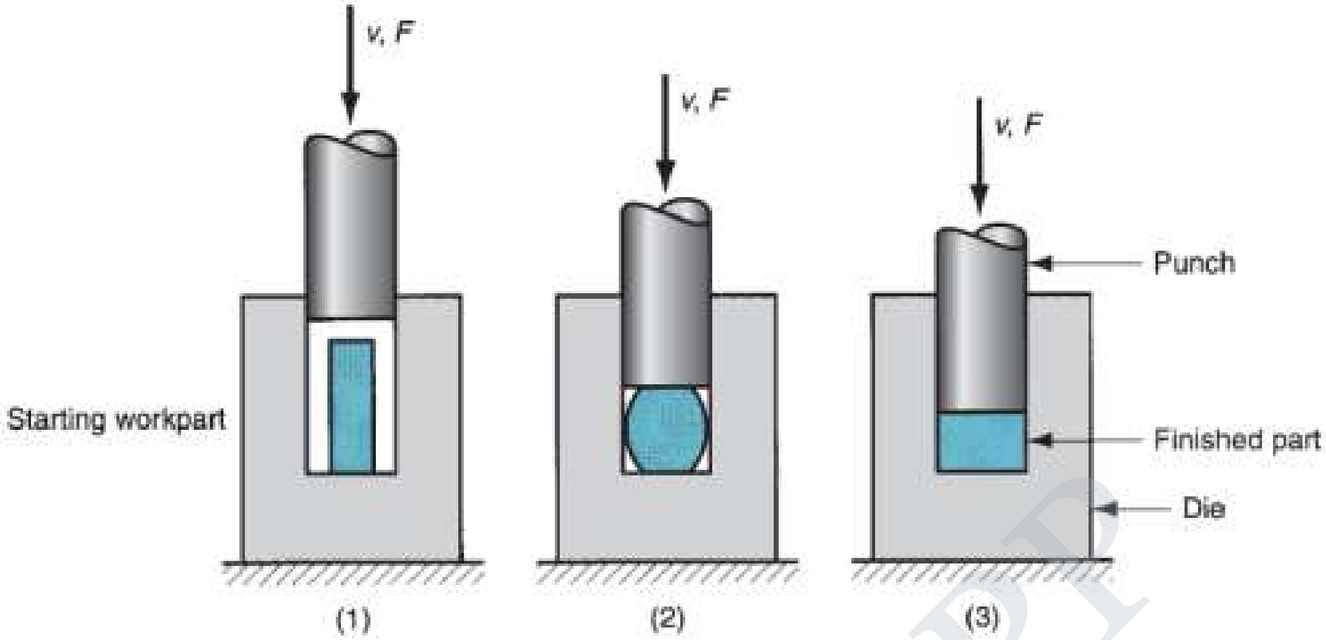
- High die cost
- Machining is often necessary
- Economical for large quantities, but not for small quantities

Flashless Forging



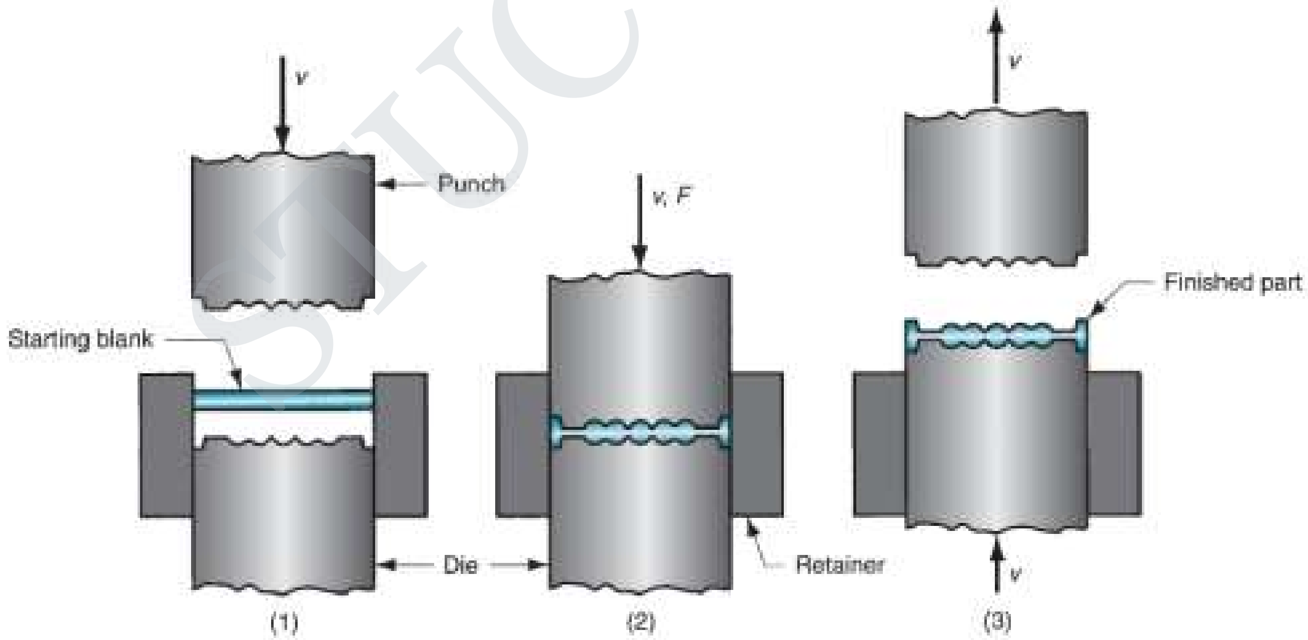
(a) Start of stroke (b) End of stroke

- ✓ Flashless forging imposes requirements on process control that are more demanding than impression-die forging.
- ✓ Most important is that the work volume must equal the space in the die cavity within a very close tolerance.
- ✓ If the starting blank is too large, excessive pressures may cause damage to the die or press. If the blank is too small, the cavity will not be filled.
- ✓ Because of the special demands made by flashless forging, the process lends itself best to part geometries that are usually simple and symmetrical, and to work materials such as aluminum and magnesiumand their alloys.
- ✓ Flashless forging is often classified as a precision forging process.
- ✓ Forces in flashless forging reach values comparable to those in impression-die forging.
- ✓ A common application of Flashless forging imposes requirements on process control that are more demanding than impression-die forging.



Flashless forging: (1) just before initial contact with work piece (2) partial compression and (3) final punch and die closure. v=velocity & F=applied force

- ✓ Coining is a special application of flashless forging in which fine details in the die are impressed into the top and bottom surfaces of the workpart.
- ✓ There is little flow of metal in coining, yet the pressures required to reproduce the surface details in the die cavity are high.



Advantages

- ✓ Close dimensional tolerances
- ✓ Very thin webs and flanges are possible

- ✓ Very little or no machining is required
- ✓ Little or no scrap after part is produced
- ✓ Cheaper to produce from less finishing operations and faster production
- ✓ Typical applications are gears, connecting rods, and turbine blades
- ✓ Common materials used in precision forging are aluminum, magnesium alloys, steel, and titanium

Limitations

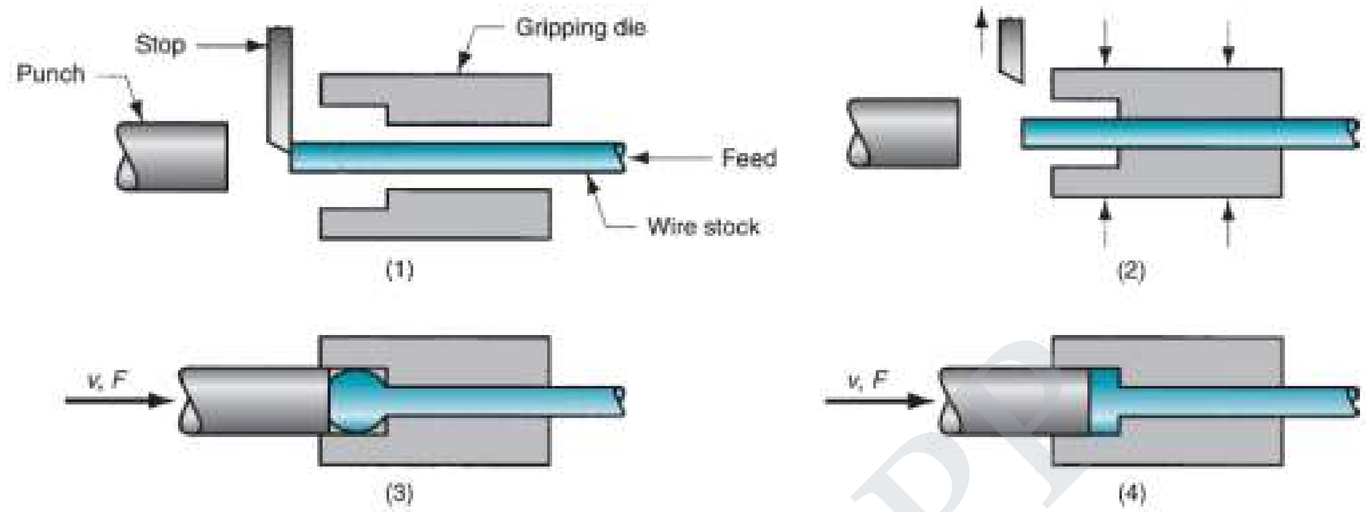
- ✓ High forging forces
- ✓ Thus higher capacity equipment is required
- ✓ Intricate dies leading to increased die cost
- ✓ Precise control over the Blank's volume and shape
- ✓ Accurate positioning of the Blank in the die cavity

OTHER DEFORMATION PROCESSES RELATED TO FORGING

Upsetting and Heading

- ✓ Upsetting (also called upset forging) is a deformation operation in which a cylindrical workpart is increased in diameter and reduced in length.
- ✓ Upsetting is widely used in the fastener industry to form heads on nails, bolts, and similar hardware products.
- ✓ In these applications, the term heading is often used to denote the operation.
- ✓ More parts are produced by upsetting than by any other forging operation.
- ✓ It is performed as a mass-production operation—cold, warm, or hot—on special upset forging machines, called headers or formers.
- ✓ These machines are usually equipped with horizontal slides, rather than vertical slides as in conventional forging hammers and presses.

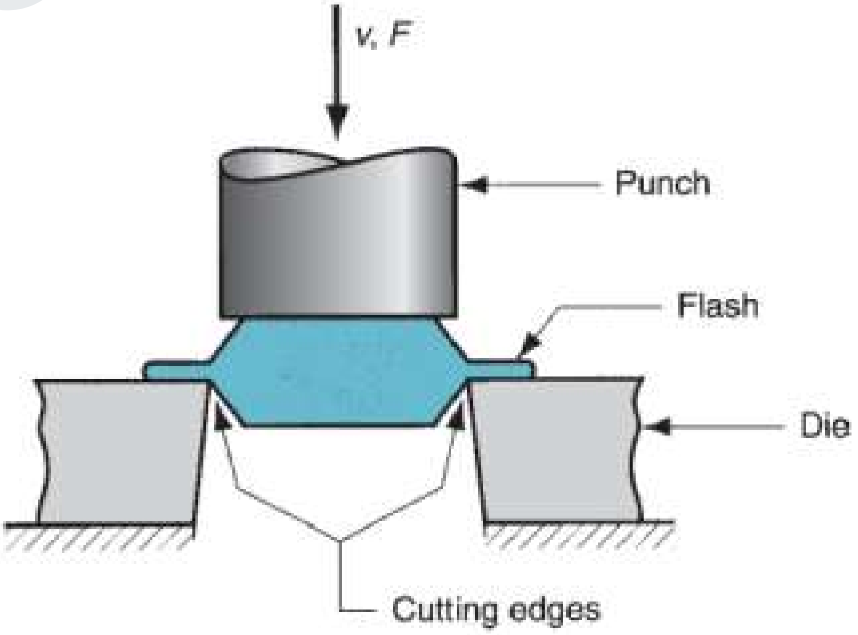
- ✓ Long wire or bar stock is fed into the machines, the end of the stock is upset forged, and then the piece is cut to length to make the desired hardware item.



An upset forging operation to form a head on a bolt or similar hardware item. The cycle is as follows: (1) wire stock is fed to the stop; (2) gripping dies close on the stock and the stop is retracted; (3) punch moves forward; and (4) bottoms to form the head.

Trimming

- ✓ Trimming is an operation used to remove flash on the workpart in impression-die forging.
- ✓ In most cases, trimming is accomplished by shearing, in which a punch forces the work through a cutting die, the blades for which have the profile of the desired part.
- ✓ Trimming is usually done while the work is still hot, which means that a separate trimming press is included at each forging hammer or press.

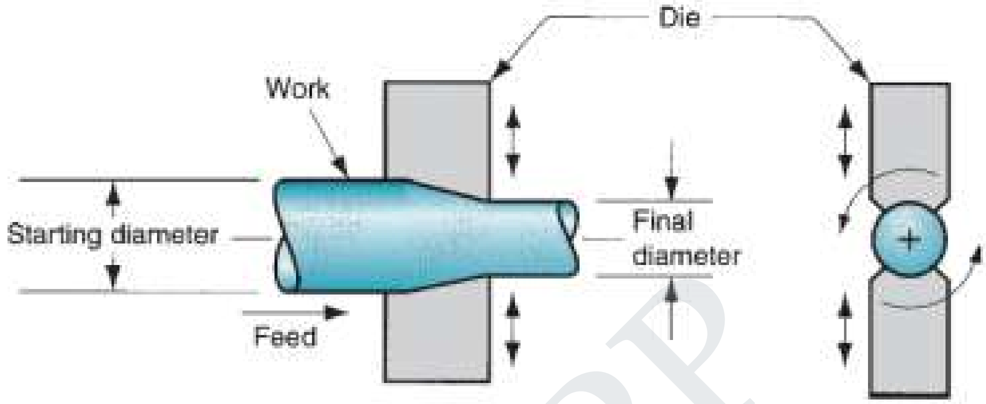


- ✓ In cases where the work might be damaged by the cutting process, trimming may be done by alternative methods, such as grinding or sawing.

Swaging and Radial Forging

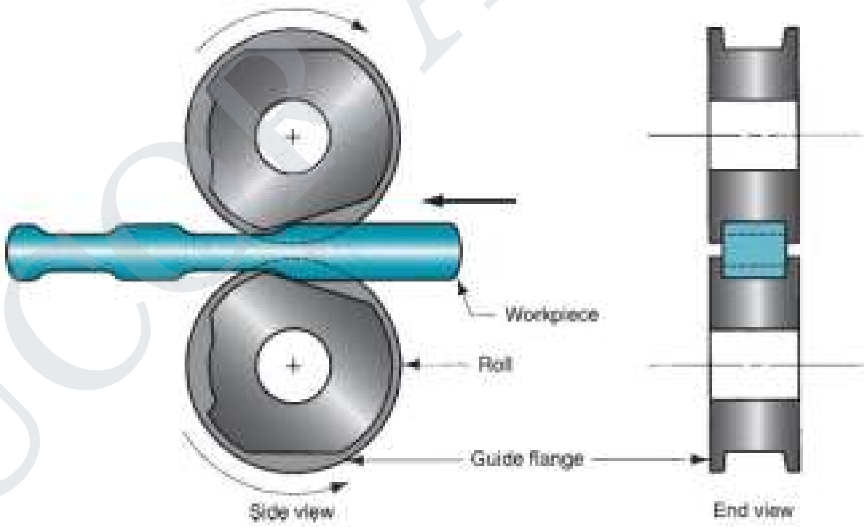
✓ Swaging and radial forging are forging processes used to reduce the diameter of a tube or solid rod.

Swaging process to reduce solid rod stock; the dies rotate as they hammer the work. In radial forging, the workpiece rotates while the dies remain in a fixed orientation as they hammer the work.



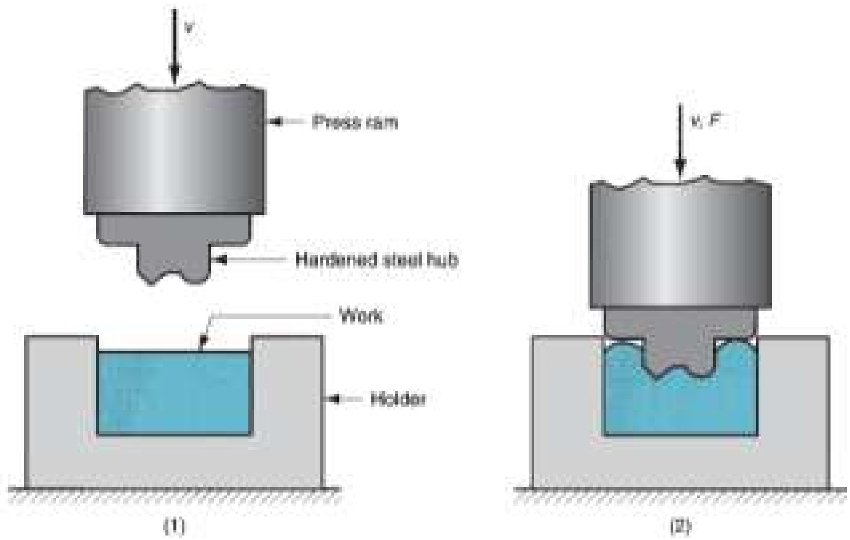
Roll Forging

✓ Roll forging is a deformation process used to reduce the cross section of a cylindrical (or rectangular) workpiece by passing it through a set of opposing rolls that have grooves matching the desired shape of the final part.



Hubbing

✓ Hubbing is a deformation process in which a hardened steel form is pressed into a soft steel (or other soft metal) block.



Isothermal Forging

- ✓ Isothermal forging is a term applied to a hot-forging operation in which the workpart is maintained at or near its starting elevated temperature during deformation, usually by heating the forging dies to the same elevated temperature.
- ✓ By avoiding chill of the workpiece on contact with the cold die surfaces as in conventional forging, the metal flows more readily and the force required to perform the process is reduced.
- ✓ Isothermal forging is more expensive than conventional forging and is usually reserved for difficult-to-forge metals, such as titanium and superalloys, and for complex part shapes.
- ✓ The process is sometimes carried out in a vacuum to avoid rapid oxidation of the die material.
- ✓ Similar to isothermal forging is hot-die forging, in which the dies are heated to a temperature that is somewhat below that of the work metal.

Orbital Forging

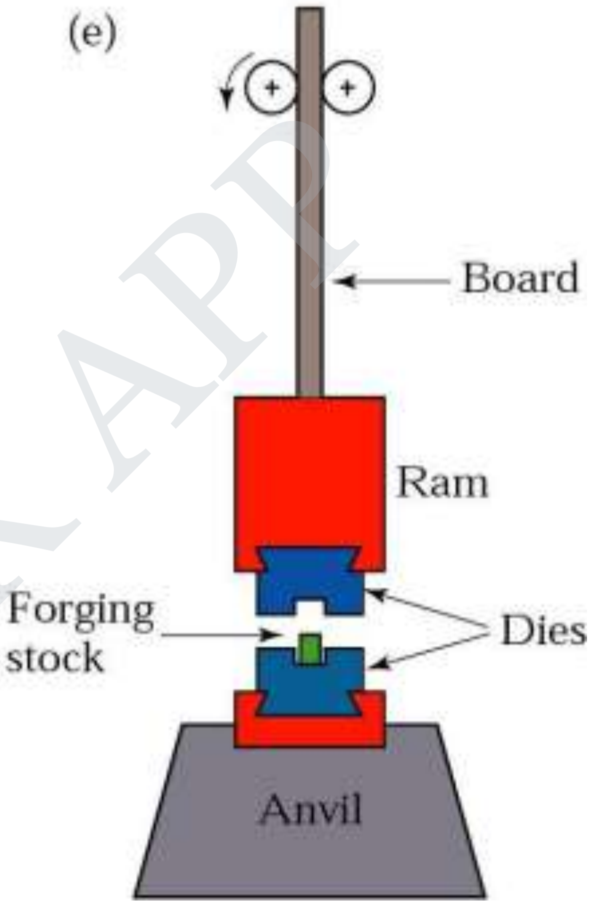
FORGING HAMMERS, PRESSES, AND DIES

- ✓ Equipment used in forging consists of forging machines, classified as forging hammers and presses, and forging dies, which are the special tooling used in these machines.
- ✓ In addition, auxiliary equipment is needed, such as furnaces to heat the work, mechanical devices to load and unload the work, and trimming stations to cut away the flash in impression-die forging.

Forging Hammers:

- ✓ Forging hammers operate by applying an impact load against the work. The term drop hammer is often used for these machines, owing to the means of delivering impact energy.
- ✓ Drop hammers are most frequently used or impression-die forging.

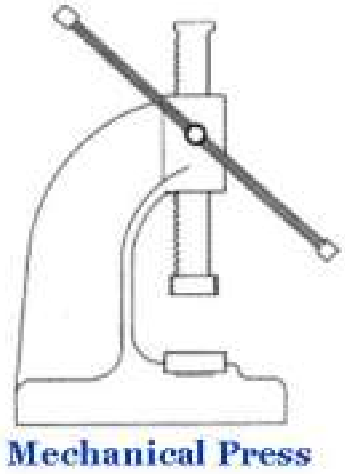
- The upper portion of the forging die is attached to the ram, and the lower portion to the anvil.
- In the operation, the work is placed on the lower die, and the ram is lifted and then dropped. When the upper die strikes the work, the impact energy causes the part to assume the form of the die cavity.
- Drop hammers can be classified as **gravity drop hammers** and **power drop hammers**.
- **Gravity drop hammers** achieve their energy by the falling weight of a heavy ram. The force of the blow is determined by the height of the drop and the weight of the ram.
- **Power drop hammers** accelerate the ram by pressurized air or steam. One disadvantage of the drop hammers is that a large amount of the impact energy is transmitted through the anvil and into the floor of the building.
- This results in a great deal of vibration for the surrounding area.

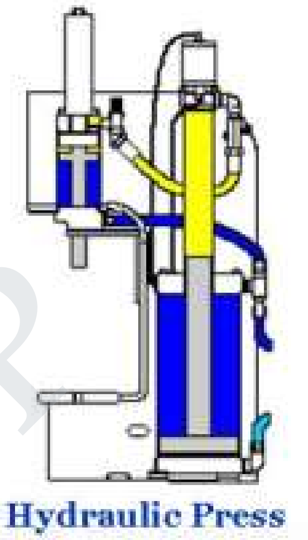


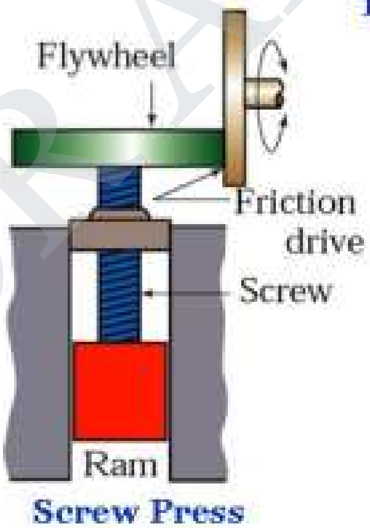
Forging Presses:

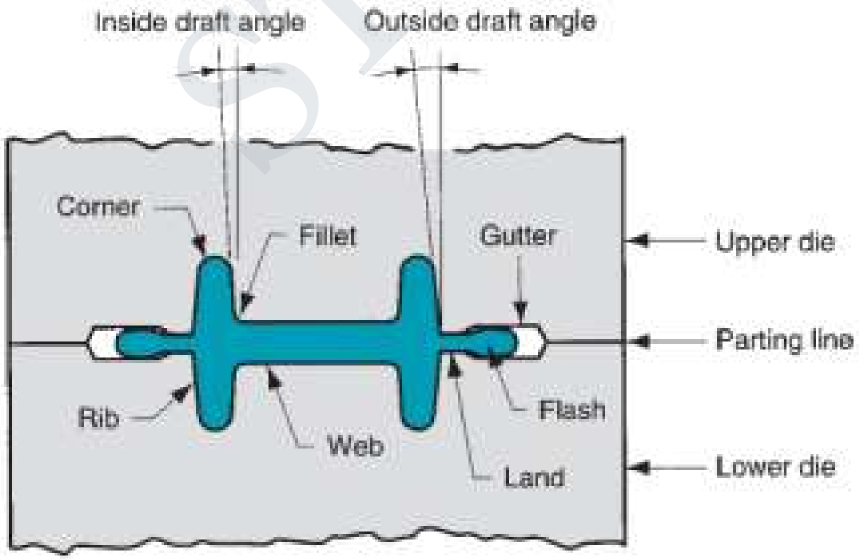
- Presses apply gradual pressure, rather than sudden impact, to accomplish the forging operation.
- Forging presses include **mechanical presses, hydraulic presses, and screw presses.**
- **Mechanical presses** typically operate by means of eccentrics, cranks, or knuckle joints, which convert the rotating motion of a drive motor into the translational motion of the ram.

- These mechanisms are very similar to those used in stamping presses. Mechanical presses typically achieve very high forces at the bottom of the forging stroke.
- **Hydraulic presses** use a hydraulically driven piston to actuate the ram.
- **Screw presses** apply force by a screw mechanism that drives the vertical ram. Both screw drive and hydraulic drive operate at relatively low ram speeds and can provide a constant force throughout the stroke. These machines are therefore suitable for forging (and other forming) operations that require a long stroke.









Dies

ROLLING

Rolling is a compressive deformation process in which the thickness of a slab or plate is reduced by two opposing cylindrical tools called rolls. The rolls rotate so as to draw the work into the gap between them and squeeze it.

- ✓ Rolling is generally the first process that is used to convert material into a finished wrought product.
- ✓ Large size starting stock (called ingot) is rolled into blooms, billets, or slabs.
- ✓ Slabs can be further rolled to produce plate, sheet, and strip. These hot-rolled products are mostly the starting material for subsequent processing such as cold forming, machining, or welding.

Bloom: A bloom has a square or rectangular cross-section, with a thickness equal to or greater than 150 mm and width ranging between 150 mm to 300 mm.

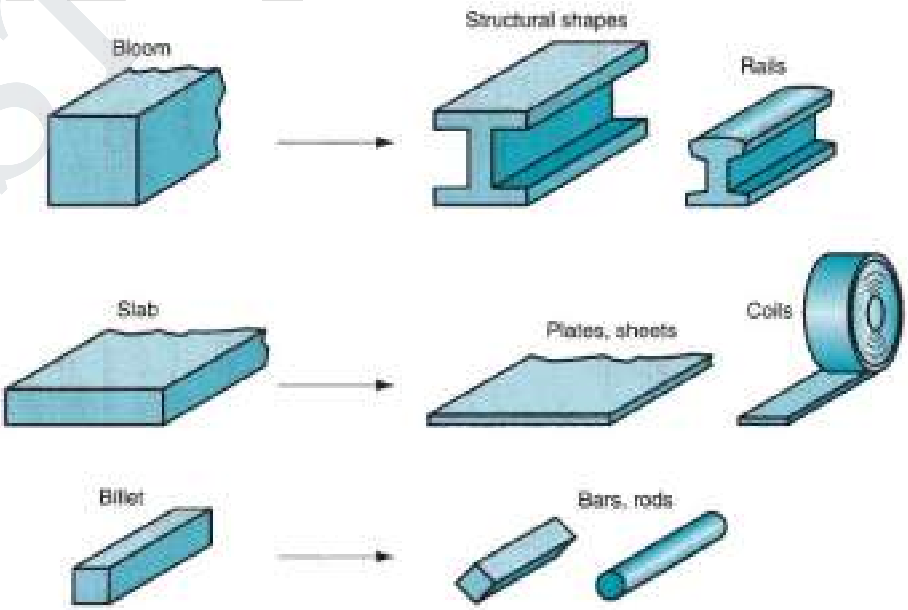
Billet: A billet is smaller than a bloom and has a square cross-section of 40 mm x 40 mm or more but less than bloom size.

Slab: A slab has a rectangular cross-section with the width greater than thrice the thickness. Generally, it is of 250 mm width x 40 mm thickness but can also be larger.

Plate: A plate is solid of rectangular cross-section having a thickness greater than 6 mm but less than 40 mm.

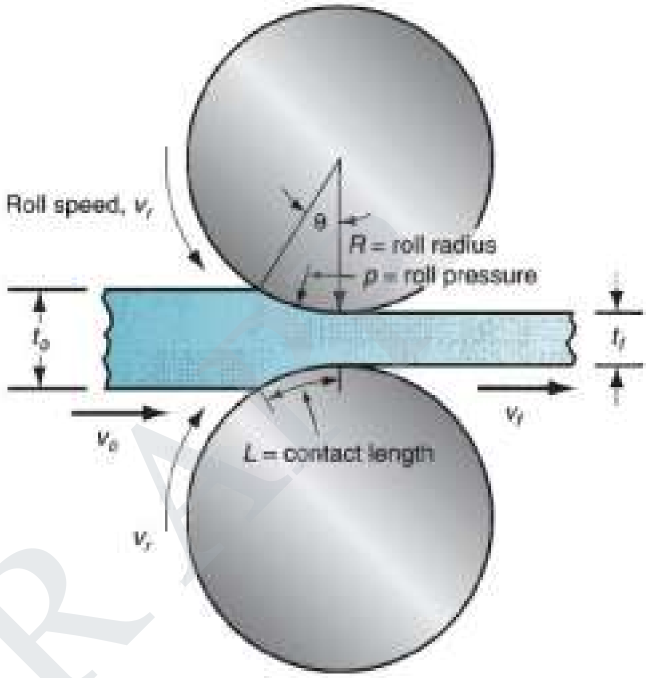
Sheet: A sheet is generally less than 6 mm thick.

Foil: A foil is a thin sheet (less than 0.01 mm thick).

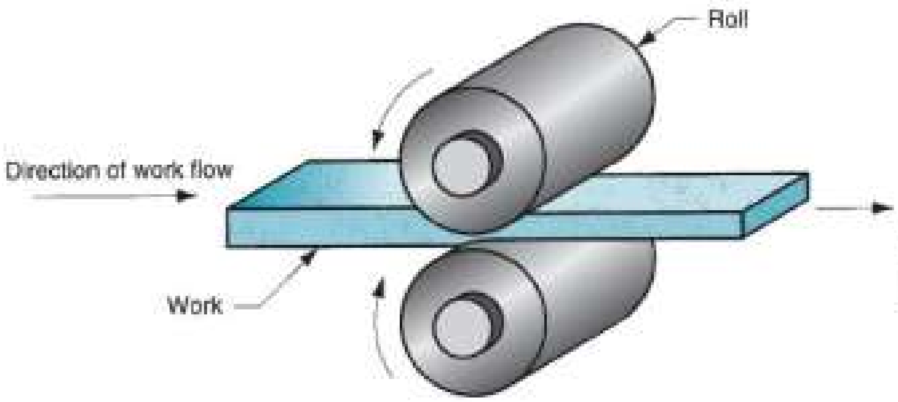


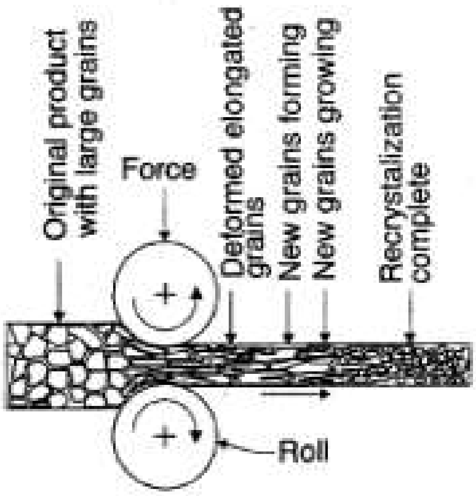
Some of the steel products made in a rolling mill

- ✓ Basically, it is a process of reducing the thickness of a long workpiece by compressive forces applied through a set of rolls.
- ✓ *Rolling is a deformation process in which the thickness of the work is reduced by compressive forces exerted by two opposing rolls.*
- ✓ The rolls rotate to pull and simultaneously squeeze the work between them. The basic process is flat rolling, used to reduce the thickness of a rectangular cross section.



- ✓ A closely related process is shape rolling, in which a square cross section is formed into a shape such as an I-beam.
- ✓ Most rolling processes are very capital intensive, requiring massive pieces of equipment, called rolling mills, to perform them. The high investment cost requires the mills to be used for production in large quantities of standard items such as sheets and plates.
- ✓ Most rolling is carried out by hot working, called hot rolling, owing to the large amount of deformation required.
- ✓ Hot-rolled metal is generally free of residual stresses, and its properties are isotropic.





Mechanics of Rolling

- ✓ *Disadvantages* of hot rolling are that the product cannot be held to close tolerances, and the surface has a characteristic oxide scale.
- ✓ Steelmaking provides the most common application of rolling mill operations.

The sequence of steps in a steel rolling mill to illustrate the variety of products made.

- ✓ The work starts out as a cast steel ingot that has just solidified.
- ✓ While it is still hot, the ingot is placed in a furnace where it remains for many hours until it has reached a uniform temperature throughout, so that the metal will flow consistently during rolling.
- ✓ For steel, the desired temperature for rolling is around 1200°C (2200°F).
- ✓ The heating operation is called soaking, and the furnaces in which it is carried out are called soaking pits.
- ✓ From soaking, the ingot is moved to the rolling mill, where it is rolled into one of three intermediate shapes called blooms, billets, or slabs.
- ✓ These intermediate shapes are subsequently rolled into final product shapes.
- ✓ Blooms are rolled into structural shapes and rails for railroad tracks.
- ✓ Billets are rolled into bars and rods. These shapes are the raw materials form a chining, wire drawing, forging, and other metalworking processes.
- ✓ Slabs are rolled into plates, sheets, and strips. Hot-rolled plates are used in shipbuilding, bridges, boilers, welded structures for various heavy machines, tubes and pipes, and many other products.
- ✓ Further flattening of hot-rolled plates and sheets is often accomplished by cold rolling, in order to prepare them for subsequent sheet metal operations.

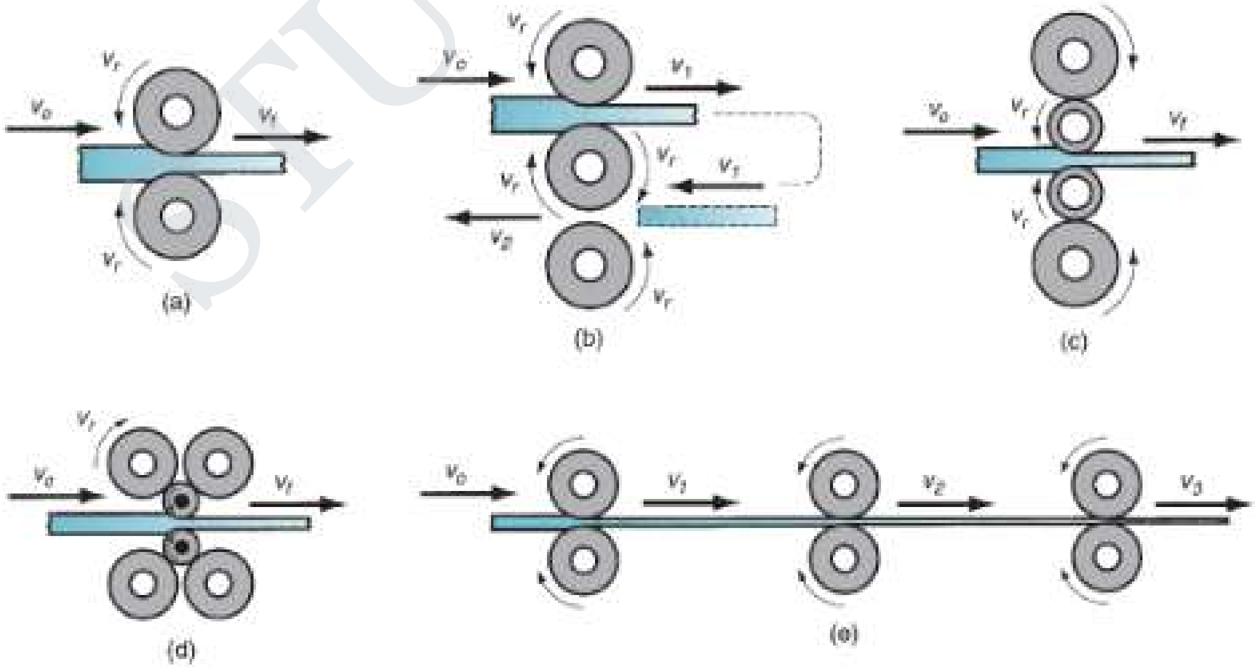
- ✓ Cold rolling strengthens the metal and permits a tighter tolerance on thickness.
- ✓ In addition, the surface of the cold-rolled sheet is absent of scale and generally superior to the corresponding hot-rolled product. These characteristics make cold-rolled sheets, strips, and coils ideal for stampings, exterior panels, and other parts of products ranging from automobiles to appliances and office furniture.

ROLLING MILLS

Various rolling mill configurations are available to deal with the variety of applications and technical problems in the rolling process.

Two-High Rolling Mill

- ✓ The basic rolling mill consists of two opposing rolls and is referred to as a two-high rolling mill.
- ✓ The rolls in these mills have diameters in the range of 0.6 to 1.4 m.
- ✓ The two-high configuration can be either reversing or non-reversing.
- ✓ In the non-reversing mill, the rolls always rotate in the same direction, and the work always passes through from the same side.
- ✓ The reversing mill allows the direction of roll rotation to be reversed, so that the work can be passed through in either direction.
- ✓ This permits a series of reductions to be made through the same set of rolls, simply by passing through the work from opposite directions multiple times.
- ✓ The disadvantage of the reversing configuration is the significant angular momentum possessed by large rotating rolls and the associated technical problems involved in reversing the direction.



Various configurations of rolling mills: (a) 2-high, (b) 3-high, (c) 4-high, (d) cluster mill, and (e) tandem rolling mill.

Three-High Rolling Mill

- ✓ In the three-high configuration, there are three rolls in a vertical column, and the direction of rotation of each roll remains unchanged.
- ✓ To achieve a series of reductions, the work can be passed through from either side by raising or lowering the strip after each pass.
- ✓ The equipment in a three-high rolling mill becomes more complicated, because an elevator mechanism is needed to raise and lower the work.
- ✓ As several of the previous equations indicate, advantages are gained in reducing roll diameter.
- ✓ Roll-work contact length is reduced with a lower roll radius, and this leads to lower forces, torque, and power.

Four-High Rolling Mill

- ✓ The four-high rolling mill uses two smaller-diameter rolls to contact the work and two backing rolls behind them.
- ✓ Owing to the high roll forces, these smaller rolls would deflect elastically between their end bearings as the work passes through unless the larger backing rolls were used to support them.

Cluster Rolling Mill

- ✓ Another roll configuration that allows smaller working rolls against the work is the cluster rolling mill.

Tandem Rolling Mill

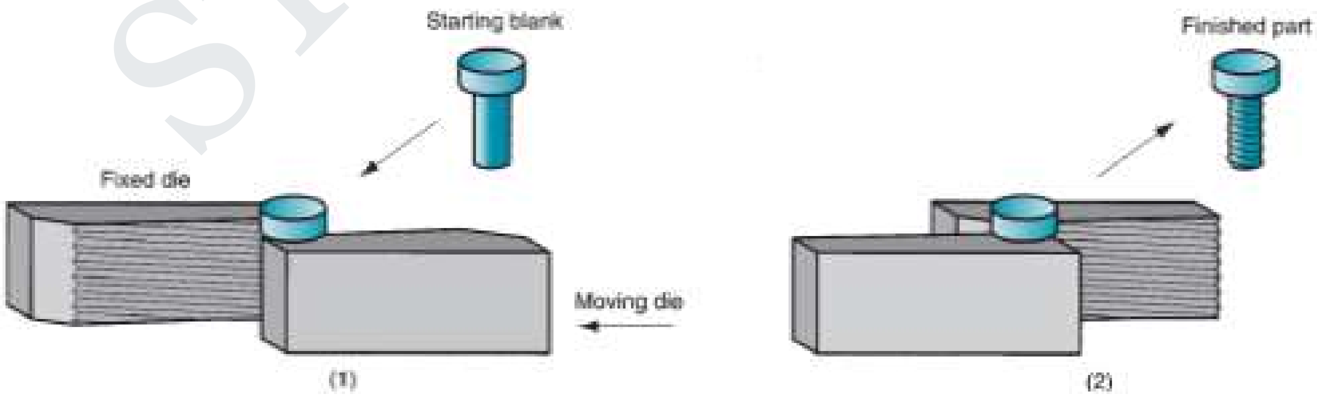
- ✓ To achieve higher throughput rates in standard products, a tandem rolling mill is often used. This configuration consists of a series of rolling stands, as represented.
- ✓ Although only three stands are shown in sketch, a typical tandem rolling mill may have *eight or ten stands*, each making a reduction in thickness or a refinement in shape of the work passing through.
- ✓ With each rolling step, work velocity increases, and the problem of synchronizing the roll speeds at each stand is a significant one.

- ✓ Modern tandem rolling mills are often supplied directly by continuous casting operations.
- ✓ These setups achieve a high degree of integration among the processes required to transform starting raw materials into finished products.
- ✓ Advantages include elimination of soaking pits, reduction in floor space, and shorter manufacturing lead times.
- ✓ These technical advantages translate into economic benefits for a mill that can accomplish continuous casting and rolling.

OTHER DEFORMATION PROCESSES RELATED TO ROLLING

Thread Rolling

- ✓ Thread rolling is used to form threads on cylindrical parts by rolling them between two dies.
- ✓ It is the most important commercial process for mass producing external threaded components (e.g., bolts and screws).
- ✓ Most thread rolling operations are performed by cold working in thread rolling machines. These machines are equipped with special dies that determine the size and form of the thread.
- ✓ The dies are of two types: (1) flat dies, which reciprocate relative to each other, and (2) round dies, which rotate relative to each other to accomplish the rolling action.

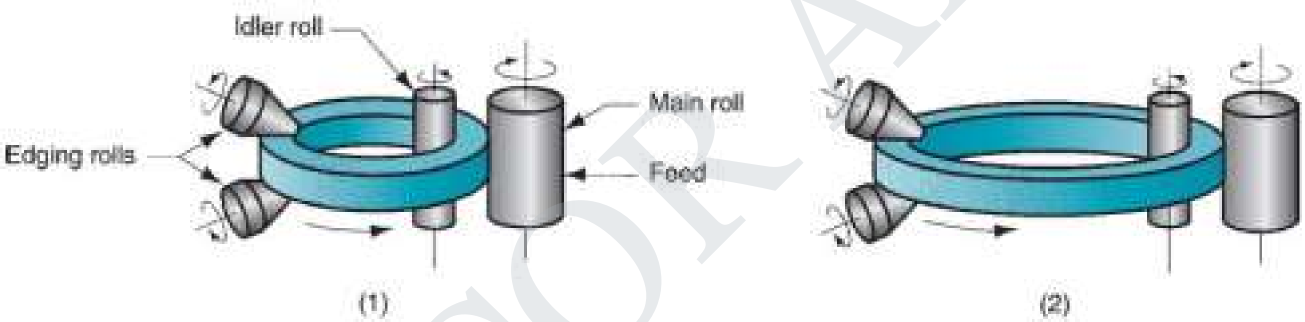


- ✓ Production rates in thread rolling can be high, ranging up to eight parts per second for small bolts and screws.

- ✓ Not only are these rates significantly higher than thread cutting, but there are other advantages over machining as well: (1) better material utilization, (2) stronger threads due to work hardening, (3) smoother surface, and (4) better fatigue resistance due to compressive stresses introduced by rolling.

Ring Rolling

- ✓ Ring rolling is a deformation process in which a thick-walled ring of smaller diameter is rolled into a thin-walled ring of larger diameter.
- ✓ As the thick-walled ring is compressed, the deformed material elongates, causing the diameter of the ring to be enlarged.
- ✓ Ring rolling is usually performed as a hot-working process for large rings and as a cold-working process for smaller rings.



- ✓ Applications of ring rolling include ball and roller bearing races, steel tires for railroad wheels, and rings for pipes, pressure vessels, and rotating machinery.
- ✓ The ring walls are not limited to rectangular cross sections; the process permits rolling of more complex shapes.
- ✓ There are several advantages of ring rolling over alternative methods of making the same parts: raw material savings, ideal grain orientation for the application, and strengthening through cold working.

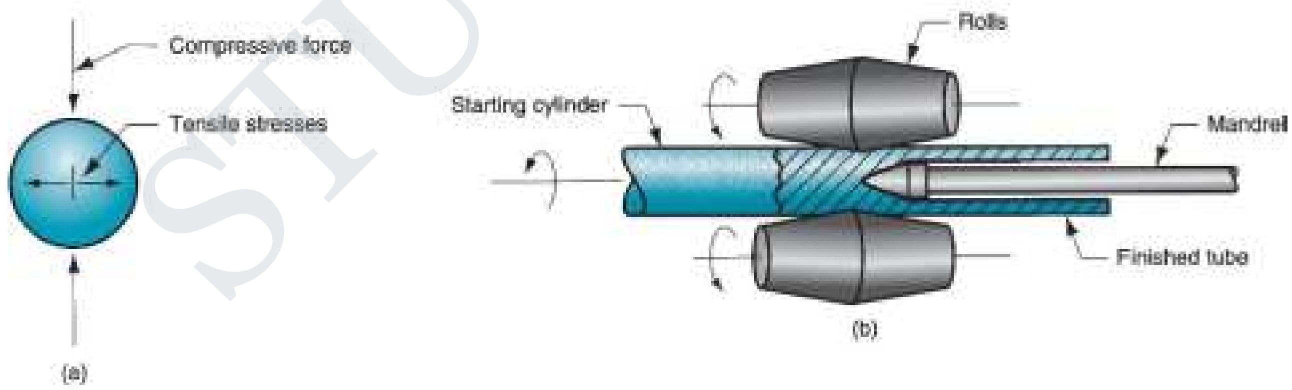
Gear Rolling

- ✓ Gear rolling is a cold working process to produce certain gears.
- ✓ The automotive industry is an important user of these products.
- ✓ The setup in gear rolling is similar to thread rolling, except that the deformed features of the cylindrical blank or disk are oriented parallel to its axis (or at an angle in the case of helical gears) rather than spiraled as in thread rolling.

- ✓ Advantages of gear rolling compared to machining are similar to those of thread rolling: higher production rates, better strength and fatigue resistance, and less material waste.

Roll Piercing

- ✓ Ring rolling is a specialized hot working process for making seamless thick-walled tubes.
- ✓ It utilizes two opposing rolls, and hence it is grouped with the rolling processes.
- ✓ The process is based on the principle that when a solid cylindrical part is compressed on its circumference, high tensile stresses are developed at its center.
- ✓ If compression is high enough, an internal crack is formed.
- ✓ In roll piercing, this principle is exploited by the setup shown. Compressive stresses on a solid cylindrical billet are applied by two rolls, whose axes are oriented at slight angles (˜6°) from the axis of the billet, so that their rotation tends to pull the billet through the rolls.
- ✓ A mandrel is used to control the size and finish of the hole created by the action. The terms rotary tube piercing and Mannesmann process are also used for this tube-making operation.



Roll piercing: (a) formation of internal stresses and cavity by compression of cylindrical part; and (b) setup of Mannesmann roll mill for producing seamless tubing.

Defects in Rolled Plates and Sheets

Surface Defects:

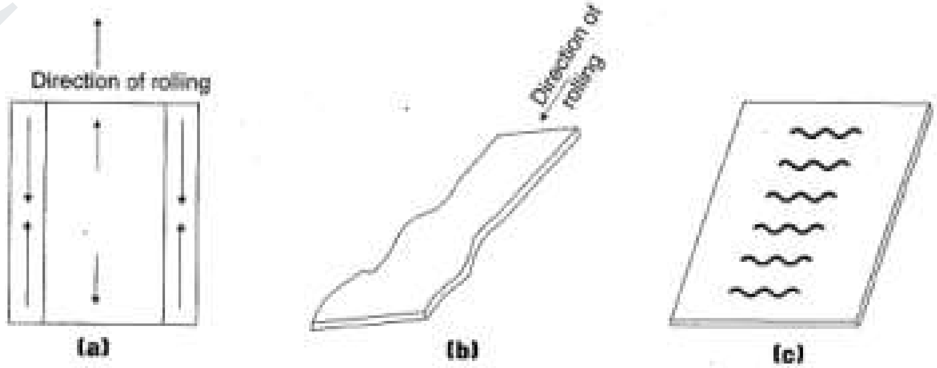
- ✓ The surface of rolled sheets may show defects such as scale, rust, scratches, cracks, pits, and gouges occurring due to the presence of impurities and inclusions of foreign material in the original cast material.
- ✓ Other possible causes responsible for such defects are improper conditions during material preparation or during rolling operation.

Structural defects:

- ✓ The defects in this category are wavy edges, zipper cracks, edge cracks, alligatoring, folds, and laminations. These defects can be further classified into:

i. Defects due to bending of rolls:

- ✓ Rolls act as straight beams loaded transversely (with rolling loads) and undergo deflection. As a result, the edges of the strip get compressed more than the central portion, i.e., edges become thinner than the central portion.
- ✓ Since the reduction in thickness is converted into increase in length of the strip, the strip elongates more at the edges than at the centre.
- ✓ However, as the material is continuous, there is adjustment of strains within the material.
- ✓ On the edges, the material experiences compressive strains while at the centre the material experiences tensile strains.
- ✓ Since the edges are restrained from expanding freely in the longitudinal (rolling) direction, wavy edges are formed on the sheet.
- ✓ Zipper cracks that occur in the central portion of strip are caused due to differential strain and the poor ductility of material at room temperature.

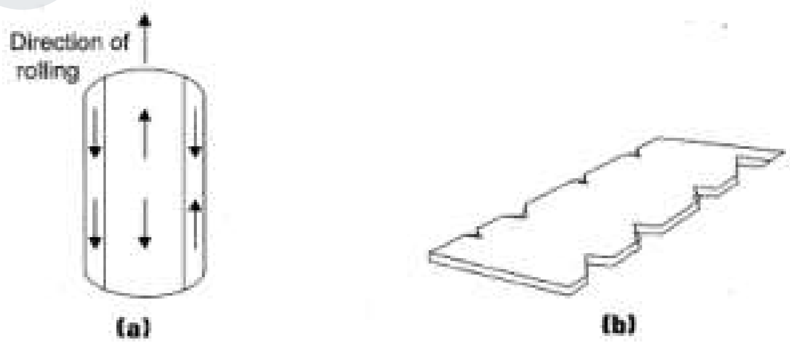


Schematic illustration of typical defects in flat rolled work material
(a) Type of strain in different regions of rolled metal; (b) Wavy edges; and (c) Zipper cracks in the central region of the strip

- ✓ The above two defects can be controlled to some extent by providing camber to the rolls.
- ✓ i.e., the diameter of rolls is slightly increased at the centre with respect to that at the ends. Under load conditions, the rolls will provide a straight uniform gap to the strip.

ii. Defects due to inhomogeneous deformation:

- ✓ Edge cracks are formed mainly due to this cause. As the material is compressed under the rolls, there is a proportionate decrease in thickness with simultaneous increase in its length and width (lateral spread).
- ✓ The decrease in thickness for the elements near the centre will be mainly converted into increase in length while for the elements at the edges, a part of the decrease in thickness is converted into increase in length and the remaining decrease in thickness is converted into lateral spread.
- ✓ Consequently, the increase in length at the centre will be greater than that at the edges making the ends of sheet rounded.
- ✓ Due to continuity of material elements, the material near the edges will be under tension while that around the centre will be under compression.
- ✓ This can lead to the formation of edge cracks, or under severe conditions, there can be centre-split of sheet.
- ✓ Another common defect which is caused due to non-uniform deformation of material during rolling is called *Alligatoring.*
- ✓ The rolled sheet appears ruptured at the central plane.



Typical defects in flat rolled work material caused due to inhomogeneous deformation (a) Length of central region greater than at the edges; and (b) Cracks or material rupture at edges due to severe tension in material in that zone

- ✓ Alligatoring is actually a complex phenomenon for which a number of factors are responsible.
- ✓ Most of the defects of rolled sheets degrade the quality of edges. In actual practice, these defects are removed from the sheets by slitting the edges.

Extrusion Process

- ✓ Extrusion is a compression process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape.
- ✓ Materials that can be extrudes are aluminum, copper, steel, magnesium, and plastics. Aluminum, copper and plastics are most suitable for extrusion.
- ✓ *The process is similar to squeezing toothpaste from its plastic tube.*

Advantages:

(1) A variety of shapes are possible, especially with hot extrusion

(2) Grain structure and strength properties are enhanced in cold and warm extrusion

(3) Fairly close tolerances are possible, especially in cold extrusion

(4) In some extrusion operations, little or no wasted material is created.

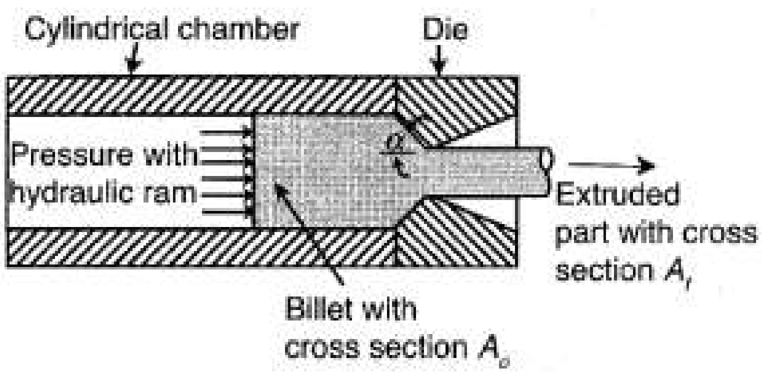
Limitations:

- ✓ The cross section of the extruded part must be uniform throughout its length.
- ✓ The force required is high, even when they are hot extruded.
- ✓ The tooling cost and setup is expensive for the extrusion process, but the actual manufactured part cost is less expensive when produced in significant quantities.

Classification of the Extrusion Process

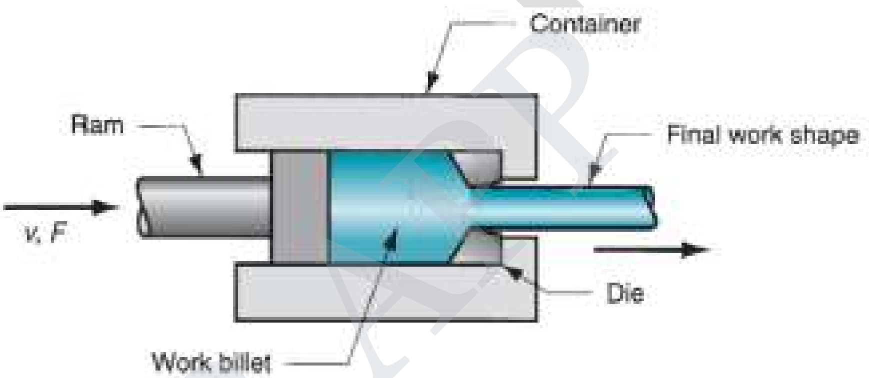
Depending on the ductility of the material used extrusions can be carried out various ways.

- ✓ By working temperature
  - Cold extrusion
  - Warm extrusion
  - Hot extrusion
- ✓ By performance technique
  - Continuous extrusion
  - Discrete extrusion
- ✓ By physical configuration
  - Forward or Direct extrusion
  - Backward or Indirect extrusion

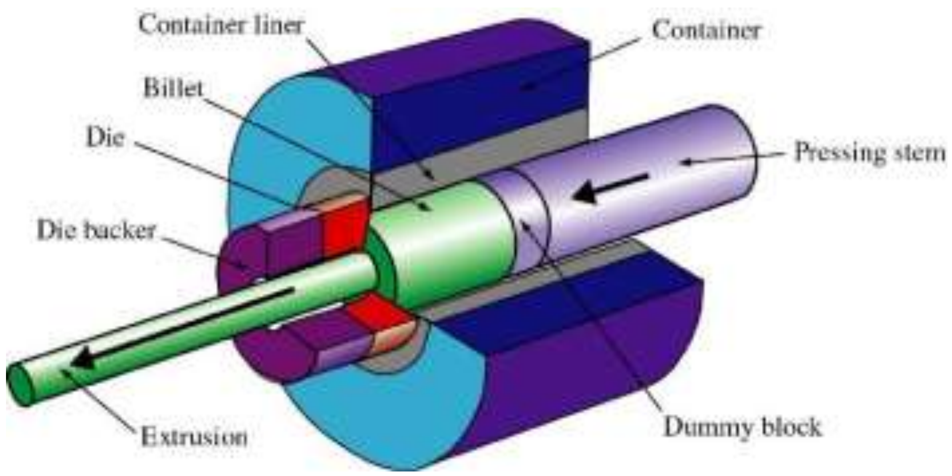


Direct Extrusion (Forward Extrusion):

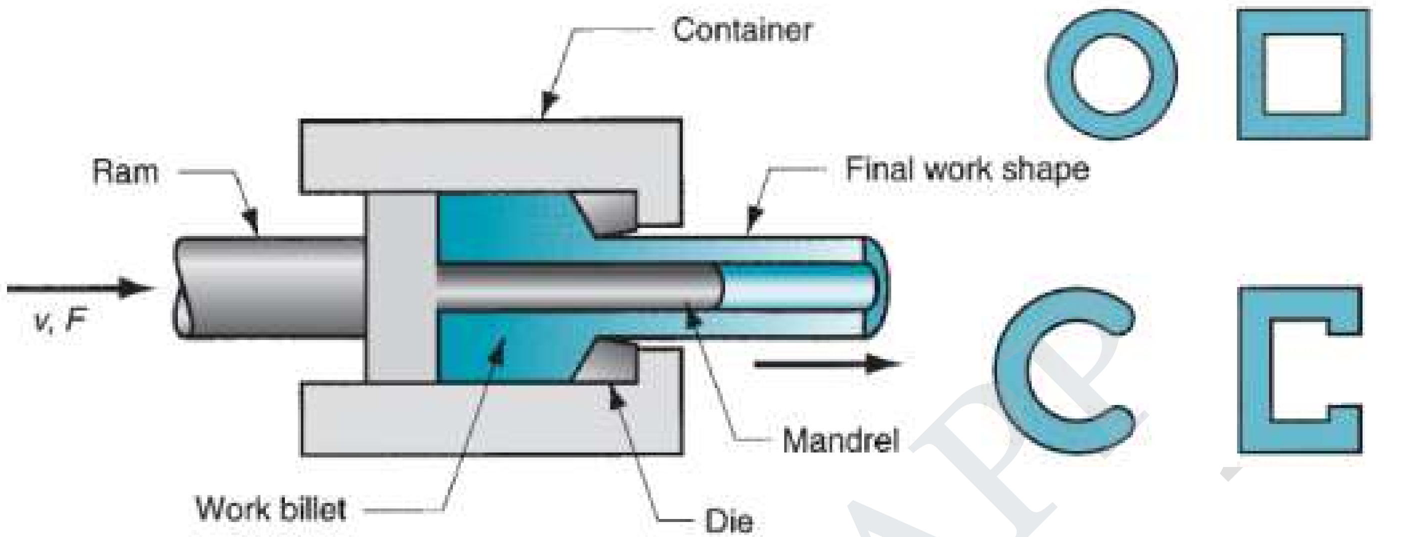
- ✓ The heated metal billet is loaded into a container.
- ✓ A ram compresses the material, forcing it to flow through the openings in a die at the opposite end of the container.
- ✓ The metal is subjected to plastic deformation, slides along the walls of the container and is forced to flow through the die opening.
- ✓ As the ram approaches the die, a small portion of the billet remains that cannot be forced through the die opening.
- ✓ This extra portion, called the butt, is separated from the product by cutting it just beyond the exit of the die.



- ✓ One of the problems in direct extrusion is the significant friction that exists between the work surface and the walls of the container as the billet is forced to slide toward the die opening.
- ✓ This friction causes a substantial increase in the ram force required in direct extrusion.
- ✓ In hot extrusion, the friction problem is aggravated by the presence of an oxide layer on the surface of the billet.
- ✓ This oxide layer can cause defects in the extruded product.
- ✓ To address these problems, a dummy block is often used between the ram and the work billet.
- ✓ The diameter of the dummy block is slightly smaller than the billet diameter.
- ✓ As a result, a thin cylindrical shell (skull), consisting mainly of the oxidized layer, is left in the container.
- ✓ The extruded product is thus free of oxides; the skull is later removed from the chamber.



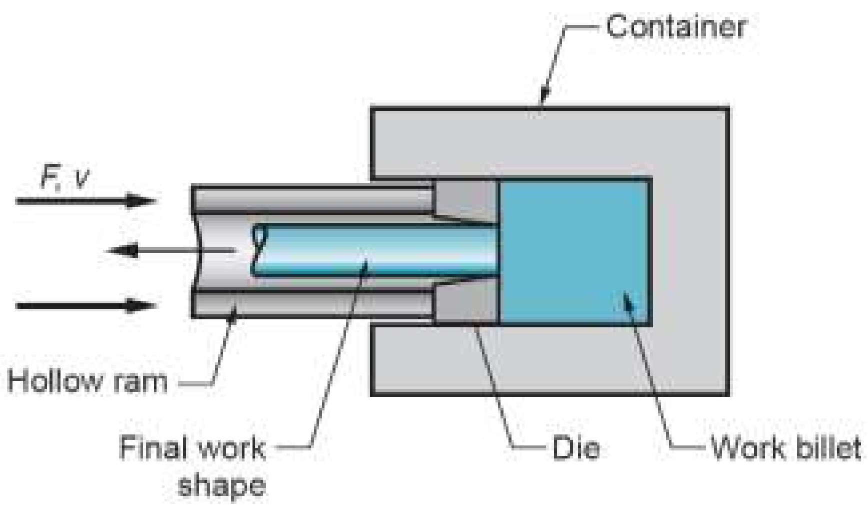
- ✓ Hollow sections (e.g., tubes) are possible in direct extrusion by the process.
- ✓ The starting billet is prepared with a hole parallel to its axis.
- ✓ This allows passage of a mandrel that is attached to the dummy block.



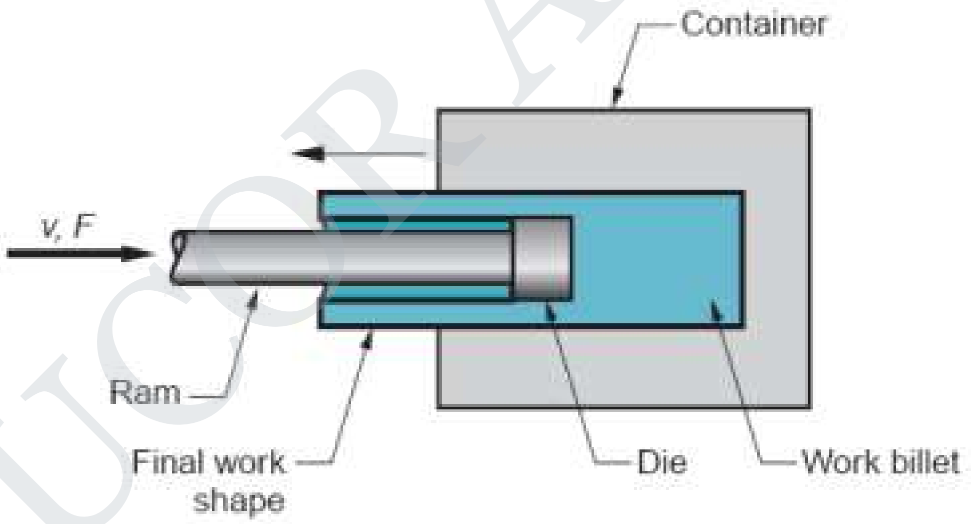
- ✓ As the billet is compressed, the material is forced to flow through the clearance between the mandrel and the die opening.
- ✓ The resulting cross section is tubular. Semi-hollow cross-sectional shapes are usually extruded in the same way.
- ✓ The starting billet in direct extrusion is usually round in cross section, but the final shape is determined by the shape of the die opening.
- ✓ Obviously, the largest dimension of the die opening must be smaller than the diameter of the billet.

Indirect Extrusion (Backward Extrusion /Reverse Extrusion)

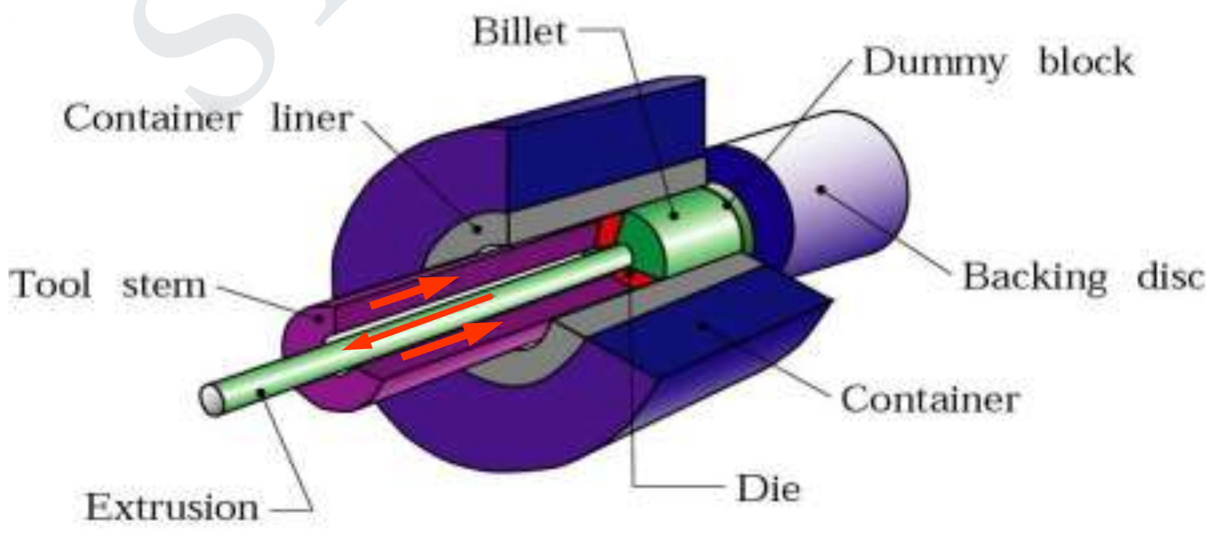
- ✓ Metal is forced to flow through the die in an opposite direction to the ram's motion.
- ✓ Lower extrusion force as the work billet metal is not moving relative to the container wall.
- ✓ The die is mounted to the ram rather than at the opposite end of the container.



- ✓ As the ram penetrates into the work, the metal is forced to flow through the clearance in a direction opposite to the motion of the ram.
- ✓ Since the billet is not forced to move relative to the container, there is no friction at the container walls, and the ram force is therefore lower than in direct extrusion.
- ✓ Limitations of indirect extrusion are imposed by the lower rigidity of the hollow ram and the difficulty in supporting the extruded product as it exits the die.
- ✓ Indirect extrusion can produce hollow (tubular) cross sections.
- ✓ In this method, the ram is pressed into the billet, forcing the material to flow around the ram and take a cup shape.
- ✓ There are practical limitations on the length of the extruded part that can be made by this method.
- ✓ Support of the ram becomes a problem as work length increases.



(a)



Hot Extrusion

- ✓ Hot extrusion involves prior heating of the billet to a temperature above its recrystallization temperature.
- ✓ This reduces strength and increases ductility of the metal, permitting more extreme size reductions and more complex shapes to be achieved in the process.
- ✓ Applicable for metals and alloys that do not have sufficient ductility at room temperature.
- ✓ Additional advantages include reduction of ram force, increased ram speed, and reduction of grain flow characteristics in the final product.
- ✓ In this extrusion, die wear can be excessive and cooling of the hot billet in the chamber can be a problem, which results in highly non-uniform deformation.
- ✓ To reduce cooling of the billet and to prolong die life, extrusion dies may be preheated, as is done in hot forging operations.
- ✓ Cooling of the billet as it contacts the container walls is a problem, and isothermal extrusion is sometimes used to overcome this problem.
- ✓ Lubrication is critical in hot extrusion for certain metals (e.g., steels), and special lubricants have been developed that are effective under the harsh conditions in hot extrusion.

Hot billet causes the following problems:

- ✓ Because the billet is hot, it develops an oxide film unless heated in an inert-atmosphere furnace. This film can be abrasive and it can affect the flow pattern of the material.
- ✓ It also results in an extruded product that may be unacceptable in cases in which good surface finish is important.

Cold Extrusion

- ✓ Extrusion carried out a ambient temperature. Often combined with forging operations.
- ✓ Cold extrusion at room temperature also eliminates the need for heating the starting billet.
- ✓ Cold extrusion and warm extrusion are generally used to produce discrete parts, often in finished (or near finished) form.

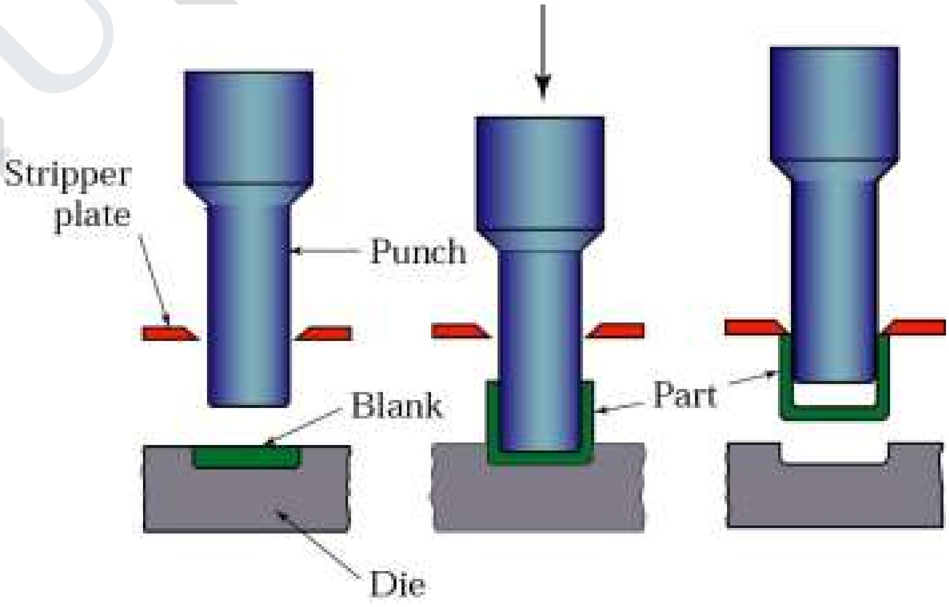
- ✓ The term impact extrusion is used to indicate high-speed cold extrusion.
- ✓ Some *important advantages* of cold extrusion include increased strength due to strain hardening, close tolerances, improved surface finish, absence of oxide layers, and high production rates.

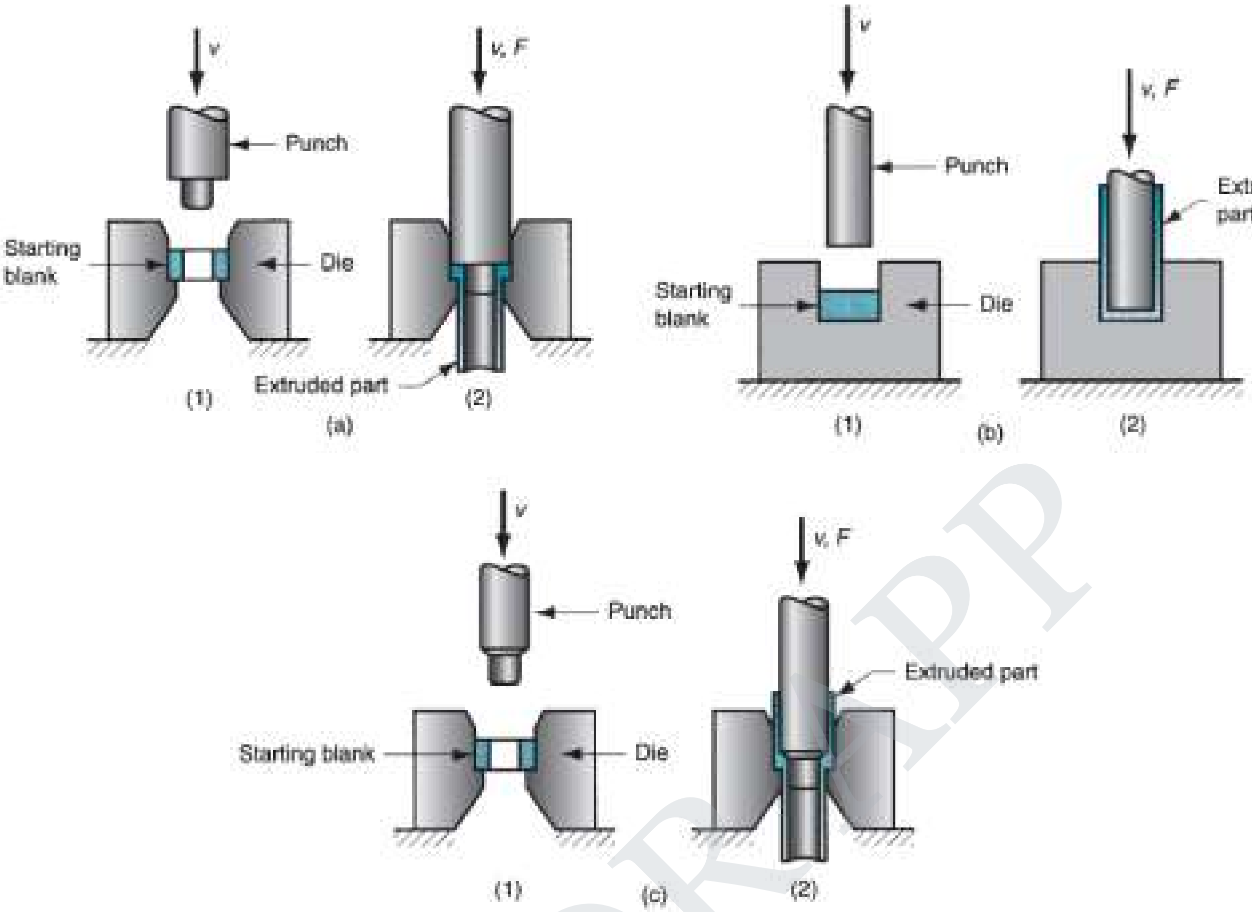
OTHER EXTRUSION PROCESSES

- ✓ Direct and indirect extrusions are the principal methods of extrusion.
- ✓ Special forms of extrusion and related processes as follows

Impact Extrusion

- ✓ Impact extrusion is performed at higher speeds and shorter strokes than conventional extrusion. It is used to make individual components.
- ✓ As the name suggests, the punch impacts the workpart rather than simply applying pressure to it.
- ✓ Impacting can be carried out as forward extrusion, backward extrusion, or combinations of these Impact extrusion is usually done cold on a variety of metals.
- ✓ Backward impact extrusion is most common.
- ✓ Products made by this process include toothpaste tubes and battery cases.
- ✓ As indicated by these examples, very thin walls are possible on impact extruded parts.
- ✓ The high-speed characteristics of impacting permit large reductions and high production rates, making this an important commercial process.



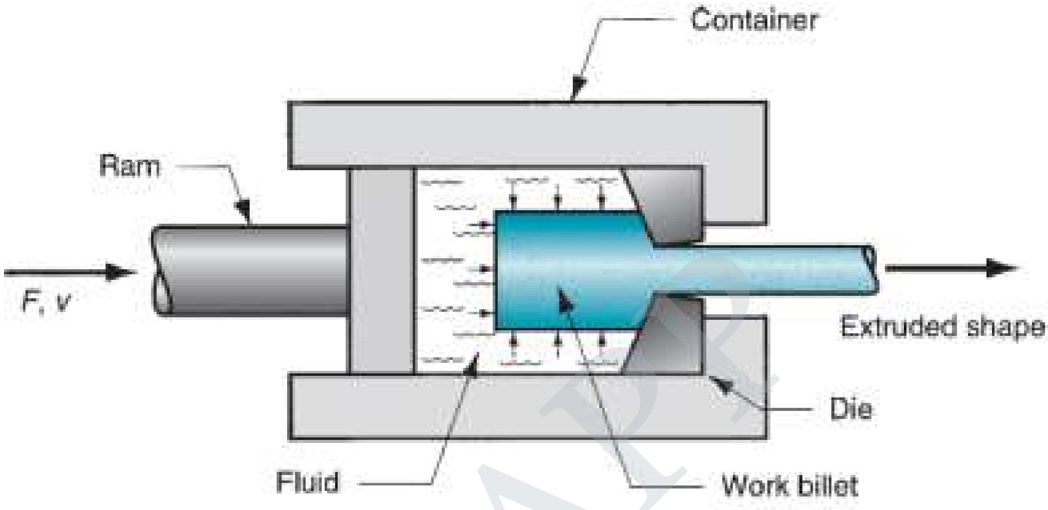


Several examples of impact extrusion: (a) forward, (b) backward, and (c) combination of forward and backward.

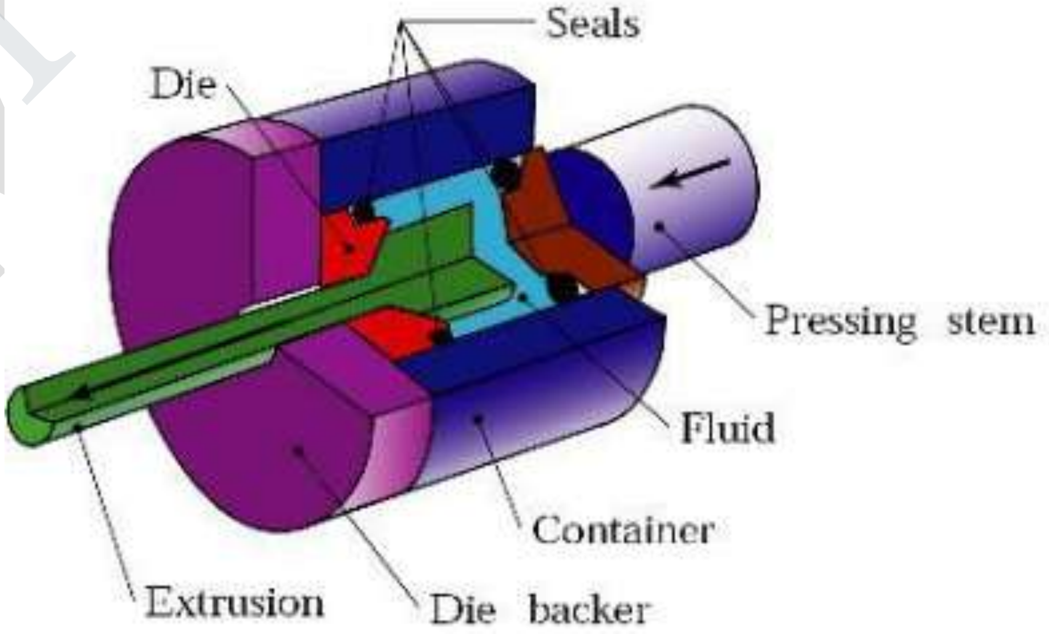
Hydrostatic Extrusion

- ✓ One of the problems in direct extrusion is friction along the billet– container interface.
- ✓ Using hydrostatic system to reduce the friction and lower the power requirement.
- ✓ The problem can be addressed by surrounding the billet with fluid inside the container and pressurizing the fluid by the forward motion of the ram.
- ✓ This way, there is no friction inside the container, and friction at the die opening is reduced.
- ✓ The Chamber is filled with a fluid. Pressure is then applied to the pressing stem
- ✓ Consequently, ram force is significantly lower than direct extrusion; no friction.
- ✓ The fluid pressure acting on all surfaces of the billet gives the process its name.
- ✓ It can be carried out at room temperature or at elevated temperatures.
- ✓ Special fluids and procedures must be used at elevated temperatures.

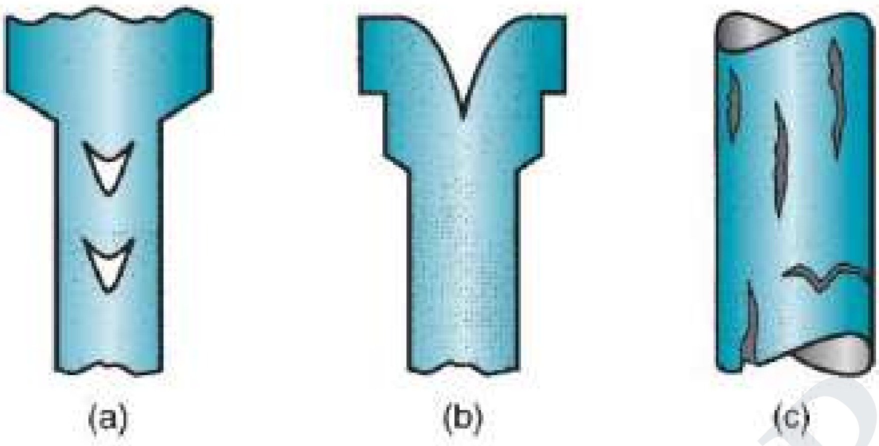
- ✓ Hydrostatic extrusion is an adaptation of direct extrusion.
- ✓ Hydrostatic pressure on the work increases the material's ductility.
- ✓ Accordingly, this process can be used on metals that would be too brittle for conventional extrusion operations.



- ✓ Ductile metals can also be hydrostatically extruded, and high reduction ratios are possible on these materials.
- ✓ One of the disadvantages of the process is the required preparation of the starting work billet.
- ✓ The billet must be formed with a taper at one end to fit snugly into the die entry angle.
- ✓ This establishes a seal to prevent fluid from squirting out the die hole when the container is initially pressurized.



DEFECTS IN EXTRUDED PRODUCTS



a) Centre-burst:

- ✓ Internal crack due to excessive tensile stress at the centre possibly because of high die angle, low extrusion ratio and impurities in the work metal that serve as starting points for crack defects.
- ✓ Other names sometimes used for this defect include arrowhead fracture, center cracking, and chevron cracking.

b) Piping:

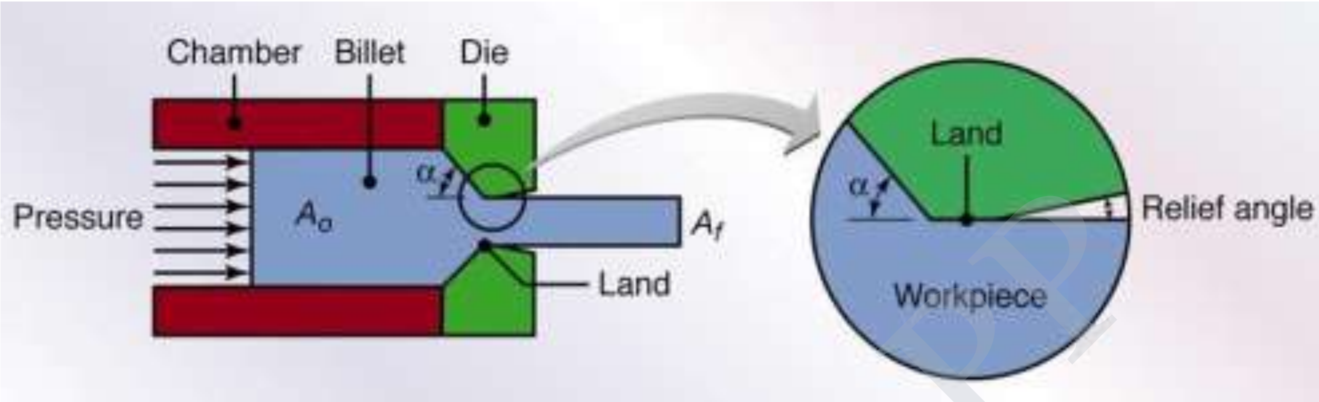
- ✓ The formation of a Sink hole at the end of billet under direct extrusion.
- ✓ Piping is a defect associated with direct extrusion.
- ✓ The use of a dummy block whose diameter is slightly less than that of the billet helps to avoid piping.
- ✓ Other names given to this defect include tailpipe and fishtailing.

c) Surface cracking:

- ✓ This defect results from high part temperature that causes cracks to develop at the surface.
- ✓ They often occur when extrusion speed is too high, leading to high strain rates and associated heat generation.
- ✓ Other factors contributing to surface cracking are high friction and surface chilling of high temperature billets in hot extrusion.

Process Variables in Direct Extrusion

- ✓ The die angle
- ✓ Reduction in cross-section
- ✓ Extrusion speed
- ✓ Extrusion pressure
- ✓ Billet temperature
- ✓ Lubrication



Advantages

- ✓ The range of extruded items is very wide. Cross-sectional shapes not possible by rolling can be extruded, such as those with re-entrant sections.
- ✓ No time is lost when changing shapes since the dies may by readily removed and replaced.
- ✓ Dimensional accuracy of extruded parts is generally superior to that of rolled ones.
- ✓ In extrusion, the ductility of the metals is higher as the metal in the container is in composite compression, this advantage being of particular importance in working poorly plastic metals and alloys.
- ✓ Very large reductions are possible as compared to rolling, for which the reduction per pass is generally 2.
- ✓ Automation in extrusion is simpler as items are produced in a single passing.
- ✓ Small parts in large quantities can be made. For example, to produce a simple pump gear, a long gear is extruded and then sliced into a number of individual gears.
- ✓ It does not need draft or flash to trim and needless machining as it is more accurate than forging.

Disadvantages

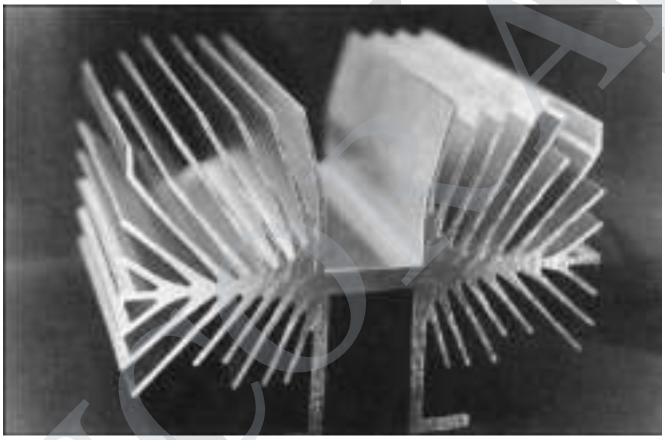
- ✓ Process waste in extrusion is higher than in rolling, where it is only 1 to 3%
- ✓ In-homogeneity in structure and properties of an extruded product is greater due to different flows of the axial and the outer layers of blanks.
- ✓ Service life of extrusion tooling is shorter because of high contact stresses and slip rates.
- ✓ Relatively high tooling costs, being made from costly alloy steel.
- ✓ In productivity, extrusion is much inferior to rolling, particularly to its continuous varieties.
- ✓ Cost of extrusion are generally greater as compared to other techniques

Applications

- ✓ Extrusion is more widely used in the manufacture of solid and hollow sections from poorly plastic non-ferrous metals and their alloys (aluminum, copper, brass and bronze etc.)
- ✓ Extrusion is applied to ductile non-ferrous metals such as aluminium, magnesium, zinc and copper alloys. Other metals can also be extruded; the force required is high, even when they are hot extruded.
- ✓ Steel and other ferrous alloys can also be successfully processed with the development of molten-glass lubricants.
- ✓ Manufacture of sections and pipes of complex configuration.
- ✓ Medium and small batch production
- ✓ Manufacture of parts of high dimensional accuracy
- ✓ The range of extruded items is very wide: rods from 3 to 250 mm in diameter, pipes of 20 to 400 mm in diameter and wall thickness of 1 mm and above and more complicated shapes which can not be obtained by other mechanical methods.

Extrusions Products

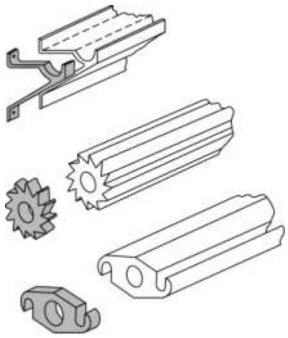
- ✓ Aluminum is probably the most ideal metal for extrusion (hot and cold), and many commercial aluminum products are made by this process (structural shapes, door and window frames, etc.)
- ✓ Typical products made by extrusion are railings for sliding doors, tubing having various cross sections, structural and architectural shapes, and door and window frames.
- ✓ Extruded products can be cut into desired lengths, which then become discrete parts such as brackets, gears and coat hangers.



Aluminium sunroof

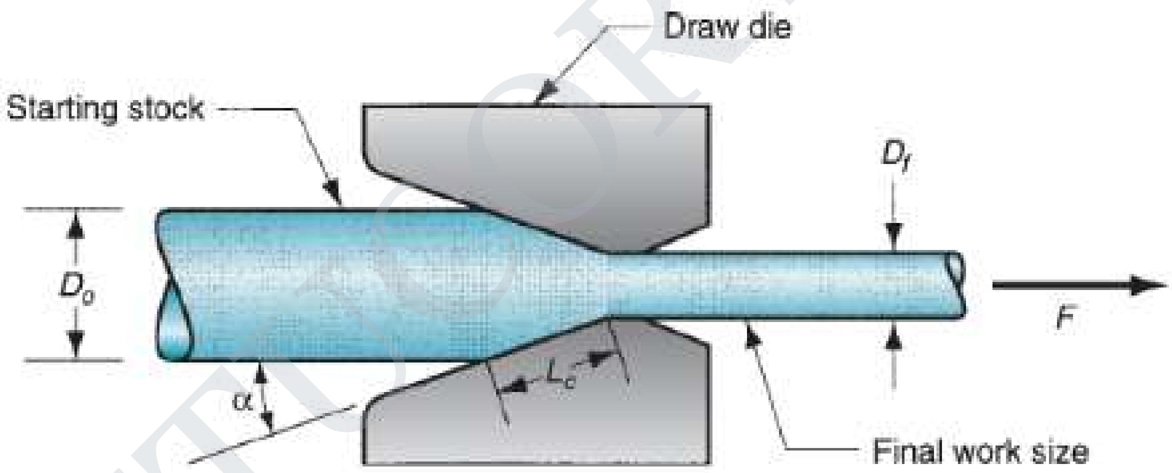
Side intrusion beams

Extruded aluminium roof



WIRE AND BAR DRAWING

- ✓ Drawing is an operation in which the cross section of a bar, rod, or wire is reduced by pulling it through a die opening.
- ✓ The general features of the process are similar to those of extrusion.
- ✓ The difference is that the work is pulled through the die in drawing, whereas it is pushed through the die in extrusion.
- ✓ Although the presence of tensile stresses is obvious in drawing, compression also plays a significant role because the metal is squeezed down as it passes through the die opening.
- ✓ For this reason, the deformation that occurs in drawing is sometimes referred to as indirect compression.



- ✓ The basic difference between bar drawing and wire drawing is the stock size that is processed.
- ✓ Bar drawing is the term used for large diameter bar and rod stock, while wire drawing applies to small diameter stock. Wire sizes down to 0.03 mm (0.001 in) are possible in wire drawing.
- ✓ Although the mechanics of the process are the same for the two cases, the methods, equipment, and even the terminology are somewhat different.

- ✓ Bar drawing is generally accomplished as a single-draft operation—the stock is pulled through one die opening.
- ✓ Because the beginning stock has a large diameter, it is in the form of a straight cylindrical piece rather than coiled.
- ✓ This limits the length of the work that can be drawn, necessitating a batch type operation.
- ✓ By contrast, wire is drawn from coils consisting of several hundred (or even several thousand) feet of wire and is passed through a series of draw dies.
- ✓ The number of dies varies typically between 4 and 12.
- ✓ The term continuous drawing is used to describe this type of operation because of the long production runs that are achieved with the wire coils, which can be butt-welded each to the next to make the operation truly continuous.
- ✓

In a drawing operation, the change in size of the work is usually given by the area reduction, defined as follows:

$$r = \frac{A_o - A_f}{A_o}$$

where r = area reduction in drawing; A_o = original area of work, mm^2 (in^2); and A_f = final area, mm^2 (in^2). Area reduction is often expressed as a percentage.

In bar drawing, rod drawing, and in drawing of large diameter wire for upsetting and heading operations, the term draft is used to denote the before and after difference in size of the processed work. The ***draft*** is simply the difference between original and final stock diameters:

$$d = D_o - D_f$$

where d = draft, mm (in); D_o = original diameter of work, mm (in); and D_f = final work diameter, mm (in).

DRAWING PRACTICE

- ✓ Drawing is usually performed as a cold working operation.
- ✓ It is most frequently used to produce round cross sections, but squares and other shapes are also drawn.

- ✓ Wire drawing is an important industrial process, providing commercial products such as electrical wire and cable; wire stock for fences, coat hangers, and shopping carts; and rod stock to produce nails, screws, rivets, springs, and other hardware items.
- ✓ Bar drawing is used to produce metal bars for machining, forging, and other processes.

Advantages of drawing in these applications include

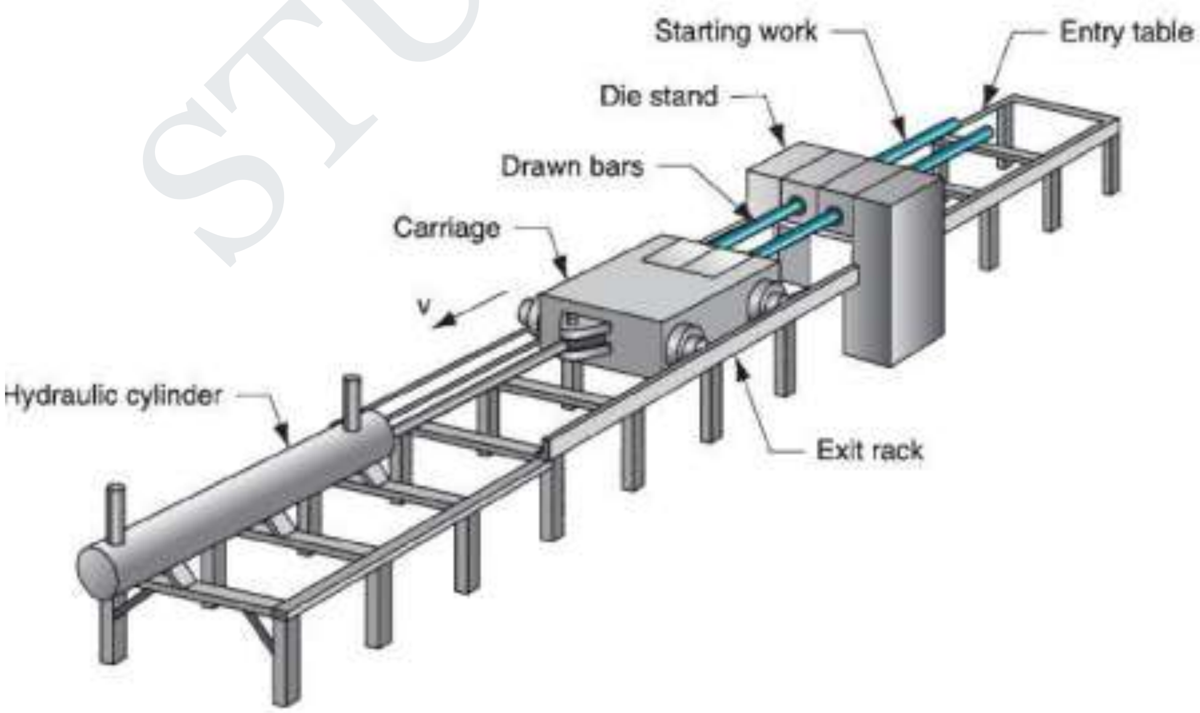
(1) Close dimensional control

(2) Good surface finish

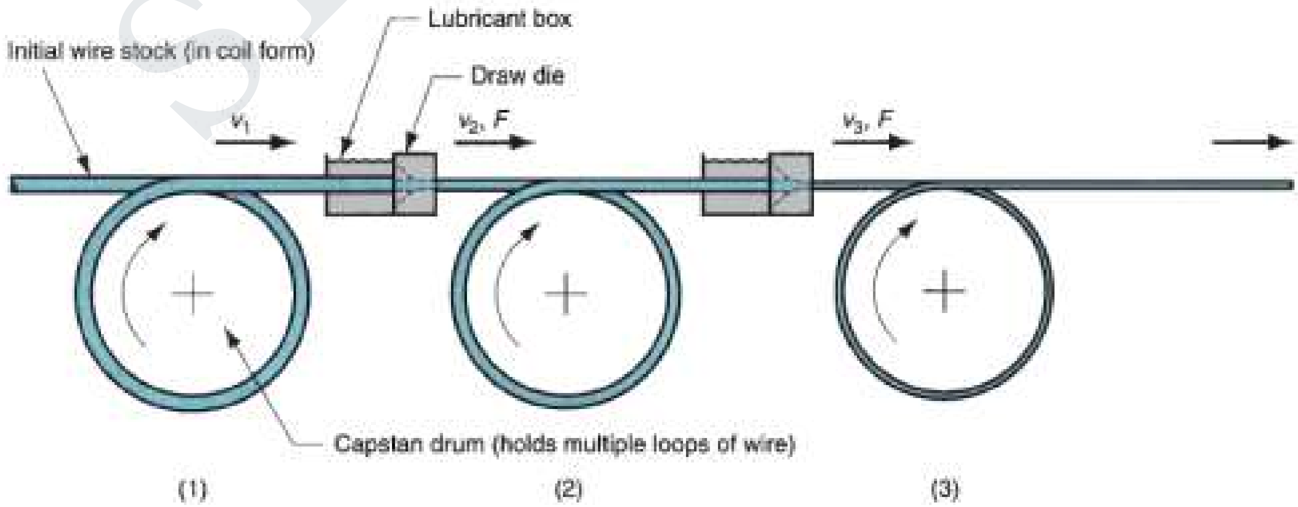
(3) Improved mechanical properties such as strength and hardness

(4) Adaptability to economical batch or mass production. Drawing speeds are as high as 50 m/s (10,000 ft/min) for very fine wire.

- ✓ In the case of bar drawing to provide stock for machining, the operation improves the machinability of the bar.
- ✓ Drawing Equipment Bar drawing is accomplished on a machine called a draw bench, consisting of an entry table, die stand (which contains the draw die), carriage, and exit rack.



- ✓ The carriage is used to pull the stock through the draw die.
- ✓ It is powered by hydraulic cylinders or motor-driven chains. The die stand is often designed to hold more than one die, so that several bars can be pulled simultaneously through their respective dies.
- ✓ Wire drawing is done on continuous drawing machines that consist of multiple draw dies, separated by accumulating drums between the dies.
- ✓ Each drum, called a capstan, is motor driven to provide the proper pull force to draw the wire stock through the upstream die.
- ✓ It also maintains a modest tension on the wire as it proceeds to the next draw die in the series.
- ✓ Each die provides a certain amount of reduction in the wire, so that the desired total reduction is achieved by the series.
- ✓ Depending on the metal to be processed and the total reduction, annealing of the wire is sometimes required between groups of dies in the series.
- ✓ Four regions of the die can be distinguished: (1) entry, (2) approach angle, (3) bearing surface (land), and (4) back relief.
- ✓ The entry region is usually a bell-shaped mouth that does not contact the work. Its purpose is to funnel the lubricant into the die and prevent scoring of work and die surfaces.

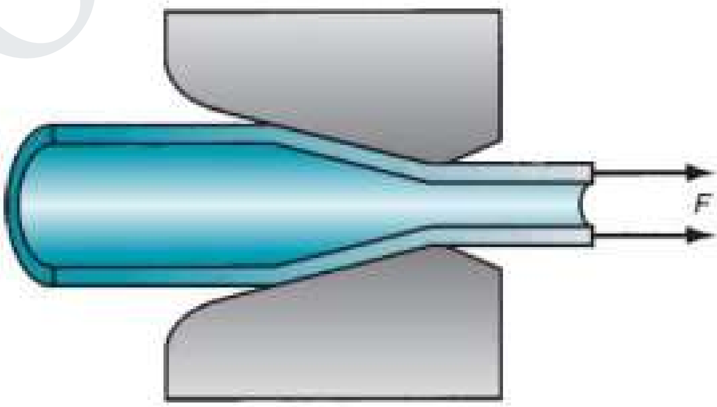


Continuous drawing of wire

- ✓ The approach is where the drawing process occurs. It is cone-shaped with an angle (half angle) normally ranging from about 6° to 20°.
- ✓ The proper angle varies according to work material. The bearing surface, or land, determines the size of the final drawn stock.
- ✓ Finally, the back relief is the exit zone. It is provided with a back relief angle (half-angle) of about 30°.
- ✓ Draw dies are made of tool steels or cemented carbides. Dies for high-speed wire drawing operations frequently use inserts made of diamond (both synthetic and natural) for the wear surfaces.

TUBE DRAWING

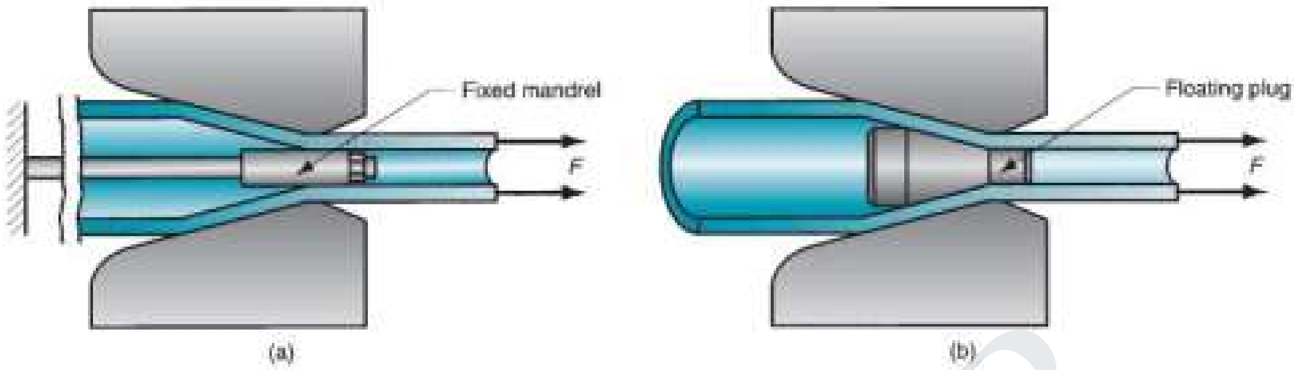
- ✓ Drawing can be used to reduce the diameter or wall thickness of seamless tubes and pipes, after the initial tubing has been produced by some other process such as extrusion.
- ✓ Tube drawing can be carried out either with or without a mandrel. The simplest method uses no mandrel and is used for diameter reduction.
- ✓ The term tube sinking is sometimes applied to this operation.



Tube drawing with no mandrel (Tube Sinking)

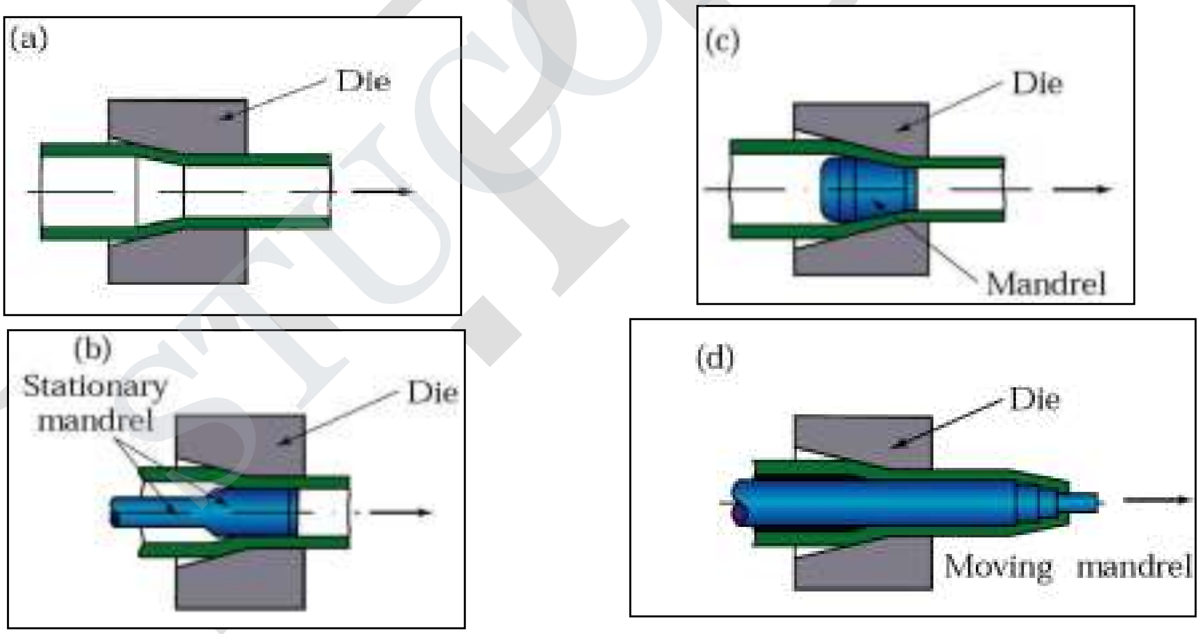
- ✓ The problem with tube drawing in which no mandrel is used, is that it lacks control over the inside diameter and wall thickness of the tube.
- ✓ This is why mandrels of various types are used.
- ✓ The first, (a), uses a fixed mandrel attached to a long support bar to establish inside diameter and wall thickness during the operation.

- ✓ Practical limitations on the length of the support bar in this method restrict the length of the tube that can be drawn.



Tube drawing with mandrels: (a) fixed mandrel, (b) floating plug.

- ✓ The second type, shown in (b), uses a floating plug whose shape is designed so that it finds a ''natural'' position in the reduction zone of the die.
- ✓ This method removes the limitations on work length present with the fixed mandrel.



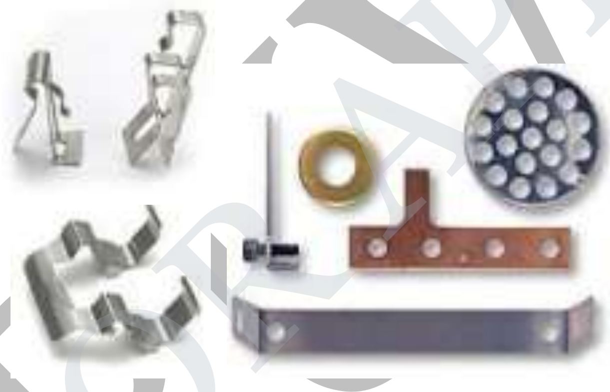
Examples of tube-drawing operations, with and without an internal mandrel. Note that a variety of diameters and wall thicknesses can be produced from the same initial tube stock (which has been made by other processes)

UNIT IV SHEET METAL PROCESSES 9

Sheet metal characteristics – shearing, bending and drawing operations – Stretch forming operations – Formability of sheet metal – Test methods –special forming processes-Working principle and applications – Hydro forming – Rubber pad forming – Metal spinning– Introduction of Explosive forming, magnetic pulse forming, peen forming, Super plastic forming – Micro forming.

Sheet Metal Processes:

Processes which bend, stretch, cut, or fracture relatively thin metal sheets or pieces into a wide variety of different forms.



SHEET METAL CHARACTERISTICS

- Sheet metal is characterized by high ratio of surface area to thickness.
- Forming is generally carried out in tensile forces
- Decreasing thickness should be avoided as far as possible as they can lead to necking and failure.
- The major factors that contribute significantly include elongation, anisotropy, grain size, residual stresses, spring back, and wrinkling.

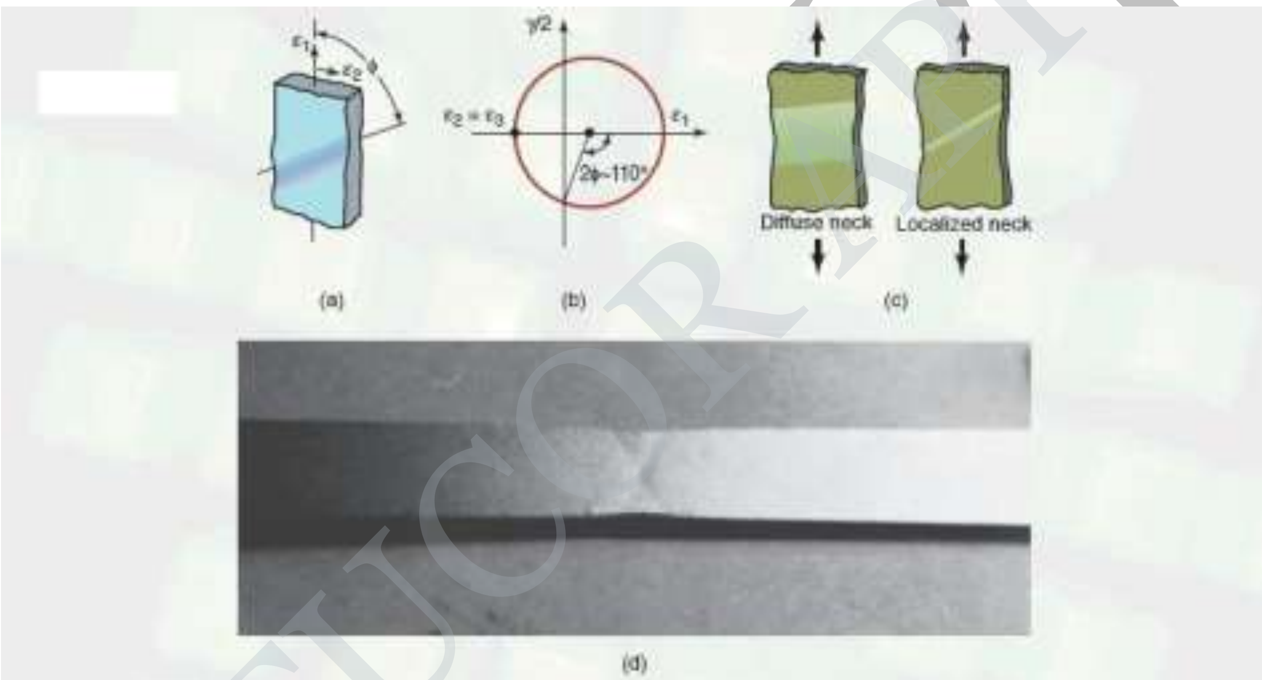
Elongation:

- ✓ Elongation determines the capacity of the sheet metal to stretch without necking or failure.
- ✓ For being able to be stretched the sheet metal must have a high strain hardening exponent (n) and strain rate sensitivity exponent (m).
- ✓ Because the material is usually being stretched in sheet forming, high uniform elongation is desirable for good formability.
    - ❖ Certain points elongate more in the specimen.

- ❖ Strain rate   elongation
- ❖ Grain size   Y.P. elongation
- ❖ Leuder's bands = stretcher strain marks

Necking:

- Necking occurs at an angle ' '
  - Localized
  - Diffuse
- Depends on strain rate sensitivity 'm' of the material.
- Post uniform elongation is higher with higher values of 'm.'
- Total elongation   'n' and 'm.'



(a) Localized necking in a sheet-metal specimen under tension. (b) Determination of the angle of neck from the Mohr's circle for strain. (c) Schematic illustrations for diffuse and localized necking, respectively. (d) Localized necking in an aluminum strip in tension; note the double neck. *Source:* S. Kalpakjian.

Anisotropy:

- ✓ Anisotropy (directionality) represents different behaviour in different planer directions.
- ✓ Two types of anisotropy characteristics are important for sheet metal processing. Planar anisotropy and normal anisotropy.
- ✓ Planar anisotropy occurs in cold rolled sheets because of preferred orientation of fibres and may cause earing during drawing operations. This can be eliminated by annealing but annealing results in decreased strength.
- ✓ Normal anisotropy means thinning of sheet metal during stretching. This may cause difficultly in deep drawing.

Grain size:

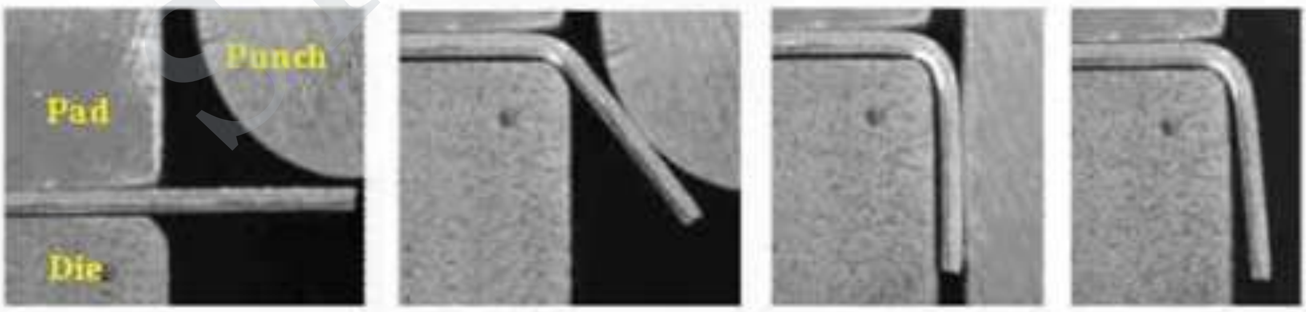
- ✓ Grain size determines the roughness on stretched sheets. Coarser the grains, rougher will be surface appearance.
- ✓ An ASTM grain size of 7 or finer is preferred for general sheet metal forming operations.

Residual stresses:

- ✓ This is caused by non uniform deformation during forming.
- ✓ Sheet metal processing being a cold working process, residual stresses can lead to distortion, corrosion or cracking.
- ✓ The stresses can be reduced by suitable stress relieving processes but it adds to the cost and increases production time per piece.
- ✓ When disturbed such as by removing a portion of it, the part may distort.

Springback:

- ✓ Spring back is caused by elastic recovery of a plastically deformed work piece after the (deforming) load is removed.
- ✓ It leads to distortion, loss of dimensional accuracy and in some cases complete rejection of the product.
- ✓ It is not possible to accurately predict the amount of spring back.
- ✓ Only trial and error methods can be used to produce acceptable components.
- ✓ It can be controlled by techniques such as overbending and bottoming of the punch.
- ✓ This effect is particularly significantly in bending and other forming operations where the bend radius to thickness ratio is high, such as in automotive body parts.

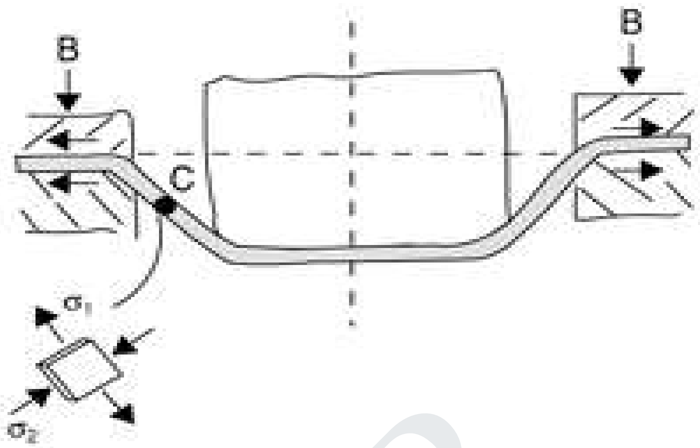


Start During Final Springback

Wrinkling:

- ✓ Wrinkles are often formed during drawing operation if the sheet is not properly gripped or the clearances provided are not correct.

- ✓ Wrinkles can be eliminated by proper tool and die design.
- ✓ Compressive stresses are formed in plane of the sheet results in wrinkling (buckling).
- ✓ The tendency of wrinkling increases with unsupported length of sheet metal, Decreasing thickness, Non uniformity in thickness, Lubricants trapped can also contribute to wrinkling.



Quality of sheared edges:

- ✓ Processed sheet metal components may have rough edges with cracks or work hardened layers.
- ✓ Quality can be improved by providing proper clearances between the punch and die, having suitable radii for the punch and die and by post processing operations like fine blanking, shaving, and lubrication.
- ✓ The edges can be rough, not square, and may contain cracks, residual stresses, and a work hardened layer all of which are detrimental to the formability of the sheet.

Surface condition of the sheets:

- ✓ Sheets produced by rolling can have surface tears, nicks etc. caused by improper design and operation of the rolling mill stand, roughness of the rolls etc.
- ✓ It depends on rolling practices. This is important in sheet forming as it can cause tearing and poor surface quality.

Sheet Metal Characteristics

Characteristic	Importance
Elongation	Determines the capability of the sheet metal to stretch without necking and failure; high strain-hardening exponent (n)and strain-rate sensitivity exponent (m)desirable.
Yield-point elongation	Observed with mild-steel sheets; also called Lueder's bands and stretcher strains; causes flamelike depressions on the sheet surfaces; can be eliminated by temper rolling, but sheet must be formed within a certain time after rolling.
Anisotropy (planar)	Exhibits different behavior in different planar directions; present in cold-rolled sheets because of preferred orientation or mechanical fibering; causes earing in drawing; can be reduced or eliminated by annealing but at lowered strength.
Anisotropy (normal)	Determines thinning behavior of sheet metals during stretching; important in deep-drawing operations.
Grain size	Determines surface roughness on stretched sheet metal; the coarser the grain, the rougher the appearance (orange peel); also affects material strength.
Residual stresses	Caused by nonuniform deformation during forming; causes part distortion when sectioned and can lead to stress-corrosion cracking; reduced or eliminated by stress relieving.
Springback	Caused by elastic recovery of the plastically deformed sheet after unloading; causes distortion of part and loss of dimensional accuracy; can be controlled by techniques such as overbending and bottoming of the punch.
Wrinkling	Caused by compressive stresses in the plane of the sheet; can be objectionable or can be useful in imparting stiffness to parts; can be controlled by proper tool and die design.
Quality of sheared edges	Depends on process used; edges can be rough, not square, and contain cracks, residual stresses, and a work-hardened layer, which are all detrimental to the formability of the sheet; quality can be improved by control of clearance, tool and die design, fine blanking, shaving, and lubrication.
Surface condition of sheet	Depends on rolling practice; important in sheet forming as it can cause tearing and poor surface quality;

Types of sheet metal processes

Shearing processes-- processes which apply shearing forces to cut, fracture, or separate the material.

Forming processes -- Processes which cause the metal to undergo desired shape changes without failure, excessive thinning, or cracking. This includes bending and stretching.

Finishing processes -- processes which are used to improve the final surface characteristics.

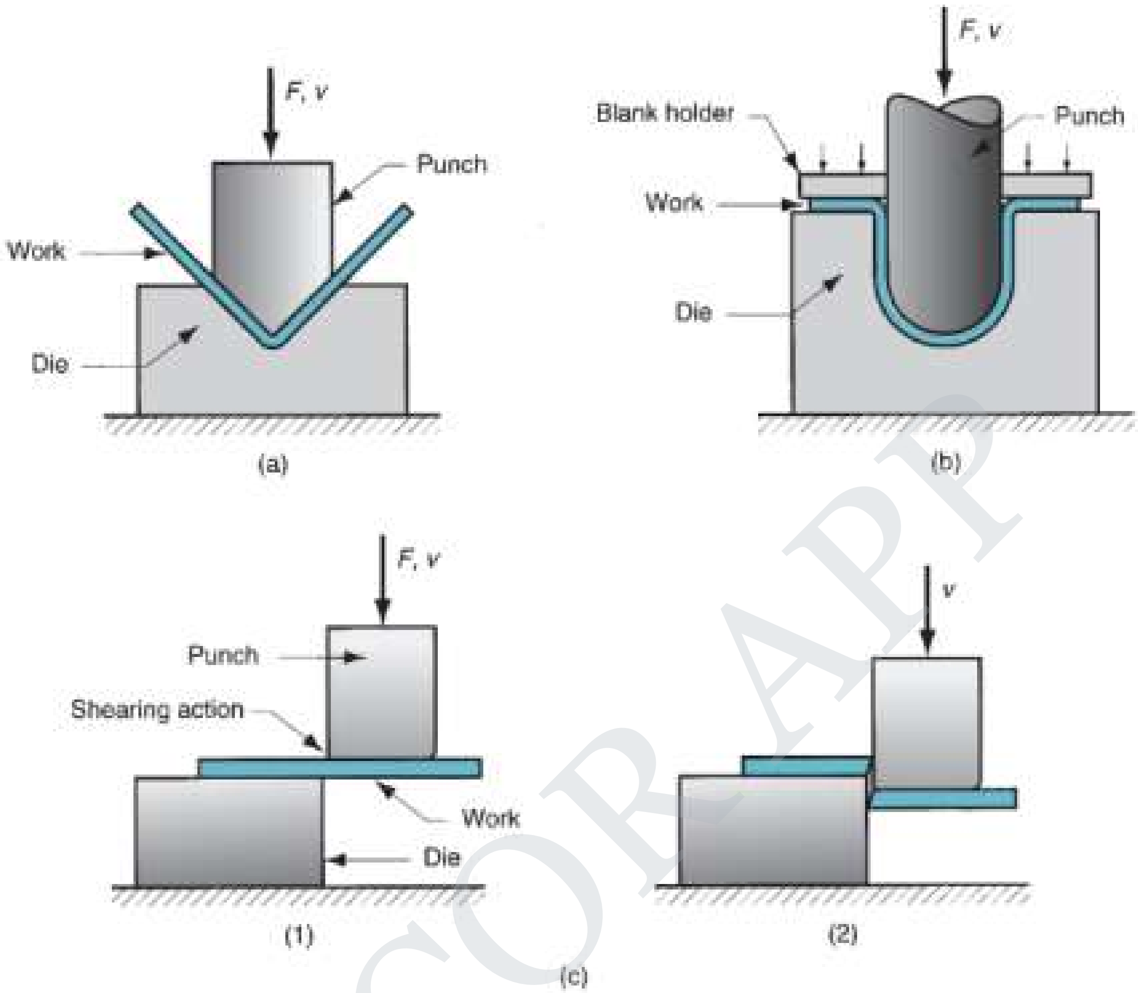
Examples of each of these include:

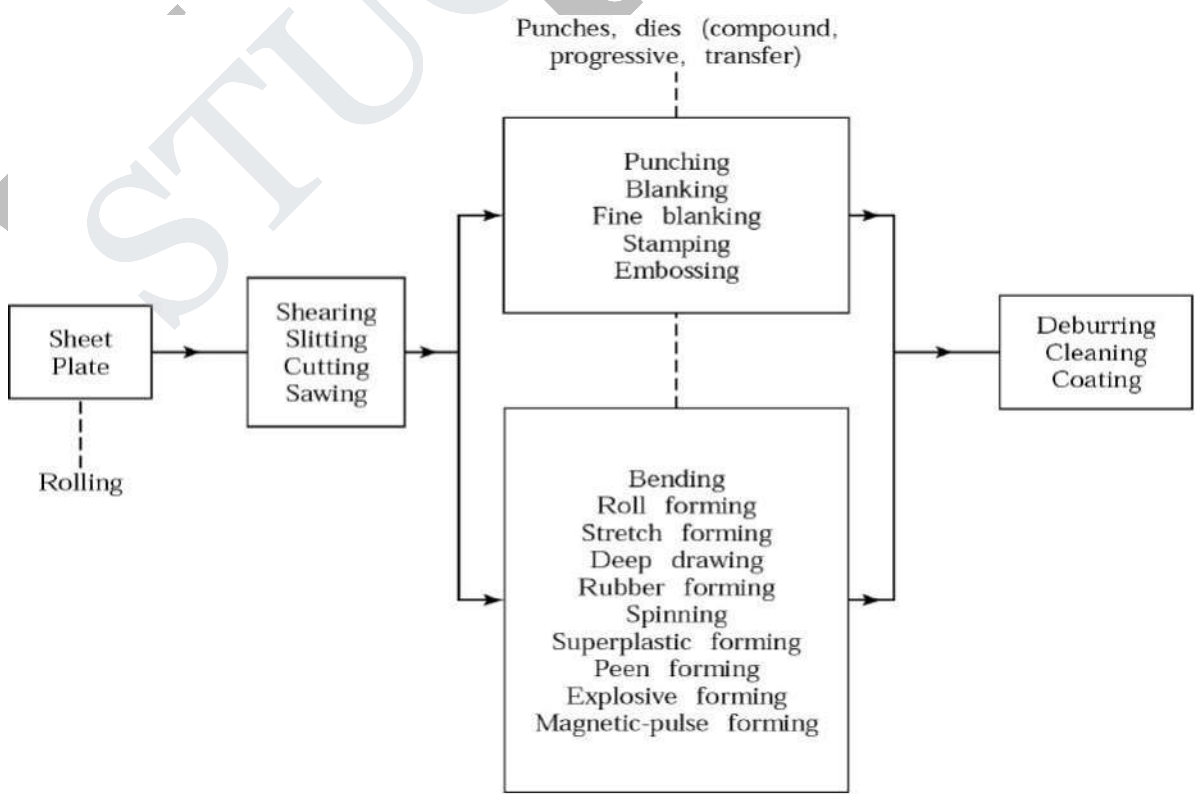
Shearing Operations	Forming Operations	Finishing Operations
Punching	Embossing	Deburring
Blanking	Bending	Cleaning
Slitting	Stretch Forming	Coating
Cutting	Deep Drawing	Painting
Sawing	Spinning	Shaving
Lancing	Rubber Forming	
Nibbling	Roll Forming	**Other Operations**
Parting	Peen Forming	Flame Cutting
Notching	Explosive Forming	Laser Beam Cutting
Perforating	Four Slide Forming	Water Jet Cutting

Sheet Metalworking

Forming on metal sheets, strips, and coils. The process is normally a cold working process using a set of *punch* and *die*.

- Bending - straining of a metal sheet to form an angle bend.
- Drawing - forming a sheet into a hollow or concave shape.
- Cutting - not a forming process but a cutting process.


F, v
Punch
Work
Die
(a)
F, v
Blank holder
Punch
Work
Die
(b)
F, v
Punch
Shearing action
Work
Die
(1)
v
(2)
(c)


Punches, dies (compound, progressive, transfer)
Punching
Blanking
Fine blanking
Stamping
Embossing
Sheet
Plate
Rolling
Shearing
Slitting
Cutting
Sawing
Deburring
Cleaning
Coating
Bending
Roll forming
Stretch forming
Deep drawing
Rubber forming
Spinning
Superplastic forming
Peen forming
Explosive forming
Magnetic-pulse forming

Cutting (Shearing) Operations

- ✓ In this operation, the workpiece is stressed beyond its ultimate strength. The stresses caused in the metal by the applied forces will be shearing stresses. The cutting operations include:

Punching (Piercing)	Lancing
Blanking	Parting
Notching	Shaving
Perforating	Trimming
Slitting	Fine blanking

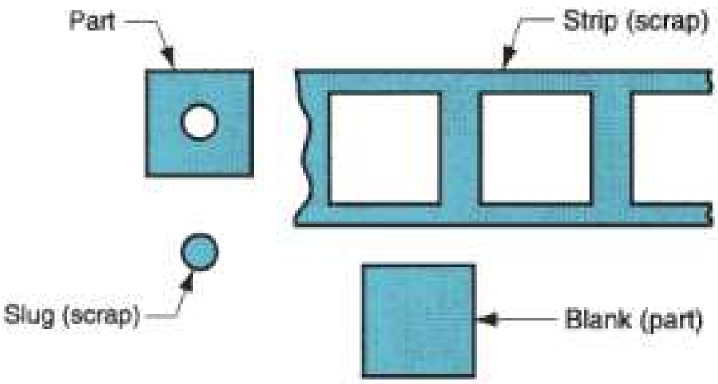
Shearing Operations

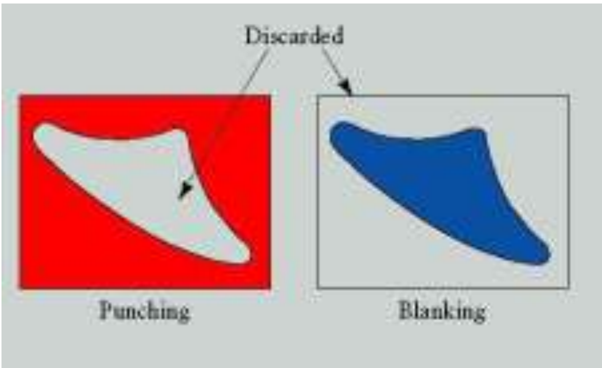
Punching (Piercing):

- ✓ It is a cutting operation by which various shaped holes are made in sheet metal.
- ✓ In punching, the hole is the desired product, the material punched out to form the hole being waste.

Blanking:

- ✓ Blanking involves cutting of the sheet metal along a closed outline in a single step to separate the piece from the surrounding stock.
- ✓ The part that is cut out is the desired product in the operation and is called the blank.
- ✓ The hole and metal left behind is discarded as waste.



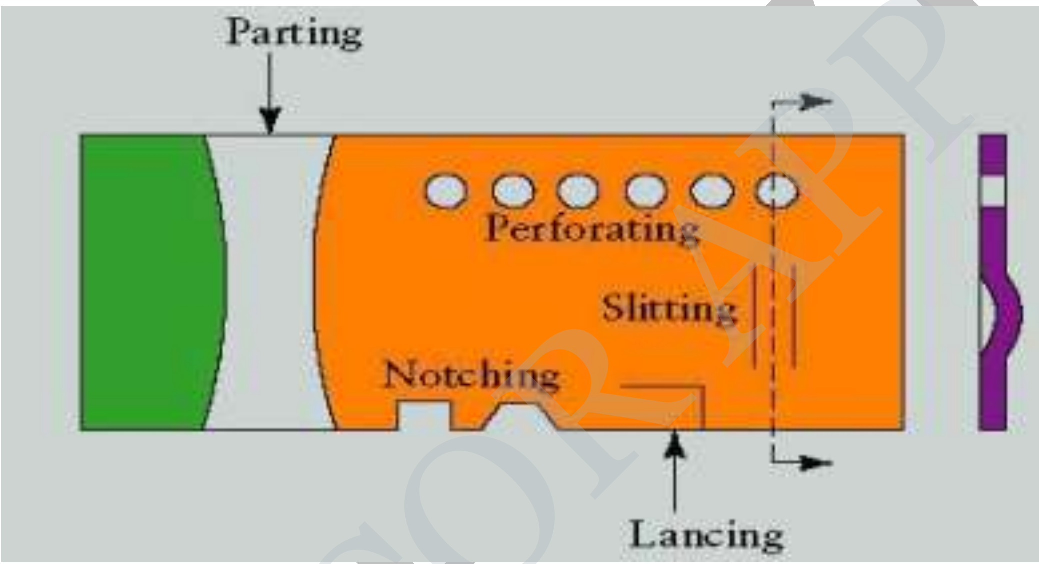


Notching: This is cutting operation by which metal pieces are cut from the edge of a sheet, strip or blank.

Notching involves cutting out a portion of metal from the side of the sheet or strip. *Seminotching* removes a portion of metal from the interior of the sheet.

Perforating: This is a process by which multiple holes which are very small and close together are cut in flat work material.

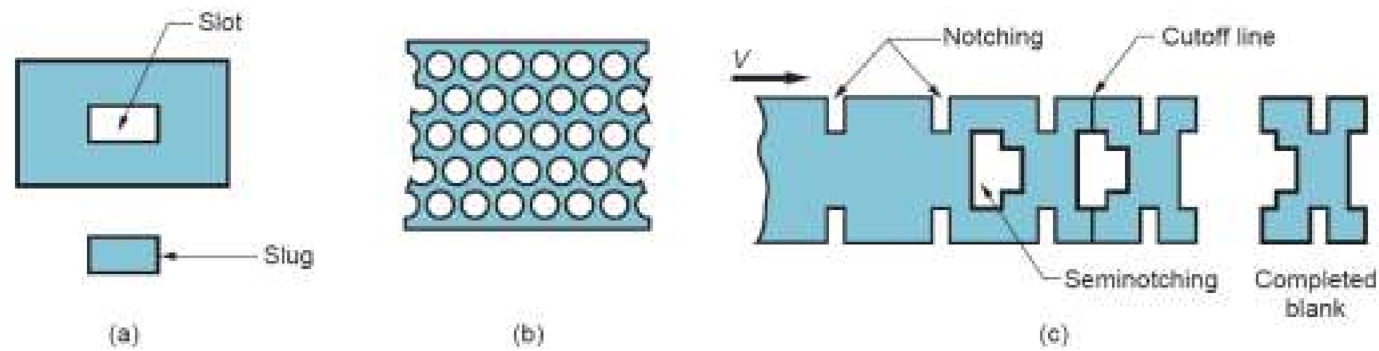
Perforating involves the simultaneous punching of a pattern of holes in sheet metal.



Lancing: This is a cutting operation in which a hole is partially cut and then one side is bent down to form a sort of tab. Since no metal is actually removed, there will be no scrap.

Slitting: It refers to the operation of making incomplete holes in a workpiece.

Slotting is the term sometimes used for a punching operation that cuts out an elongated or rectangular hole.

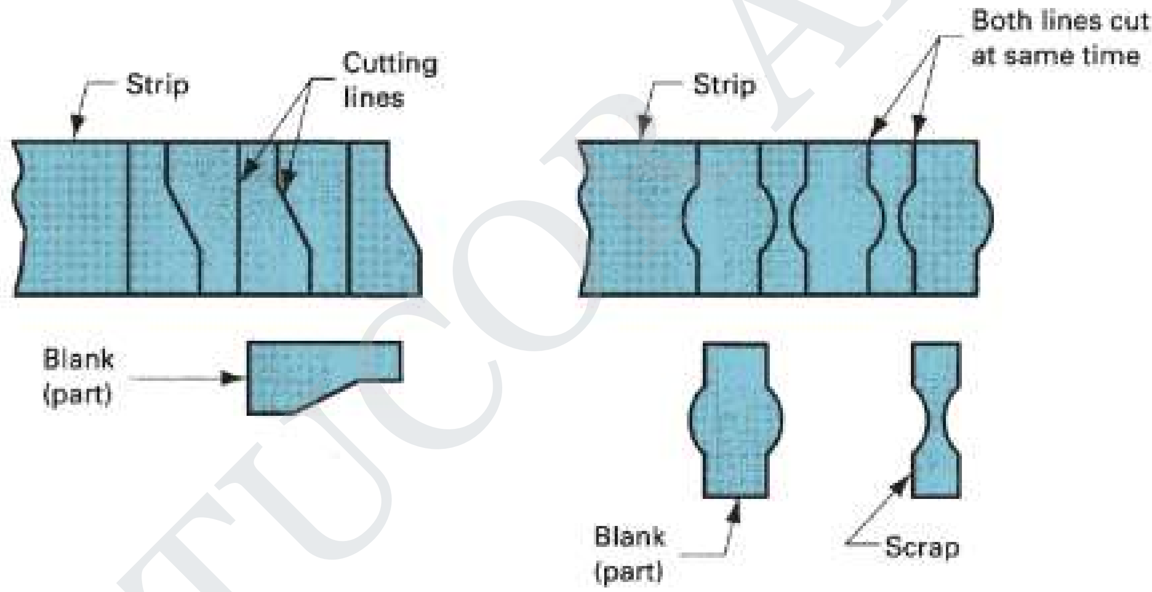


(a) Slotting, (b) perforating, (c) notching and seminotching. Symbol v indicates motion of strip.

Cutoff is a shearing operation in which blanks are separated from a sheet-metal strip by cutting the opposite sides of the part in sequence. With each cut, a new part is produced. The features of a cutoff operation that distinguish it from a conventional shearing operation are (1) the cut edges are not necessarily straight, and (2) the blanks can be nested on the strip in such a way that scrap is avoided.

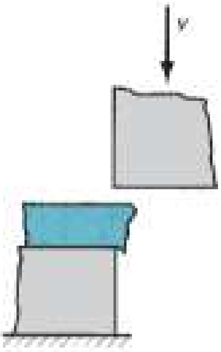
Parting involves cutting a sheet-metal strip by a punch with two cutting edges that match the opposite sides of the blank.

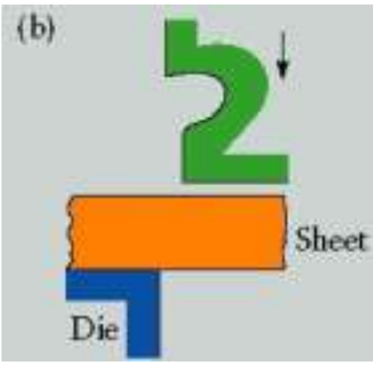
This might be required because the part outline has an irregular shape that precludes perfect nesting of the blanks on the strip. Parting is less efficient than cutoff in the sense that it results in some wasted material.

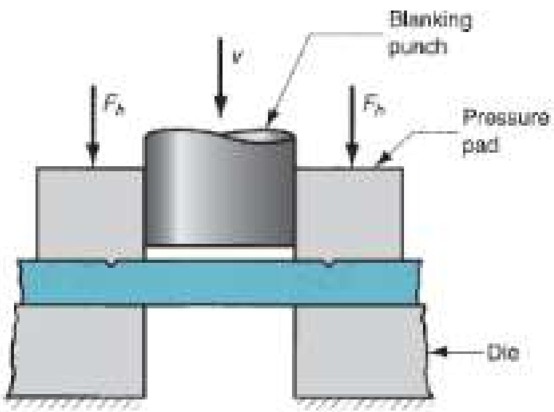


Trimming is a cutting operation performed on a previously formed part to remove excess/unwanted metal and establish size. The term has the same basic meaning as in forging. A typical example in sheet metalwork is trimming the upper portion of a deep drawn cup to leave the desired dimensions on the cup.

Shaving is a shearing operation performed with very small clearance to obtain accurate dimensions and cut edges that are smooth and straight. Shaving is typically performed as a secondary or finishing operation on parts that have been previously cut.



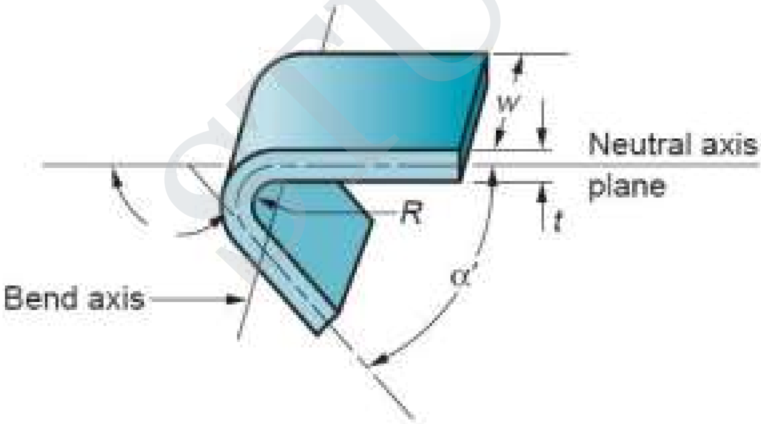


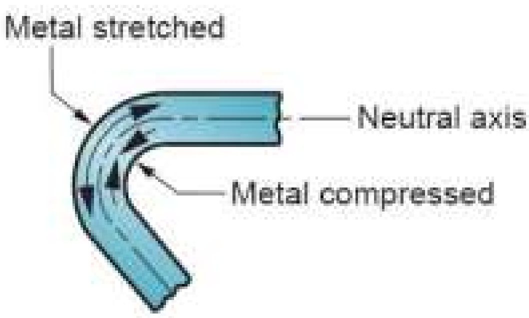


Fine blanking is a operation used to blank sheet metal parts with close tolerances and smooth, straight edges in one step. The process is usually reserved for relatively small stock thicknesses.

BENDING OPERATIONS

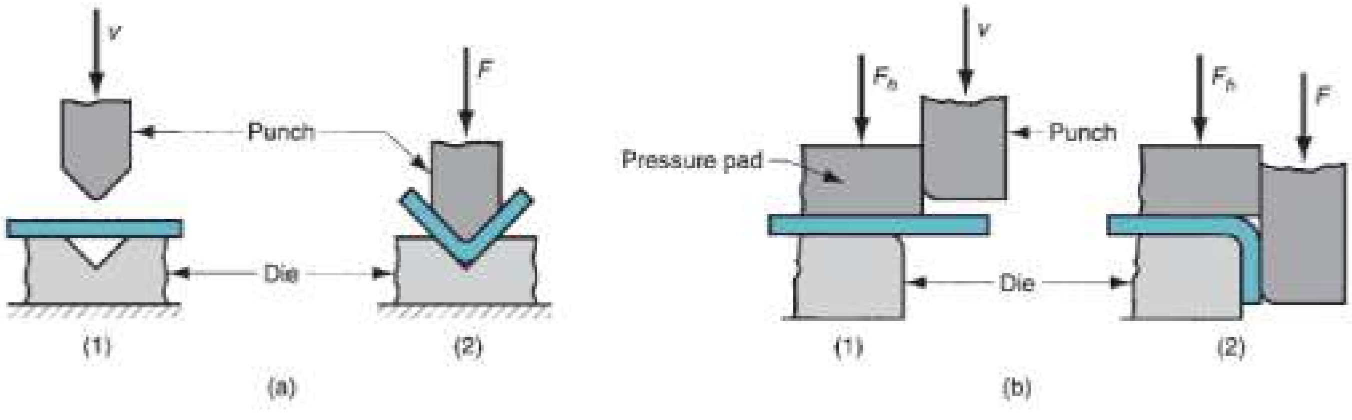
- ✓ Bending in sheet-metalwork is defined as the straining of the metal around a straight axis.
- ✓ During the bending operation, the metal on the inside of the neutral plane is compressed, while the metal on the outside of the neutral plane is stretched.
- ✓ The metal is plastically deformed so that the bend takes a permanent set upon removal of the stresses that caused it.
- ✓ Bending produces little or no change in the thickness of the sheet metal.





V-BENDING AND EDGE BENDING

- ✓ Bending operations are performed using punch and die tooling.
- ✓ The two common bending methods and associated tooling are V-bending, performed with a V-die; and edge bending, performed with a wiping die.



Two common bending methods: (a) V-bending and (b) edge bending; (1) before and (2) after bending. Symbols: v = motion, F = applied bending force, F_h = blank.

- ✓ In *V-bending*, the sheet metal is bent between a V-shaped punch and die.
- ✓ Included angles ranging from very obtuse to very acute can be made with V-dies.
- ✓ V-bending is generally used for low-production operations.
- ✓ It is often performed on a press brake, and the associated V-dies are relatively simple and inexpensive.
- ✓ *Edge bending* involves cantilever loading of the sheet metal.
- ✓ A pressure pad is used to apply a force F_h to hold the base of the part against the die, while the punch forces the part to yield and bend over the edge of the die.
- ✓ Edge bending is limited to bends of 90 or less.
- ✓ More complicated wiping dies can be designed for bend angles greater than 90 .
- ✓ Because of the pressure pad, wiping dies are more complicated and costly than V-dies and are generally used for high-production work.

Bend Allowance

- ✓ If the bend radius is small relative to stock thickness, the metal tends to stretch during bending.
- ✓ It is important to be able to estimate the amount of stretching that occurs, if any, so that the final part length will match the specified dimension.
- ✓ The problem is to determine the length of the neutral axis before bending to account for stretching of the final bent section.
- ✓ This length is called the bend allowance.

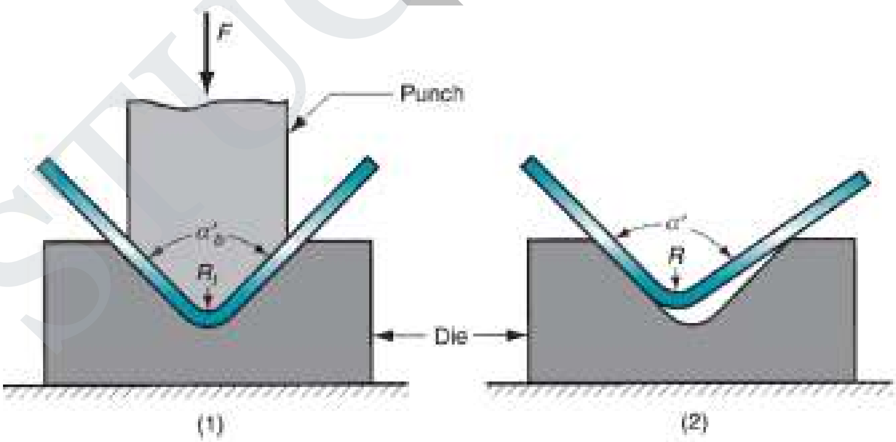
Springback

- When the bending pressure is removed at the end of the deformation operation, elastic energy remains in the bent part, causing it to recover partially toward its original shape.
- This elastic recovery is called springback, defined as the increase in included angle of the bent part relative to the included angle of the forming tool after the tool is removed.

$$SB = \frac{\alpha' - \alpha'_t}{\alpha'_t}$$

where SB = springback; α' = included angle of the sheet-metal part, degrees; and α'_t = included angle of the bending tool, degrees. Although not as obvious, an increase in the bend radius also occurs due to elastic recovery. The amount of springback increases with modulus of elasticity E and yield strength Y of the work metal.

- Compensation for springback can be accomplished by several methods.
- Two common methods are overbending and bottoming.
- In *overbending*, the punch angle and radius are fabricated slightly smaller than the specified angle on the final part so that the sheet metal springs back to the desired value.
- Bottoming involves squeezing the part at the end of the stroke, thus plastically deforming it in the bend region.



Springback in bending shows itself as a decrease in bend angle and an increase in bend radius: (1) during the operation, the work is forced to take the radius R_t and included angle α'_t = determined by the bending tool (punch in V-bending); (2) after the punch is removed, the work springs back to radius R and included angle α'. Symbol: F = applied bending force.

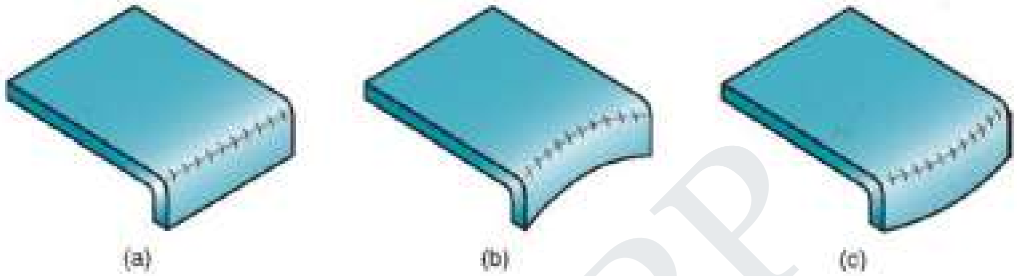
Bending Force

- The force required to perform bending depends on the geometry of the punch-and-die and the strength, thickness, and length of the sheet metal.

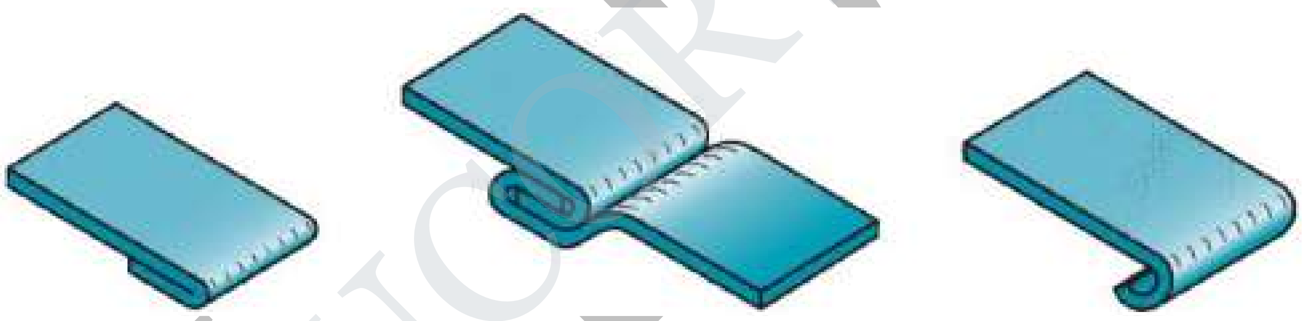
OTHER BENDING AND FORMING OPERATIONS

- ✓ *Flanging* is a bending operation in which the edge of a sheet-metal part is bent at a 90 angle (usually) to form a rim or flange.
- ✓ It is often used to strengthen or stiffen sheet metal.
- ✓ The flange can be formed over a straight bend axis, or it can involve some stretching or shrinking of the metal.

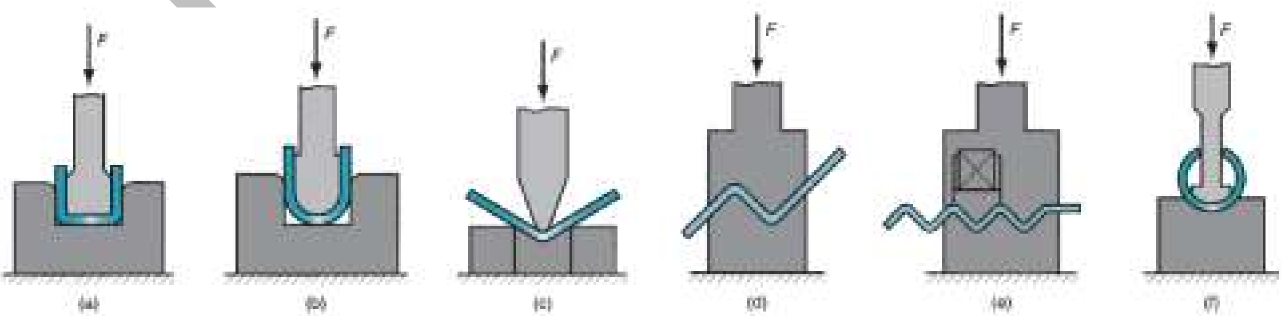
Flanging: (a) straight flanging, (b) stretch flanging, and (c) shrink flanging.



- ✓ *Hemming* involves bending the edge of the sheet over on itself, in more than one Bending step.
- ✓ This is often done to eliminate the sharp edge on the piece, to increase stiffness, and to improve appearance.



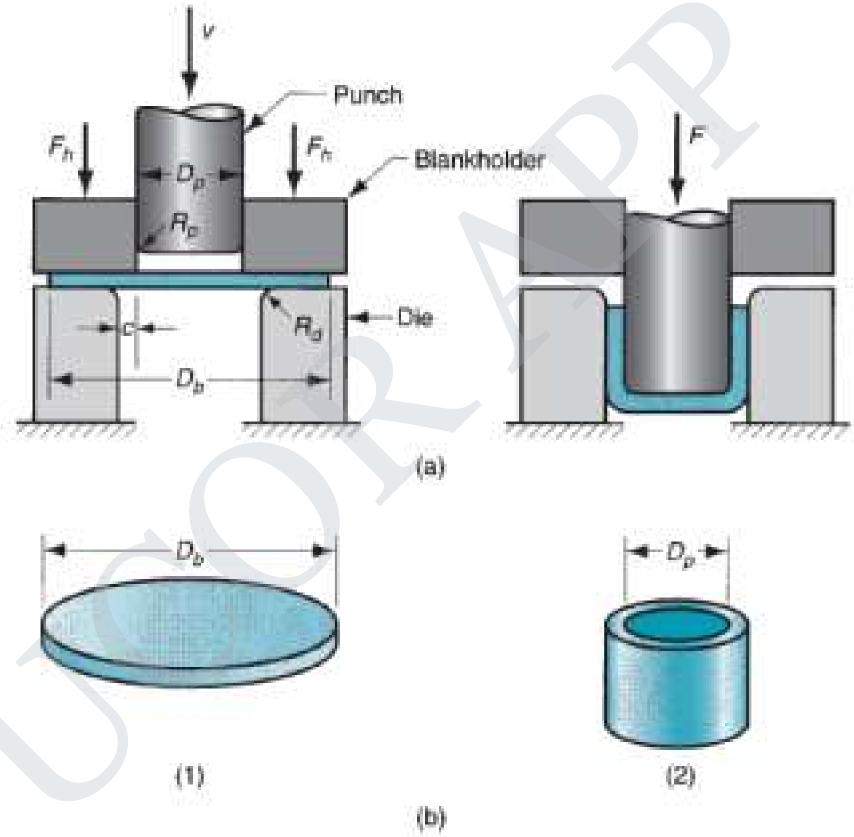
- ✓ *Seaming* is a related operation in which two sheet-metal edges are assembled.
- ✓ *Curling*, also called beading, forms the edges of the part into a roll or curl. As in hemming, it is done for purposes of safety, strength, and aesthetics.
- ✓ Examples of products in which curling is used include hinges, pots and pans, and pocket-watch cases.



a)Channel Bending b) U- bending c) air bending d) offset bending e) corrugating f) tube forming; F represents applied force

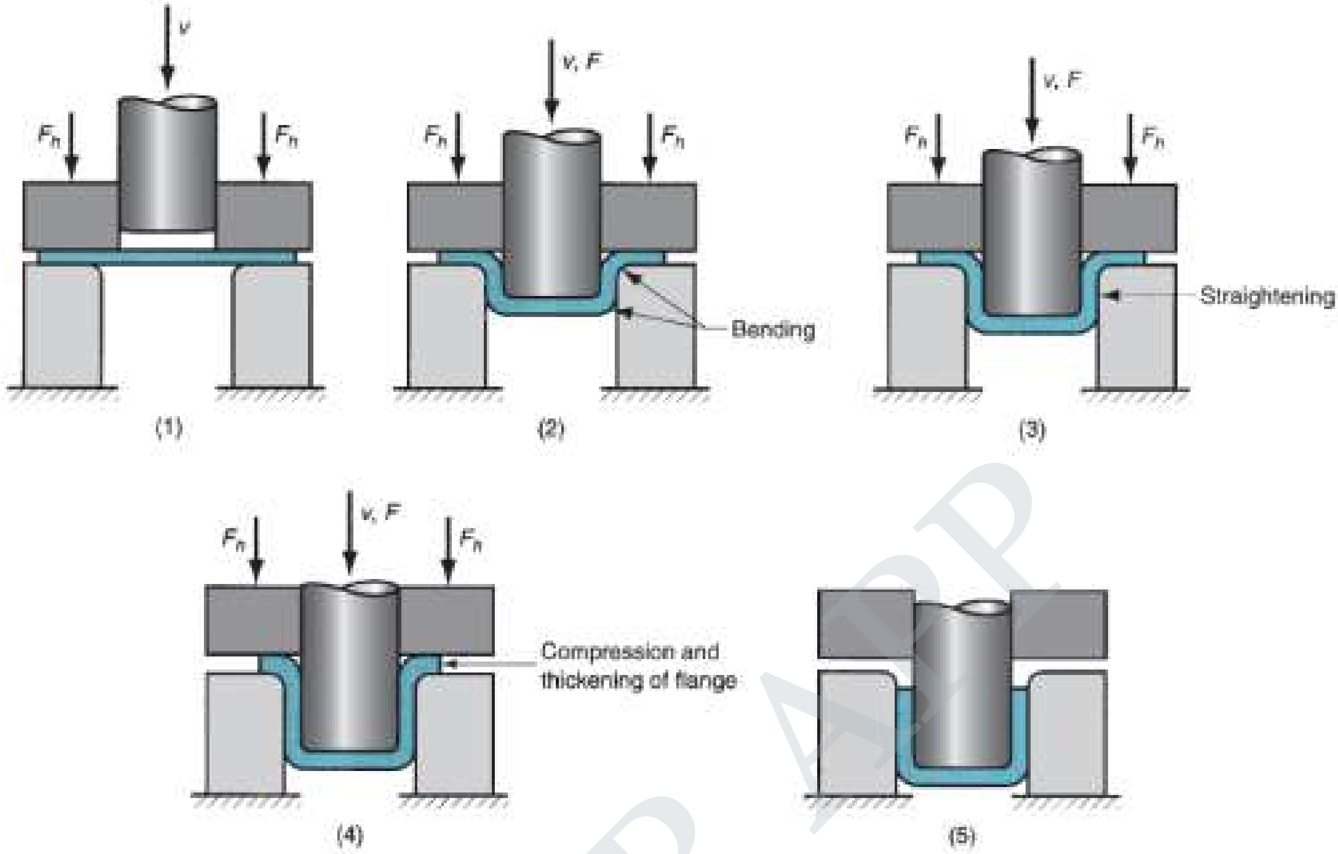
DRAWING

- ✓ Drawing is a sheet-metal-forming operation used to make cup-shaped, box-shaped, or other complex-curved and concave parts. It is performed by placing a piece of sheet metal over a die cavity and then pushing the metal into the opening with a punch.
- ✓ The blank must usually be held down flat against the die by a blank holder.
- ✓ Common parts made by drawing include beverage cans, ammunition shells, sinks, cooking pots, and automobile body panels.



(a) Drawing of a cup-shaped part: (1) start of operation before punch contacts work, and (2) near end of stroke; and (b) corresponding workpart: (1) starting blank, and (2) drawn part. Symbols: c = clearance, D_b = blank diameter, D_p = punch diameter, R_d = die corner radius, R_p = punch corner radius, F = drawing force, F_h = holding force.

- ✓ As the punch proceeds downward toward its final bottom position, the work experiences a complex sequence of stresses and strains as it is gradually formed into the shape defined by the punch and die cavity.
- ✓ As the punch first begins to push into the work, the metal is subjected to a bending operation.
- ✓ The sheet is simply bent over the corner of the punch and the corner of the die.
- ✓ The outside perimeter of the blank moves in toward the center in this first stage, but only slightly.
- ✓ As the punch moves further down, a straightening action occurs in the metal that was previously bent over the die radius.



Stages in deformation of the work in deep drawing: (1) punch makes initial contact with work, (2) bending, (3) straightening, (4) friction and compression, and (5) final cup shape showing effects of thinning in the cup walls. Symbols: v = motion of punch, F = punch force, F_h = blankholder force.

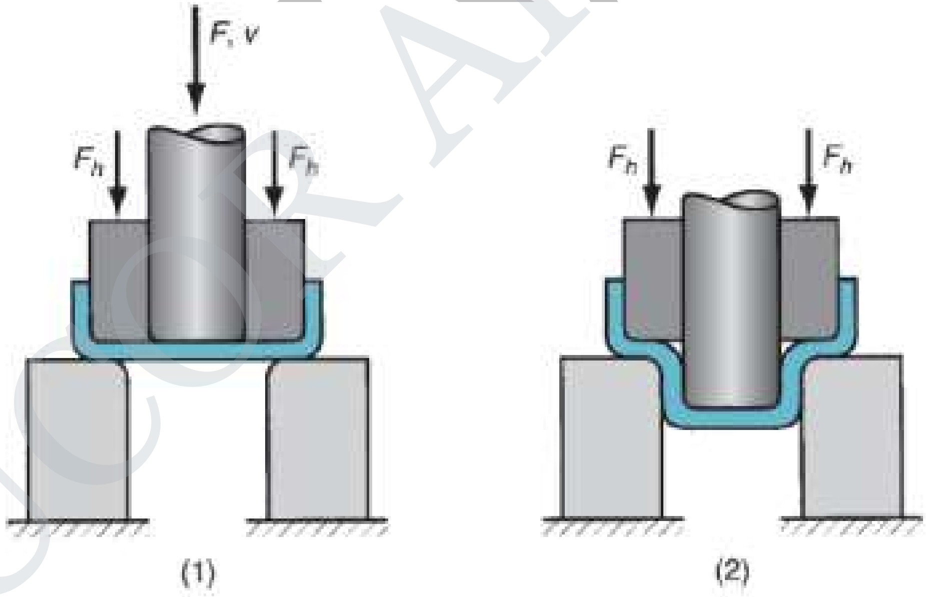
- ✓ The metal at the bottom of the cup, as well as along the punch radius, has been moved downward with the punch, but the metal that was bent over the die radius must now be straightened in order to be pulled into the clearance to form the wall of the cylinder.
- ✓ At the same time, more metal must be added to replace that being used in the cylinder wall.
- ✓ This new metal comes from the outside edge of the blank.
- ✓ The metal in the outer portions of the blank is pulled or drawn toward the die opening to resupply the previously bent and straightened metal now forming the cylinder wall.
- ✓ This type of metal flow through a constricted space gives the drawing process its name.
- ✓ During this stage of the process, friction and compression play important roles in the flange of the blank.

- ✓ In order for the material in the flange to move toward the die opening, friction between the sheet metal and the surfaces of the blank holder and the die must be overcome.
- ✓ Initially, static friction is involved until the metal starts to slide; then, after metal flow begins, dynamic friction governs the process.
- ✓ The magnitude of the holding force applied by the blankholder, as well as the friction conditions at the two interfaces, are determining factors in the success of this aspect of the drawing operation.
- ✓ Lubricants or drawing compounds are generally used to reduce friction forces.
- ✓ In addition to friction, compression is also occurring in the outer edge of the blank.
- ✓ As the metal in this portion of the blank is drawn toward the center, the outer perimeter becomes smaller.
- ✓ Because the volume of metal remains constant, the metal is squeezed and becomes thicker as the perimeter is reduced.
- ✓ This often results in wrinkling of the remaining flange of the blank, especially when thin sheet metal is drawn, or when the blankholder force is too low. It is a condition which cannot be corrected once it has occurred.
- ✓ The holding force applied by the blankholder is now seen to be a critical factor in deep drawing.
- ✓ If it is too small, wrinkling occurs. If it is too large, it prevents the metal from flowing properly toward the die cavity, resulting in stretching and possible tearing of the sheet metal.
- ✓ Determining the proper holding force involves a delicate balance between these opposing factors.
- ✓ Progressive downward motion of the punch results in a continuation of the metal flow caused by drawing and compression. In addition, some thinning of the cylinder wall occurs.
- ✓ The force being applied by the punch is opposed by the metal in the form of deformation and friction in the operation.
- ✓ A portion of the deformation involves stretching and thinning of the metal as it is pulled over the edge of the die opening.
- ✓ Up to 25% thinning of the side wall may occur in a successful drawing operation, mostly near the base of the cup.

OTHER DRAWING OPERATIONS

Redrawing

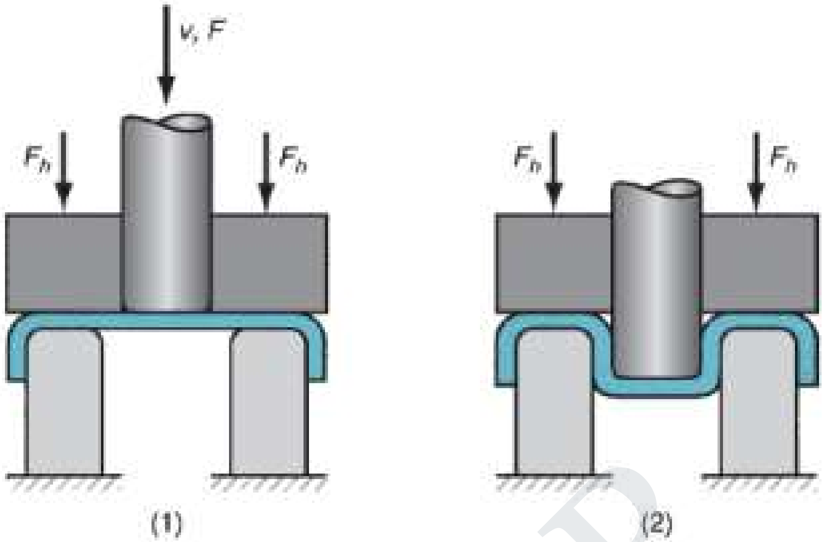
- ✓ If the shape change required by the part design is too severe (drawing ratio is too high), complete forming of the part may require more than one drawing step.
- ✓ The *second drawing step* and any further drawing steps if needed, are referred to as redrawing.
- ✓ When the part design indicates a drawing ratio that is too large to form the part in a single step, the following is a general guide to the amount of reduction that can be taken in each drawing operation:
- ✓ For the first draw, the maximum reduction of the starting blank should be 40% to 45%; for the second draw (first redraw), the maximum reduction should be 30%; and for the third draw (second redraw), the maximum reduction should be 16%.



Redrawing of a cup: (1) start of redraw, and (2) end of stroke. Symbols: v = punch velocity, F = applied punch force, F_h = blankholder force.

Reverse Drawing

- ✓ A related operation is reverse drawing, in which a drawn part is positioned face down on the die so that the second drawing operation produces a configuration.
- ✓ Although it may seem that reverse drawing would produce a more severe deformation than redrawing, it is actually easier on the metal.
- ✓ The reason is that the sheet metal is bent in the same direction at the outside and inside corners of the die in reverse drawing; while in redrawing the metal is bent in the opposite directions at the two corners.
- ✓ Because of this difference, the metal experiences less strain hardening in reverse drawing and the drawing force is lower.



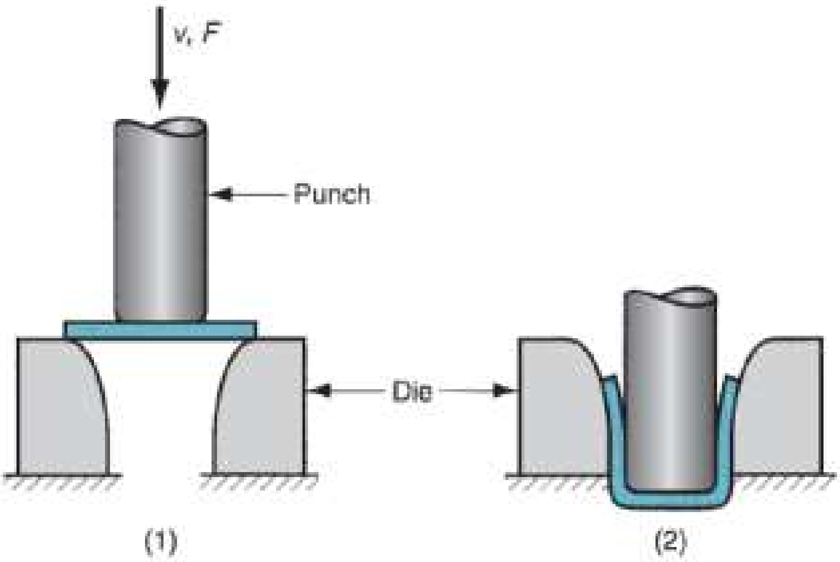
Reverse drawing: (1) start and (2) completion. Symbols: v = punch velocity, F = applied punch force, F_h = blankholder force.

Drawing of Shapes Other than Cylindrical Cups

- ✓ Many products require drawing of shapes other than cylindrical cups.
- ✓ The variety of drawn shapes include square or rectangular boxes (as in sinks), stepped cups, cones, cups with spherical rather than flat bases, and irregular curved forms (as in automobile body panels).
- ✓ Each of these shapes presents unique technical problems in drawing. Eary and Reed provide a detailed discussion of the drawing of these kinds of shapes.

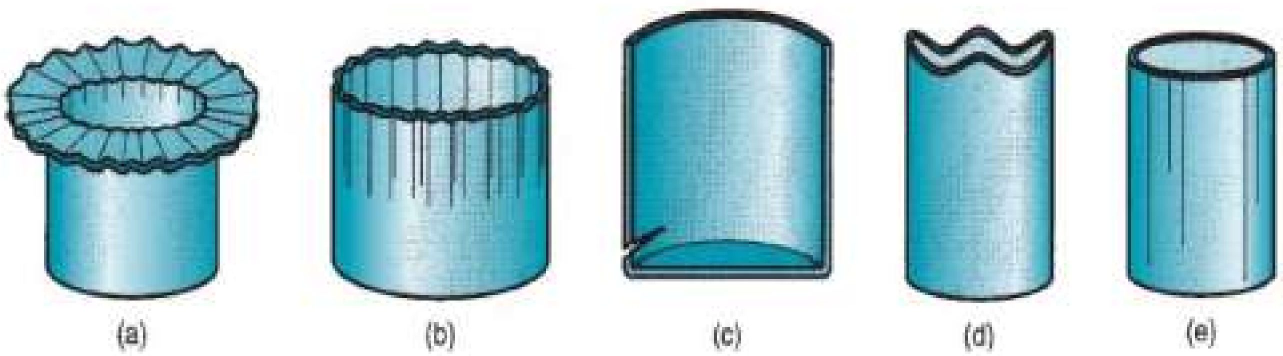
Drawing without a Blankholder

- ✓ One of the primary functions of the blankholder is to prevent wrinkling of the flange while the cup is being drawn.
- ✓ The tendency for wrinkling is reduced as the thickness-to-diameter ratio of the blank increases. If the t/D_b ratio is large enough, drawing can be accomplished without a blankholder.



Drawing without a blankholder: (1) start of process, (2) end of stroke. Symbols v and F indicate motion and applied force, respectively.

DEFECTS IN DRAWING



Common defects in drawn parts: (a) wrinkling can occur either in the flange or (b) in the wall, (c) tearing, (d) earing, and (e) surface scratches.

(a) Wrinkling in the flange

✓ Wrinkling in a drawn part consists of a series of ridges that form radially in the undrawn flange of the workpart due to *compressive buckling.*

(b) Wrinkling in the wall

✓ If and when the wrinkled flange is drawn into the cup, these ridges appear in the *vertical wall.*

(c) Tearing

✓ Tearing is an open crack in the vertical wall, usually near the base of the drawn cup, due to *high tensile stresses* that cause thinning and failure of the metal at this location. This type of failure can also occur as the metal is pulled over a sharp die corner.

(d) Earing

✓ This is the formation of irregularities (called ears) in the upper edge of a deep drawn cup, *caused by anisotropy* in the sheet metal.

✓ If the material is perfectly isotropic, ears do not form.

(e) Surface scratches

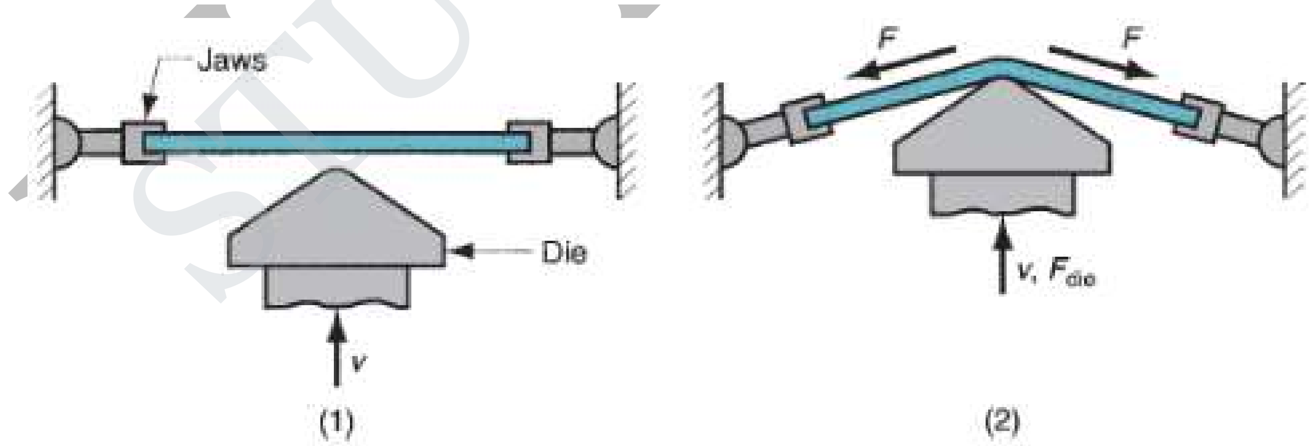
✓ Surface scratches can occur on the drawn part if the punch and die are not smooth or if lubrication is insufficient.

STRETCH FORMING

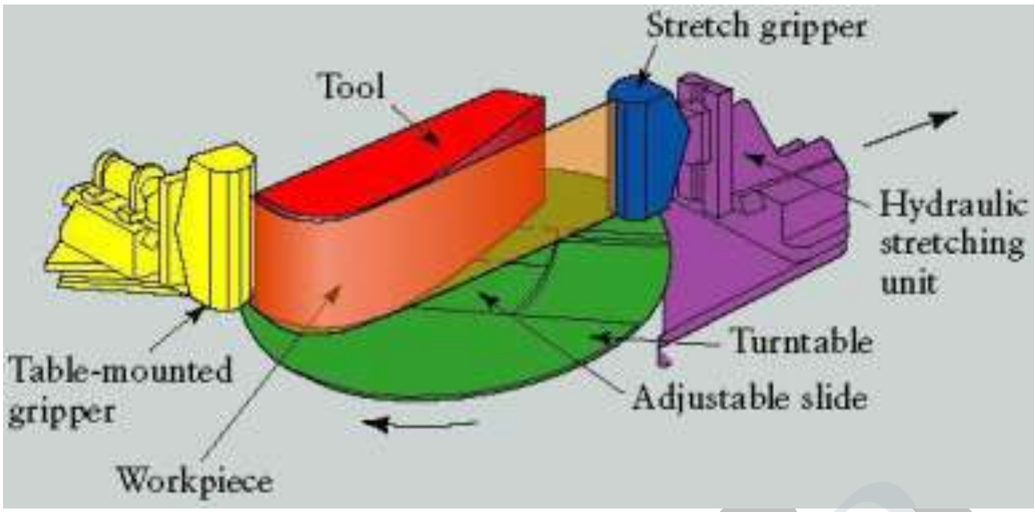
- Stretch forming is a sheet-metal deformation process in which the sheet metal is intentionally stretched and simultaneously bent in order to achieve shape change.
- The process is relatively simple and gradual bend.
- The workpart is gripped by one or more jaws on each end and then stretched and bent over a positive die containing the desired form.
- The metal is stressed in tension to a level above its yield point.
- When the tension loading is released, the metal has been plastically deformed.
- The combination of stretching and bending results in relatively little springback in the part.
- An estimate of the force required in stretch forming can be obtained by multiplying the cross-sectional area of the sheet in the direction of pulling by the flow stress of the metal.
- In equation form,

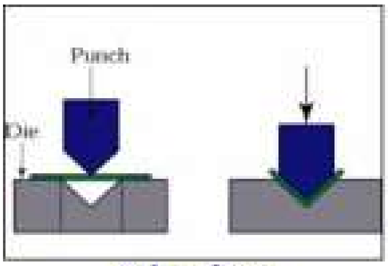
$$F = LtY_f$$

where F = stretching force, N (lb); L = length of the sheet in the direction perpendicular to stretching, mm (in); t = instantaneous stock thickness, mm (in); and Y_f = flow stress of the work metal, MPa (lb/in^2). The die force F_{die} shown in the figure can be determined by balancing vertical force components.

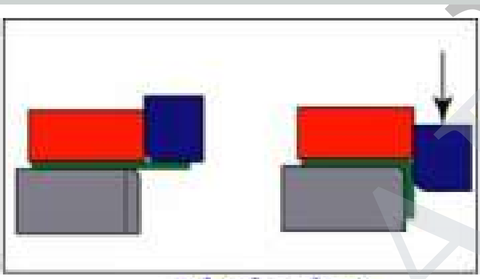


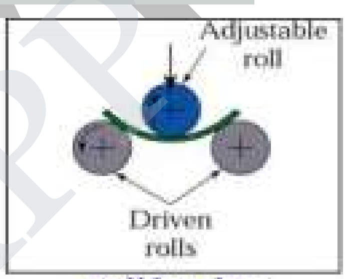
- More complex contours than that shown in our figure are possible by stretch forming, but there are limitations on how sharp the curves in the sheet can be.
- Stretch forming is widely used in the *aircraft and aerospace industries* to economically produce large sheet-metal parts in the low quantities characteristic of those industries.



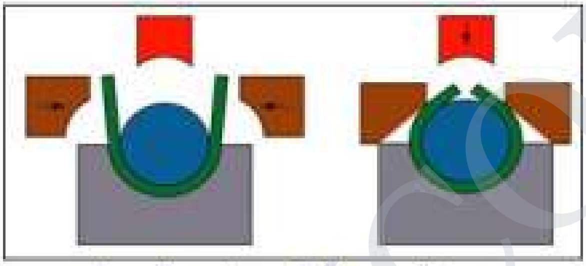


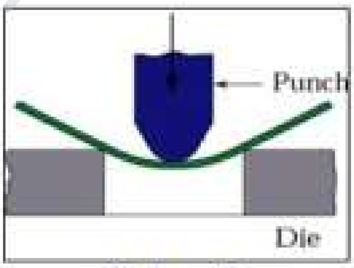
V-bending


Edge bending



Roll bending

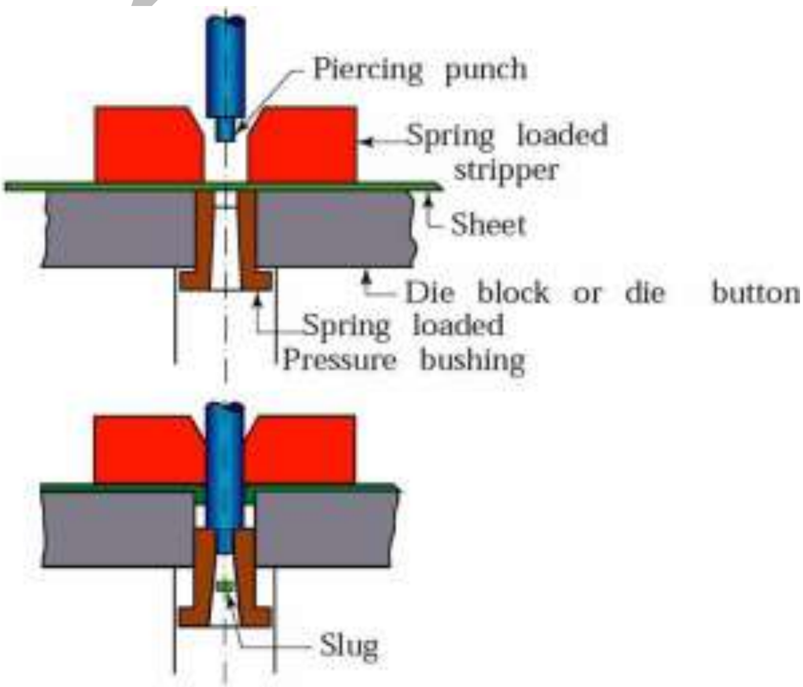

Bending in 4-slide machine



Air bending

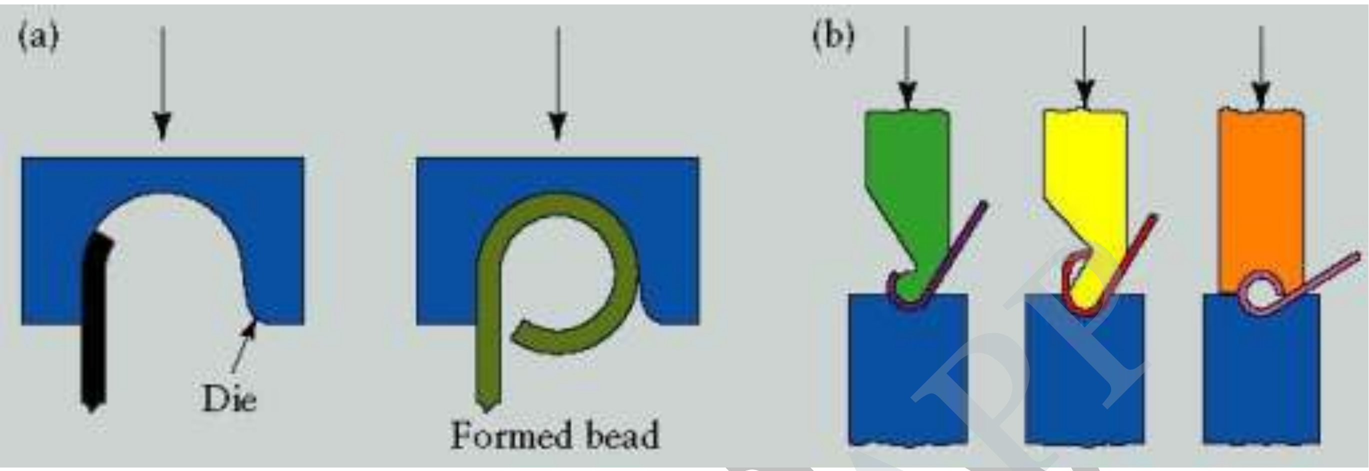
Dimpling:

- ✓ Punching a hole, followed immediately by flanging the edges.
- ✓ Flanges can be produced by piercing with shaped punch.
- ✓ When bend angle < 90 degrees as in fitting conical ends its called flanging.



Beading:

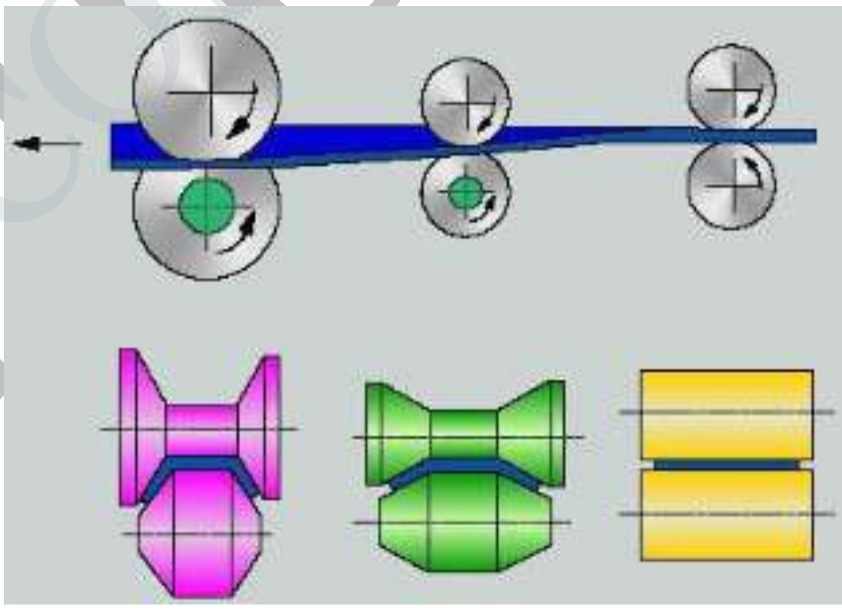
- ✓ In beading the edge of the sheet metal is bent into the cavity of a die.
- ✓ The bead gives stiffness to the part by increasing the moment on inertia of the edges.
- ✓ Also, it improves the appearance of the part and eliminates exposed sharp edges



(a) Bead forming with a single die. (b) Bead forming with two dies, in a press brake.

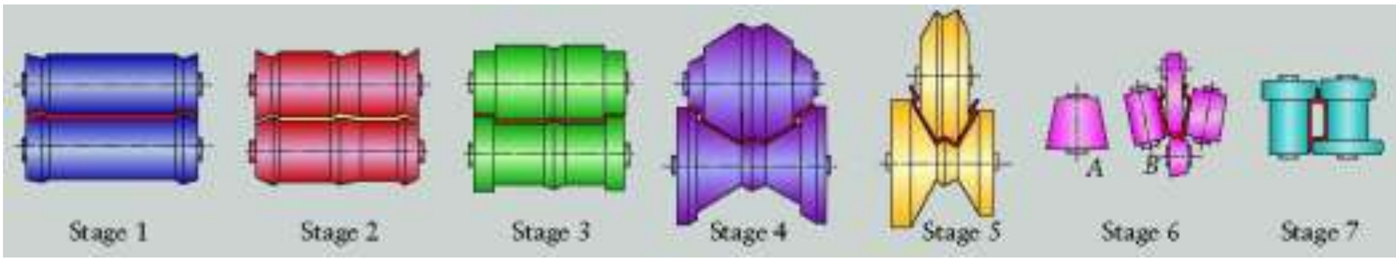
Roll forming:

- ✓ For bending continuous lengths of sheet metal and for large production runs, roll forming is used.
- ✓ The metal strip is bent in stages by passing it through a series of rolls.



Roll-forming process

- ✓ Stages in roll forming of a sheet-metal door frame.
- ✓ In Stage 6, the rolls may be shaped as in A or B.

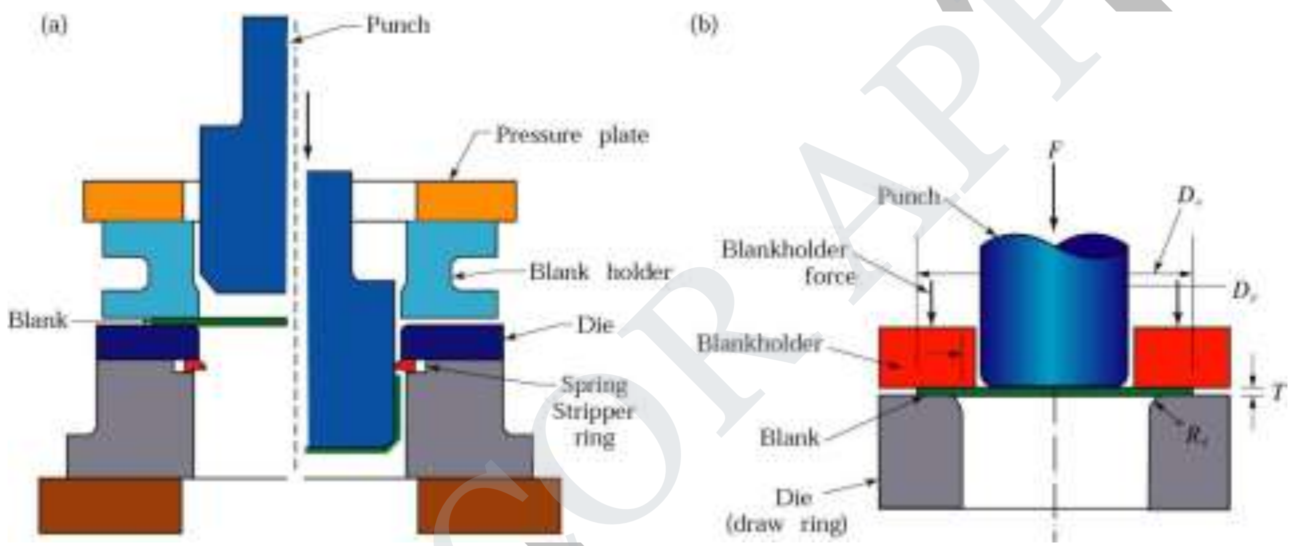


Deep Drawing Processes

✓ Drawing operation is the process of forming a flat piece of material (blank) into a hollow shape by means of a punch, which causes the blank to flow into the die-cavity.

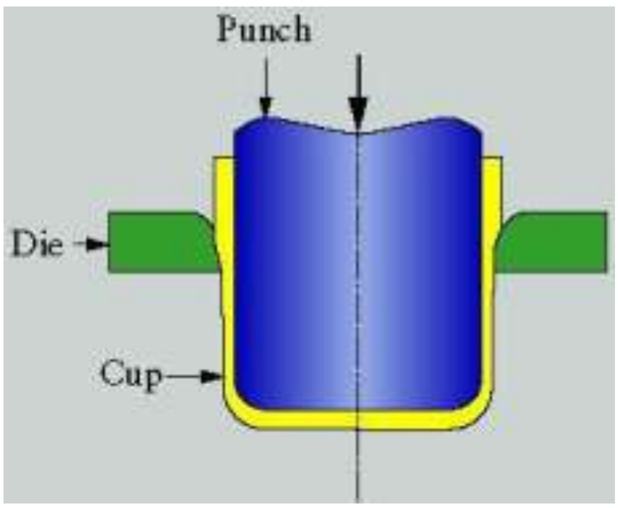
✓ Round sheet metal block is placed over a circular die opening and held in a place with blank holder & punch forces down into the die cavity. Wrinkling occurs at the edges.

- Shallow drawing: depth of formed cup D/2
- Deep/moderate drawing: depth of formed cup > D/2



(a) deep-drawing process on a circular sheet-metal blank. The stripper ring facilitates the removal of the formed cup from the punch. (b) Process variables in deep drawing. Except for the punch force, F, all the parameters indicated in the figure are independent variables.

Ironing Process



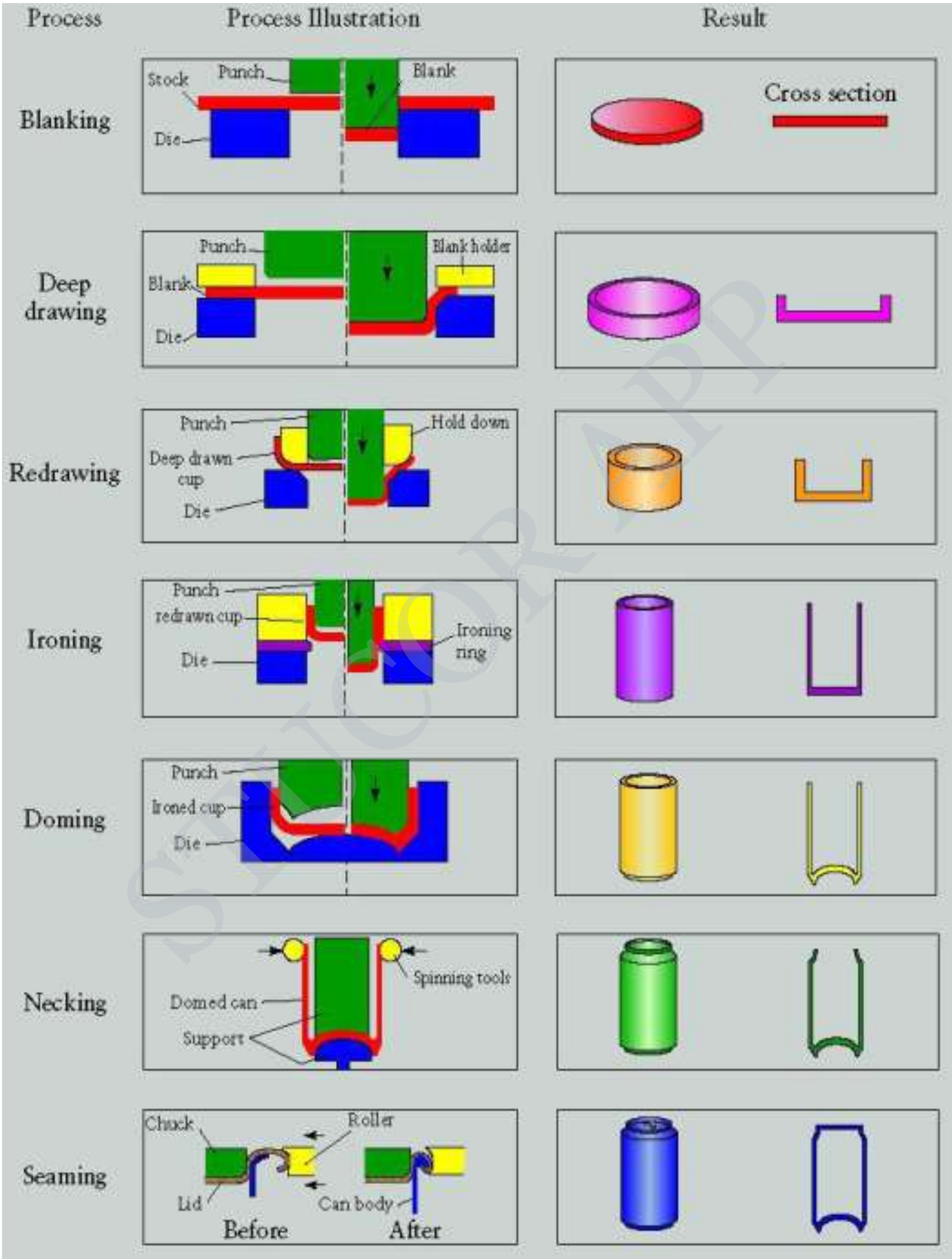
✓ If the thickness of the sheet as it enters the die cavity is more than the clearance between the punch and the die, the thickness will have to be reduced;

✓ This effect is known as ironing.

✓ Ironing produces a cup with constant wall thickness thus, the smaller the clearance, the greater is the amount of ironing.

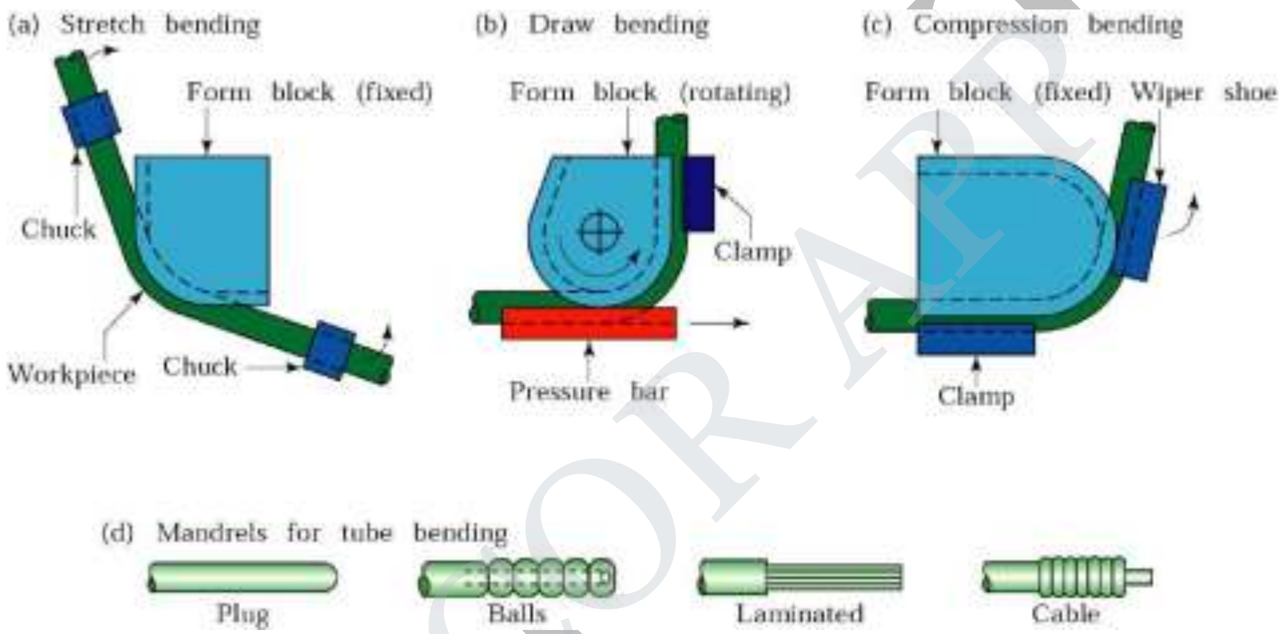
✓ All beverage cans without seams (known as two-piece cans) are ironed, generally in three steps, after being deep drawn into a cup. (Cans with separate tops and bottoms are known as three-piece cans.)

METAL-FORMING PROCESS FOR BEVERAGE CAN



Tube Bending

- ✓ Bending and forming tubes and other hollow sections require special tooling to avoid buckling and folding.
- ✓ The oldest method of bending a tube or pipe is to pack the inside with loose particles, commonly used sand and bend the part in a suitable fixture.
- ✓ This techniques prevents the tube from buckling. After the tube has been bent, the sand is shaken out.
- ✓ Tubes can also be plugged with various flexible internal mandrels.

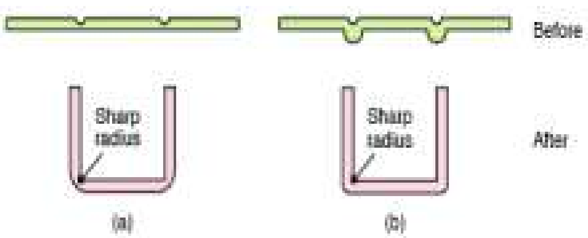


Methods of bending tubes

- ✓ Internal mandrels, or the filling of tubes with particulate materials such as sand, are often necessary to prevent collapse of the tubes during bending.
- ✓ Solid rods and structural shapes can also be bent by these techniques.

Embossing:

- ✓ An operation consisting of shallow or moderate draws, made with male and female dies, usually used for stiffening flats panels or for decoration.



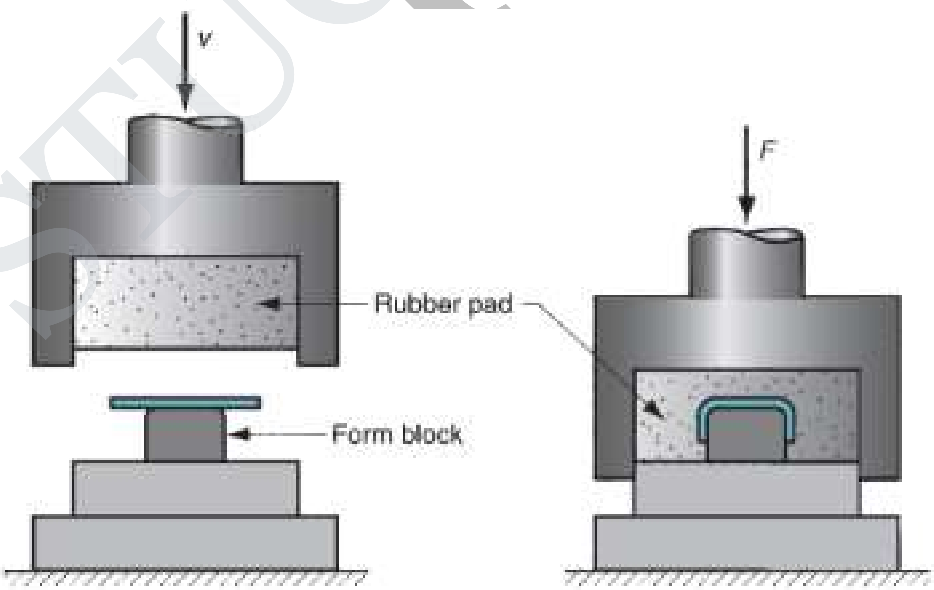
Application of (a) scoring, or (b) embossing to obtain a sharp inner radius in bending. However, unless properly designed, these features can lead to fracture. Source: Society of Manufacturing Engineers.

RUBBER FORMING PROCESSES

- ✓ The two operations are performed on conventional presses, but the tooling is unusual in that it uses a flexible element (made of rubber or similar material) to effect the forming operation.
- ✓ The operations are
  (1) Rubber Pad Forming /The Guerin process, and (2) Hydroforming.

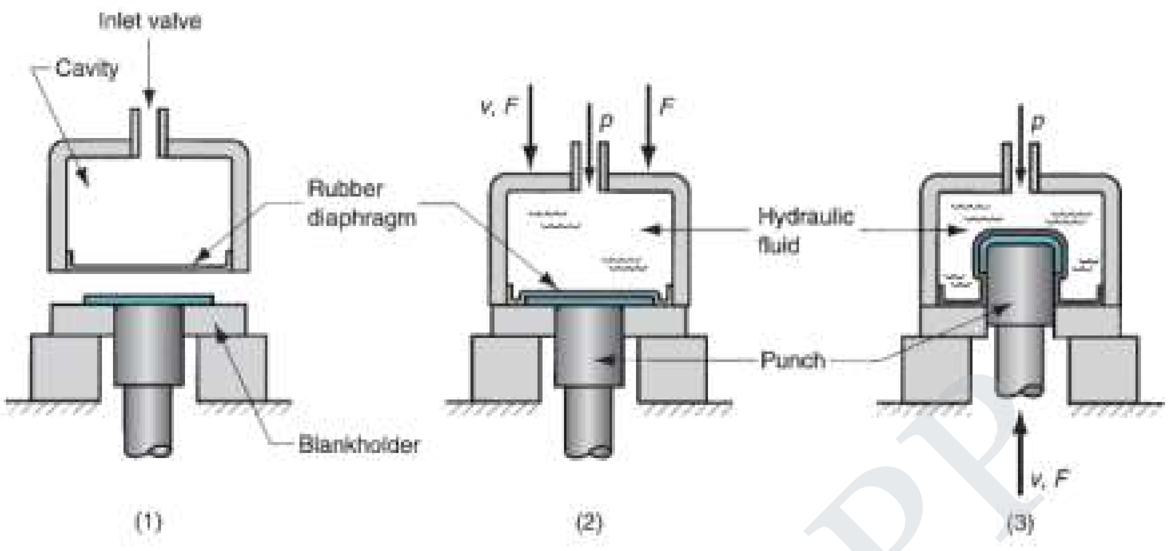
Rubber Pad Forming /The Guerin process

- ✓ Guerin process uses a thick rubber pad (or other flexible material) to form sheet metal over a positive form block.
- ✓ The rubber pad is confined in a steel container.
- ✓ As the ram descends, the rubber gradually surrounds the sheet, applying pressure to deform it to the shape of the formblock.
- ✓ It is limited to relatively shallow forms, because the pressures developed by the rubber (up to about 10 MPa) are not sufficient to prevent wrinkling in deeper formed parts.
- ✓ The *advantage* of the Guerin process is the relatively low cost of the tooling.
- ✓ The form block can be made of wood, plastic, or other materials that are easy to shape, and the rubber pad can be used with different form blocks.
- ✓ These factors make rubber forming attractive in small-quantity production, such as the aircraft industry, where the process was developed.



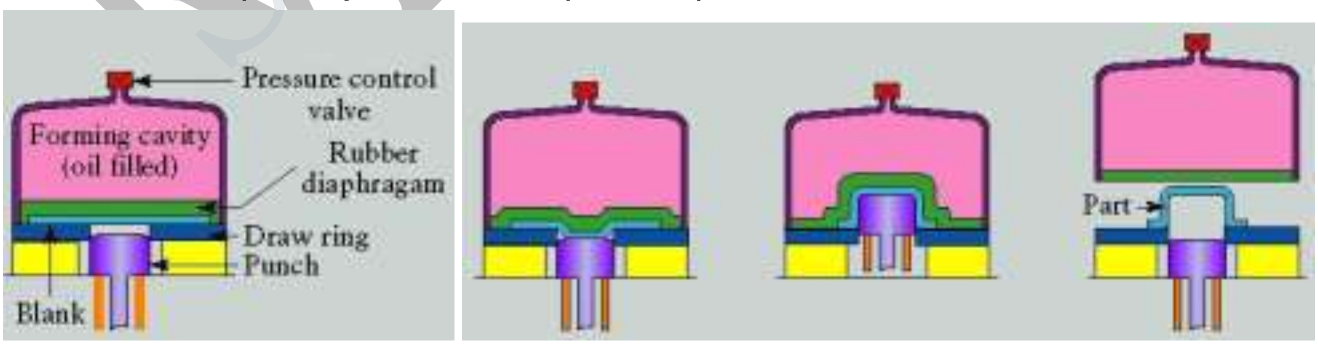
- ✓ In rubber pad forming , one of the dies in a set is made of flexible material, such as a rubber or polyurethane membrane.
- ✓ Polyurethanes are used widely because of their resistance to abrasion, long fatigue life and resistance to damage by burrs or sharp edges of the sheet blank.

Hydroform (or) Fluid Forming Process



Hydroform process: (1) start-up, no fluid in cavity; (2) press closed, cavity pressurized with hydraulic fluid; (3) punch pressed into work to form part. Symbols: v = velocity, F = applied force, p = hydraulic pressure.

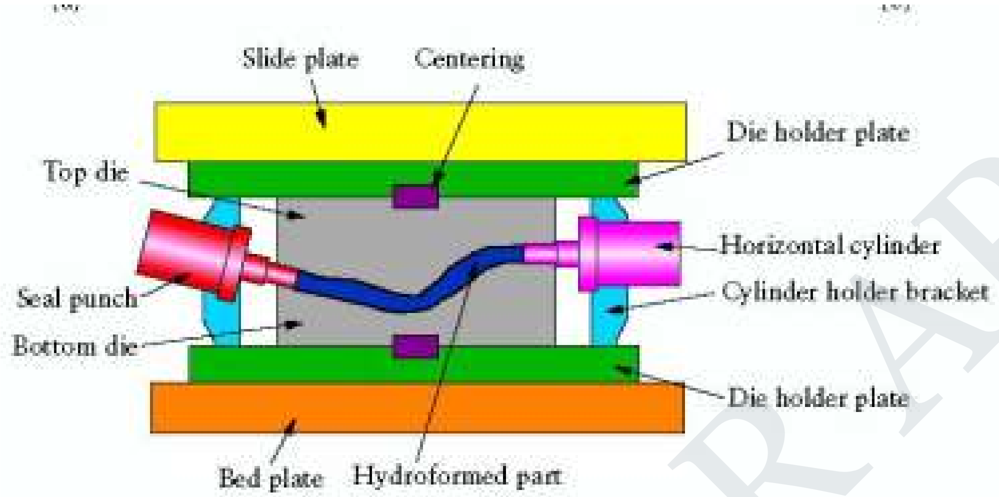
- ✓ In hydroforming or fluid forming process, the pressure over the rubber membrane is controlled throughout the forming cycle, with maximum pressure reaching 100 MPa.
- ✓ This procedure allows close control of the part during forming to prevent wrinkling or tearing.
- ✓ When selected properly, rubber forming and hydroforming processes have the following *advantages*:
  - Low tooling cost
  - Flexibility and ease of operation
  - Low die wear
  - No damage to the surface of the sheet and
  - Capability to form complex shapes.



- ✓ Note that, in contrast to the ordinary deep-drawing process, the pressure in the dome forces the cup walls against the punch.
- ✓ The cup travels with the punch; in this way, deep drawability is improved.

Tube-Hydroforming Process

- In tube hydroforming, steel or other metal tubing is formed in a die and pressurized by a fluid.
- This procedure can form simple tubes or it can form intricate hollow tubes as shown in the following Figure.
- Applications of tube-hydroformed parts include automotive exhaust and structural components.



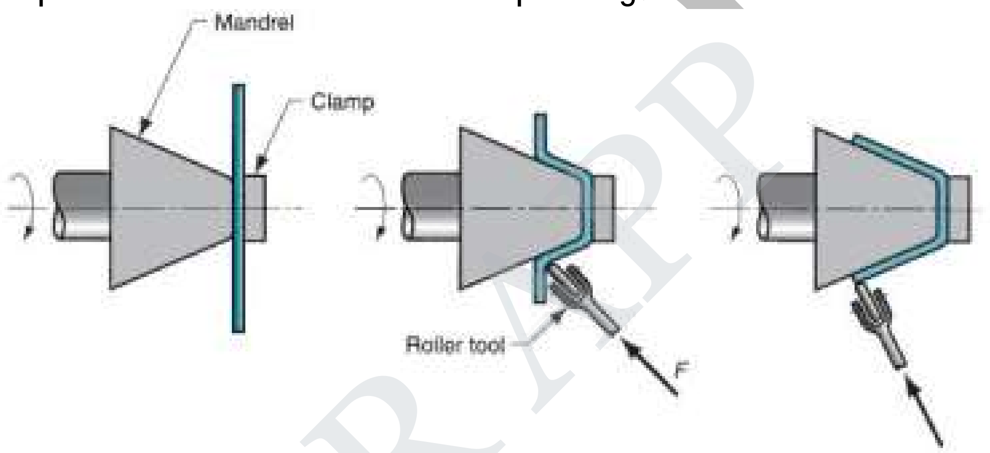
SPINNING / METAL SPINNING

- Spinning is a metal-forming process in which an axially symmetric part is gradually shaped over a mandrel or form by means of a rounded tool or roller.
- The tool or roller applies a very localized pressure (almost a point contact) to deform the work by axial and radial motions over the surface of the part.
- Basic geometric shapes typically produced by spinning include cups, cones, hemispheres, and tubes.
- There are three types of spinning operations: (1) conventional spinning, (2) shear spinning, and (3) tube spinning.

Conventional Spinning :

- Conventional spinning is the basic spinning operation.
- A sheet-metal disk is held against the end of a rotating mandrel of the desired inside shape of the final part, while the tool or roller deforms the metal against the mandrel.
- In some cases, the starting workpart is other than a flat disk.

- ✓ The process requires a series of steps, as indicated in the figure, to complete the shaping of the part.
- ✓ The tool position is controlled either by a human operator, using a fixed fulcrum to achieve the required leverage, or by an automatic method such as numerical control.
- ✓ These alternatives are manual spinning and power spinning.
- ✓ Power spinning has the capability to apply higher forces to the operation, resulting in faster cycle times and greater work size capacity.
- ✓ It also achieves better process control than manual spinning.
- ✓ Conventional spinning bends the metal around a moving circular axis to conform to the outside surface of the axisymmetric mandrel.



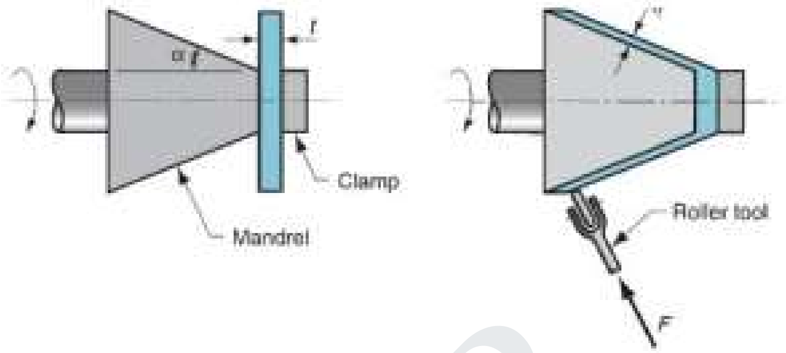
- ✓ The thickness of the metal therefore remains unchanged (more or less) relative to the starting disk thickness.
- ✓ The diameter of the disk must therefore be somewhat larger than the diameter of the resulting part.
- ✓ The required starting diameter can be figured by assuming constant volume, before and after spinning.
- ✓ *Applications* of conventional spinning include production of conical and curved shapes in low quantities. Very large diameter parts (up to 5m or more) can be made by spinning.
- ✓ Alternative sheet-metal processes would require excessively high die costs.
- ✓ The form mandrel in spinning can be made of wood or other soft materials that are easy to shape.
- ✓ It is therefore a low-cost tool compared to the punch and die required for deep drawing, which might be a substitute process for some parts.

Shear Spinning *(Flow turning/ shear forming/ spin forging)*

- ✓ In shear spinning, the part is formed over the mandrel by a shear deformation process in which the outside diameter remains constant and the wall thickness is therefore reduced.

- ✓ This shear straining (and consequent thinning of the metal) distinguishes this process from the bending action in conventional spinning.

  he process has been applied in the aerospace industry to form large parts such as *rocket nose cones.*



- ✓ There are limits to the amount of thinning that the metal will endure in a spinning operation before fracture occurs.
- ✓ The maximum reduction correlates well with reduction of area in a tension test
- ✓

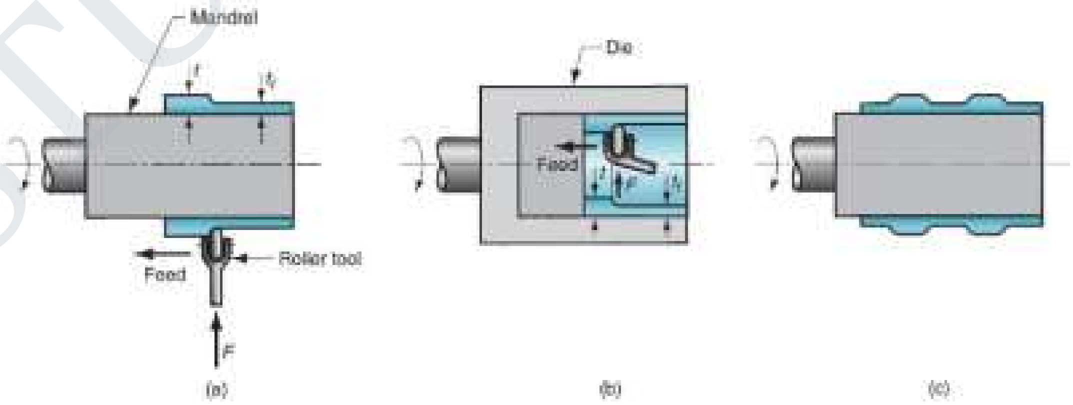
For the simple conical shape in our figure, the resulting thickness of the spun wall can be readily determined by the sine law relationship:

$$t_f = t \sin \alpha$$

where t_f = the final thickness of the wall after spinning, t = the starting thickness of the disk, and α = the mandrel angle (actually the half angle).

Tube Spinning

- ✓ Tube spinning is used to reduce the wall thickness and increase the length of a tube by means of a roller applied to the work over a cylindrical mandrel.
- ✓ Tube spinning is similar to shear spinning except that the starting workpiece is a tube rather than a flat disk.
- ✓ The operation can be performed by applying the roller against the work externally (using a cylindrical mandrel on the inside of the tube) or internally (using a die to surround the tube).

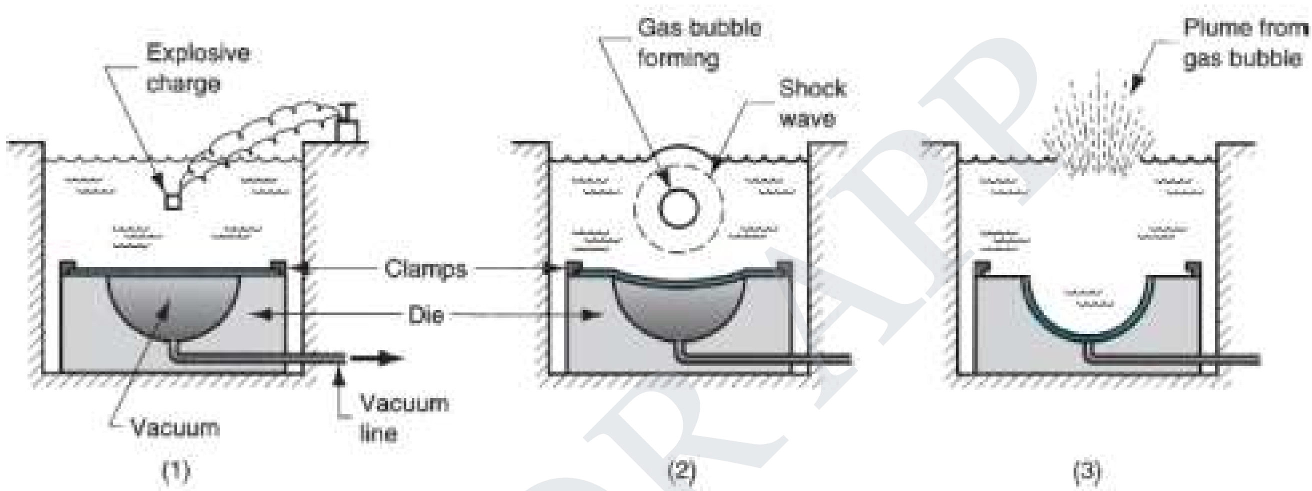


Tube spinning: (a) external; (b) internal; and (c) profiling.

- ✓ It is also possible to form profiles in the walls of the cylinder, by controlling the path of the roller as it moves tangentially along the wall.

Explosive Forming Process

- Explosive forming involves the use of an explosive charge to form sheet (or plate) metal into a die cavity.
- The workpart is clamped and sealed over the die, and a vacuum is created in the cavity beneath.
- The apparatus is then placed in a large vessel of water.

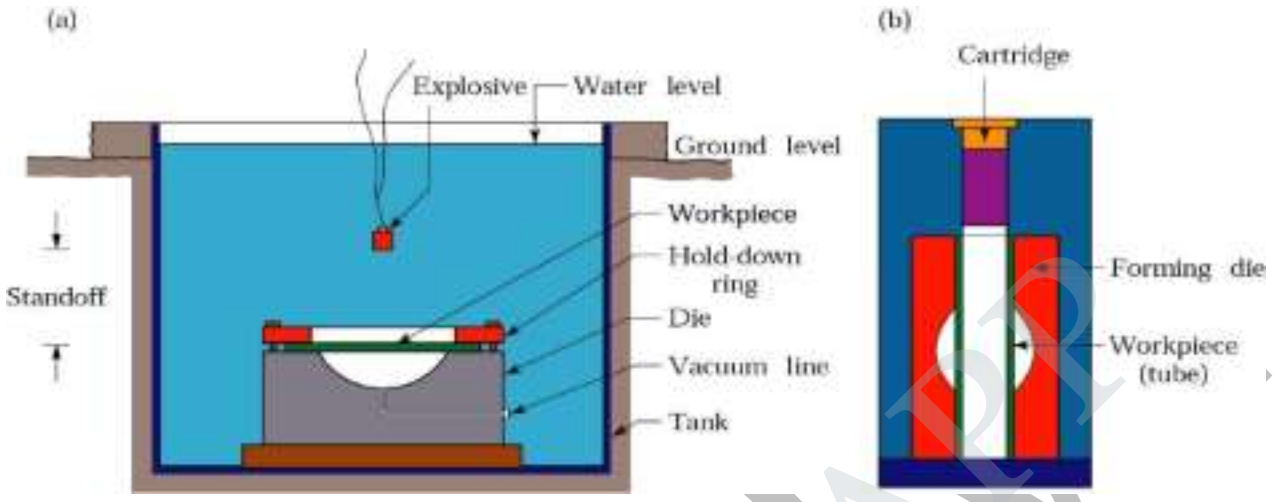


- An explosive charge is placed in the water at a certain distance above the work.
- Detonation of the charge results in a shock wave whose energy is transmitted by the water to cause rapid forming of the part into the cavity.
- On detonation of the explosive, a pressure pulse of very high intensity is produced. A gas bubble is also produced which expands spherically and then collapses. When the pressure pulse impinges against the work piece, the metal is deformed into the die with as high velocity as 120 m/s.
- The size of the explosive charge and the distance at which it is placed above the part are largely a matter of art and experience.
- The process has been successfully used to form steel plates 25 mm thick x 4 m diameter and to bulge steel tubes as thick as 25 mm.

Contact Technique:

- The explosive charge in the form of cartridge is held in direct contact with the work piece while the detonation is initiated.

✓ The detonation builds up extremely high pressures (upto 30,000MPa) on the surface of the work piece resulting in metal deformation, and possible fracture.



(a) Explosive forming process. (b) Confined method of explosive bulging of tubes.

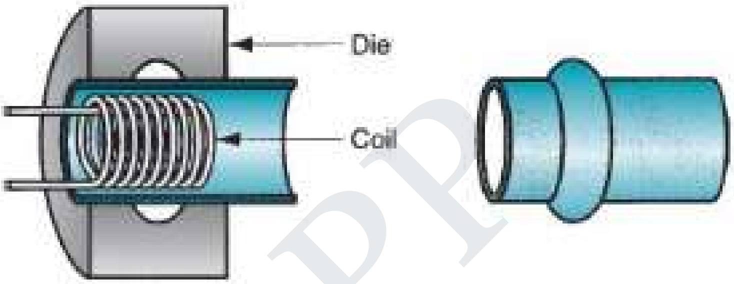
Applications:

✓ Explosive forming is mainly used in the aerospace industries but has also found successful applications in the production of automotive related components.

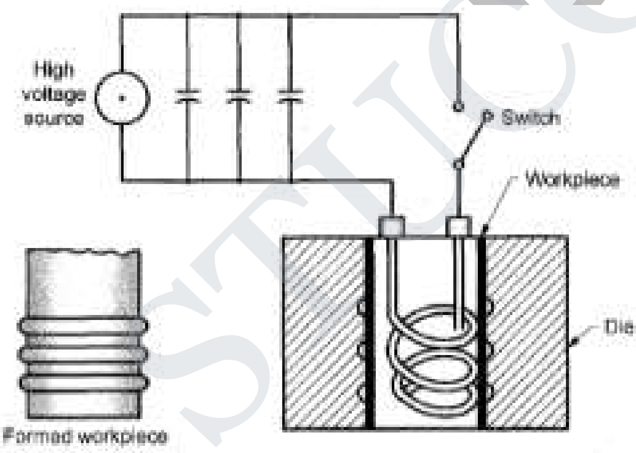
✓ The process has the greatest potential in limited – production prototype forming and for forming large size components for which conventional tooling costs are prohibitively high.

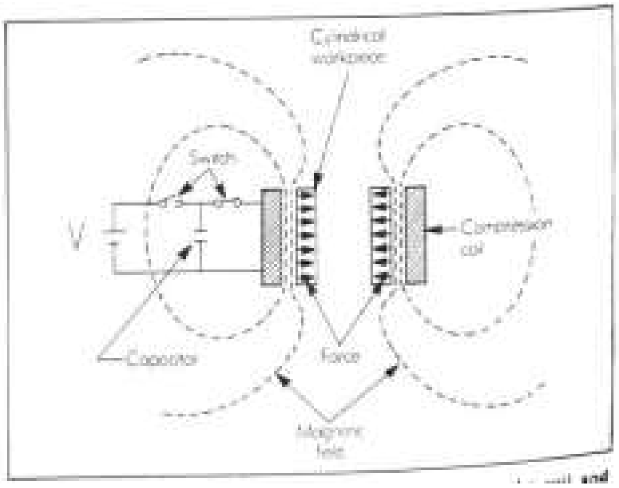
Magnetic Pulse Forming / Electromagnetic Forming

- ✓ Developed in the 1960s, electromagnetic forming is the most widely used HERF process.
- ✓ It is a process in which sheet metal is deformed by the mechanical force of an electromagnetic field induced in the workpart by an energized coil.
- ✓ It is typically used to form tubular parts.
- ✓ The coil, energized by a capacitor, produces a magnetic field.
- ✓ The forming is done in an intense magnetic field round a coil placed inside, outside or near a workpiece.
- ✓ A high voltage source charges a bank of capacitors in a very short time.

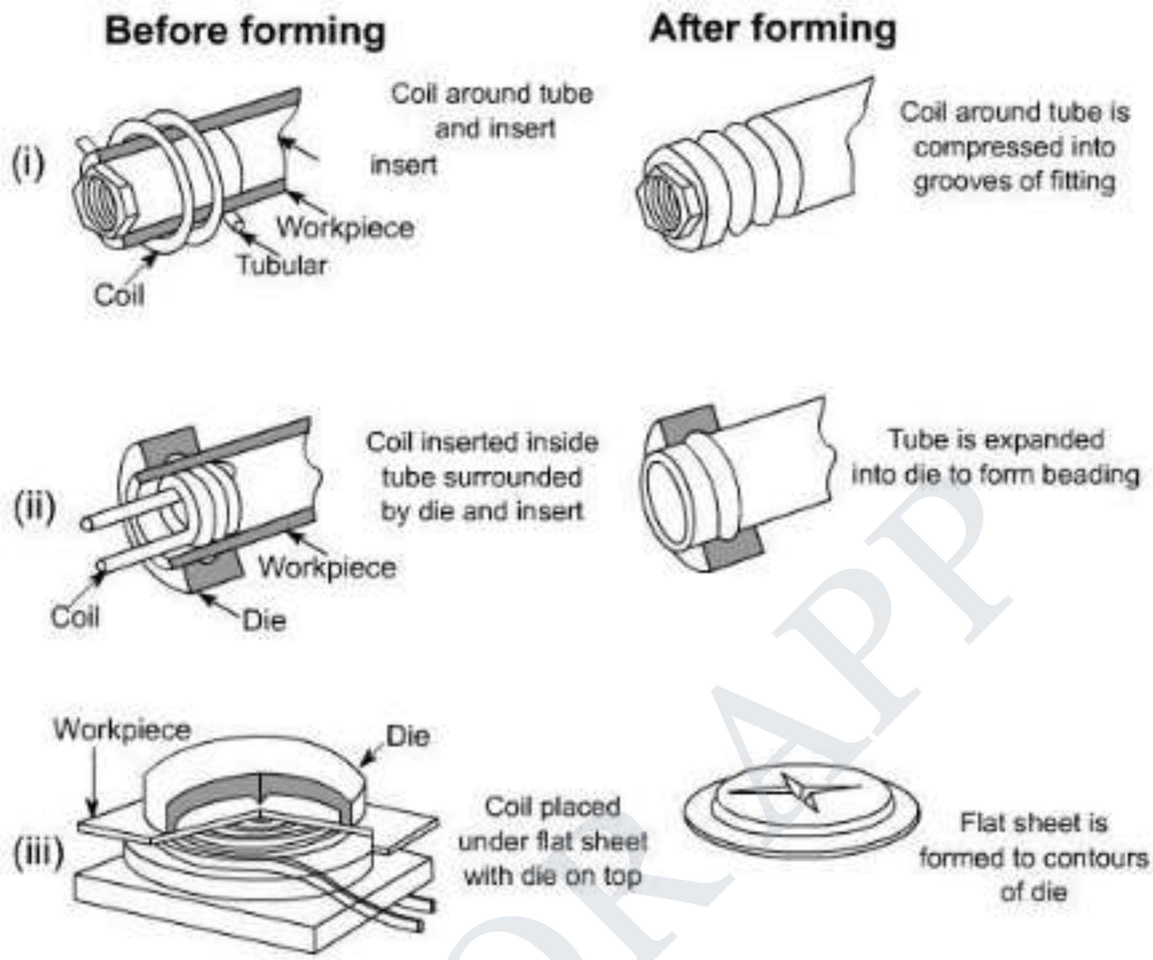


- ✓ The stored energy is triggered by a switch through the coil setting up a high intensity magnetic field.
- ✓ Eddy currents are induced in the workpiece setting up strong repulsive forces which force the workpiece to take the shape of the surrounding die block.





- ✓ The amount of energy stored can be varied by increasing the number of capacitors in the capacitor bank or by increasing the supply voltage.
- ✓ When forming poor conductors a thin layer of copper coating on the sheet is helpful.
- ✓ The process is very useful for operations like expanding, swaging, bulging, flanging, forming and drawing.
- ✓ With suitable coil design flat pieces may also be blanked or embossed.
- ✓ The process can be easily automated.

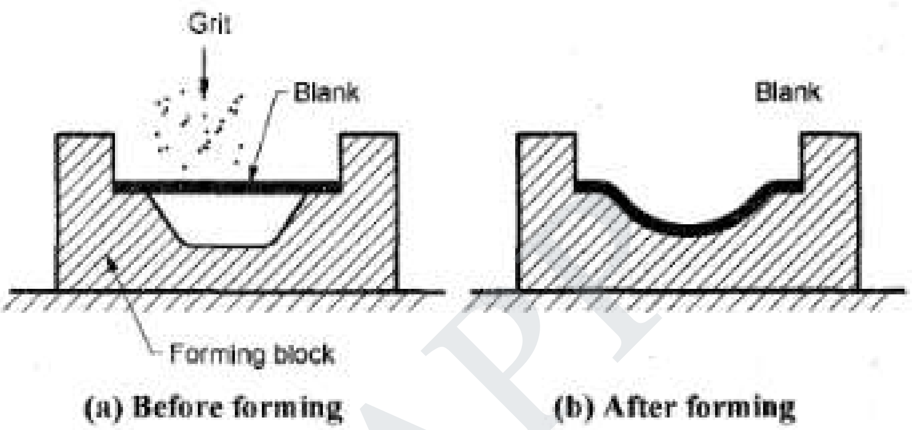


Applications:

- ✓ Electromagnetic forming process is capable of a wide variety of forming and assembly operations.
- ✓ It has found extensive applications in the fabrication of hollow, non – circular, or asymmetrical shapes from tubular stock.
- ✓ The compression applications involve swaging to produce compression, tensile, and torque joints or sealed pressure joints, and swaging to apply compression bands or shrink rings for fastening components together.
- ✓ Flat coils have been used on flat sheets to produce stretch (internal) and shrink (external) flanges on ring and disc – shaped work pieces.
- ✓ Electromagnetic forming has also been used to perform shearing, piercing, and rivettting.

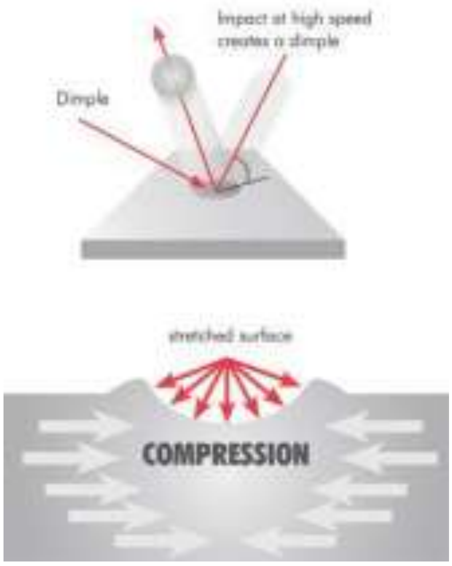
Peen Forming

- Peen forming also known as free forming is a mechanical forming process with an operation similar to shot metal peening.
- It is a dieless forming process (No punch/die) that is performed at room temperature.
- In this process the sheet metal blank is clamped and then bombarded with a stream of metal grit at a very high velocity.
- The blank may be placed on a flat surface, suspended or stretched over a block shaped to the desired contour.
- Under the force of the blast the sheet takes the shape of the block.



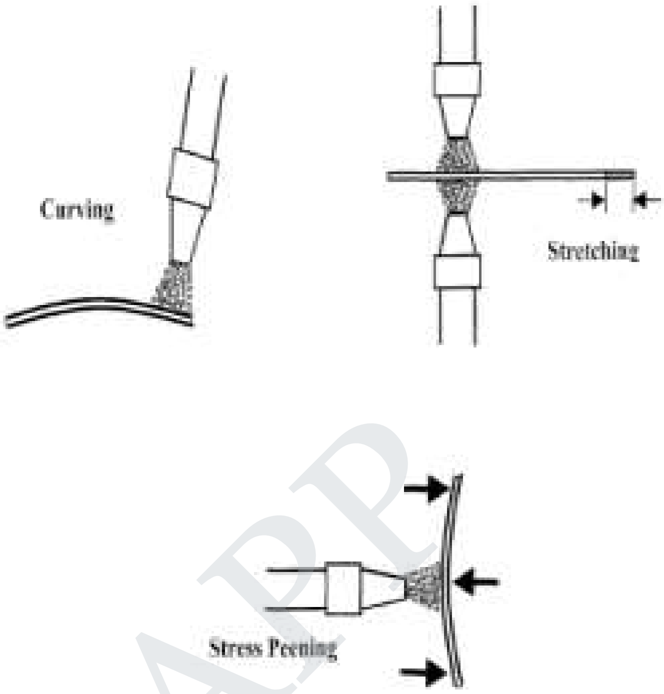
(a) Before forming (b) After forming

- The process can be used for producing sections of connecting rods, cranks, gears etc.
- It is also useful for producing honeycomb panels for aircraft etc
- Peen forming is the preferred method of forming aerodynamic contours into aircraft wing skins.
- The process is ideal for forming wing and empennage panel shapes for even the largest aircraft.
- It is best suited for forming curvatures where the radii are within the elastic range of the metal.
- Through the peen forming process, residual compressive stress acts to elastically stretch the peened side as shown in Figure. The surface will bend or "arc" towards the peened side.
- The resulting curvature will force the lower surface into a compressive state.
- Typically an aircraft wing skin has a large surface area and thin cross sectional thickness.
- Therefore, significant forces are generated from the shot peening residual stress over this large surface area.



- The thin cross section is able to be manipulated into desired contours when the peen forming is properly engineered and controlled.

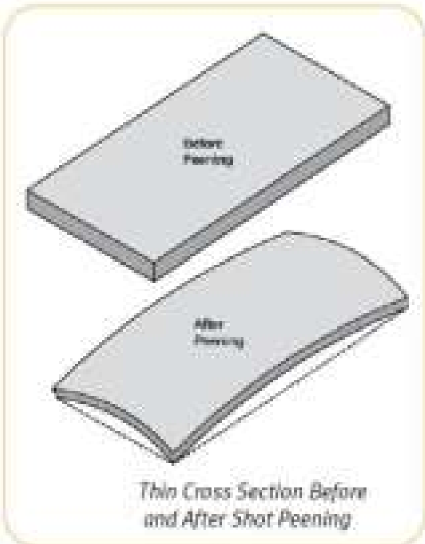
Advantages :



- ✓ No forming dies are required.
- ✓ Process is performed at room temperature.
- ✓ Wingskin design changes are easily accomplished by altering the peen forming procedure. There is no expensive modification of dies required.
- ✓ Complex contours generally in sheets of soft materials like aluminium alloys can be easily produced.
- ✓ The process can also be used for salvaging or correcting of damaged parts.

Disadvantages:

- ✓ Additional equipment is required for shooting the metal grit.
- ✓ The process generally takes a long time.
- ✓ Peen formed parts exhibit increased resistance to flexural bending fatigue and stress corrosion cracking as a result.
- ✓ Peen formed skins exhibit compressive stress on the top and bottom surfaces.

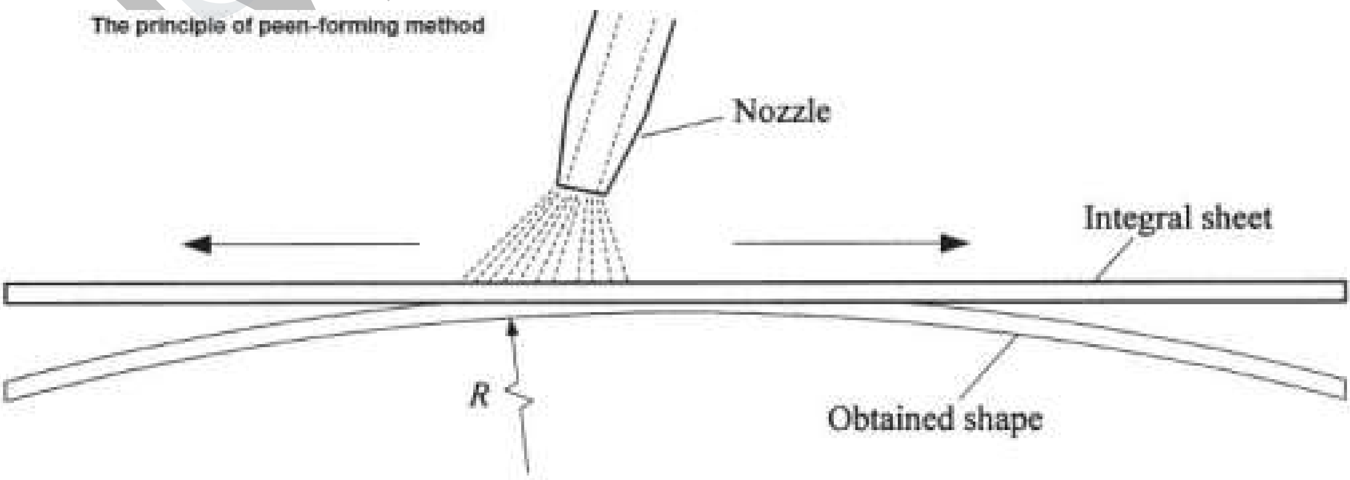


Thin Cross Section Before and After Shot Peening

Applications:

- ✓ The majority of aircraft in production with aerodynamically formed aluminum alloy wingskins employ the peen forming process.
- ✓ A properly engineered peen forming procedure will compensate for varying curvature requirements, varying wingskin thickness, cutouts, reinforcements and pre-existing distortion.

The principle of peen-forming method



Superplastic Forming

- ✓ Super plasticity can be defined as the ability of certain materials to undergo very high tensile strains at specific temperature and strain rate.
- ✓ Material that have been developed to show super plastic behaviour include the following :

  Bismuth- tin.

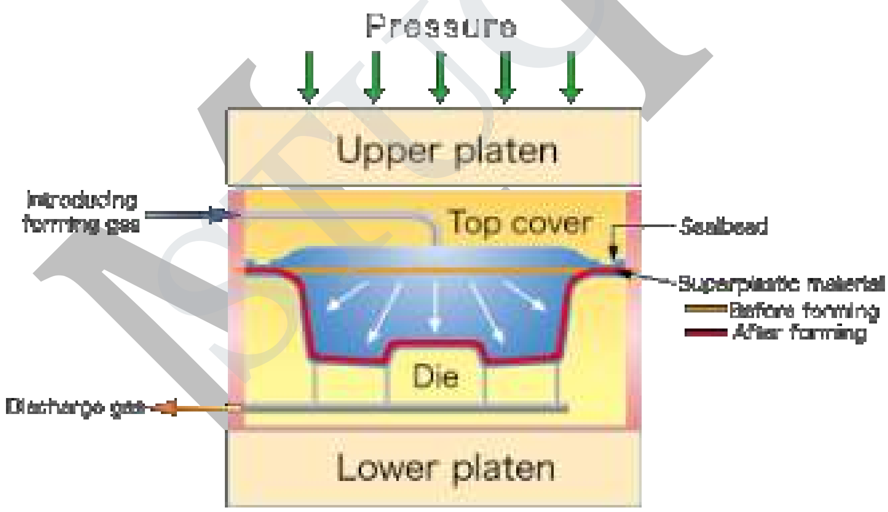
  Zinc-aluminium.

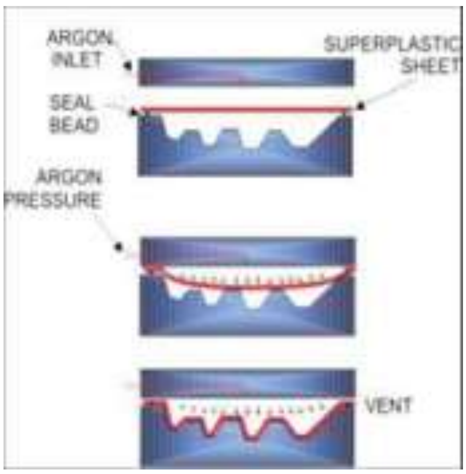
  Aluminium.

  Titanium.

  Aluminium-lithium alloy.

- ✓ Superplasticity in metals is defined by very high tensile elongations, ranging from two hundred to several thousand percent.
- ✓ Process, conducted under controlled temperature and strain rates, dramatically increases the formability of certain aluminum alloys, and allows production of highly integrated, net-shape components that often consolidate many parts into one.
- ✓ The number of parts, fasteners, and assembly operations required for complex automotive and aerospace applications, and enables the use of aluminum in place of steel at competitive costs.





- ✓ When processed at the correct temperature and strain rate the super plastic material, can show very high tensile elongation from 200 to several thousand percent of the normal elongation at room temperature.
- ✓ Super plastic forming process has therefore been used to produce very complex shapes and structures that are lighter and stronger than those produced by any other method.

- The process is finding extensive application in aerospace industry.
- In carrying out the super plastic forming the alloy is first heated to around 1000 C (for steel; normally 0.6 T_m to 0.75 T_m) by using an inert gas with pressure of up to 50 bars and then formed to the required shape.
- The blank is mounted in the form die and then heated to the required super plastic temperature.
- Once the temperature is reached it is controlled very accurately because the range in which materials show super plasticity is usually very narrow.
- The pressure of the gas slowly inflates the blank do takes the inside contour of the forming die as shown.

Advantages

- Very complex contours can be produced in one step.
- Elongations obtained are much higher than those obtainable at room temperature.
- The final contour is obtained without the need for any joints.
- There is no need for any finishing operations.
- Produce complex shapes (3D) with essentially constant section thickness.
- Shapes with close tolerances can be made
- Weight and material savings
- Little or no residual stress and springback occurs in the formed parts
- Products can also be made larger to eliminate assemblies or reduce weight, which is critical in aerospace applications.

Disadvantages

- Materials must not be superplastic at service temperatures
- Longer cycle times (2 min to 2 hours)
- Require controlled conditions of appropriate temperature and strain rate, by using low force.
- Good surface finishes.
- special microstructure conditions and careful control of alloying elements to obtain an extremely fine structure with a grain size < 10μm
- Poor creep due to small grain size.

Press for Sheet Metal

Press selection for sheet metal forming operations depends on several factors:

- ✓ Type of forming operation, and dies and tooling required
- ✓ Size and shape of work pieces
- ✓ Length of stroke of the slide, stroke per minute, speed and shut height (distance from the top of the bed to the bottom of the slide, with the stroke down)
- ✓ Number of slides (single action, double action and triple action)
- ✓ Maximum force required (press capacity, tonnage rating)
- ✓ Type of controls
- ✓ Die changing features
- ✓ Safety features

Punch and Die Shapes: As the surfaces of the punch and die are flat; thus, the punch force builds up rapidly during shearing, because the entire thickness of the sheet is sheared at the same time.

TYPES OF DIES

The type of die considered above performs a single blanking operation with each stroke of the press and is called a simple die. Other dies that perform a single operation include V-dies.

A compound die performs two operations at a single station, such as blanking and punching, or blanking and drawing. A good example is a compound die that blanks and punches a washer.

Compound Dies: Several operations on the same strip may be performed in one stroke with a compound die in one station. These operations are usually limited to relatively simple shearing because they are somewhat slow and the dies are more expensive than those for individual shearing operations.

A combination die is less common; it performs two operations at two different stations in the die. Examples of applications include blanking two different parts (e.g., right-hand and left-hand parts), or blanking and then bending the same part.

Progressive Dies: Parts requiring multiple operations, such as punching, blanking and notching are made at high production rates in progressive dies.

Transfer Dies: In a transfer die setup, the sheet metal undergoes different operations at different stations, which are arranged along a straight line or a circular path. After each operation, the part is transfer to the next operation for additional operations.

Process	Characteristics
Roll forming	Long parts with constant complex cross-sections; good surface finish; high production rates; high tooling costs.
Stretch forming	Large parts with shallow contours; suitable for low-quantity production; high labor costs; tooling and equipment costs depend on part size.
Drawing	Shallow or deep parts with relatively simple shapes; high production rates; high tooling and equipment costs.
Stamping	Includes a variety of operations, such as punching, blanking, embossing, bending, flanging, and coining; simple or complex shapes formed at high production rates; tooling and equipment costs can be high, but labor costs are low.
Rubber-pad forming	Drawing and embossing of simple or complex shapes; sheet surface protected by rubber membranes; flexibility of operation; low tooling costs.
Spinning	Small or large axisymmetric parts; good surface finish; low tooling costs, but labor costs can be high unless operations are automated.
Superplastic forming	Complex shapes, fine detail, and close tolerances; forming times are long, and hence production rates are low; parts not suitable for high-temperature use.
Peen forming	Shallow contours on large sheets; flexibility of operation; equipment costs can be high; process is also used for straightening parts.
Explosive forming	Very large sheets with relatively complex shapes, although usually axisymmetric; low tooling costs, but high labor costs; suitable for low-quantity production; long cycle times.
Magnetic-pulse forming	Shallow forming, bulging, and embossing operations on relatively low-strength sheets; most suitable for tubular shapes; high production rates; requires special tooling.

General characteristics of sheet-metal forming processes.

Formability of sheet metal

- ✓ *Formability is the ability of sheet metal to undergo shape change without failure by necking or tearing.*
- ✓ Formability is a measure of the amount of deformation a material can withstand prior to fracture or excessive thinning.
- ✓ Sheet metal forming ranges from simple bending, to stretching, to deep drawing of complex parts. Therefore, determining the extent to which a material can deform is necessary for designing a reproducible forming operation.
- ✓ Formability may be defined as the ability of a material to be formed by application of suitable stresses.
- ✓ Formability depends on two variables namely:

  1. Material variables 2. Process variables
- ✓ Material variables are the basic variable that govern the ductility of the material.
- ✓ Ductility of the material reflects the ability of the material to distribute the localized stresses there by lowering the tendency of crack formation. It is commonly expressed on percentage elongation or percentage strain at the fracture points.
- ✓ The maximum plastic strain that a material can withstand without localized deformation is the strain corresponding to the ultimate stress of the material where necking starts.
- ✓ This strain is used as an index of formability of the material for some sheet metal operations.
- ✓ The process variables that govern the formability of a material include the following. (i) Applied stress system (ii) Interface friction (iii) Lubrication at the interface (iv) Shape and size of the product (v) Die design
- ✓ Mathematically formability may be expressed as

  Formability = (F_l, F_2)

  Where, F_1 = Material variables

  F_2 = Process variables

Formability Test

1. Tests based on tensile test
2. Simulative drawing tests
3. Full scale forming tests

TESTS BASED ON TENSILE TEST:

- ✓ These tests are important for stretching and drawing operations and indicate the material behaviour for these operations.
- ✓ Tests for stretch forming consist of determination of the tendency of the material to fracture in terms of its local thinning.
- ✓ The strain hardening behaviour of the material can be expressed forms of σ = K ^{n}

  σ represents the applied stress on the material,

  ε is the strain,

  K is the strength coefficient.

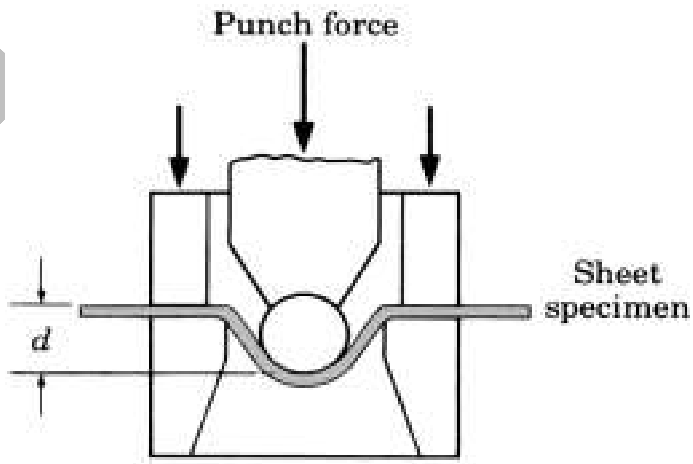
  N is the strain hardening exponent. (The value lies between 0 and 1. A value of 0 means that a material is a perfectly plastic solid, while a value of 1 represents a 100% elastic solid)
- ✓ Higher values of n indicate more uniform distribution of strain and hence the possibility of obtaining deepen pressing.
- ✓ Tests for drawing operation consist of deforming the sheet metal by thinning under biaxial stresses : Average value of sheet metal radius is determined by orienting the metal flow at 0°, 45° and 90°.

SIMULATIVE TESTS:

- ✓ Simulative tests are tests conducted in terms of cup forming operations.
- ✓ Four varieties of these tests are in use:

(i) Erichsen Test: (used in Europe)

- ✓ This test is mainly carried out to determine the stretchability of sheet metal.
- ✓ A standard specimen 90 mm wide is clamped rigidly over a die having a 27 mm diameter opening.



- ✓ A 20 mm diameter spherical punch is moved against the sheet metal till a fracture starts and a bulge is formed below the punch.
- ✓ The depth of the bulge gives the Erichsen number which indicates *stretchability* of the sheet metal.

(ii) Olsen Test:

- ✓ The test is similar to the Erichsen test except that the diameter of the die opening used is 25.4 mm and the specimen is clamped lightly. (Used is America)

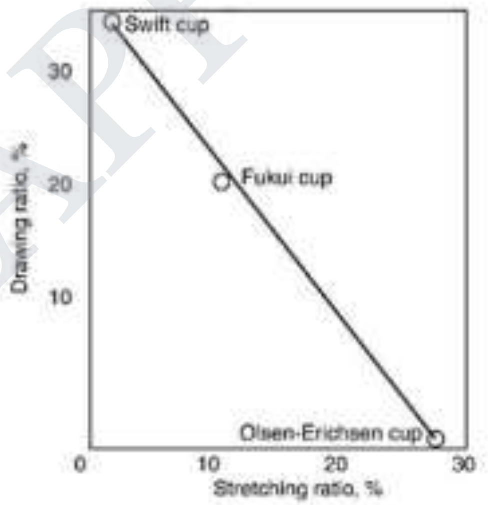
- This test is also carried out for assessing *stretchability*.

(iii) Swift Test:

- In this test flat bottomed cups of uniform diameter are formed from a series of sheet metal blanks of difference diameter.
- The test is continued till a blank size is determined at which all cups fracture.
- The ratio Blank diameter/punch diameter called Limiting Drawing Ratio (L.D.R) is used as an indicator of the *drawability* of the sheet.
- The main drawback of the test is the formation of edge wrinkles on the lightly clamped blanks.

(iv) Fukui Test:

- This test is used for judging stretchability and drawability of the sheet metal.
- In this test both the die and the punch have a conical shape.
- A fixed diameter blank is drawn between the die and the punch.
- The holding pressure on the blank is gradually increased till the edge winkling is completely eliminated.



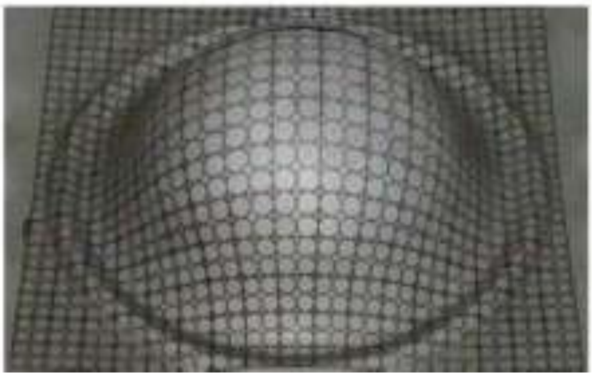
- The cup depth measured at maximum load called formability index indicates both the *drawability and stretchability* of the sheet metal.

Full scale forming test:

- This test is carried out to obtain the Forming Limit Diagram for the material under different load conditions.
- A forming limit diagram, also known as a forming limit curve, is used in sheet metal forming for predicting forming behaviour of sheet metal. The diagram attempts to provide a graphical description of material failure tests, such as a punched dome test.
- For the test a grid pattern or a number of concentric circles arc impregnated on the sheet and the sheet is pressed.
- During pressing the concentric circles are stretched into elliptical shape with major and minor axes of the ellipse being along the direction.

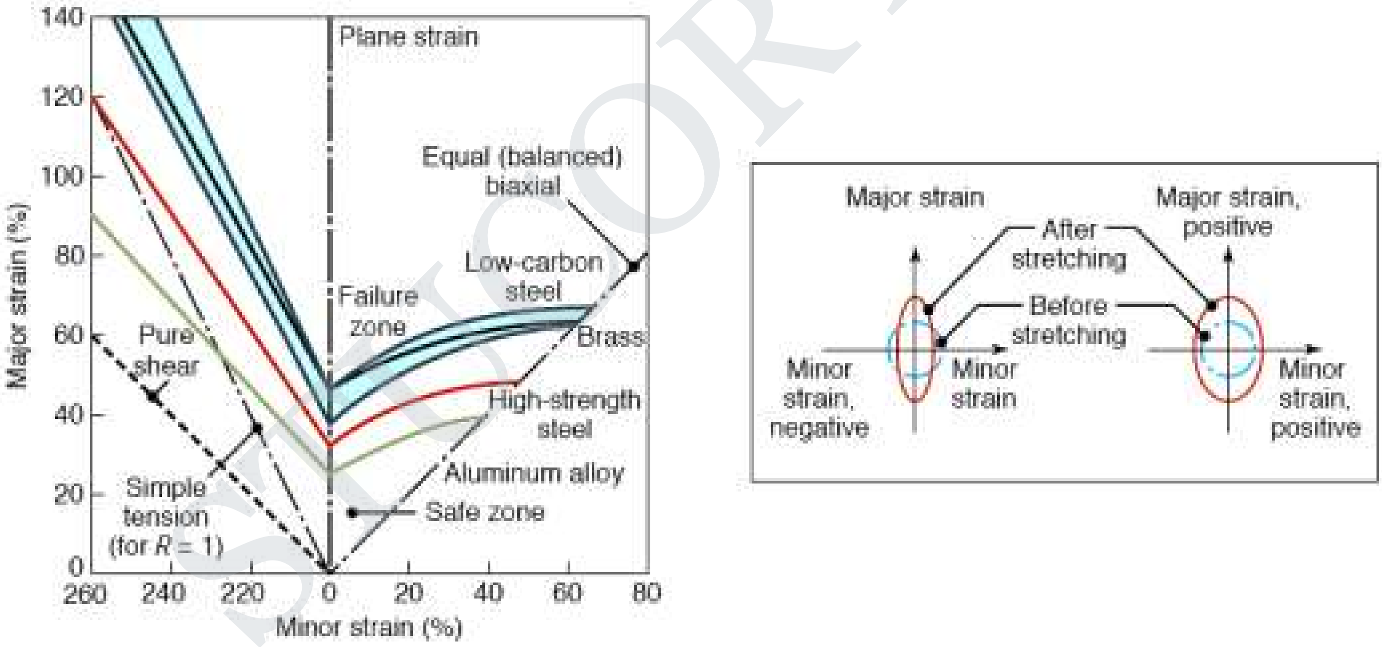
- ✓ The magnitude of strain is calculated using the relation.

$$\epsilon = \frac{l - d}{d}$$



where ϵ = The strain along the axis
l = The length of the major or minor axis
d = diameter of the original concentric circle.

- ✓ Surface strain is maximum along the major axes and minimum along the minor axes.
- ✓ The results are plotted on the form of graph between the major and minor strains.
- ✓ For the left hand side of the graph $_2$ is negative. This indicates combined tension and compression for deep drawing operation.
- ✓ The right hand side shows positive minor strains which indicates bi-axial tension for stretching operation.



(a) (b)

(a) Forming-limit diagram (FLD) for various sheet metals. Note that the major strain is always positive. The region above the curves is the failure zone; hence, the state of strain in forming must be such that it falls below the curve for a particular material; *R* is the normal anisotropy. (b) Illustrations of the definition of positive and negative minor strains. If the area of the deformed circle is larger than the area of the original circle, the sheet is thinner than the original thickness because the volume remains constant during plastic deformation. *Source:* After S.S. Hecker and A.K. Ghosh.

UNIT V MANUFACTURE OF PLASTIC COMPONENTS 9

Types and characteristics of plastics – Moulding of thermoplastics – working principles and typical applications – injection moulding – Plunger and screw machines – Compression moulding, Transfer Moulding – Typical industrial applications – introduction to blow moulding –Rotational moulding – Film blowing – Extrusion – Thermoforming – Bonding of Thermoplastics.

Polymers

- ✓ A polymer is a compound consisting of long-chain molecules, each molecule made up of repeating units connected together.
- ✓ There may be thousands, even millions of units in a single polymer molecule.
- ✓ The word is derived from the Greek words poly, meaning many, and meros (reduced to mer), meaning part.
- ✓ Most polymers are based on carbon and are therefore considered organic chemicals.
- ✓ Polymers can be separated into plastics and rubbers.
- ✓ As engineering materials, they are relatively new compared to metals and ceramics, dating only from around the mid-1800s.
- ✓ It is appropriate to divide them into the following three categories

Thermoplastic polymers (*thermoplastics/TP*)

Thermosetting polymers (*thermosets/TS*)

Elastomers (*rubbers/E*)

Thermoplastic polymers (thermoplastics)

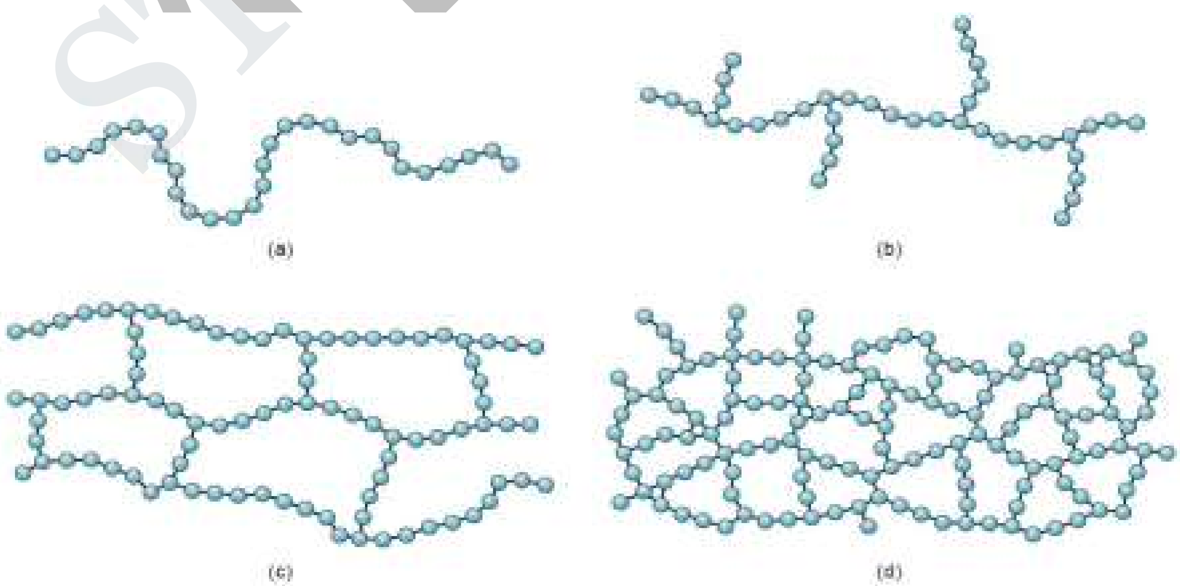
- ✓ TP Solid materials at room temperature, but they become viscous liquids when heated to temperatures of only a few hundred degrees.
- ✓ This characteristic allows them to be easily and economically shaped into products.
- ✓ They can be subjected to this heating and cooling cycle repeatedly without significant degradation of the polymer.
- ✓ The most important thermoplastics are:
  - ✓ Acrylics (*Plexiglas*) : lenses, window glazing
  - ✓ Fluorocarbons (*Teflon*) : nonstick coatings, bearings, seals
  - ✓ Polyamides (*Nylons, Kevlar*) : fibers
  - ✓ Polycarbonates (*Lexan*) : helmets, bullet-resistance windows, wind-shields
  - ✓ Polyesters (*Dacron, Mylar, Kodel*) : gears, cams, rollers
  - ✓ Polyvinyl chloride (*PVC*) : pipes, cable insulation, packaging, flooring, toys
  - ✓ Polyethylene : bottles, cans, packaging materials

Thermosetting polymers (Thermosets)

- ✓ TS cannot tolerate repeated heating cycles as thermoplastics can.
- ✓ When initially heated, they soften and flow for molding, but the elevated temperatures also produce a chemical reaction.
- ✓ The most important thermosets are:
  - ✓ Epoxies : fiber-reinforced materials
  - ✓ Phenolics (*Bakelite*) : knobs, handles, cases
  - ✓ Polyesters : fiber-reinforced materials
  - ✓ Silicones : waterproof and heat resistance materials

Elastomers (rubbers)

- ✓ Elastomers are the rubbers. Elastomers (E) are polymers that exhibit extreme elastic extensibility when subjected to relatively low mechanical stress.
- ✓ Some elastomers can be stretched by a factor of 10 and yet completely recover to their original shape.
- ✓ Although their properties are quite different from thermosets, they have a similar molecular structure that is different from the thermoplastics.
- ✓ The most important rubbers are:
  - ✓ Natural rubber (*Latex*): : tires, shoes, seals
  - ✓ Silicones: : seals, thermal insulation, electronics
  - ✓ Polyurethane: : seals, gaskets
- ✓ *The difference in properties of the polymers are attributable to so-called cross-linking, which occurs in thermosets and partially in elastomers:*



Various structures of polymer molecules: (a) linear, characteristic of thermoplastics; (b) branched; (c) loosely cross-linked as in an elastomer; and (d) tightly cross-linked or networked structure as in a thermoset.

ADDITIVES

- The properties of a polymer can often be beneficially changed by combining them with additives.
- Additives either alter themolecular structure of the polymer or add a second phase to the plastic, in effect transforming a polymer into a composite material.
- Additives can be classified by function as (1) fillers, (2) plasticizers, (3) colorants, (4) lubricants, (5) flame retardants, (6) cross-linking agents, (7) ultraviolet light absorbers, and (8) antioxidants.

Filler

- Fillers are solid materials added to a polymer usually in particulate or fibrous form to alter its mechanical properties or to simply reduce material cost.
- Other reasons for using fillers are to improve dimensional and thermal stability. Examples of fillers used in polymers include cellulosic fibers and powders (e.g., cotton fibers and wood flour, respectively); powders of silica (SiO_2), calcium carbonate ($CaCO_3$), and clay (hydrous aluminum silicate); and fibers of glass, metal, carbon, or other polymers.
- Fillers that improve mechanical properties are called reinforcing agents, and composites thus created are referred to as reinforced plastics; they have higher stiffness, strength, hardness, and toughness than the original polymer.
- Fibers provide the greatest strengthening effect.

Plasticizers

- Plasticizers are chemicals added to a polymer to make it softer and more flexible, and to improve its flow characteristics during forming.
- The plasticizer works by reducing the glass transition temperature to below room temperature.
- Whereas the polymer is hard and brittle below Tg, it is soft and tough above it.
- Addition of a plasticizer to polyvinylchloride (PVC) is a good example; depending on the proportion of plasticizer in the mix, PVC can be obtained in a range of properties, from rigid and brittle to flexible and rubbery.

Colorants

- An advantage of many polymers over metals or ceramics is that the material itself can be obtained in most any color.
- This eliminates the need for secondary coating operations.
- Colorants for polymers are of two types: pigments and dies.

- ✓ Pigments are finely powdered materials that are insoluble in andmust be uniformly distributed throughout the polymer in very low concentrations, usually less than1%.
- ✓ They often add opacity as well as color to the plastic.
- ✓ Dies are chemicals, usually supplied in liquid form, that are generally soluble in the polymer.
- ✓ They are normally used to color transparent plastics such as styrene and acrylics.

Other Additives

- ✓ Lubricants are sometimes added to the polymer to reduce friction and promote flow at the mold interface.
- ✓ Lubricants are also helpful in releasing the part from the mold in injection molding. Mold-release agents, sprayed onto the mold surface, are often used for the same purpose.
- ✓ Nearly all polymers burn if the required heat and oxygen are supplied. Some polymers are more combustible than others.
- ✓ *Flame retardants* are chemicals added to polymers to reduce flammability by any or a combination of the following mechanisms: (1) interfering with flame propagation, (2) producing large amounts of incombustible gases, and/or (3) increasing the combustion temperature of the material.
- ✓ The chemicals may also function to (4) reduce the emission of noxious or toxic gases generated during combustion.
- ✓ We should include among the additives those that cause cross-linking to occur in thermosetting polymers and elastomers.
- ✓ The term *cross-linking agent* refers to a variety of ingredients that cause a cross-linking reaction or act as a catalyst to promote such a reaction.
- ✓ Important commercial examples are (1) sulfur in vulcanization of natural rubber, (2) formaldehyde for phenolics to form phenolic thermosetting plastics, and (3) peroxides for polyesters.
- ✓ Manypolymers are susceptible to degradation by ultraviolet light (e.g., from sunlight) and oxidation.
- ✓ The degradation manifests itself as the breaking of links in the long chainmolecules.
- ✓ Polyethylene, for example, is vulnerable to both types of degradation, which lead to a loss of mechanical strength.
- ✓ *Ultraviolet light absorbers and antioxidants* are additives that reduce the susceptibility of the polymer to these forms of attack.

IMPORTANT COMMERCIAL THERMOPLASTICS

- ✓ Thermoplastic products include molded and extruded items, fibers, films, sheets, packaging materials, paints, and varnishes.
- ✓ The starting raw materials for these products are normally supplied to the fabricator in the form of powders or pellets in bags, drums, or larger loads by truck or rail car.

Acetals

- ✓ Acetal is the popular name given to polyoxymethylene, an engineering polymer prepared from formaldehyde (CH_2O) with high stiffness, strength, toughness, and wear resistance.
- ✓ In addition, it has a high melting point, low moisture absorption, and is insoluble in common solvents at ambient temperatures.
- ✓ Because of this combination of properties, acetal resins are competitive with certain metals (e.g., brass and zinc) in automotive components such as door handles, pump housings, and similar parts; appliance hardware; and machinery components.

Acrylics

- ✓ The acrylics are polymers derived from acrylic acid ($C_3H_4O_2$) and compounds originating from it.
- ✓ The most important thermoplastic in the acrylics group is polymethyl-methacrylate (PMMA) or Plexiglas (Rohm & Haas's trade name for PMMA).
- ✓ It is an amorphous linear polymer. Its outstanding property is excellent transparency, which makes it competitive with glass in optical applications.
- ✓ Examples include automotive tail-light lenses, optical instruments, and aircraft windows.
- ✓ Its limitation when compared with glass is a much lower scratch resistance.
- ✓ Other uses of PMMA include floor waxes and emulsion latex paints. Another important use of acrylics is in fibers for textiles; polyacrylonitrile (PAN) is an example that goes by the more familiar trade names Orlon (DuPont) and Acrilan (Monsanto).

Acrylonitrile–Butadiene–Styrene

- ✓ ABS is called an engineering plastic due to its excellent combination of mechanical properties.
- ✓ ABS is a two phase terpolymer, one phase being the hard copolymer styrene acrylonitrile, while the other phase is styrene-butadiene copolymer that is rubbery.
- ✓ The name of the plastic is derived from the three starting monomers, which may be mixed in various proportions.

- Typical applications include components for automotive, appliances, business machines; and pipes and fittings.

Cellulosics

- Cellulose($C_6H_{10}O_5$) is a carbohydrate polymer commonly occurring in nature.
- Wood and cotton fibers, the chief industrial sources of cellulose, contain about 50% and 95%of the polymer, respectively.
- When cellulose is dissolved and reprecipitated during chemical processing, the resulting polymer is called regenerated cellulose. When this is produced as a fiber for apparel it is known as rayon (of course, cotton itself is a widely used fiber for apparel).
- When it is produced as a thin film, it is cellophane, a common packaging material.
- Cellulose itself cannot be used as a thermoplastic because it decomposes before melting when its temperature is increased.
- However, it can be combined with various compounds to form several plastics of commercial importance; examples are cellulose acetate (CA) and cellulose acetate–butyrate(CAB).
- CA, is produced in the form of sheets (for wrapping), film (for photography), and molded parts.
- CAB is a better molding material than CA and has greater impact strength, lower moisture absorption, and better compatibility with plasticizers.
- The cellulosic thermoplastics share about 1%of the market.

Fluoropolymers

- Polytetrafluorethylene (PTFE), commonly known as Teflon, accounts for about 85% of the family of polymers called fluoropolymers, in which Fatoms replace H atoms in the hydrocarbon chain.
- PTFE is extremely resistant to chemical and environmental attack, is unaffected by water, good heat resistance, and very low coefficient of friction.
- These latter two properties have promoted its use in nonstick household cookware.
- Other applications that rely on the same property include nonlubricating bearings and similar components.
- PTFE also finds applications in chemical equipment and food processing.

Polyamides

- An important polymer family that forms characteristic amide linkages (CO-NH) during polymerization is the polyamides (PA).

- The most important members of the PA family are nylons, of which the two principal grades are nylon-6 and nylon-6,6(the numbers are codes that indicate the number of carbon atoms in the monomer).
- Nylon is strong, highly elastic, tough, abrasion resistant, and self-lubricating. It retains good mechanical properties at temperatures up to about 125 C.
- One shortcoming is that it absorbs water with an accompanying degradation in properties.
- The majority of applications of nylon (about90%) are in fibers for carpets,apparel, and tire cord.
- The remainder(10%)are in engineering components; nylon is commonly a good substitute for metals in bearings, gears, and similar parts where strength and low friction are needed.
- A second group of polyamides is the armies (aromatic polyamides) of which Kevlar (DuPont trade name) is gaining in importance as a fiber in reinforced plastics. The reason for the interest in Kevlar is that its strength is the same as steel at 20% of the weight.

Polycarbonate

- Polycarbonate (PC) is noted for its generally excellent mechanical properties, which include high toughness and good creep resistance.
- It is one of the best thermoplastics for heat resistance—it can be used to temperatures around 125 C.
- In addition, it is transparent and fire resistant.
- Applications include molded machinery parts, housings for business machines, pump impellers, safety helmets, and compact disks (e.g., audio, video, and computer). It is also widely used in glazing (window and windshield) applications.

Polyesters

- The polyesters form a family of polymers made up of the characteristic sester linkages (CO–O). They can be either thermoplastic or thermosetting, depending on whether cross-linking occurs.
- Of the thermoplastic polyesters, a representative example is polyethylene terephthalate (PET). It can be either amorphous or partially crystallized (up to about 30%), depending on how it is cooled after shaping. Fast cooling favors the amorphous state, which is highly transparent.

- ✓ Significant applications include blow-molded beverage containers, photographic films, and magnetic recording tape. In addition, PET fibers are widely used in apparel.
- ✓ Polyester fibers have low moisture absorption and good deformation recovery, both of which make them ideal for ''wash and wear'' garments that resist wrinkling.
- ✓ The PET fibers are almost always blended with cotton or wool. Familiar trade names for polyester fibers include Dacron (DuPont), Fortrel (Celanese), and Kodel (Eastman Kodak).

Polyethylene

- ✓ Polyethylene (PE) was first synthesized in the 1930s, and today it accounts for the largest volume of all plastics.
- ✓ The features that make PE attractive as an engineering material are low cost, chemical inertness, and easy processing.
- ✓ Polyethylene is available in several grades, the most common of which are low-density polyethylene (LDPE) and high density polyethylene(HDPE).
- ✓ The low-density grade is a highly branched polymer with lower crystallinity and density.
- ✓ Applications include squeezable bottles, frozen food bags, sheets, film, and wire insulation.
- ✓ HDPE has a more linear structure, with higher crystallinity and density. These differences make HDPE stiffer and stronger and give it a higher melting temperature. HDPE is used to produce bottles, pipes, and housewares.
- ✓ Both grades can be processed by most polymer shaping methods.

Polypropylene

- ✓ Polypropylene (PP) has become a major plastic, especially for injection molding, since its introduction in the late 1950s.
- ✓ PP can be synthesized in isotactic, syndiotactic, or atactic structures, the first of these being the most important and for which the characteristics are given in the table.
- ✓ It is the lightest of the plastics, and its strength-to-weight ratio is high. PP is frequently compared with HDPE because its cost and many of its properties are similar.
- ✓ However, the high melting point of polypropylene allows certain applications that preclude use of polyethylene—for example, components that must be sterilized.
- ✓ Other applications are injection molded parts for automotive and houseware, and fiber products for carpeting.

- A special application suited to polypropylene is one-piece hinges that can be subjected to a high number of flexing cycles without failure.

Polystyrene

- There are several polymers, copolymers, and terpolymers based on the monomer styrene (C_8H_8), of which polystyrene (PS) is used in the highest volume.
- It is a linear homopolymer with amorphous structure that is generally noted for its brittleness. PS is transparent, easily colored, and readily molded, but degrades at elevated temperatures and dissolves in various solvents.
- Because of its brittleness, some PS grades contain 5% to 15% rubber and the term high-impact polystyrene (HIPS) is used for these types.
- They have higher toughness, but transparency and tensile strength are reduced.
- In addition to injection molding applications (e.g.,molded toys,housewares), polystyrene also finds uses in packaging in the form of PS foams.

Polyvinylchloride

- Polyvinylchloride (PVC) is a widely used plastic whose properties can be varied by combining additives with the polymer.
- In particular, plasticizers are used to achieve thermoplastics ranging from rigid PVC (no plasticizers) to flexible PVC (high proportions of plasticizer).
- The range of properties makes PVC a versatile polymer, with applications that include rigid pipe (used in construction, water and sewer systems, irrigation), fittings, wire and cable insulation, film, sheets, food packaging, flooring, and toys.
- PVC by itself is relatively unstable to heat and light, and stabilizers must be added to improve its resistance to these environmental conditions.
- Care must be taken in the production and handling of the vinyl chloride monomer used to polymerize PVC, due to its carcinogenic nature.

THERMOSETTING POLYMERS

- Thermosetting (TS) polymers are distinguished by their highly cross-linked structure.
- In effect, the formed part (e.g., the pot handle or electrical switch cover) becomes one large macromolecule.
- Thermosets are always amorphous and exhibit no glass transition temperature.
- In this section, we examine the general characteristics of the TS plastics and identify the important materials in this category.

- ✓ Owing to differences in chemistry and molecular structure, properties of thermosetting plastics are different from those of thermoplastics.
- ✓ In general, thermosets are (1) more rigid—modulus of elasticity is 2 to 3 times greater; (2) brittle—they possess virtually no ductility; (3) less soluble in common solvents; (4) capable of higher service temperatures; and (5) not capable of being remelted—instead they degrade or burn.
- ✓ The differences in properties of the TS plastics are attributable to cross-linking, which forms a thermally stable, three-dimensional, covalently bonded structure with in the molecule.
- ✓ Cross-linking is accomplished in three ways :

  1. Temperature-activated systems—In the most common systems, the changes are caused by heat supplied during the part-shaping operation (e.g., molding). The startingmaterial is a linear polymer in granular form supplied by the chemical plant. As heat is added, the material softens for molding; continued heating results in cross-linking of the polymer. The term thermosetting is most aptly applied to these polymers.

  2. Catalyst-activated systems—Cross-linking in these systems occurs when small amounts of a catalyst are added to the polymer, which is in liquid form.
  Without the catalyst, the polymer remains stable; once combined with the catalyst, it changes into solid form.

  3. Mixing-activated systems—Most epoxies are examples of these systems. The mixing of two chemicals results in a reaction that forms a cross-linked solid polymer. Elevated temperatures are sometimes used to accelerate the reactions.
- ✓ The chemical reactions associated with cross-linking are called curing or setting. Curing is done at the fabrication plants that shape the parts rather than the chemical plants that supply the starting materials to the fabricator.

IMPORTANT THERMOSETTING POLYMERS

- ✓ Thermosetting plastics are not as widely used as the thermoplastics, perhaps because of the added processing complications involved in curing the TS polymers.
- ✓ The largest volume thermosets are phenolic resins,whose annual volume is about 6%of the total plastics market.
- ✓ This is significantly less than polyethylene, the leading thermoplastic, whose volume is about 35%of the total.

Amino Resins

- ✓ Amino plastics, characterized by the amino group (NH_2), consist of two thermosetting polymers, urea-formaldehyde and melamine-formaldehyde, which are produced by the reaction of formaldehyde (CH_2O) with either urea ($CO(NH_2)_2$) or melamine ($C_3H_6N_6$), respectively.
- ✓ In commercial importance, the amino resins rank just below the other formaldehyde resin, phenol-formaldehyde, discussed below.
- ✓ Urea–formaldehyde is competitive with the phenols in certain applications, particularly as a plywood and particle-board adhesive.
- ✓ The resins are also used as a molding compound. It is slightly more expensive than the phenol material.
- ✓ Melamine–formaldehyde plastic is water resistant and is used for dishware and as a coating in laminated table and counter tops (Formica, trade name of Cyanamid Co.).
- ✓ When used as molding materials, amino plastics usually contain significant proportions of fillers, such as cellulose.

Epoxies

- ✓ Epoxy resins are based on a chemical group called the epoxides. The simplest formulation of epoxide is ethylene oxide (C_2H_3O).
- ✓ Epichlorohydrin (C_3H_5OCl) is a much more widely used epoxide for producing epoxy resins. Uncured, epoxides have a low degree of polymerization.
- ✓ To increase molecular weight and to cross-link the epoxide, a curing agent must be used.
- ✓ Possible curing agents include polyamines and acid anhydrides. Cured epoxies are noted for strength, adhesion, and heat and chemical resistance.
- ✓ Applications include surface coatings, industrial flooring, glass fiber-reinforced composites, and adhesives.
- ✓ Insulating properties of epoxy thermosets make them useful in various electronic applications, such as encapsulation of integrated circuits and lamination of printed circuit boards.

Phenolics

- ✓ Phenol (C_6H_5OH) is an acidic compound that can be reacted with aldehydes (dehydrogenated alcohols), formaldehyde (CH2O) being the most reactive.
- ✓ Phenolformaldehyde is the most important of the phenolic polymers; it was first commercialized around 1900 under the trade name Bakelite.
- ✓ It is almost always combined with fillers such as wood flour, cellulose fibers, and minerals when used as a molding material.

- ✓ It is brittle, possesses good thermal, chemical, and dimensional stability. Its capacity to accept colorants is limited—it is available only in dark colors.
- ✓ Molded products constitute only about 10% of total phenolics use.
- ✓ Other applications include adhesives for plywood, printed circuit boards, counter tops, and bonding material for brake linings and abrasive wheels.

Polyesters

- ✓ Polyesters, which contain the characteristic ester linkages (CO–O), can be thermosetting as well as thermoplastic.
- ✓ Thermosetting polyesters are used largely in reinforced plastics (composites) to fabricate large items such as pipes, tanks, boat hulls, auto body parts, and construction panels.
- ✓ They can also be used in various molding processes to produce smaller parts. Synthesis of the starting polymer involves reaction of an acid or anhydride such as maleic anhydride ($C_4H_2O_3$) with a glycol such as ethylene glycol ($C_2H_6O_2$).
- ✓ This produces an unsaturated polyester of relatively low molecular weight (MW=1000 to 3000).
- ✓ This ingredient is mixed with a monomer capable of polymerizing and cross linking with the polyester.
- ✓ Curing is done at the time of fabrication (molding or other forming process) and results in cross-linking of the polymer.
- ✓ An important class of polyesters is the alkyd resins (the name derived by abbreviating and combining thewords alcohol and acid and changing a few letters).
- ✓ They are used primarily as bases for paints, varnishes, and lacquers.

Polyimides

- ✓ These plastics are available as both thermoplastics and thermosets, but the TS types are more important commercially.
- ✓ They are available under brand names such as Kapton(Dupont) and Kaptrex (Professional Plastics) in several forms including tapes, films, coatings, and molding resins. TS polyimides (PI) are noted for chemical resistance, high tensile strength and stiffness, and stability at elevated temperatures. They are called high temperature polymers due to their excellent heat resistance.
- ✓ Applications that exploit these properties include insulating films, molded parts used in elevated temperature service, flexible cables in laptop computers, medical tubing, and fibers for protective clothing.

Polyurethanes

- This includes a large family of polymers, all characterized by the urethane group (NHCOO) in their structure.
- The chemistry of the polyurethanes is complex, and there are many chemical varieties in the family.The characteristic feature is the reaction of a polyol, whose molecules contain hydroxyl (OH) groups, such as butylene ether glycol ($C_4H_{10}O_2$); and an isocyanate, such as diphenylmethane diisocyanate ($C_{15}H_{10}O_2N_2$).
- Through variations in chemistry, cross-linking, and processing, polyurethanes can be thermoplastic, thermosetting, or elastomeric materials, the latter two being the most important commercially.
- The largest application of polyurethane is in foams. These can range between elastomeric and rigid, the latter being more highly cross-linked.
- Rigid foams are used as a filler material in hollow construction panels and refrigerator walls. In these types of applications, the material provides excellent thermal insulation, adds rigidity to the structure, and does not absorb water in significant amounts.
- Many paints, varnishes, and similar coating materials are basedon urethane systems.

Silicones

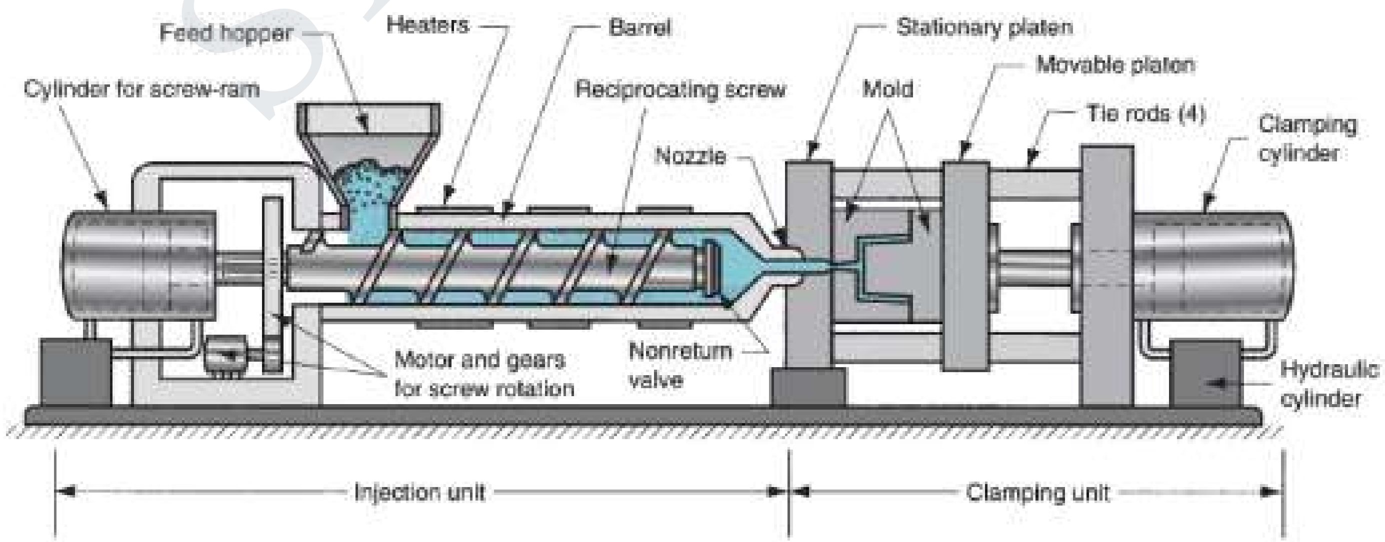
- Silicones are inorganic and semi-inorganic polymers, distinguished by the presence of the repeating siloxane link (–Si–O–) in their molecular structure.
- A typical formulation combines the methyl radical (CH3) with (SiO) in various proportions to obtain the repeating unit -$(CH_3)_m$-(SiO)-, where m establishes the proportionality.
- By variations in composition and processing, polysiloxanes can be produced in three forms: (1) fluids, (2) elastomers, and (3) thermosetting resins.
- When highly crosslinked, polysiloxanes form rigid resin systems used for paints, varnishes, and other coatings; and laminates such as printed circuit boards.
- They are also used as molding materials for electrical parts.
- Curing is accomplished by heating or by allowing the solvents containing the polymers to evaporate. Silicones are noted for their good heat resistance and water repellence, but their mechanical strength is not as great as other cross-linked polymers.

Injection Molding of Thermoplastics

- ✓ Injection molding is a process in which a polymer is heated to a highly plastic state and forced to flow under high pressure into a mold cavity, where it solidifies.
- ✓ The molded part, called a molding, is then removed from the cavity.
- ✓ The process produces discrete components that are almost always net shape.
- ✓ The production cycle time is typically in the range of 10 to 30 sec, although cycles of 1 min or longer are not uncommon for large parts.
- ✓ Also, the mold may contain more than one cavity, so that multiple moldings are produced each cycle.
- ✓ Complex and intricate shapes are possible with injection molding.
- ✓ The challenge in these cases is to fabricate a mold whose cavity is the same geometry as the part and that also allows for part removal.
- ✓ Part size can range from about 50 g up to about 25 kg , the upper limit represented by components such as refrigerator doors and automobile bumpers.
- ✓ The mold determines the part shape and size and is the special tooling in injection molding.
- ✓ For large, complex parts, the mold can cost hundreds of thousands of dollars.
- ✓ For small parts, the mold can be built to contain multiple cavities, also making the mold expensive.
- ✓ Thus, injection molding is economical only for large production quantities.
- ✓ Injection molding is the most widely used molding process for thermoplastics.
- ✓ Some thermosets and elastomers are injection molded, with modifications in equipment and operating parameters to allow for cross-linking of these materials.

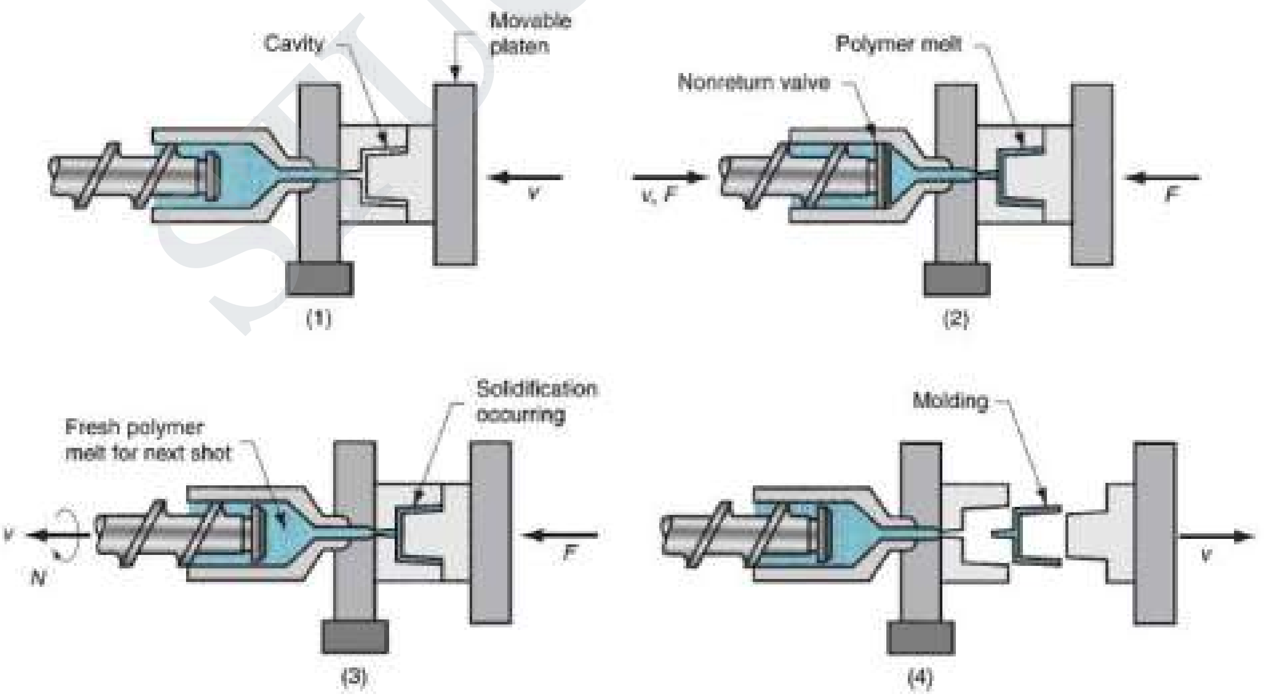
PROCESS AND EQUIPMENT

- ✓ The main component of an injection-molding machine are (1) the injection unit which melts the molding material and forces it into the mold; (2) the clamping unit which opens the mold and closes it under pressure; (3) the mold used; and (4) the machine controls.



- ✓ The injection unit is much like an extruder.

- ✓ It consists of a barrel that is fed from one end by a hopper containing a supply of plastic pellets.
- ✓ Inside the barrel is a screw whose operation surpasses that of an extruder screw in the following respect: in addition to turning for mixing and heating the polymer, it also acts as a ram that rapidly moves forward to inject molten plastic into the mold.
- ✓ A nonreturn valve mounted near the tip of the screw prevents the melt from flowing backward along the screw threads.
- ✓ Later in the molding cycle the ram retracts to its former position. Because of its dual action, it is called a reciprocating screw, a name that also identifies the machine type.
- ✓ *Older injection molding machines used a simple ram (without screw flights), but the superiority of the reciprocating screw design has led to its widespread adoption in today's molding plants.*
- ✓ To summarize, the functions of the injection unit are to melt and homogenize the polymer, and then inject it into the mold cavity.
- ✓ The clamping unit is concerned with the operation of the mold. Its functions are to (1) hold the two halves of the mold in proper alignment with each other; (2) keep the mold closed during injection by applying a clamping force sufficient to resist the injection force; and (3) open and close the mold at the appropriate times in the molding cycle. The clamping unit consists of two platens, a fixed platen and a moveable platen, and a mechanism for translating the latter. The mechanism is basically a power press that is operated by hydraulic piston or mechanical toggle devices of various types.
- ✓ Clamping forces of several thousand tons are available on large machines.
- ✓ The cycle for injection molding of a thermoplastic polymer proceeds in the following sequence.



Typical molding cycle: (1) mold is closed, (2) melt is injected into cavity, (3) screw is retracted, and (4) mold opens, and part is ejected.

Let us pick up the action with the mold open and the machine ready to start a new molding:

(1) The mold is closed and clamped.

(2) A shot of melt, which has been brought to the right temperature and viscosity by heating and the mechanical working of the screw, is injected under high pressure into the mold cavity. The plastic cools and begins to solidify when it encounters the cold surface of the mold. Ram pressure is maintained to pack additional melt into the cavity to compensate for contraction during cooling.

(3) The screw is rotated and retracted with the nonreturn valve open to permit fresh polymer to flow into the forward portion of the barrel. Meanwhile, the polymer in the mold has completely solidified.

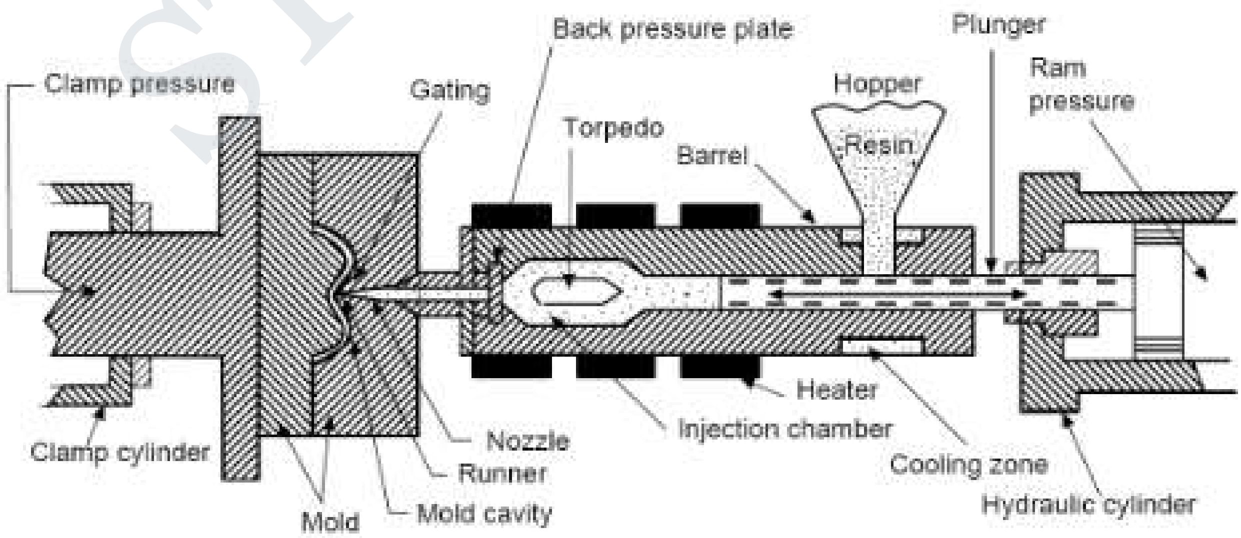
(4) The mold is opened, and the part is ejected and removed.

✓ The machines used earlier were basically *plunger-type machines (Shown in below figure)*. But in the late 1960s' shortly after the development of screw-transfer machines, the concept of screw-injection molding of thermosets, also known as direct screw transfer (or DST), was introduced.

✓ The potential of this technique for low cost, high-volume production of molded thermoset parts was quickly recognized, and today screw injection machines are available in all clamp tonnages up to 1,200 tons and shot sizes up to 10 lb.

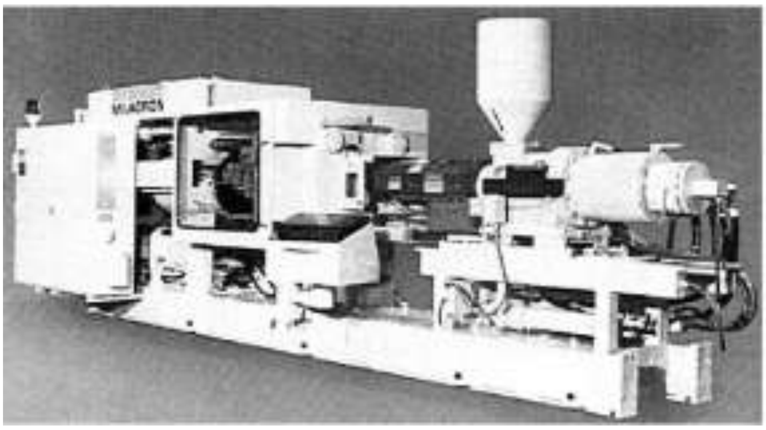
✓ Coupled with this, there has been a new series of thermosetting molding materials developed specifically for injection molding.

✓ This difference in screw configuration is a major difference between thermoplastic- and thermosetting-molding machines.



Injection-molding machines

The illustration shows an injection-molding machine with CNC control

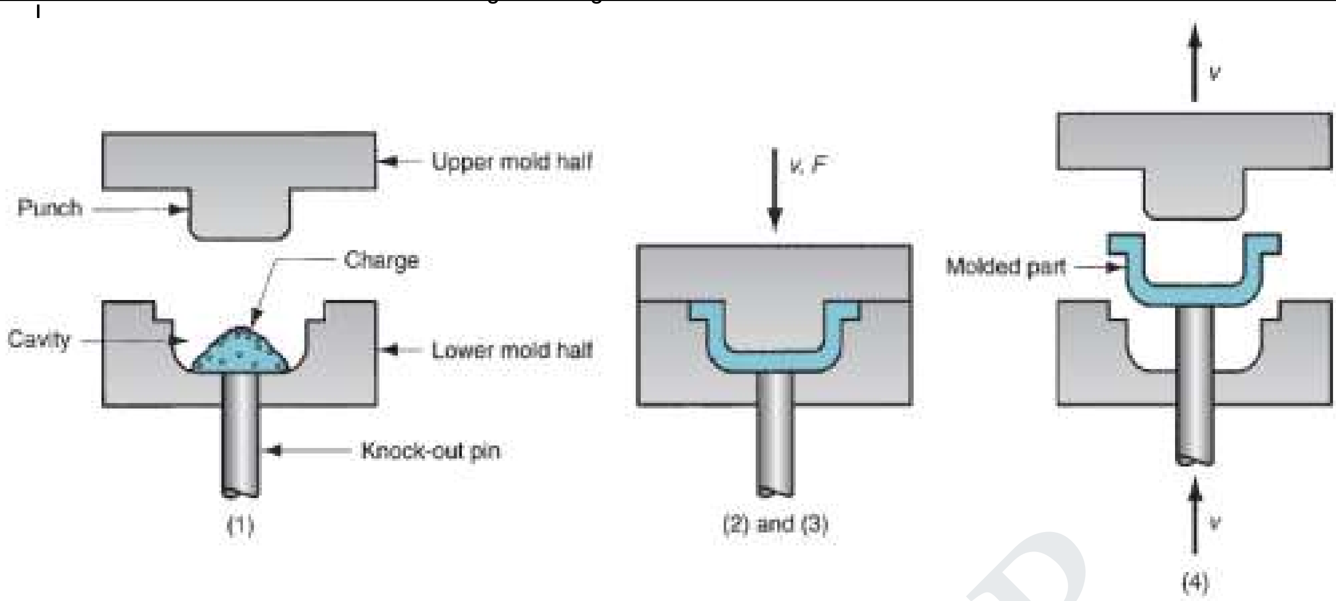


250-ton CNC injection molding machine

Large parts with complex shapes are easily produced

COMPRESSION MOLDING

- ✓ Compression molding is an old and widely used molding process for thermosetting plastics.
- ✓ Its applications also include rubber tires and various polymer matrix composite parts.
- ✓ The process, for a TS plastic, consists of (1) loading a precise amount of molding compound, called the charge, into the bottom half of a heated mold; (2) bringing the mold halves together to compress the charge, forcing it to flow and conform to the shape of the cavity; (3) heating the charge by means of the hot mold to polymerize and cure the material into a solidified part; and (4) opening the mold halves and removing the part from the cavity.
- ✓ The initial charge of molding compound can be any of several forms, including powders or pellets, liquid, or preform.
- ✓ The amount of polymer must be precisely controlled to obtain repeatable consistency in the molded product.
- ✓ It has become common practice to preheat the charge before its placement into the mold; this softens the polymer and shortens the production cycle time.
- ✓ Preheating methods include infrared heaters, convection heating in an oven, and use of a heated rotating screw in a barrel.
- ✓ The latter technique (borrowed from injection molding) is also used to meter the amount of the charge.
- ✓ Compression molding presses are oriented vertically and contain two platens to which the mold halves are fastened.
- ✓ The presses involve either of two types of actuation: (1) upstroke of the bottom platen or (2) downstroke of the top platen, the former being the more common machine configuration.

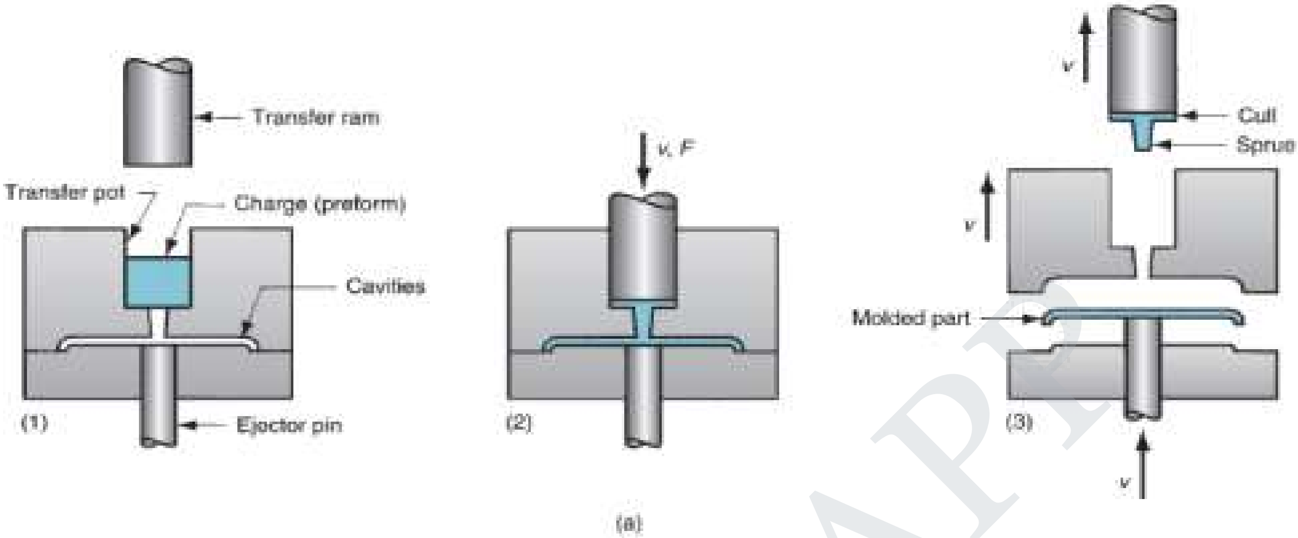


Compression molding for thermosetting plastics: (1) charge is loaded; (2) and (3) charge is compressed and cured; and (4) part is ejected and removed (some details omitted).

- ✓ They are generally powered by a hydraulic cylinder that can be designed to provide clamping capacities up to several hundred tons.
- ✓ Molds for compression molding are generally simpler than their injection mold counter parts.
- ✓ There is no sprue and runner system in a compression mold, and the process itself is generally *limited to simpler* part geometries because of the lower flow capabilities of the starting thermosetting materials.
- ✓ However, provision must be made for heating the mold, usually accomplished by electric resistance heating, steam, or hot oil circulation.
- ✓ Compression molds can be classified as hand molds, used for trial runs; semiautomatic, in which the press follows a programmed cycle but the operator manually loads and unloads the press; and automatic, which operate under a fully automatic press cycle (including automatic loading and unloading).
- ✓ *Materials for compression molding include phenolics, melamine, urea-formaldehyde, epoxies, urethanes, and elastomers.*
- ✓ Typical moldings include electric plugs and sockets, pot handles, and dinnerware plates.
- ✓ *Advantages* of compression molding in these applications include (1) molds that are simpler and less expensive, (2) less scrap, and (3) low residual stresses in the molded parts.
- ✓ A *typical disadvantage* is longer cycle times and therefore lower production rates than injection molding.

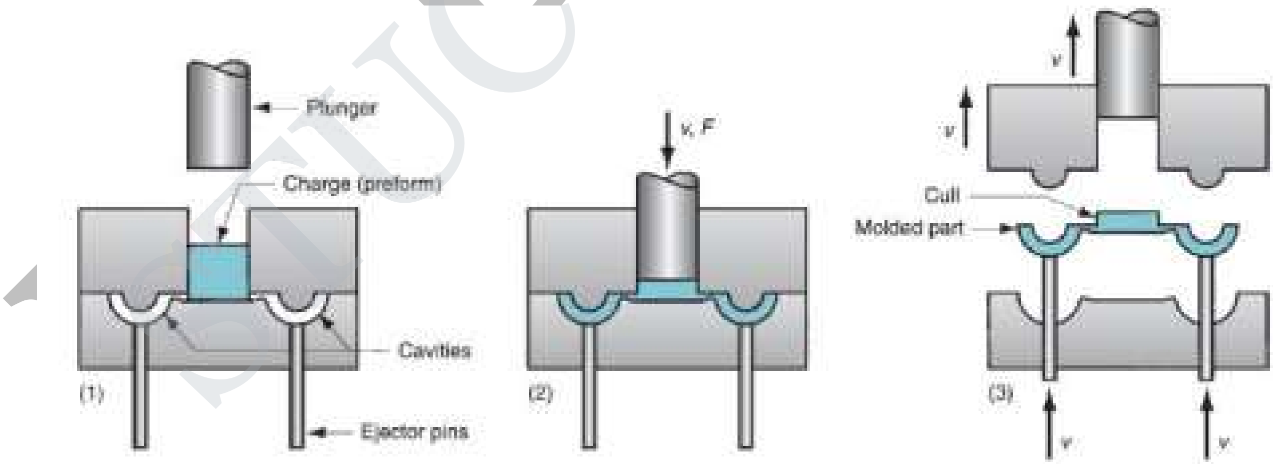
TRANSFER MOLDING

In this process, a thermosetting charge is loaded into a chamber immediately ahead of the mold cavity, where it is heated; pressure is then applied to force the softened polymer to flow into the heated mold where curing occurs.



(a) Pot transfer molding, (1) charge is loaded into pot, (2) softened polymer is pressed into mold cavity and cured, and (3) part is ejected.

- ✓ There are two variants of the process; (a) *pot transfer molding*, in which the charge is injected from a ''pot'' through a vertical sprue channel into the cavity; and (b) *plunger transfer molding*, in which the charge is injected by means of a plunger from a heated well through lateral channels into the mold cavity.



- ✓ In both cases, scrap is produced each cycle in the form of the leftover material in the base of the well and lateral channels, called the cull.
- ✓ In addition, the sprue in pot transfer is scrap material. Because the polymers are thermosetting, the scrap cannot be recovered.
- ✓ Transfer molding is closely related to compression molding, because it is used on the same polymer types (thermosets and elastomers).
- ✓ Similarities to injection molding, in the way the charge is preheated in a separate chamber and then injected into the mold.

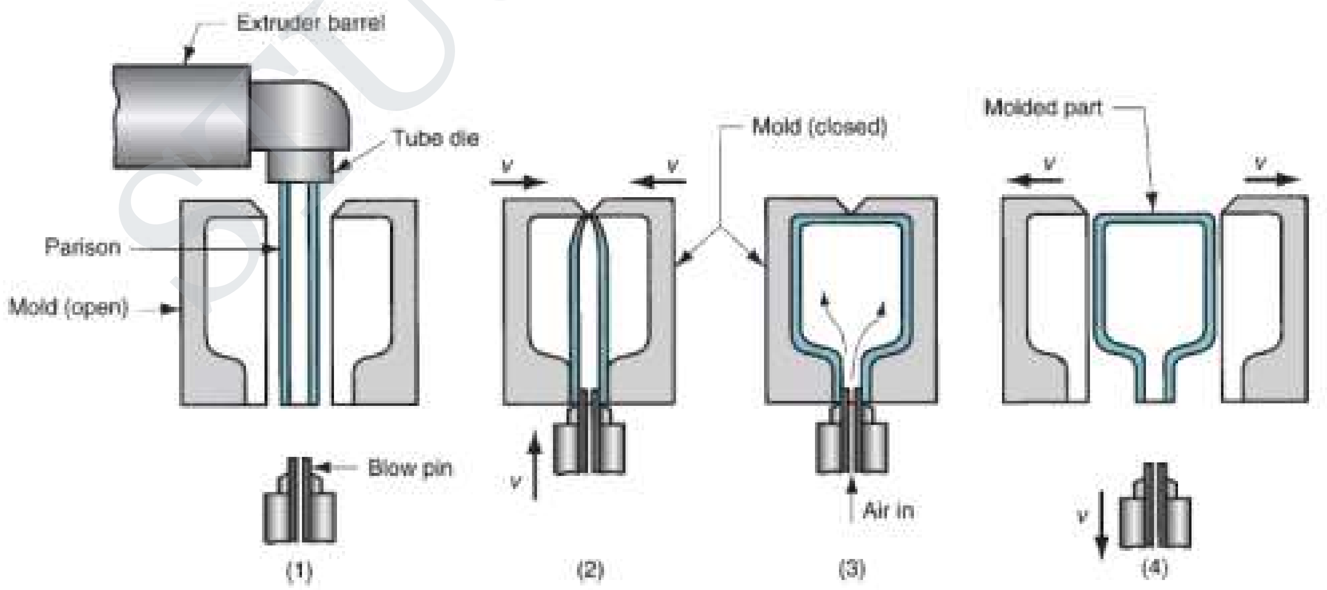
- ✓ Transfer molding is capable of molding part shapes that are more intricate than compression molding but not as intricate as injection molding.
- ✓ Transfer molding also lends itself to molding with inserts, in which a metal or ceramic insert is placed into the cavity before injection, and the heated plastic bonds to the insert during molding.

BLOW MOLDING AND ROTATIONAL MOLDING

- ✓ Both of these processes are used to make hollow, seamless parts out of thermoplastic polymers.
- ✓ Rotational molding *can also be used for thermosets.*
- ✓ Parts range in size from small plastic bottles of only 5 mL to large storage drums of 38,000-L capacity.
- ✓ Although the two processes compete in certain cases, generally they have found their own niches.
- ✓ Blow molding is more suited to the mass production of small disposable containers, whereas rotational molding favors large, hollow shapes.

Blow molding

- ✓ Blow molding is a molding process in which air pressure is used to inflate soft plastic inside a mold cavity.
- ✓ It is an important industrial process for making one-piece hollow plastic parts with thin walls, such as bottles and similar containers.



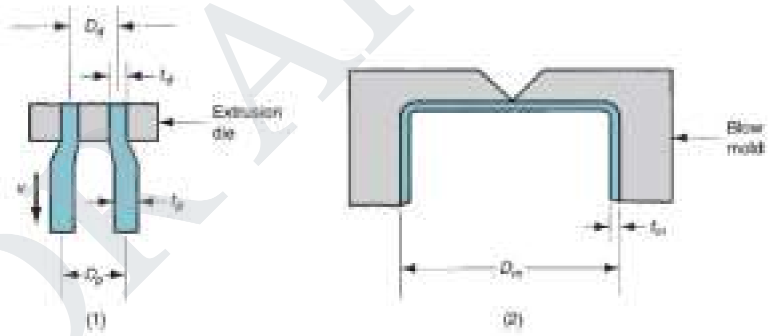
Extrusion blow molding: (1) extrusion of parison; (2) parison is pinched at the top and sealed at the bottom around a metal blow pin as the two halves of the mold come together; (3) the tube is inflated so that it takes the shape of the mold cavity; and (4) mold is opened to remove the solidified part.

- ✓ Because many of these items are used for consumer beverages for mass markets, production is typically organized for very high quantities.
- ✓ The technology is borrowed from the glass industry with which plastics compete in the disposable and recyclable bottle market.
- ✓ Blow molding is accomplished in two steps: (1) fabrication of a starting tube of molten plastic, called a parison (same as in glass-blowing); and (2) inflation of the tube to the desired final shape.
- ✓ Forming the parison is accomplished by either extrusion or injection molding.

Extrusion Blow Molding:

- ✓ This form of blow molding consists of the cycle illustrated in above figure. In most cases, the process is organized as a very high production operation for making plastic bottles.
- ✓ The sequence is automated and often integrated with downstream operations such as bottle filling and labeling.

(1) Dimensions of extrusion die, showing parison after die swell; and (2) final blow-molded container in extrusion blow molding.



- ✓ It is usually a requirement that the blown container be rigid, and rigidity depends on wall thickness among other factors.
- ✓ The wall thickness of the blown container can be related to the starting extruded parison, assuming a cylindrical shape for the final product.
- ✓ The effect of die swell on the parison is shown in below figure.
- ✓ The mean diameter of the tube as

it exits the die is determined by the mean die diameter D_d. Die swell causes expansion to a mean parison diameter D_p. At the same time, wall thickness swells from t_d to t_p. The swell ratio of the parison diameter and wall thickness is given by

$$r_s = \frac{D_p}{D_d} = \frac{t_p}{t_d}$$

When the parison is inflated to the blow mold diameter D_m, there is a corresponding reduction in wall thickness to t_m. Assuming constant volume of cross section, we have

$$\pi D_p t_p = \pi D_m t_m$$

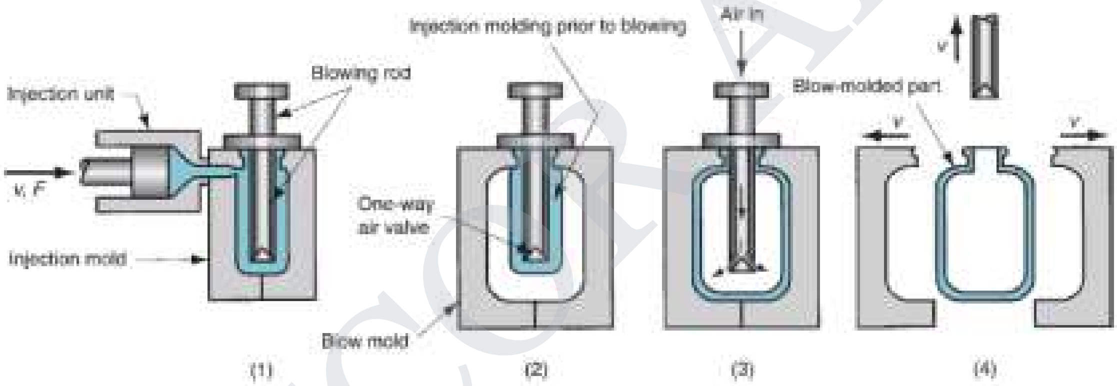
Solving for t_m, we obtain

$$t_m = \frac{D_p t_p}{D_m}$$

- The amount of die swell in the initial extrusion process can be measured by direct observation; and the dimensions of the die are known.
- Thus, we can determine the wall thickness on the blow-molded container.

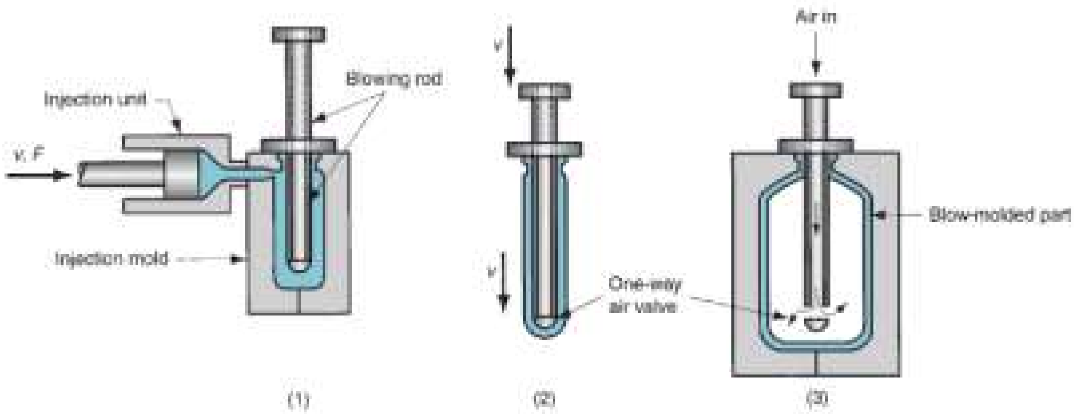
Injection Blow Molding:

- In this process, the starting parison is injection molded rather than extruded.
- Compared to its extrusion-based competitor, injection blow molding usually has the following advantages: (1) higher production rate, (2) greater accuracy in the final dimensions, (3) lower scrap rates, and (4) less wasteful of material.
- On the other hand, larger containers can be produced with extrusion blow molding because the mold in injection molding is so expensive for large parisons.
- Also, extrusion blow molding is technically more feasible and economical for double-layer bottles used for storing certain medicines, personal care products, and various chemical compounds.



Injection blow molding: (1) parison is injected molded around a blowing rod; (2) injection mold is opened and parison is transferred to a blow mold; (3) soft polymer is inflated to conform to the blow mold; and (4) blow mold is opened, and blown product is removed.

- In a variation of injection blow molding, called *stretch blow molding*, the blowing rod extends downward into the injection molded parison during step 2, thus stretching the soft plastic and creating a more favorable stressing of the polymer than conventional injection blow molding or extrusion blow molding.



Stretch blow molding: (1) injection molding of parison, (2) stretching, and (3) blowing.

- ✓ The resulting structure is more rigid, with higher transparency and better impact resistance.
- ✓ The most widely used material for stretch blow molding is polyethylene terephthalate (PET), a polyester that has very low permeability and is strengthened by the stretch-blow-molding process.
- ✓ The combination of properties makes it ideal as a container for carbonated beverages (e.g., 2-L soda bottles).

Materials and Products

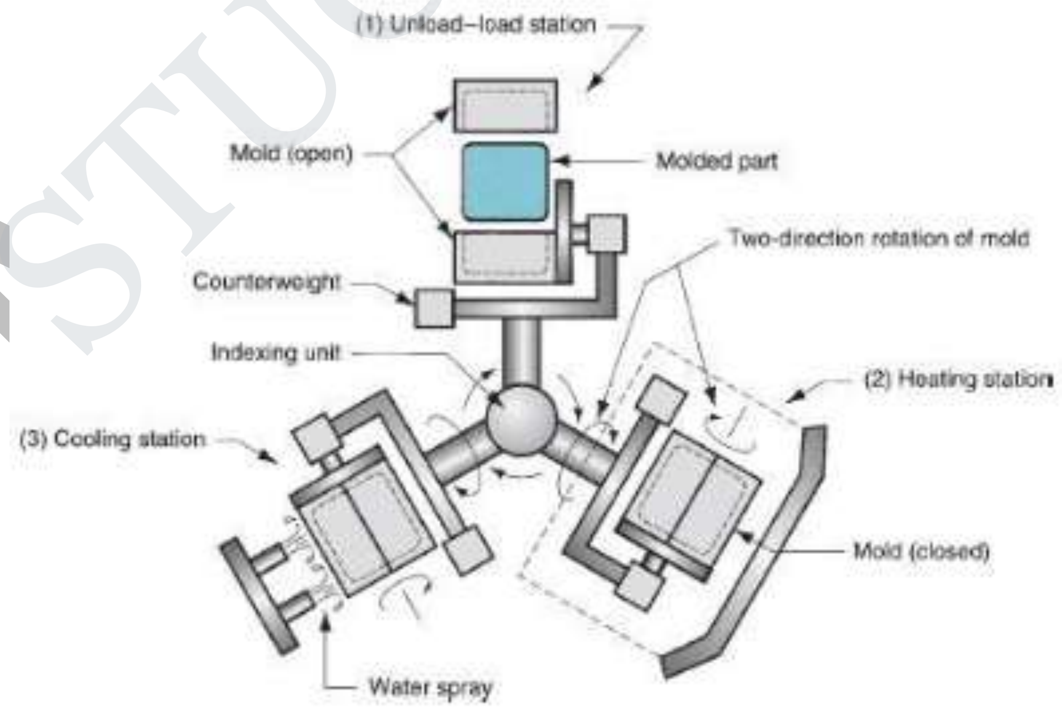
- ✓ Blow molding is limited to thermoplastics.
- ✓ Polyethylene is the polymer most commonly used for blow molding—in particular, high density and high molecular weight polyethylene (HDPE and HMWPE).
- ✓ In comparing their properties with those of low density PE given the requirement for stiffness in the final product, it is more economical to use these more expensive materials because the container walls can be made thinner.
- ✓ Other blow moldings are made of polypropylene (PP), polyvinylchloride (PVC), and polyethylene terephthalate.
- ✓ Disposable containers for packaging liquid consumer goods constitute the major share of products made by blow molding; but they are not the only products.
- ✓ Other items include large shipping drums (55-gal) for liquids and powders, large storage tanks (2000-gal), automotive gasoline tanks, toys, and hulls for sail boards and small boats.
- ✓ In the latter case, two boat hulls are made in a single blow molding and subsequently cut into two open hulls.

ROTATIONAL MOLDING

- ✓ Rotational molding uses gravity inside a rotating mold to achieve a hollow form.
- ✓ Also called *rotomolding*, it is an alternative to blow molding for making large, hollow shapes.
- ✓ It is used principally for thermoplastic polymers, but applications for thermosets and elastomers are becoming more common.
- ✓ Rotomolding tends to favor more complex external geometries, larger parts, and lower production quantities than blow molding.
- ✓ The process consists of the following steps: (1) A predetermined amount of polymer powder is loaded into the cavity of a split mold. (2) The mold is then heated and simultaneously rotated on two perpendicular axes, so that the powder impinges on all internal surfaces of the mold, gradually forming a fused layer of uniform

thickness. (3) While still rotating, the mold is cooled so that the plastic skin solidifies. (4) The mold is opened, and the part is unloaded.

- ✓ Rotational speeds used in the process are relatively slow. It is gravity, not centrifugal force, that causes uniform coating of the mold surfaces.
- ✓ Molds in rotational molding are simple and inexpensive compared with injection molding or blow molding, but the production cycle is much longer, lasting perhaps 10 min or more.
- ✓ To balance these advantages and disadvantages in production, rotational molding is often performed on a multicavity indexing machine, such as the three-station machine shown in figure.
- ✓ The machine is designed so that three molds are indexed in sequence through three workstations.
- ✓ Thus, all three molds are working simultaneously. The first workstation is an unload–load station in which the finished part is unloaded from the mold, and the powder for the next part is loaded into the cavity.
- ✓ The second station consists of a heating chamber where hot-air convection heats the mold while it is simultaneously rotated. Temperatures inside the chamber are around 375 C depending on the polymer and the item being molded.
- ✓ The third station cools the mold, using forced cold air or water spray, to cool and solidify the plastic molding inside.



Rotational molding cycle performed on a three-station indexing machine: (1) unload-load station; (2) heat and rotate mold; (3) cool the mold

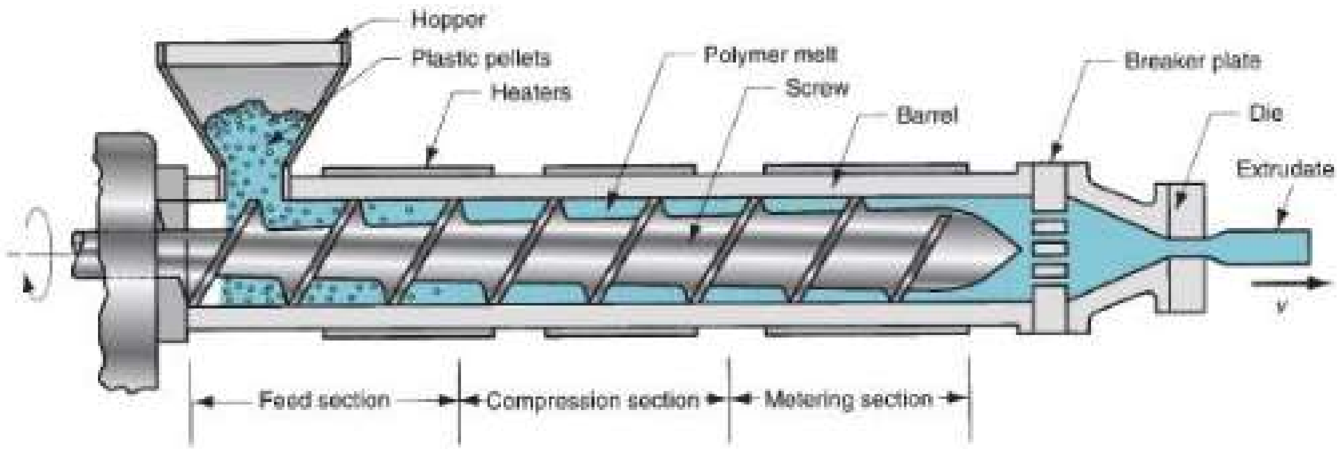
- A fascinating variety of articles are made by rotational molding.
- The list includes hollow toys such as hobby horses and playing balls; boat and canoe hulls, sandboxes, small swimming pools; buoys and other flotation devices; truck body parts, automotive dashboards, fuel tanks; luggage pieces, furniture, garbage cans; fashion mannequins; large industrial barrels, containers, and storage tanks; portable outhouses, and septic tanks.
- The most popular molding material is polyethylene, especially HDPE. Other plastics include polypropylene, ABS, and high-impact polystyrene.

EXTRUSION

- Extrusion is one of the fundamental shaping processes, for metals and ceramics as well as polymers.
- Extrusion is a compression process in which material is forced to flow through a die orifice to provide long continuous product whose cross-sectional shape is determined by the shape of the orifice.
- As a polymer shaping process, it is widely used for thermoplastics and elastomers (but rarely for thermosets) to mass produce items such as tubing, pipes, hose, structural shapes (such as window and door molding), sheet and film, continuous filaments, and coated electrical wire and cable.
- For these types of products, extrusion is carried out as a continuous process; the extrudate (extruded product) is subsequently cut into desired lengths.

PROCESS AND EQUIPMENT

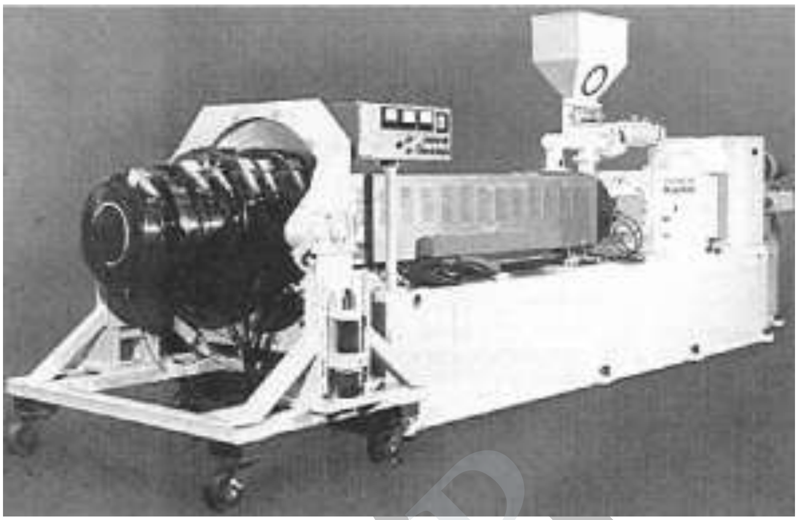
- The increase in pressure applied to the polymer melt in the three sections of the barrel is determined largely by the channel depth d_c. In Figure, d_c is relatively large in the feed section to allow large amounts of granular polymer to be admitted into the barrel.
- In the compression section, d_c is gradually reduced, thus applying increased pressure on the polymer as it melts.
- In the metering section, d_c is small and pressure reaches a maximum as flow is restrained by the screen pack and backer plate.
- The three sections of the screw are shown as being about equal in length in Figure; this is appropriate for a polymer that melts gradually, such as low-density polyethylene.



Components and features of a (single-screw) extruder for plastics and elastomers.

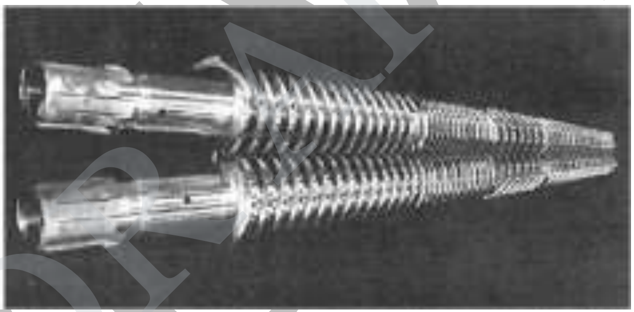
- ✓ For other polymers, the optimal section lengths are different. For crystalline polymers such as nylon, melting occurs rather abruptly at a specific melting point; therefore, a short compression section is appropriate.
- ✓ Amorphous polymers such as polyvinylchloride melt more slowly than LDPE, and the compression zone for these materials must take almost the entire length of the screw.
- ✓ Although the optimal screw design for each material type is different, it is common practice to use general-purpose screws.
- ✓ These designs represent a compromise among the different materials, and they avoid the need to make frequent screw changes, which result in costly equipment downtime.
- ✓ Progress of the polymer along the barrel leads ultimately to the die zone.
- ✓ Before reaching the die, the melt passes through a screen pack—a series of wire meshes supported by a stiff plate (called a breaker plate) containing small axial holes.
- ✓ The screen pack assembly functions to (1) filter contaminants and hard lumps from the melt; (2) build pressure in the metering section; and (3) straighten the flow of the polymer melt and remove its ‘‘memory’’ of the circular motion imposed by the screw.
- ✓ This last function is concerned with the polymer’s viscoelastic property; if the flow were left unstraightened, the polymer would play back its history of turning inside the extrusion chamber, tending to twist and distort the extrudate.
- ✓ In polymer extrusion, the feedstock is fed into an extrusion barrel where it is heated, melted, and forced to flow through a die opening by means of rotating screw:

The illustration shows an extruder for plastic pipe. The specific tooling for this product is attached to the machine on the left side (*in black*):



The internal diameter of the barrel is usually 25 to 150 mm, and the L/D ratio is between 10 and 30. The screw rotates at about 60 rev/min.

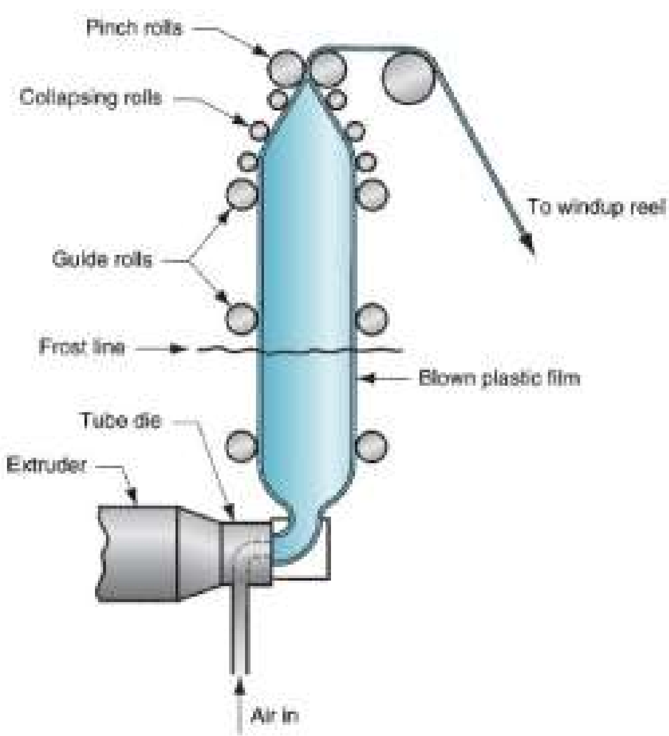
The raw materials not only in extrusion but also in most polymer processes are plastic pellets:



Plastic pellets are the raw material in many shaping processes for polymers *Twin extruder screws*

Film Blowing / Blown-Film Extrusion Process

- ✓ This is the other widely used process for making thin polyethylene film for packaging.
- ✓ It is a complex process, combining extrusion and blowing to produce a tube of thin film.
- ✓ The process begins with the extrusion of a tube that is immediately drawn upward while still molten and simultaneously expanded in size by air inflated into it through the die mandrel.
- ✓ A ''frost line'' marks the position along the upward moving bubble where solidification of the polymer occurs.



- ✓ Air pressure in the bubble must be kept constant to maintain uniform film thickness and tube diameter.
- ✓ The air is contained in the tube by pinch rolls that squeeze the tube back together after it has cooled.
- ✓ Guide rolls and collapsing rolls are also used to restrain the blown tube and direct it into the pinch rolls.
- ✓ The flat tube is then collected onto a windup reel.
- ✓ The effect of air inflation is to stretch the film in both directions as it cools from the molten state.
- ✓ This results in isotropic strength properties, which is an advantage over other processes in which the material is stretched primarily in one direction.
- ✓ Other advantages include the ease with which extrusion rate and air pressure can be changed to control stock width and gage.
- ✓ Comparing this process with slit-die extrusion, the blown film method produces stronger film (so that a thinner film can be used to package a product), but thickness control and production rates are lower.
- ✓ The final blown film can be left in tubular form (e.g., for garbage bags), or it can be subsequently cut at the edges to provide two parallel thin films.

Thermoforming

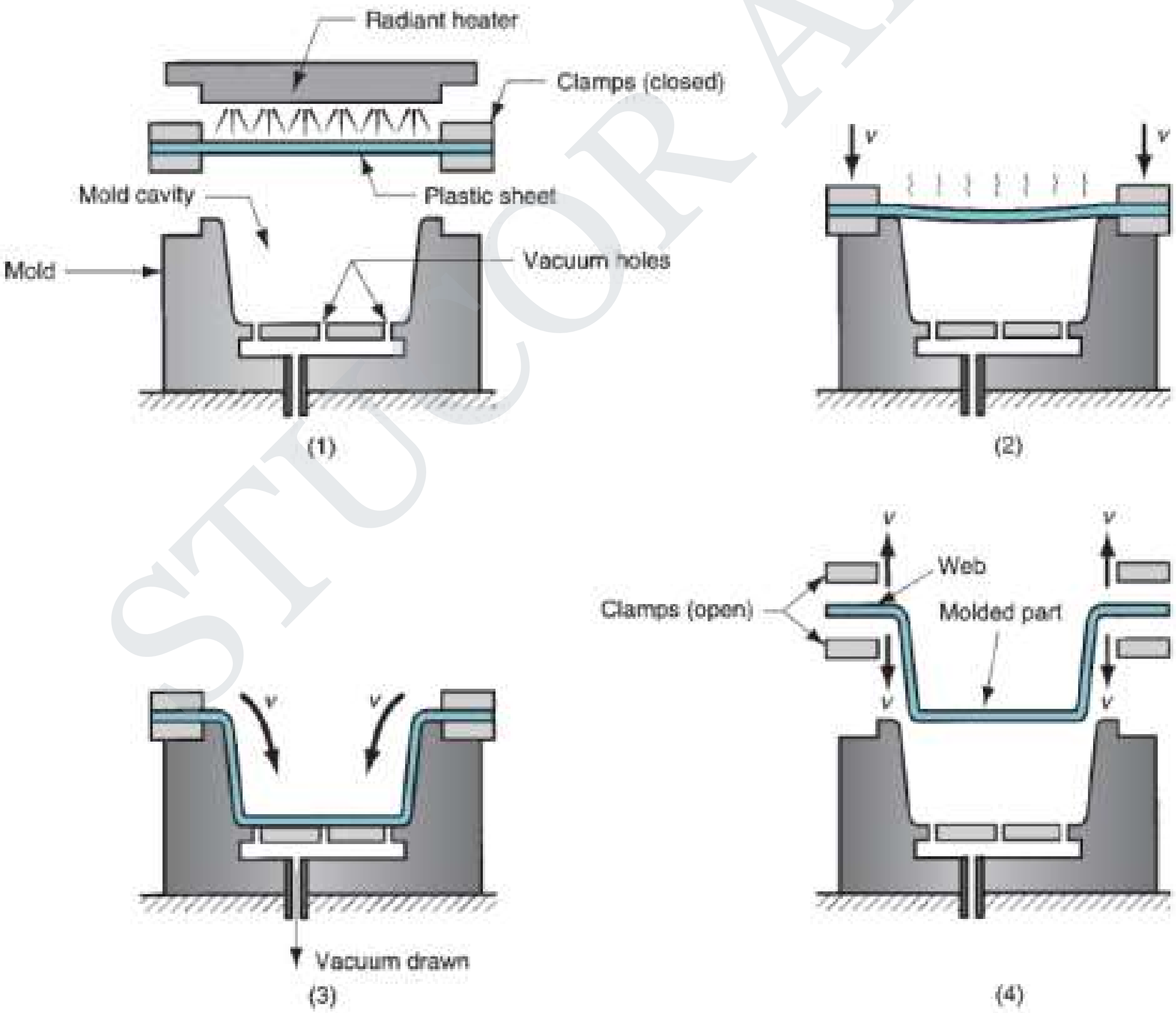
Thermoforming is a process in which a flat thermoplastic sheet is heated and deformed into desired shape.

- ✓ The classical process involves the use of vacuum and is called vacuum forming.
- ✓ Other similar processes are pressure thermoforming and mechanical thermoforming. Mechanical thermo-forming uses positive and negative molds that are brought together against the heated plastic sheet, forcing it to assume their shape.
- ✓ The process is widely used in packaging of consumer products and fabricating large items such as bathtubs, contoured skylights, and internal door liners for refrigerators.
- ✓ Thermoforming consists of two main steps: heating and forming.
- ✓ Heating is usually accomplished by radiant electric heaters, located on one or both sides of the starting plastic sheet at a distance of roughly 125mm. Duration of the heating cycle needed to sufficiently soften the sheet depends on the polymer—its thickness and color.

- Methods by which forming is accomplished can be classified into three basic categories: (1) vacuum thermoforming, (2) pressure thermoforming, and (3) mechanical thermoforming. In our discussion of these methods, we describe the forming of sheet stock, but in the packaging industry most thermoforming operations are performed on thin films.

Vacuum Thermoforming

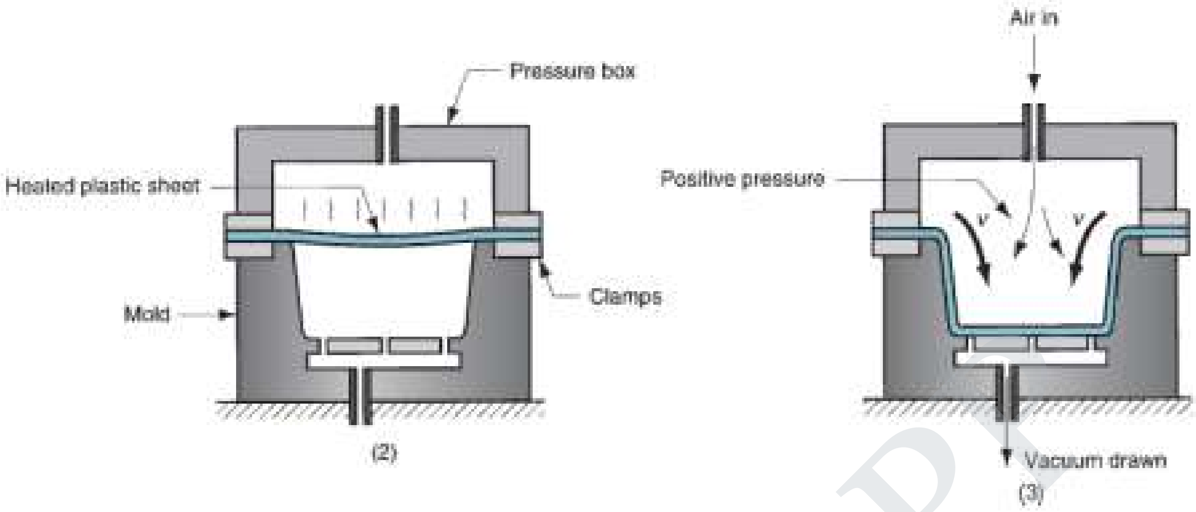
- This was the first thermoforming process (simply called vacuum forming when it was developed in the 1950s).
- Negative pressure is used to draw a preheated sheet into a mold cavity.
- The most basic form of the process is explained in the Figure.
- The holes for drawing the vacuum in the mold are on the order of 0.8 mm in diameter, so their effect on the plastic surface is minor.



Vacuum thermoforming: (1) a flat plastic sheet is softened by heating, (2) soften sheet is placed over the mold cavity, (3) a vacuum draws the sheet into the cavity, and (4) after cooling and solidification, part is removed and subsequently trimmed

Pressure Thermoforming

- ✓ An alternative to vacuum forming involves positive pressure to force the heated plastic into the mold cavity.



Pressure thermoforming. The sequence is similar to the previous figure, the difference being: (2) sheet is placed over a mold cavity; and (3) positive pressure forces the sheet into the cavity.

- ✓ This is called pressure thermoforming or blow forming; its advantage over vacuum forming is that higher pressures can be developed because the latter is limited to a theoretical maximum of 1 atm.
- ✓ Blow-forming pressures of 3 to 4 atm are common.
- ✓ The process sequence is similar to the previous, the difference being that the sheet is pressurized from above into the mold cavity.
- ✓ Vent holes are provided in the mold to exhaust the trapped air.

Mechanical Thermoforming

- ✓ The third method, called mechanical thermoforming, uses matching positive and negative molds that are brought together against the heated plastic sheet, forcing it to assume their shape.

Applications

- ✓ Thermoforming is a secondary shaping process, the primary process being that which produces the sheet or film.
- ✓ Only thermoplastics can be thermoformed, because extruded sheets of thermosetting or elastomeric polymers have already been cross-linked and cannot be softened by reheating.
- ✓ Common thermoforming plastics are polystyrene, cellulose acetate and cellulose acetate butyrate, ABS, PVC, acrylic (polymethylmethacrylate), polyethylene, and polypropylene.

- ✓ Mass production thermoforming operations are performed in the packaging industry.
- ✓ The starting sheet or film is rapidly fed through a heating chamber and then mechanically formed into the desired shape.
- ✓ The operations are often designed to produce multiple parts with each stroke of the press using molds with multiple cavities.
- ✓ In some cases, the extrusion machine that produces the sheet or film is located directly upstream from the thermoforming process, thereby eliminating the need to reheat the plastic.
- ✓ For best efficiency, the filling process to put the consumable food item into the container is placed immediately downstream from thermoforming.
- ✓ Thin film packaging items that are mass produced by thermoforming include blister packs and skin packs.
- ✓ They offer an attractive way to display certain commodity products such as cosmetics, toiletries, small tools, and fasteners (nails, screws, etc.).
- ✓ Thermoforming applications include large parts that can be produced from thicker sheet stock.
- ✓ Examples include covers for business machines, boat hulls, shower stalls, diffusers for lights, advertising displays and signs, bathtubs, and certain toys. Contoured skylights and internal door liners for refrigerators are made, respectively, out of acrylic (because of its transparency) and ABS (because of its ease in forming and resistance to oils and fats found in refrigerators).

Bonding of Thermoplastics

Mechanical Fastening

- ✓ It is the simplest way to join plastic parts. In this method a fastening element given is formed into the parts to be joined.
- ✓ Only the stronger, tougher plastics are suitable for this method since the joint must survive the strain of assembly, service load and repeated use.
- ✓ This is suitable only for lightly loaded, non-rigid assemblies where precision is not significant.
- ✓ Mechanical fasteners such as screws, rivets, pins, sheet-metal nuts are the commonly used joining methods.

Spin Welding

- ✓ In the spin welding of plastics, one part is held stationary and the other is attached to a spindle which is brought upto pre-determined speed and then force against the stationary part.
- ✓ Thus, the parts fuse together under the heat generated by friction. One limitation is that the rotating parts must be symmetrical.

Solvent Bonding

- ✓ In this method thermoplastics are joined by softening them by solvent, and then clamping or pressing together.
- ✓ Plastic molecules intermingle and the parts bond together when the solvent evaporates. It is a slow process.

Ultrasonic Welding

- ✓ In this method two parts to be joined are placed together and the pulses are transmitted from a generator to the parts by a vibrating tool causing them to vibrate against each other at frequencies around 20 KHz.
- ✓ The parts are heated and fused together. It is a very fast process and requires fairly rigid materials and best suited to spot weld plastic sections.

Induction Welding

- ✓ In this method, two pieces of same thermoplastics to be joined together are pressed with a metal wire of insert in the joint area and the high frequency about 450 KHz magnetic field is passed around it, which causes the encased metal to be heated up thereby melting the plastic, and the compression produces a good fusion weld.
- ✓ The metal remains inside the part.
- ✓ It is a high cost technique and is suitable for shapes that cannot be fitted into an ultrasonic welding machine.

Dielectric welding

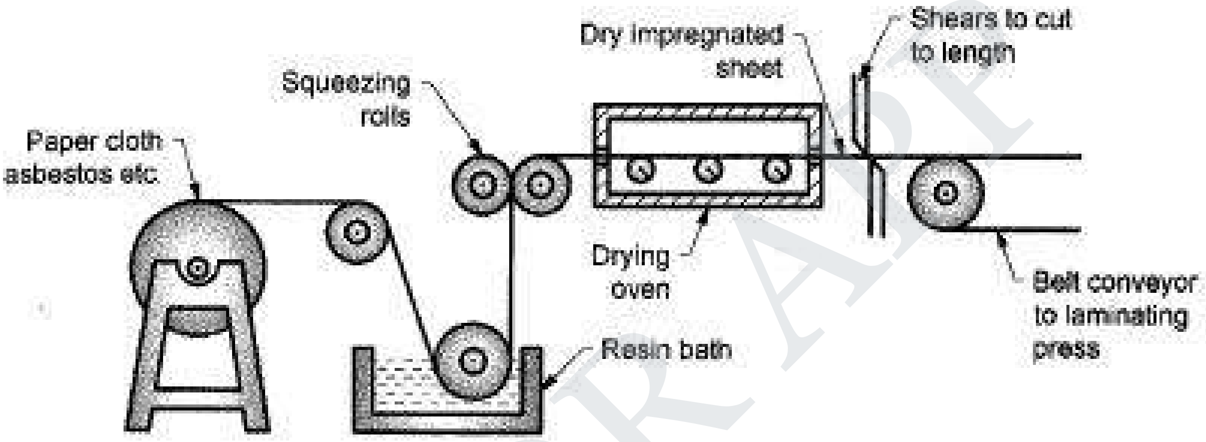
- ✓ This method finds applications in packaging process.
- ✓ It utilizes the technique of breaking down the plastic under high voltages and frequencies 10 to 100 MHz to produce dielectric heating and fuse the plastic.

Hot-Platen Welding

- ✓ In this method, the thermoplastic is first softened contacting it with a heated tool and then pressed together.
- ✓ The sticking between the hot tool and the plastic material is prevented by coating the tool with fluorocarbon.
- ✓ It can be used for welding large, irregularly shaped moulded or extruded parts.

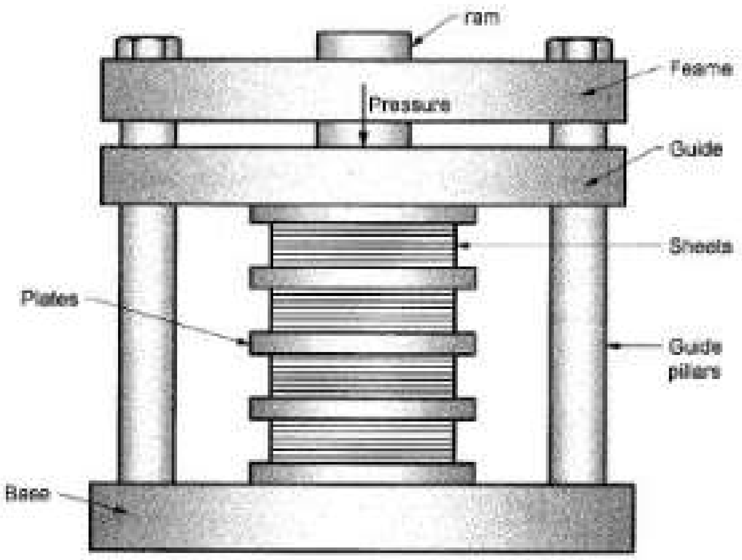
Laminating

- Laminating is the process of impregnating or coating sheets of paper, fabric, asbestos nylon, wood or other similar materials with resins and joining them by the application of heat and pressure.
- Sheets, tubes, rods and shells are commonly manufactured by this method.
- The resins used for impregnation include phenolics, melamine, epoxies and silicones.
- A schematic diagram for producing high pressure laminates is given in Figure.



(a) Preparation of sheet material for lamination

- The resin to be used as binder is dissolved in a solvent to convert it into liquid varnish.
- The base material which may be paper, cloth or asbestos is continuously passed through a bath of this liquid resin for impregnation.
- After removing excess resin with the help of two squeeze rolls this impregnated material is passed through driers for evaporating the solvent leaving a stiff sheet impregnated with the resin.
- The sheet coming out of the driers is cut to required size and then carried to the laminating press on a belt conveyor.



(b) Laminating press

- At the laminating press a number of cut pieces depending upon the final thickness of the sheet desired are stacked together between top and bottom plates.
- These stacks are mounted on the press as shown in Fig and pressed at pressure, ranging from 8 to 24 MPa.
- A hard rigid plate is formed due to the application of pressure and heat.
- Laminated tubing is made by winding impregnated sheets on a mandrel, heating and curing the resin and then removing the mandrel.
- The winding is done by rotating the mandrel between three large rollers which apply pressure on the sheet as it is being wound.
- Curing is done in an oven after which the mandrel can be removed.
- Rods are produced by first producing impregnated tubes with very small holes and then closing these holes during curing.
- The impregnated sheet is rolled on a very thin mandrel and the mandrel is withdrawn.
- The hollow tube so produced is placed in a suitable mould which closes the narrow hole as heat and pressure is applied for curing.
- High pressure laminates are strong, wear resistant, tough materials which are not affected by moisture or heat.
- They can be further processed by machining. Their, properties depend largely on the base material used.
- Laminates produced from paper are comparatively weaker and are used in electrical products.
- Fabric base laminates have higher strength and toughness and find application in gears, bushings, and other stressed materials, Asbestos and fiber glass base materials have excellent resistance to heat and very low water absorption.
- Common trade names for laminated plastics are Formica, Micarta and Limicold.