UNIT – I

METAL CASTING PROCESSES

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 - CO2 process – Stir casting; Defects in Sand casting

Introduction:

In manufacturing engineering industries, most of the components are made by ferrous and non-ferrous material such as iron, steel, aluminium, copper and so on. The easiest way to manufacturing the complicated shaped components is casting while compare with any other manufacturing method.

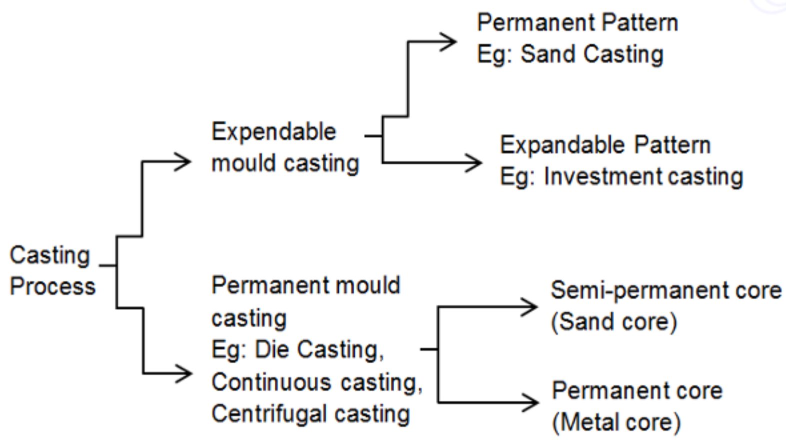
Casting:

The first traces of the Sand Moulding were found during 645 B.C. With technological advances, metal casting is playing a greater role in our everyday lives and is more essential than it has ever been.

Casting is a manufacturing process by which a liquid material is poured into a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting. The flow of molten metal into the mold cavity depends on several factors like minimum section thickness of the part, presence of corners, non-uniform cross-section of the cast, and so on.

The casting processes can be broadly classified into

1. Expendable mold casting
2. Permanent mold casting processes.



Expendable Mold Casting

Expendable mold casting is a generic classification that includes sand, plastic, shell, plaster, and investment (lost-wax technique) molds. All these methods use temporary, non-reusable molds. After the molten metal in the mold cavity solidifies, the mold is broken to take out the solidified cast. Expendable mold casting processes are suitable for very complex shaped parts and materials with high melting point temperature. However, the rate of production is often limited by the time to make mold rather than the casting itself. Following are a few examples of expendable mold casting processes.

Permanent Mold Casting processes

Permanent mold casting processes involve the use of metallic dies that are permanent in nature and can be used repeatedly. The metal molds are also called dies and provide superior surface finish and close tolerance than typical sand molds. The permanent mold casting processes broadly include pressure die casting, squeeze casting, centrifugal casting, and continuous casting.

Sand Casting

Sand casting is widely used for centuries because of the simplicity of the process. The sand casting process involves the following basic steps:

(a) Place a wooden or metallic pattern in sand to create a mold,
(b) Fit in the pattern and sand in a gating system,
(c) Remove the pattern,
(d) Fill the mold cavity with molten metal,
(e) Allow the metal to cool, and
(f) Break the sand mold and remove the casting.

The sand casting process is usually economical for small batch size production. The quality of the sand casting depends on the quality and uniformity of green sand material that is used for making the mold. Figure 1.1 schematically shows a two-part sand mold, also referred to as a cope-and-drag sand mold. The molten metal is poured through the pouring cup and it fills the mold cavity after passing through down sprue, runner and gate. The core refers to loose pieces which are placed inside the mold cavity to create internal holes or open section. The riser serves as a reservoir of excess molten metal that facilitates additional filling of mold cavity to compensate for volumetric shrinkage during solidification.

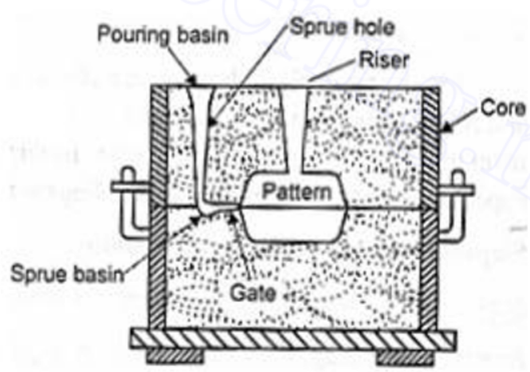


Fig.1.1 Method of sand casting

Advantages of sand castings process.

(a) It can be employed for all types of metal.
(b) The tooling cost is low and
(c) It can be used to cast very complex shapes.

Disadvantages of sand casting

(a) Rough surface.
(b) Poor dimensional accuracy.
(c) High machining tolerances.
(d) Coarse Grain structure.
(e) Limited wall thickness: not higher than 2.5-5 mm.

Pattern

The pattern is the primary 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.

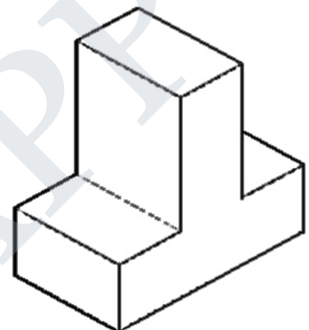


Fig.1.2 Single Piece Pattern or Solid Pattern

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.

Types of pattern

1. Single piece pattern (or) solid pattern

This is the simplest type of pattern, exactly like the desired casting. For making a mould, the pattern is accommodated either in cope or drag. Used for producing a few large castings, for example, stuffing box of steam engine. Refer Figure 1.2

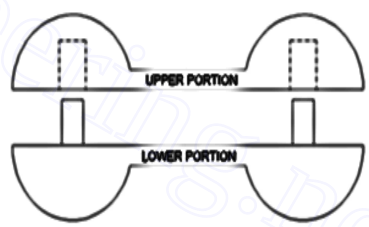


Fig.1.3 Split Pattern

2. Split pattern or Cope and drag pattern

These patterns are split along the parting plane (which may be flat or irregular surface) to facilitate the extraction of the pattern out of the mould before the pouring operation. The two part of the pattern are joined together with the help of dowel pins. For a more complex casting, the pattern may be split in more than two parts. Refer Figure 1.3

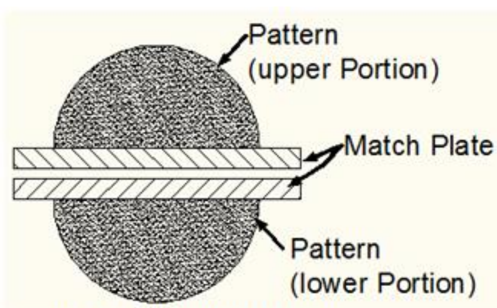


Fig.1.4 Match Plate Pattern

3. Match Plate pattern

A match plate pattern is a split pattern having the cope and drags portions mounted on opposite sides of a plate (usually metallic), called the "match plate" that conforms to the contour of the parting surface. The gates and runners are also mounted on the match plate, so that very little hand work is required. This results in higher productivity. This type of pattern is used for a large number of castings. Several patterns are mounted on one match plate if the size of the casting is small. Generally match plate pattern are used for moulding by moulding machine. Piston rings of I.C. engines are produced by this process. Refer Figure 1.4

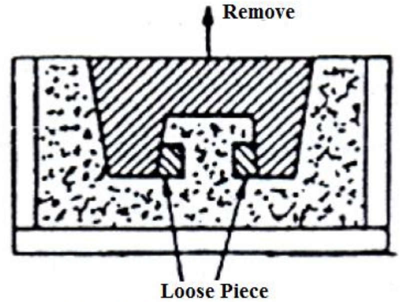


Fig. 1.5 Loose Piece Pattern

4. Loose piece pattern

When a one piece solid pattern has projections or back drafts which lie above or below the parting plane, it is impossible to with draw it from the mould. With such patterns, the projections are made with the help of loose pieces. A loose piece is attached to the main body of the pattern by a pin or with a dovetail slide. While moulding, the sand was rammed properly, then the loose piece was removed. One drawback of loose feces is that their shifting is possible during ramming. Refer Figure 1.5

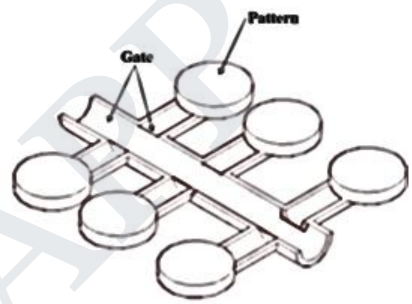


Fig. 1.6 Gated Pattern

5. Gated pattern

A gated pattern is simply one or more loose patterns having attached gates and runners. Because of their higher cost, these patterns are used for producing small castings in mass production systems and on molding machines. Refer Figure 1.6

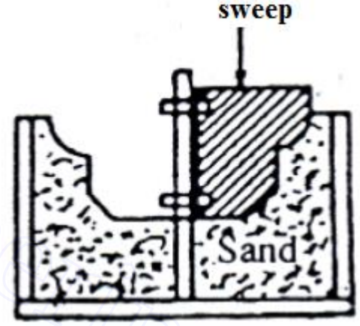


Fig.1.7 Sweep Pattern

6. Sweep pattern

A sweep is a section or board (wooden) of proper contour that is rotated about one edge to shape mould cavities having shapes of rotational 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. Refer Figure 1.7

7. Skeleton pattern

For large castings having simple geometrical shapes, skeleton patterns are used. Just like sweep patterns, these are simple wooden frames that outline the shape of the part to be cast and are also used as guides by the molder in the hand shaping of the mould. This type of pattern is also used in pit or floor molding process. Refer Figure 1.8

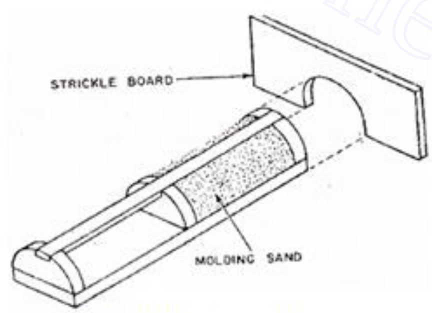


Fig. 1.8 Skeleton Pattern

8. Segmental pattern

Its function is similar to sweep pattern in the sense, that both employ a part of the pattern instead of a complete pattern, for getting the required shape of the mould. The segmental pattern is in the form of a segment, (refer figure 1.9) and is used for making moulding parts having circular shapes. To create the mould, it is rotated about the post in the same way as in sweep pattern, but it is not revolve continuously about the post to prepare the mould. Rather it prepares the mould by parts. When one portion of the mould is completed, the pattern is lifted up and moves to the next portion to make the next segment of the mould. This process is continued until the entire mould is completed. Example of product: Big gears and wheel rims (refer figure 1.9).

9. Shell pattern

It is a hollow pattern. The outer shape is used as mould, the core is placed inside the pattern, and hence it is also named as block pattern. This pattern is made of two half similar to split pattern but only for curved path, joined by dowel pin (refer figure 1.10. Example of product: curved drainage fitting.

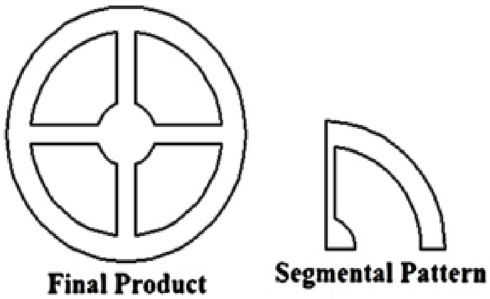


Fig.1.9 Segmental Pattern

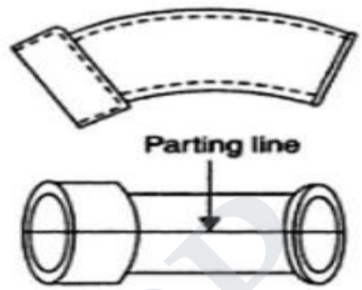


Fig.1.10 Shell Pattern

Pattern Material

Patterns may be constructed from the following materials. Each material has its own advantages, limitations, and field of application. Some materials used for making patterns are: wood, metals and alloys, plastic, plaster of Paris, plastic and rubbers, wax, and resins. 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

The usual pattern materials are wood, metal, and plastics. The most commonly used pattern material is wood, since it is readily available and of low weight. Also, it can be easily shaped and is relatively cheap. The main disadvantage of wood is its absorption of moisture, which can cause distortion and dimensional changes. Hence, proper seasoning and upkeep of wood is almost a pre-requisite for large-scale use of wood as a pattern material.

Based on the above factor, we can choose the pattern material as follows:

Short run production or piece production	: Wood
Large scale and mass production	: Metal
Batch Production	: Plastic, gypsum and cement

Wood:

Wood is a common material for the preparation for pattern and it should be dried and seasoned. It should not contain more than 10% moisture to avoid warping and distortion during subsequent drying. It should be straight grained and free from knots.

Merits:

1. Light in weight
2. Comparatively inexpensive
3. Good workability
4. Lends itself to gluing and joining
5. Holds well varnishes and paints
6. Can be repaired easily.

Demerits:

1. Non-uniform structure
2. Possess poor wear and abrasion resistance
3. Cannot withstand rough handling
4. Absorbs and gives off moisture

Types of wood

Commonly used material are : White pine, Mahogany, Maple, Birch, Cherry

Others material like : teak kail, shisham, deodar

Metal:

A metal pattern can be either cast from master wooden pattern or may be machined by using the usual methods of machining. Metal pattern are widely used for machine moulding. These types of pattern mostly used for large number of casting are to be manufactured.

Merits:

1. More accuracy and durability than wooden material
2. Having smooth surface
3. Mass production is possible
4. Possibility for rough handling
5. Resistance to wear, abrasion and swelling

Demerits:

1. It cannot be easily modified
2. Costlier and heavier than wood
3. Possibility for corrosion
4. Not suitable for piece production

Types of wood

Commonly used material are : cast iron, brass, aluminium, white metal

Gypsum:

Gypsum pattern are capable of producing casting with intricate details and to very close tolerance. There are two main types of gypsum (1) soft – plaster of paris and (2) hard – plaster

Benefits of gypsum material

1. Easily formed
2. Good plasticity
3. Easy to repair

Plastic:

It is also cast from the wooden pattern.

Benefits of plastic material

1. Light in weight compared with wood and metal
2. More economical in cost and labour
3. No moisture absorption
4. Strong and dimensionally stable
5. Highly resistance to corrosion

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Types of plastics

Plastic pattern are composition with based on epoxy, phenol formaldehyde and polyester resin. Commonly used material are : poly acrylates, polyethylene, polyvinylchloride

Wax:

Wax pattern are generally used in investment casting. Common materials are paraffin wax, shellac wax and microcrystalline wax.

Benefits of wax material

1. Good surface finish
2. High dimensional accuracy
3. Easy to work
4. Prevent moisture absorption.
5. Low cost

Drawback:

Suitable to small work piece only

Pattern Allowances

Pattern allowance is a vital feature as it affects the dimensional characteristics of the casting. Thus, 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 or contraction allowance
2. Draft or taper allowance
3. Machining or finish allowance
4. Distortion or camber allowance
5. Rapping allowance

Shrinkage or Contraction

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

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actually measure 4 -1/24 inch, thus compensating for the shrinkage. The various rate of contraction of various materials are given below

C.I., Malleable iron	= 10 mm/m
Brass, Cu, Al	= 15 mm/m
Steel	= 20 mm/m
Zinc, Lead	= 25 mm/m

Machining Allowance

In case the casting designed to be machined, they are cast over-sized in those dimensions shown in the finished working drawings. Where machining is done, the machined part is made extra thick which is called machining allowance.

Machining allowance is given due to the following reasons:

1. Castings get oxidized inside mould and during heat treatment. Scale thus formed requires to be removed.
2. For removing surface roughness, slag, dirt and other imperfections from the casting.
3. For obtaining exact dimensions on the casting.
4. To achieve desired surface finish on the casting.

The dimension of the pattern to be increased because of the extra metal required (i.e. finish or machining allowance) depends upon the following factors:

1. Method of machining used (turning, grinding, boring, etc.). Grinding removes lesser metal than turning.
2. Characteristics of metal (ferrous or non-ferrous, hard and easily machinable or soft). Ferrous metals get oxidised, aluminium does not.
3. Method of casting used. Centrifugal casting requires more allowance on the inner side. Die castings need little machining, sand castings require more.
4. Size and shape of the casting. For long castings, warpage is more and greater allowance is required. Thicker sections solidify late and impurities tend to collect there. This necessitates more machining allowance.
5. Degree of finish required. A higher degree of finishing requires more machining allowance.

The standard machining allowances for different metals and alloys are shown below

Material Cast	Overall length of external surface, cm			
	0 – 30	30 – 60	60 – 105	105 – 150
Al alloys	1.6	3.2	3.0	4.8
Brass, Bronze	1.6	3.2	3.0	4.8
Cast Iron	2.4	3.2	4.8	6.4
C.S	3.2	4.8	6.0	9.6

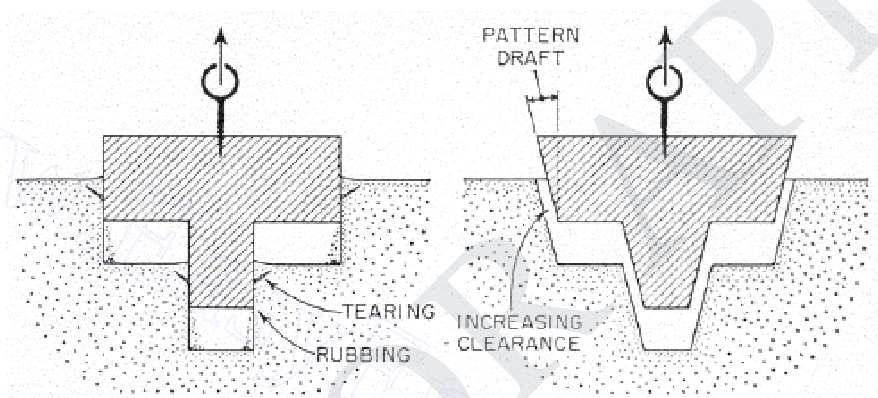
Draft Allowance or Taper Allowance

When a pattern is drawn from a mould, there is always a possibility of damaging the edges of the mould. Draft is taper made on the vertical faces of a pattern to make easier drawing of pattern out of the mould (Fig. 1.3). The draft is expressed in millimeters per metre on a side or in degrees.

The amount of draft needed depends upon (1) the shape of casting, (2) depth of casting, (3) moulding method, and (4) moulding material.

Generally, the size of draft is 5 to 30 mm per metre, or average 20 mm per metre. But draft made sufficiently large, if permissible, will make moulding easier. For precision castings, a draft of about 3 to 6 mm per metre is required.

Table shows different taper allowances used for different moulding methods.



TAPER ALLOWANCES USED FOR DIFFERENT MOULDING METHODS.				
Height of Pattern mm	Shell Moulding	Sand Moulding		
		Metal	Wood	
		Machine drawn	Manual drawn	Machine drawn
Up to 20	0° 45’	1° 30’	3°	3°
20 to 50	0° 30’	1°	1° 30’	1° 30’
100 to 200	0° 20’	0° 30’	0° 45’	0° 45’

Rapping or Shaking Allowance

When the pattern is shaken for easy withdrawal, the mould cavity, hence the casting is slightly increased in size. In order to compensate for this increase, the pattern should be initially made slightly smaller. For small and medium sized castings, this allowance can be ignored. But for large sized and precision castings, however, shaking allowance is to be considered. The amount of this allowance is given based on previous experience.

Distortion or Camber Allowance

Sometimes castings, because of their size, shape and type of metal, tend to warp or distort during the cooling period depending on the cooling speed. This is due to the uneven shrinkage of different parts of the casting. Expecting the amount of warpage, a pattern may be made with allowance of warpage. It is called camber. For example, a U-shaped casting will be distorted during cooling with the legs diverging, instead of parallel (Fig. 1.4). For compensating this warpage, the pattern is made with the legs converged but, as the casting cools, the legs straighten and remain parallel.

TYPICAL DISTORTION ALLOWANCE.							
Length in MM		3000			6000		
Wall Thickness in MM		12	25	50	12	25	50
Distorsion allowance for depth, in MM	450	12	8	3	27	20	50
	600	7.5	5	2	18	12.5	5

Moulding material

In foundry, various types of materials are playing a vital role in the manufacturing of casting product. These are grouped in to two categories: (1) Basic and (2) Auxiliary

Basic moulding materials includes silica sands, which forms the base and the various binders

Auxiliary groups include various additives which impart desired properties to the moulding and core sand.

The essential constitutions of a moulding sand are: Silica sand, Binder, Additives and water

Silica sand is widely used moulding material it has 80 to 90 % of silicon dioxide also gives refractoriness to the sand. A typical mixture by volume could be 89% sand, 4% water, 7% clay. Control of all aspects of the properties of sand is crucial.

It has the following advantage.

1. Cheap, plentiful and easily available
2. High softening temperature and thermal stability
3. Easily moulded, reusable and capable of giving good

Binder: In sand casting, the sand must contain some type of binder that acts to hold the sand particles together. Clay serves an essential purpose in the sand casting manufacturing process, as a binding agent to adhere the molding sand together. In manufacturing industry other agents may be used to bond the molding sand together in place of clay.

Additives: Additives impart to the moulding sand special properties (strength, thermal stability, permeability, refractoriness, thermal expansion etc….)

Sand: based on the amount of clayey content, they contain. The moulding sands are classified as follows:

1	Silica sand	Upto 2% clay
2	Lean or weak sand	2 to 10% clay
3	Moderately strong sand	10 to 20% clay
4	Strong sand	Upto 30% clay
5	Extra strong sand (loam sand)	Upto 50% clay

There are three types of sand

1. Natural sand
2. Synthetic sand
3. Chemically coated sand

Naturally Bonded- Naturally bonded sand is less expensive but it includes organic impurities that reduce the fusion temperature of the sand mixture for the casting, lower the binding strength, and require higher moisture content.

Synthetic Sand- Synthetic sand is mixed in a manufacturing lab starting with a pure (SiO2) sand base. In this case, the composition can be controlled more accurately, which imparts the casting sand mixture with higher green strength, more permeability, and greater refractory strength. For these reasons, synthetic sand is mostly preferred in sand casting manufacture.

Chemically coated sand: clean silica grains are sometimes coated with a non-thermosetting hydrocarbon resin, which act as a binder. An additional binder in the form of clay can also be used. The advantage of this sand is that the carbon in the resin which is an excellent refractory surrounds the sand grains and does not allow the molten metal to reach the sand grains. This produces casting with clean surface as the sand does not get fused in them. The moisture content in this sand is kept to above 3%

1. **Olivine Sand** : This sand is complex mix of ortho-silicates of Iron and Magnesium (Mg_2SiO_4: Fosterite, Fe_2SiO_4:Fayalite). This is prepared from the mineral Dunite. Olivine sand does not contain free-silica. And hence does not react with basic metals.

   It has a melting point of 1800°C.

2. **Chromite Sand** : It is a solid solution of complex metallic oxides having spinel structure. It has low silica content and exhibits very good thermal conductivity. In India availability of this sand is limited. In Odisha however, Chromite deposits are there. Chromite sand is produced by crushing Chromite ore.

   Typical composition is: Cr_2O_3: 44%, Fe_2O_3: 28%, SiO_2: 2.5%, CaO:

0.5%, Al_2O_3+MgO: 25%

3. Zircon Sand: : It is a combination of Zirconia (ZrO_2) 67% and Silica (SiO_2) 33%. The specific gravity is twice that of silica sand. It has a very high melting point of 2600 °C and a low coefficient of thermal expansion: 0.25% at 900 °C. Due to excellent quality and limited availability, it costs six times that of Silica sand. Supply is restricted by BARC due to the use of zirconia in nuclear applications. In India it is available in the Quilon beaches of Kerala and Gopalpur beaches of Odisha.

Typical composition of Quilon sand is: ZrO_2: 66.25%, SiO_2: 30.96%, Al_2O_3: 1.92%, Fe_2O_3: 0.74%

Zircon sand is used as wash and facing sand in casting. It is also used in precision castings.

4. Chamotte Sand: : These are obtained by calcining Al_2O_3-SiO_2 above 1100 °C. Chamotte sand has a melting point of 1750 °C and a coefficient of thermal expansion 0.5% at 900 °C. It has a very coarse grain size. Hence it is used in heavy castings (especially steel).

Moulding sand has maximum strength at maximum moisture content of 4% for lean sands and of 6 to 7 % for loam sands.

A typical green sand moulding sand for gray iron moulding are given as below

Silica sand	= 68 to 86%
Clay	= 10 to 20%
Water	= 3 to 6%
Additives	= 1 to 6%

Binder:

In sand casting, binders are used to hold the sand particles together. There are two types' namely (1) organic binder and (2) inorganic binder. Among these two organic binders are mainly used for core baking.

Clay binders are the most common inorganic binders. Clay are formed by the weathering and decomposition of rocks. The common types of clay used in moulding sand are: Fireclay, Kaolinite, Illite and Bentonite. Kaolinite and Bentonite clays are most popular, because they have high thermochemical stability.

Fire-clay : It is a refractory clay usually found in the coal measures

Kaolinite : It is one of the decomposition products of the slow weathering of the granite and basalt (a kind of black rock). It is the main constituent of china fire clay. Its melting point is 1750 to 1787°C

Its general composition is Al_2O_3 $2SiO_2$ $2H_2O$

Illite	:	It is formed from the weathering of mica rocks. Its particle size is about the same as the kaolinite clay and has similar moulding properties Its general composition is K_2O Al_2O_3 SiO_2 H_2O
Bentonite	:	It is formed from the weathering of volcanic or igneous rocks. It is creamy white powder. Its melting point is 1250 to 1300°C Its general composition is M_gO Al_2O_3 SiO_2 H_2O

The basic constituent which gives refractoriness to a clay is alumina, Al_2O_3 of all clays, bentonite is the most commonly used clay. It needs smaller amount of water to obtain a given degree of plasticity.

Other binders can be: Portland cement and sodium silicate.

The percentage of binder in the moulding sand is of great importance. The bond must be strong enough to with stand the pressure of and erosion by the melt; however the bond must not destroy the permeability of the sand so that the gases present in the melt can be escape.

Organic binder: these binders are mostly used for making core. Cereals binders are obtained from wheat corn or rye. Resin, drying oil for example linseed oil, fish oil, soyabean oil, and some mineral oils: pitch and molasses

Additives:

Additives are added to the moulding sand to improve the properties like refractoriness, permeability and strength of the moulding sand. These are helps to give good surface finish. Additives are not for binding purpose. There are various additives to meet the good surface finish. They are:

Sea coal: It is also named as coal dust. It tends to obtained smoother and cleaner surfaces of casting and also reduces the adherence of sand particles to the casting. It also increases the strength of the moulding sand. It is added upto 8% and also improves the permeability of the moulding sand.

Saw dust: It improves the permeability and deformability of the mould and cores. It must be dry. Instead of saw dust, Peat (fertilizer) having 70-73% of volatile (i.e. explosive) substances, not over 5 - 6% ash and 25 - 30% moisture can also be used.

Cereals: It is finely ground corn flour or corn starch. It increases the strength of the moulding sand by 0.25 - 2%. It is added about 1% with the moulding sand.

Wood flour: About 1% is added. It is ground wood particles or other cellulose materials such as grain hulls. They serve the same purpose as cereals except that they do not increase strength as like cereals

Silica flour: It is very fine powder. It is generally mixed with about twice as much conventional moulding sand to make facing sand. It is applied around the pattern. Because of its purity, it improves the strength and surface finish. It also resists metal penetration and minimizes sand expansion defects.

Special additives:

Fuel oil	:	It improves the mouldability of the sand
Iron oxide	:	It develops hot strength.

Dextrin : It increases the toughness and collapsibility and prevents sand from rapid drying.

Molasses : It is the by - product of sugar industry. It imparts high dry strength and collapsibility to mould and cores.

Moulding sand:

There are various types of moulding sand:

1. Green sand : It is composed of a mixture of silica sand (68 - 86%), clay (16 - 30%) and water (5 - 8%). The word “green” is associated with the condition of wetness or freshness. Hence in named as green sand
2. Dry sand : It is basically green sand. But mixed with 1 to 2% of cereals and 1 to 2 % of peat are added additives with the green sand also dried at 110 to 260°C for several hours. It is used for making large casting. It has greater strength and rigidity.
3. Facing sand : This sand is directly cover the surface of the pattern and provides a smoother casting surface and should be of fine texture. It is made of silica sand and clay. The layer of the facing sand in the mould usually ranges from 25 to 50mm.
4. Backing sand : This is the sand which is used to back up the facing sand and to fill the whole volume of the flask. The old sand may be repeatedly used for this purpose.
5. System sand : In mechanized foundries, where machine moulding is employed a so called system sand is used to fill the whole flask. Because of this, the system sand must have the higher strength, permeability and refractoriness than the backing sand.
6. Parting sand : Parting sand is usually applied on the pattern surface, to avoid its sticking and permit its easy withdrawal from the mould, when the pattern is made of two half with cope and drag.

   Dry parting material : charcoal, limestone, groundnut shell, talc and calcium sulphate

   Wet parting material : wax based preparation, petroleum jelly mixed with oil, paraffin and stearic acid

7. Loam sand It consists of fine sand plus finely ground refractories, clay, graphite and fibrous reinforcements. In this sand percentage of clay is in the order of 50%. It is used in pit moulding process for making mould for very heavy and large parts (engine body, machine tool bed and so on ….).

Moulding sand properties:

The quality of the casting product is mainly depends on the quality of the moulding sand.

Moulding sand is must have the following requirements:

1. It should be able to retain and reproduce the details as imparted by the pattern.
2. It should be able to retain the bulk structure.
3. It should not be too much sticky either to the pattern or to the casting.

4. It should prevent reaction with the liquid metal.
5. It should let the casting cool at an optimum rate so as to develop desired microstructure.

To achieve the above requirement, the moulding sand must have the following properties

1. Permeability or porosity
2. Plasticity or flowability
3. Adhesiveness
4. Cohesiveness or strength
5. Refractoriness
6. Collapsibility

Permeability: During pouring and subsequent solidification of a casting, a large amount of gases and steam is generated. These gases are those that have been absorbed by the metal during melting, air absorbed from the atmosphere and the steam generated by the molding and core sand. If these gases are not allowed to escape from the mold, they would be entrapped inside the casting and cause casting defects. To overcome this problem the molding material must be porous. Proper venting of the mold also helps in escaping the gases that are generated inside the mold cavity.

Flowability: It is the measure of the moulding sand to flow around and over a pattern during ramming and to uniform fill the flask. This property may be enhanced by adding clay and water to the silica sand.

Adhesiveness: This is the property of the sand mixture to adhere to another body. The moulding sand should cling to the sides of the moulding boxes so that it does not fall out when the flasks are lifted and turned over. This property depends on the type and amount of binder used in the sand mix.

Cohesiveness:
Green Strength: The molding sand that contains moisture is termed as green sand. The green sand particles must have the ability to cling to each other to impart sufficient strength to the mold. The green sand must have enough strength so that the constructed mold retains its shape.

Dry Strength: When the molten metal is poured in the mold, the sand around the mold cavity is quickly converted into dry sand as the moisture in the sand evaporates due to the heat of the molten metal. At this stage the molding sand must possess the sufficient strength to retain the exact shape of the mold cavity and at the same time it must be able to withstand the metallostatic pressure of the liquid material.

Hot Strength: As soon as the moisture is eliminated, the sand would reach at a high temperature when the metal in the mold is still in liquid state. The strength of the sand that is required to hold the shape of the cavity is called hot strength.

Refractoriness: It is the ability of the molding material to resist the temperature of the liquid metal to be poured so that it does not get fused with the metal. The refractoriness of the silica sand is highest.

Collapsibility: The molding sand should also have collapsibility so that during the contraction of the solidified casting it does not provide any resistance, which may result in cracks in the castings. Besides these specific properties the molding material should be cheap, reusable and should have good thermal conductivity.

SAND TESTING

1. Molding sand and core sand depend upon shape, size composition and distribution of sand grains, amount of clay, moisture and additives.
2. The increase in demand for good surface finish and higher accuracy in castings necessitates certainty in the quality of mold and core sands.
3. Sand testing often allows the use of less expensive local sands. It also ensures reliable sand mixing and enables a utilization of the inherent properties of molding sand.

4. Sand testing on delivery will immediately detect any variation from the standard quality, and adjustment of the sand mixture to specific requirements so that the casting defects can be minimized.

Generally the following tests are performed to judge the molding and casting characteristics of foundry sands:

1. Moisture content Test
2. Clay content Test
3. Fineness test
4. Refractoriness of sand
5. Strength Test
6. Permeability Test
7. Flowability Test
8. Mould hardness Test.

Moisture Content Test

The moisture content of the molding sand mixture may determine by difference in weight of moist sand and dry sand.

1. Measurement by evaporation method:
   - Sample of moulding sand weighing about 20 to 50 grams are allowed to heat at a constant temperature up to 100°C in an oven for about one hour.
   - It is then cooled to a room temperature and then reweighing the molding sand.
   - The moisture content in molding sand is thus evaporated.
   - The loss in weight of molding sand due to loss of moisture, gives the amount of moisture which can be expressed as a percentage of the original sand sample.

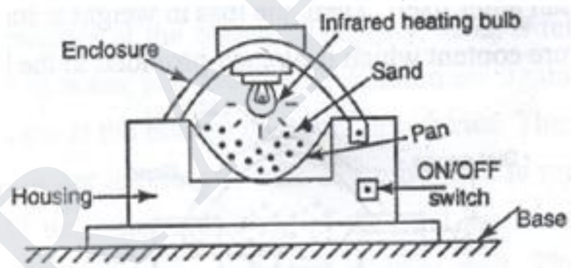


Fig.1.11 Evaporation method

2. Measurement by moisture teller method:
   - Sample of moulding sand placed in teller pan having 600 mesh screens at bottom. Hot air allows blowing over the moulding sand about 3 – 6 minute, now the moisture present in the moulding sand is removed. Once the moisture is removed, weighing the sample and find the deviation in weight of sample before and after placing in the teller pan. This method was quite faster than the evaporation method.

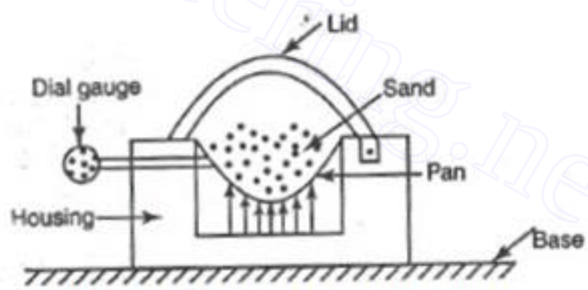


Fig.1.12 Moisture teller test

3. Measurement by moisture teller chemical reaction method:
   - This based worked on the principle that when water and calcium carbide react, they form acetylene gas which can be measured and this will be directly proportional to the moisture content.
   - Sample of moulding sand is placed in teller pan along with calcium carbide (CaC_2). This reaction will produce C_2H_2

$$CaC_2 + 2H_2O \longrightarrow C_2H_2 + Ca(OH)_2$$

   - The amount of C_2H_2 produced is directly proportional to the moisture content in the moulding sand.

- This instrument is provided with a pressure gauge calibrated to read directly the percentage of moisture present in the molding sand.

Clay Content Test

- The sample of molding sand weighing about 50 grams is mixed with water and 1% NaOH and allows stirring for 4-7 minute, and then waiting for 10-15 minute for sedimentation. Now the sand was settling down. The dirty water is present at the top portion of the pan
- The above process is repeated until to achieve clean water at the top portion of the pan. The water is drained off.
- The sand is dried and weighted. The loss of weight gives the clay content.

Refractoriness Test

- The refractoriness of the molding sand is judged by heating the A.F.S standard sand specimen to very high temperatures ranges depending upon the type of sand.
- The heated sand test pieces are cooled to room temperature and examined under a microscope for surface characteristics or by scratching it with a steel needle.
- If the silica sand grains remain sharply defined and easily give way to the needle. Sintering has not yet set in.
- In the actual experiment the sand specimen in a porcelain boat is placed into an electric furnace. It is usual practice to start the test from l000°C and raise the temperature in steps of 100°C to 1300°C and in steps of 50° above 1300°C till sintering of the silica sand grains takes place.
- At each temperature level, it is kept for at least three minutes and then taken out from the oven for examination under a microscope for evaluating surface characteristics or by scratching it with a steel needle.

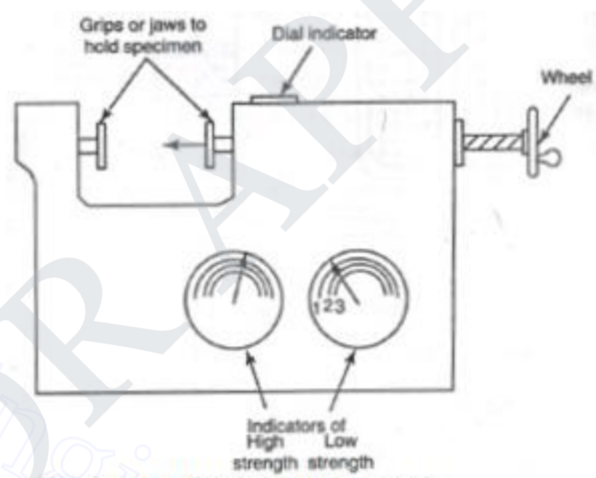


Fig.1.14 Strength Tester

Grain Fineness Test

- GFN is a measure of the average size of the particles (or grains) in a sand sample. The grain fineness of molding sand is measured using a test called sieve analysis.
- The test is carried out in power-driven shaker consisting of number of sieves fitted one over the other.
  1. A representative sample of the sand is dried and weighed, then passed through a series of progressively finer sieves (screens) while they are agitated and tapped for a 15-minute test cycle. The series are placed in order of fineness from top to bottom.
  2. The sand retained on each sieve (grains that are too large to pass through) is then weighed and recorded.
  3. The weight retained on each sieve is carried out through calculations to get the AFS-GFN.

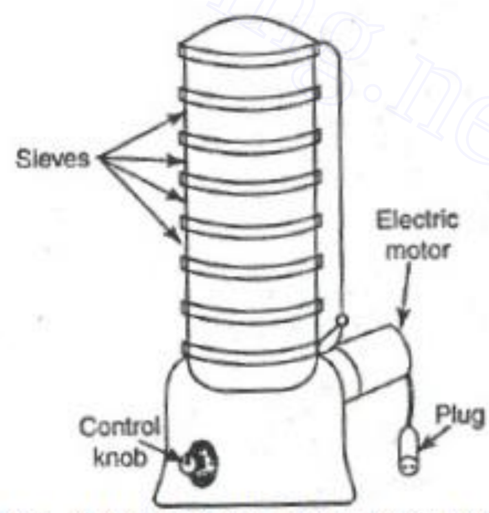


Fig. 1.13 Grain finess tester

*AFS = American Foundrymens's Society

Sieve Number	6	12	20	30	40	50	70	100	140	200	270	Pan
Weightage factor	3	5	10	20	30	40	50	70	100	140	200	300

Example: weight retained on each sieve is given as: 0.5, 1.0, 1.5, 2.0, 2.5, 4.5, 10, 15, 7.5, 3.5, 1.5, and 0.5

Sieve Number	Retained sample (g) Fi	Retained percentage (Pi)	Weightage factor (Wi)	$WiFi$	$WiPi$
6	0.5	1	3	1.5	3
12	1.0	2	5	5.0	10
20	1.5	3	10	15.0	30
30	2.0	4	20	40	80
40	2.5	5	30	75	150
50	4.5	9	40	180	360
70	10	20	50	500	1000
100	15	30	70	1050	2100
140	7.5	15	100	750	1500
200	3.5	7	140	490	980
270	1.5	3	200	300	600
Pan	0.5	1	300	150	300
	∑ = 50	**∑ = 100**		**∑ = 3556.5**	**∑ = 7113**

$$\therefore GFN = \frac{3556.5}{50} = 71.13 \quad (or) \quad \frac{7113}{100} = 71.13$$

Strength Test

- This is the strength of tempered sand expressed by its ability to hold a mold in shape. Sand molds are subjected to compressive, tensile, shearing, and bending stresses.
- The green compressive strength test and dry compressive strength is the most used test in the foundry.

Compression tests

a. A rammed specimen of tempered molding sand is produced that is 2 inches in diameter and 2 inches in height.
b. The rammed sample is then subjected to a load which is gradually increased until the sample breaks.
c. The point where the sample breaks is taken as the compression strength.

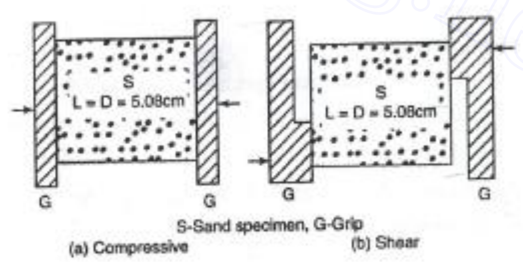


Fig.1.15

Shear tests

a. The compressive loading system is modified to provide offset loading of the specimen.
b. Under most conditions the results of shear tests have been shown to be closely related to those of compression tests, although the latter property increases proportionately more at high ramming densities.

Tensile test

a. A special waisted specimen is loaded in tension through a pair of grips.

Bending test

1. A plain rectangular specimen is supported on knife edges at the ends and centrally loaded to fracture.

Permeability Test

- Permeability of the moulding sand is determined by measuring the rate of flow of air through a compacted specimen under standard conditions. It is measured in terms of permeability number.
- A sample of moulding sand is placed in a tube. Time taken for 2000 CM^3 of air at a pressure of 10 g/cm^2 to pass through the specimen is noted
- Permeability meter consisting of the balanced tank, water tank, nozzle, adjusting lever, nose piece for fixing sand specimen and a manometer. The permeability is directly measured.
- Permeability number P is volume of air (in cm^3) passing through a sand specimen of 1 cm^2 cross-sectional area and 1 cm height, at a pressure difference of 1 gm/cm^2 in one minute.

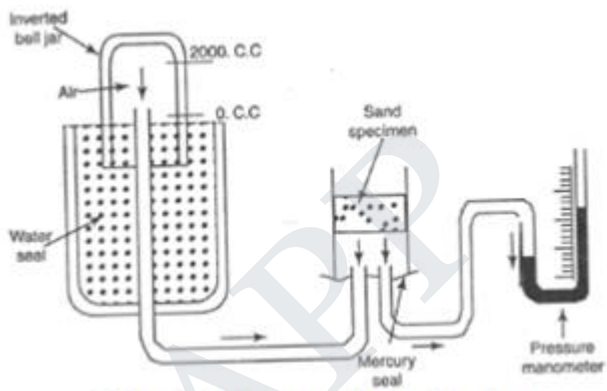


Fig. 1.16 Permeability Tester

$$P = \frac{Vh}{atp}$$

Where,

P = permeability
v = volume of air passing through the specimen in c.c.
h = height of specimen in cm
p = pressure of air in gm/cm^2
a = cross-sectional area of the specimen in cm^2
t = time in minutes.

Mold Hardness Test

- This test is performed by a mold hardness tester.
- The working of the tester is based on the principle of Brinell hardness testing machine.
- In an A.F.S. standard hardness tester a half inch diameter steel hemi-spherical ball is loaded with a spring load of 980 gm.
- This ball is made to penetrate into the mold sand or core sand surface.
- The penetration of the ball point into the mold surface is indicated on a dial in thousands of an inch.
- The dial is calibrated to read the hardness directly i.e. a mold surface which offers no resistance to the steel ball would have zero hardness value and a mold which is more rigid and is capable of completely preventing the steel ball from penetrating would have a hardness value of 100.
- The dial gauge of the hardness tester may provide direct readings

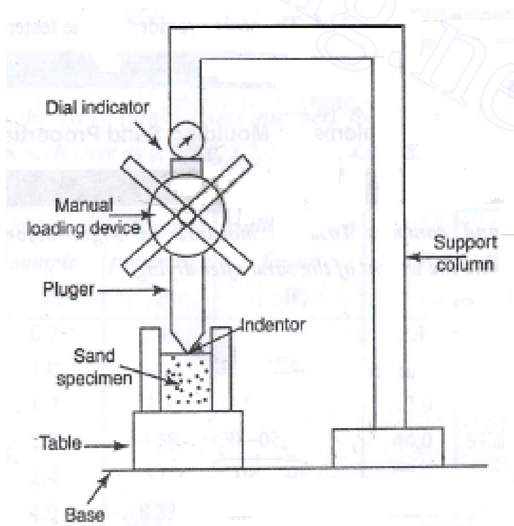


Fig. 1. 17 Mould Hardness Tester

Compatibility and flowability

- The compatibility test is widely accepted as both simple to perform and directly related to the behavior of sand in molding, particularly when involving squeeze compaction.
- A fixed volume of loose sand is compacted under standard conditions and the percentage reduction in volume represents the compatibility.

CORES

A core is a body made of refractory material, which is used for making cavity or a hole in casting. Its shape is similar to the required cavity in the casting. It is also used for making recess, projections, undercuts and internal cavities.

Core Print is a projection provided on the casting product. It forms a seat in the mould.

There are seven requirements for core:

1. Green Strength: In the green condition there must be adequate strength for handling.
2. In the hardened state it must be strong enough to handle the forces of casting; therefore the compression strength should be 100 to 300 psi.
3. Permeability must be very high to allow for the escape of gases.
4. Friability: As the casting or molding cools the core must be weak enough to break down as the material shrinks. Moreover, they must be easy to remove during shakeout.
5. Good refractoriness is required as the core is usually surrounded by hot metal during casting or molding.
6. A smooth surface finish.
7. Minimum generation of gases during metal pouring.

Purpose of cores:

1. It may form a part of green sand mould
2. Cores may be employed to improve the mould surface.
3. It helps to strengthen the mould.
4. Cores may be used to form the gating system of large size mould.
5. It acts as an internal cavity for hollow casting.

Core making material:

Core sand	:	It consists of refractory material such as silica sand, zircon, olivine, carbon and chamotte sand
Binder	:	Vegetable oil or mineral oil, core flour, resin water, fire clay bentonite, urea
Additives	:	Wood flour, coal powder, cow dung, straw and so on…

Core binder:

1. To bind the sand grains together
2. To give strength and hardness
3. To prevent breaking
4. To give collapsibility to core
5. To prevent moisture absorption.

Other binders:

Oil binders	:	1. It is commonly used binder. 2. Linseed is the example of this oil binder. 3. 0.5 to 3% is added depends on the hardness and other properties
Water soluble binder	:	1. Dextrin starch are example of water soluble binder 2. It gets hardened at 180°C. Its mixing ratio is 1:8. 3. It gives green strength and edge hardness to the core
Resin binder	:	1. Phenol formaldehyde and urea are example for resin binder. 2. It gives hardness at 200°C. 3. It gives good strength and short time to bake and less gas will be formed.
Inorganic binder	:	1. Fire clay, silica flour, kerosene etc…are the example; 2. They are used in the powder form. 3. It develops greater strength and gives smooth surface.

Types of core boxes

Half core box : It is used to form semicircular core (refer figure 1.18). After baking, if needed, the two core pieces will pasted together to form the complete core

Dump core box : This type is helpful for making complete core in polygon size like square, rectangle and so on.. (Refer figure 1.19)

Split core box : This is similar to half core box, but it has two half and it must connect by dowel pin on either side of box. After preparation, box are separated (Refer figure 1.20)

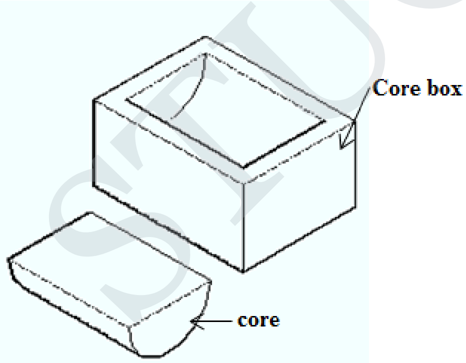


Fig.1.18 Half core box

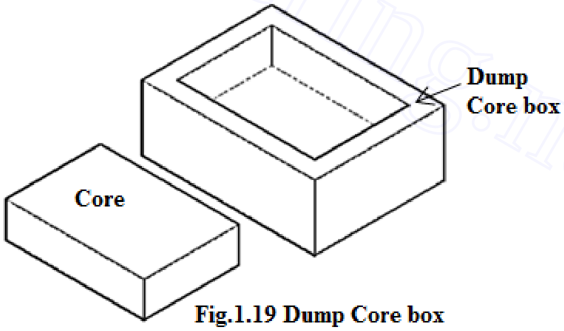


Fig.1.19 Dump Core box

Gang core box	**:**	During manufacturing, sometimes, we need an 'n' number of cores. In that occasion, we can go for gang core box instead of any other single core box (Refer figure 1.21).
Left and right core box	**:**	For the preparation of curved core, the manufacturer can opt for left and right hand core box is best option for easiest preparation of core (Refer figure 1.22)
Strickle core box	**:**	To make an irregular shaped core, the strickle core box will fulfill the need of the manufacturer. Here, box will fill with required sand and rammed properly by using strickle board (Refer figure 1.23).

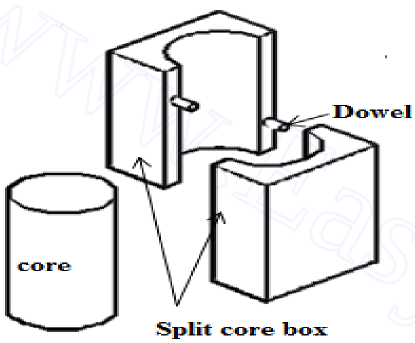


Fig. 1.20 Split core box

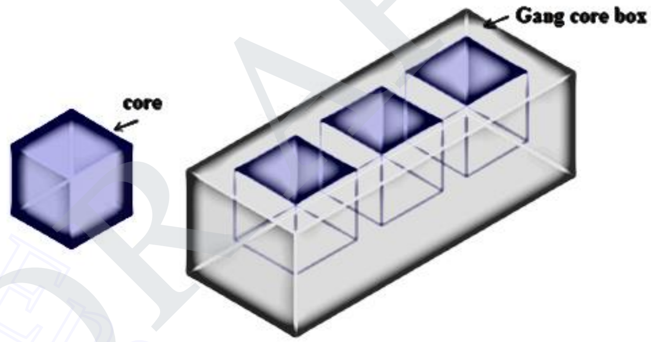


Fig. 1.21 Gang Core box

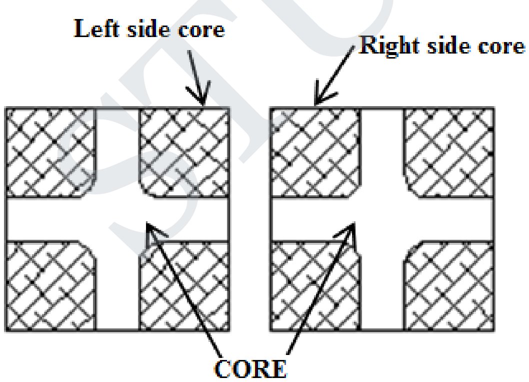


Fig.1.22 Left Hand and Right Hand core box

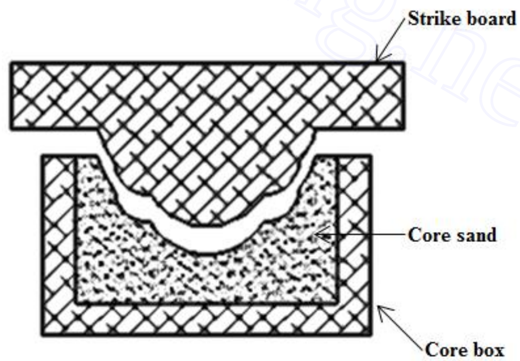


Fig. 1.23 Strike core box

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Core making process:

The core may be manufactured either by manual or machine based on needed. The chart shown here are the important steps for making core.

Sand preparation

↓

Making

↓

Baking

↓

Finishing

Sand preparation:

Sands are mixed properly to meet the requirement with the help of any one of the following mechanical means.

1. Roller mills
2. Core sand mixer
    a. Vertical revolving arm type.
    b. Horizontal paddle type.

In the case of roller mills, the rolling action of the mullers along with the turning over action caused by the ploughs gives a uniform and homogeneous mixture.

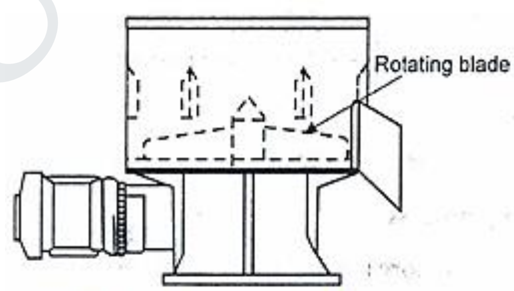

Fig.1.24 Core sand Mixer

Core making machine: It is broadly classified as follows.

- Core blowing machine
- Core ramming machine
- Core drawing machine
- Core extrusion machine

Core blowing machines:

The basic principle of core blowing consists of filling core sand into the core box by using the medium of compressed air. The velocity of the compressed air is kept high to obtain a *high* velocity of sand particles, thus ensuring their deposit in the remote comers of the core box. As the sand with high kinetic energy comes, the shaping and ramming is done simultaneously in the core box.

The core blowing machines can be classified into two basic groups.

- Small bench blowers
- Large floor blowers

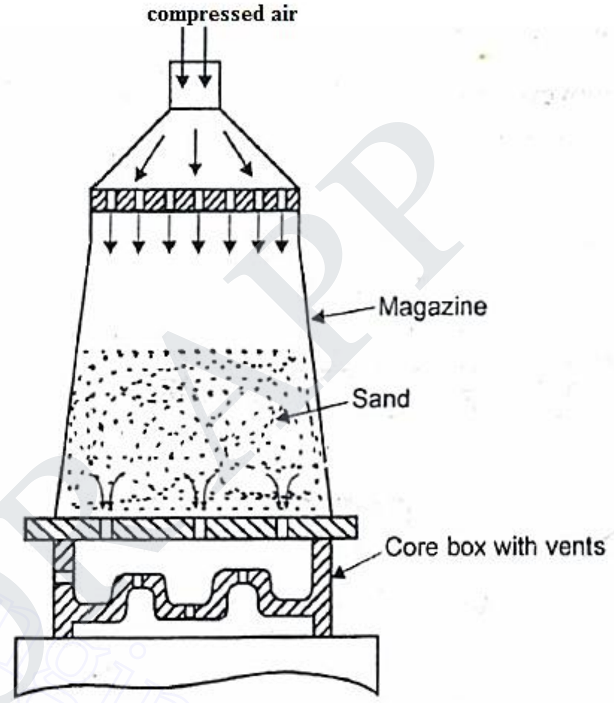

Fig.1.25 Core Blowing Machine

Core ramming machines:

Cores can also be prepared by ramming core sands in the core boxes by machines based on the following principles.

- Jolting
- Squeezing
- Slinging

Out of these three, machines based on jolting and slinging are more commonly used for core making.

Core drawing machines:

The core drawing is preferred when the core boxes have deep draws. After ramming sand in it, the core box is placed on a core plate supported on the machine bed. A rapping action on the core box is produced by a vibrating vertical plate. This rapping action helps in drawing off the core box from the core. After rapping the box is raised leaving the core on the core plate.

Core extrusion machine:

Simple cores of regular shape uniform cross-section can be extruded easily on a core extrusion machine. Cores of square, round, hexagonal and over sections are produced made rapidly on a core extrusion machine. A core extrusion machine has a hopper through which the core sand is fed to a horizontal spiral conveyor (situated below the hopper). As the spiral conveyor is rotated. It forces core and through a die of specified shape (square, round, etc.). Long cores thus produced can be cut to the desired length.

Core baking

Cores are baked to remove the moisture and to develop the strength the strength of the binder in care ovens. The cores are dried in ovens equipped with drawers, shelves or other holding devices. They are dried in batches or continuously over moving shelves. The heat in oven is produced by burning oil or core or by electric resistance. The core drying time depends upon the quantity of moisture and binder used in the sand size of the core and temperature of the oven. According to the type of production, the core drying ovens or core baking ovens are classified as

- Batch type
- Continuous type
- Dielectrically heated type

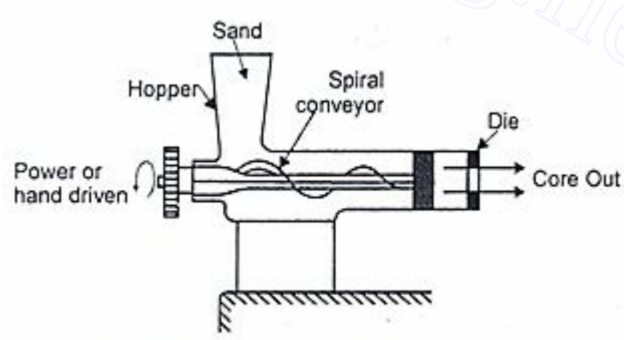

Fig.1.26 Core Extrusion Machine

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Batch type ovens

These make use of portable racks. The racks loaded with cores are transported by lift trucks or mono-rail conveyors to the oven. Large cores are moved directly into the oven by rail. The racks are admitted into the oven either through two doors which swing open on hinges or through a single sliding door of counter balanced type.

Continuous type ovens

In this type oven the core racks move slowly through the oven on a continuous rail or chain. The loading and unloading are continuous. The baking time is controlled by the rate of travel of the conveyor.

The temperatures of the various parts of the oven and the conveyor speed are coordinated in such a way that the core comes out from the oven not only baked but also cooled. In some of the designs, for saving the floor space, the cores move vertically upwards through the oven and get baked. They get cooled on their return trip downwards.

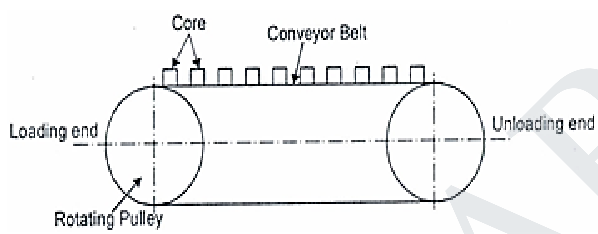


Fig.1.27 Continuous type oven

Dielectrically heated type

These are modem core ovens employed for high quality cores using plastic binders. The cores to be heated dielectrically are placed between the parallel plates or electrodes and a very high frequency current is passed. This high frequency current tends to deform the sand molecules. The sand molecules resist the deformation and required heating effect is produced. In core ovens proper temperature control is necessary for maintaining the most effective temperature.

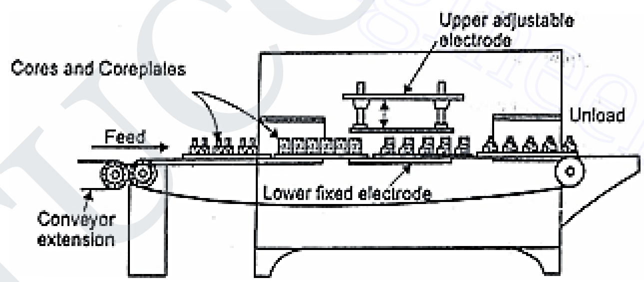


Fig.1.28 Di - electrically heated oven

Core finishing

After baking, the cores are given certain finishing operations before they are finally set in the mould. The fins, bumps or other sand projections are removed from the surface of the cores by rubbing or filing. The dimensional inspection of the cores is very necessary. Cores are also coated with refractory or protective materials to improve their refractoriness and surface finish.

Types of cores

There are many types of cores available. The selection of the correct type of core depends on production quantity, production rate, required precision, required surface finish, and the type of metal being used.

For example, certain metals are sensitive to gases that are given off by certain types of core sands; other metals have too low of a melting point to properly break down the binder for removal during the shakeout.

The cores as classified as follows.

a. *According to the shape and position of the core*
- Horizontal core
- Vertical core
- Hanging or cover core
- Balanced core
- Drop core or Stop off core
- Ram up core
- Kiss core

b. *According to the State or condition of Core*
- Green sand core
- Dry sand core
- Sodium silicate cores

c. *According to the type of core-hardening process employed*
- C02-process
- The hot box process
- The cold set process
- Fluid (or) Castable sand process
- Nishiyama process.
- Furan No-Bake system
- Oil-No-Bake Process

The horizontal and vertical cores are used in foundry work frequently. A horizontal core is placed horizontally in the mould. The ends of the core rest in the seats provided by core prints on the pattern.

A vertical core is placed vertically in the mould. The upper end of the core is forced in the cope and the lower end in the drag.

A balanced core is used when the casting has opening only on one side and only one core print is available on the pattern. It extends horizontally in the mould cavity.

A cover core extends vertically downwards. It is suspended from the top of the mould

A hanging core hangs from the top and does not have any support at the bottom in the drag.

A ram-up core is set in the mould with the pattern before ramming. It is used when the cored detail is located in an inaccessible position.

When the pattern is not provided with core prints and no seat is available for the core to rest, the core is held in position between the cope and drag simply due to the pressure of the cope. Such a core is known as *'Kiss core '*.

Green sand cores

Green sand cores are formed by' the pattern itself. A green sand core is a part of the mould. It is made out of the same sand from which the rest of mould has been made.

Dry sand cores

Dry sand cores, unlike green sand cores are not produced as a part of the moulding. Dry sand cores are made separately and independent of the mould. A dry sand core is made up of core sand which differs very much from the sand out of which differs very much from the sand out of which the mould is constructed.

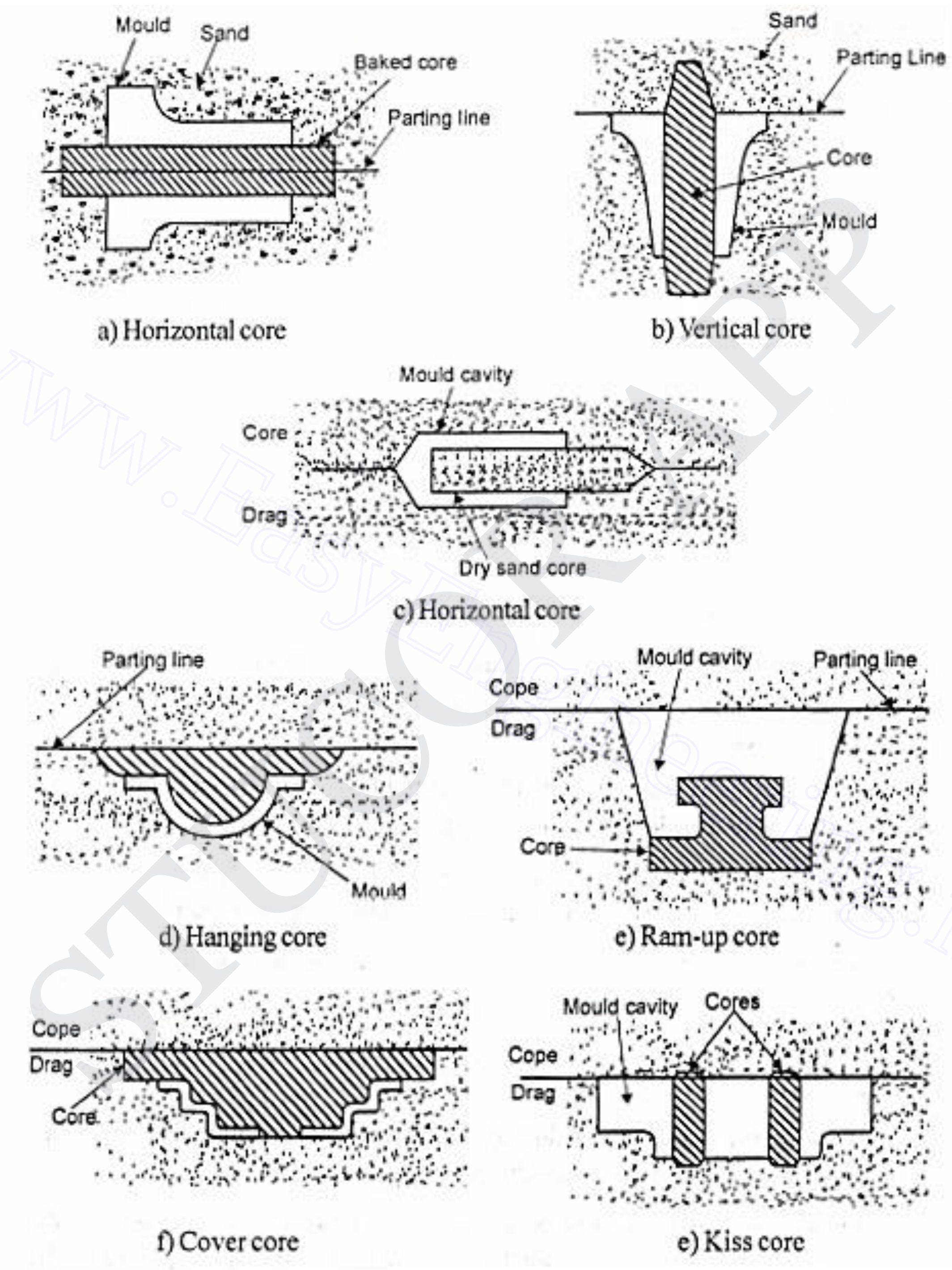


Fig.1.29 Various types of cores

Oil bonded cores

Conventional sand cores produced by mixing silica sand with a small percentage of linseed oil. Oil bonded cores base themselves on the principle of the oxidation and polymerization of a combination of oils containing chemical additives which, when activated by an oxygen bearing material, set in a pre-determined time.

Resin-bonded cores

It is the type of cores phenol resin bonded sand is rammed in a core box. The core is removed from the core box and baked in a core oven at 375 to 450°F to harden the core.

Sodium Silicate and CO_2 cores

These cores use a core material consisting of clean, dry sand mixed with a solution of sodium silicate. The sand mixture is rammed into the core box. The rammed core while it is in the core box is gassed for several seconds with Carbon-di-Oxide gas. As a result a silica gel forms which binds sand grains into a strong, solid form

$$Na_2SiO_3 + CO_2 \longrightarrow Na_2\,CO_3 + SiO_2 \text{ (Silica gel)}$$

The Hot box process

It uses heated core boxes for the production of cores. The core box is made up of cast iron, steel or aluminium and possesses vents and ejectors for removing core gases and stripping core form the core box respectively, Core box is heated from 350 to 500°F. Heated core boxes are employed for making shell cores dry resin bonded mixtures.

The cold set process

While mixing the core-sand, an accelerator is added to the binder. The sand mixture is very flowable and is easily rammed. Curing begins immediately with the addition of accelerator and continues until the core is strong to be removed from the core box. A little heating of the core hardens it completely. Cold set process is preferred for jobbing production. Cold set process is employed for making large cores.

Castable sand process

A setting or hardening agent such as Dicalcium silicate is added to sodium silicate at the time of core sand mixing. The sand mixture possesses high flowability and after being poured in the core box, it chemically hardens after a short interval of time.

Nishiyama process

Nishiyama process uses sodium silicate bonded sand, which is mixed with 2% finely powdered ferrosilicon, Hardening occurs because of exothermic reaction of silicon with NaOH produced bydrolysis in the solution of sodium silicate. Cores thus made possess short bench life.

Furan-no-bake system

The core sand mixture contains washed and dried sand with clay content less than 0.5% furan no-bake resin 2% and activator (phosphoric acid) 40%. The basic reaction between the furan resin and phosphoric acid results in an acid dehydration of the resin. The core sand mixture has high flowability and needs reduced rodding (to handle the core). Uniform core hardness, exact core dimensions, better fitting cores, lower machining and layout costs, and reduction of oven baking are some of the good characteristics of cores made by Furan-No-Bake system.

Oil-no-bake process

The process employs a synthetic oil-binder which when mixed with basic sands and activated chemically, produces cores that can be cured at room temperature.

Moulding process

The process of forming moulds is called moulding. It is an important operation involved in the casting. After preparing moulds at the moulding shop and making cores at the core room of the foundry, the next important operation is the assembly of moulds for pouring.

Moulding tools

Shovel

It is just like rectangular pan fitted with a handle. It is used for mixing the moulding sand and for moving it from one place to the other.

Riddle

It is used for removing foreign materials like nails, shot metal splinters of wood, etc., from the moulding sand.

Rammer

It is a wooden tool used for ramming or packing the sand in the mould. Rammers are made in different shapes.

Strike-off bar

It is a cast iron or wrought iron bar with a true straight edge. It is used to remove the surplus sand from the mould after the ramming has been completed.

Vent wire

It is a mild steel wire used for making vents or openings in the mould.

Lifter

It is a metal piece used for patching deep section of the mould and removing loose sand from pockets of the mould.

Slick

Different types of slicks are used for repairing and finishing moulds.

Trowel

It contains of a flat and thick metal sheet with upwards projected handle at one end. It is used for making joints and finishing flat surfaces of a mould.

Swab

It is made of flax or hemp. It is used for applying water to the mould around the edge of the pattern.

Draw spike

It is a metal rod with a pointed or screwed end. It is used for removing the pattern from the mould.

Rawhide mallet

It is a mallet to loosen the pattern in the mould by striking slightly, so that it can be withdrawn without damaging the mould.

Gate cutter

It is a metal piece to the gate- the opening that connects tee sprue with the mould cavity.

Rapping plate (or) Lifting plate

It is used to facilitate shaking and lifting large pattern from the mould.

Spirit level

It is used to check that the sand bed, moulding box or table of moulding machine is horizontal.

Clamps

Clamps are used to hold the cope and drag of the complete mould together so that the cope may not float or rise when the molten metal is poured into the mould.

Gaggers (or) Lifters

These are iron rods bent at one or both ends. These are used to reinforce the moulding sand in the top portion of the moulding box and for supporting hanging sand.

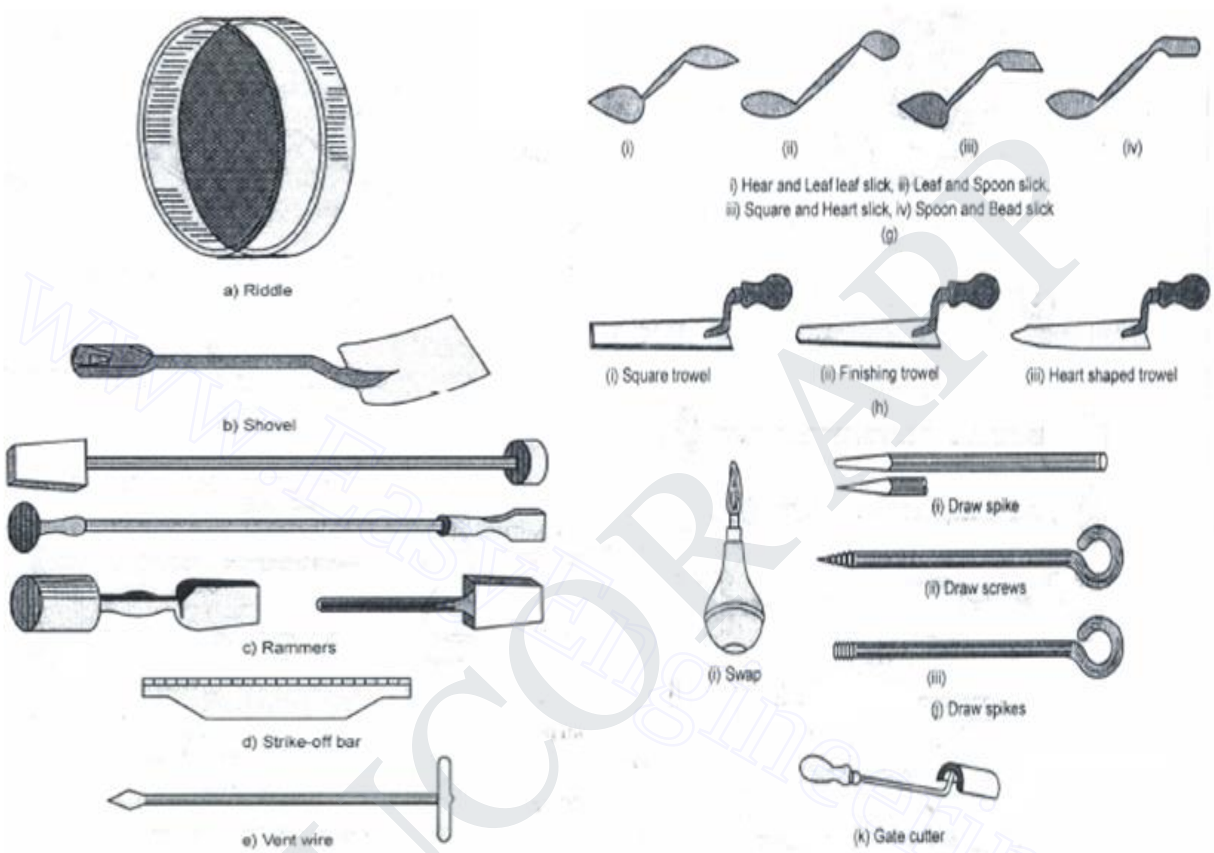


Fig. 1.30 Moulding Tools

Sand moulding process:

Moulding Process

- Hand Moulding
- Machine Moulding
- According to the method used
  1. Bench moulding
  2. Floor moulding
  3. Pit moulding
  4. Sweep moulding
  5. Plate moulding
- According to the moulding materials used
  1. Green sand moulding
  2. Dry sand moulding
  3. Loam moulding

Sand mould can be made either by manual or on moulding machine. Manual moulding is done for piece and for small lot production, whereas machine moulding is employed in large lot and mass production.

Based on the nature of work place, the manual moulding can be classified as

Bench Moulding	:	This is done only for small work
Floor Moulding	:	This process is done on the foundry floor and is employed for medium sized large casting
Pit Moulding	:	This method is used for very large casting and is done on the foundry floor. However, a pit dug in the floor acts as the lower flask(drag) and the upper flask (cope) is placed over the pit to complete the assembly

Machine moulding: All the operations are done by machine, and then it is called as machine moulding. The operations includes – compacting the sands, rolling the mould over and drawing the pattern from the mould and so on…..

GREEN SAND MOULDING

A green sand mould is composed of a mixture of sand (silica sand SiO_2), clay (act as binder), and water. The word green is associated with the condition of wetness or freshness and because the mould is left in the damp condition, hence the name “green sand mould”. This type of mould is the cheapest and has the advantage that used sand is readily reclaimed. But the mould being in the damp condition, is weak and cannot be stored for a longer period. Hence such moulds are used for small and medium sized casting.

Principal Methods of Green-sand Moulding are:

- Open-sand method
- Bedded-in-method
- Turn-over method

Open-sand Method

It is simplest form of green sand moulding, particularly suitable for solid patterns. For convenience in working and pouring, the entire mould is made in the foundry floor or in a bed of sand above floor level. Moulding box is not necessary and the upper surface of the mould is open to air. After proper levelling the pattern is pressed in the sand bed for making mould. Pouring basin is made at one end of the mould, and the overflow channel cut at the exact height from the bottom face of the mould for giving necessary thickness.

Bedded-in method

In this method, the pattern is hammered down or pressed to bed it into the sand of the foundry floor or in a drag filled partially with sand to form the mould cavity. The sand should be rammed close to the pattern sand; a cope is placed over the pattern. The cope is rammed up, runners and risers are cut and the cope box is lifted. Now the pattern is withdrawn, the surfaces of drag and cope replaced in its correct position for completing the mould.

iii)Turn-over method

One pattern-halfis placed with its flat side on a moulding board, a drag is rammed and rolled over. The other pattern half and a cope box are placed in position. After ramming the cope is lifted off and the two pattern halves shaken and withdrawn. Now the cope is replaced on the drag for assembling the mould.

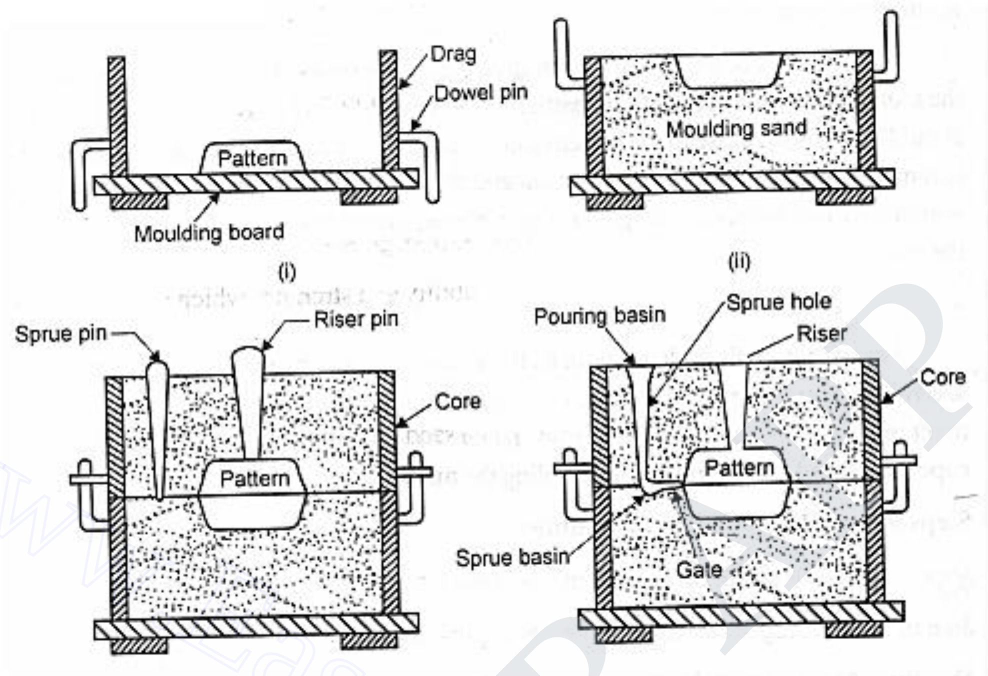


Fig. 1.31 Green sand Moulding Processes

Steps involved in Green sand moulding

- First one half of the pattern is placed on the moulding board.
- The drag is placed with the dowel pins down.
- Moulding sand is filled in the moulding box to cover the pattern.
- The drag is completely filled with sand up to the top and rammed by the peen end of the hand rammer.
- Excess sand is levelled by a strike-off bar.
- The drag is tilled upside down.
- Parting sand is applied on the surface.
- The other half of the pattern is how placed correctly on the already placed half
- The cope is placed in position on the drag and aligned using dowel pins.
- The sprue pin is placed vertically for the purpose of pouring the molten metal.
- The risers are placed over the highest point of the pattern for the purpose of escaping the gases and identify the level of molten metal.
- Again the moulding sand filled in the cope box, and rammed.
- The riser and the sprue pin are removed.
- The funnel shaped opening called a pouring basin is cut at the top of the sprue pinhole.
- The cope is lifted, turned over and placed on the floor.
- The pattern pieces are carefully removed.
- The gate is cut that is connecting the sprue basin and the mould cluity.
- The cope is placed carefully over the drag.
- Pouring the molten metal.

Advantages

- Green sand moulds are softer than dry sand moulds. This allows greater freedom in construction when the castings solidify and cool.
- Green sand mou1ds are quite strong for small depths, as the gases escape from them.
- Green sand moulds do not require any backing operations or equipment, but dry sand cores are to be used.

Disadvantages

- The green sand moulds cannot be stored for long time.
- The green sand moulds are not so strong as other moulds are liable to be damaged during handling or pouring.
- The surface finish of the casting obtained from green sand mould is not very smooth.
- The green sand mould lacks permeability and strength, which causes certain defects like blow holes etc.

DRY SAND MOULD

Dry sand moulds are basically green sand moulds with two essential differences: the sand used for dry sand moulds contains 1 to 2% cereal flour and 1to 2% of pitch, whereas the sand mixture for green sand moulds may not contain these additives. Also the prepared moulds are baked in an oven at 110° to 260°C for several hours. The additives increase the hot strength due to evaporation of water as well as by the oxidation and polymerization of the pitch. So, dry sand moulds can be used for large casting. This give better surface finish and also reduce the incidence of the casting defects such as blow holes, porosity that may occur as a result of steam generation in the mould. However, due to the greater strength of these moulds, tearing may occur in hot strength materials.

LOAM SAND MOULD

Loam sand consists of fine sand plus finely grounded refractories, clay, graphite and fibrous reinforcement. It differ from ordinary moulding sand in that the percentage of clay in it is very high (of the order of 50%)

Loam is sand and clay milled with water to form a thin plastic mixture to the consistency of mould. This loam mortar is applied as plaster (6 to 12 mm layer) to the rough structure of the mould. The loam sand mould is constructed to porous brick cemented together with loam mortar. Cast iron plates and bars are used to reinforce the brickwork which retains the moulding material. Loam moulds require adequate ventilation so as to open out pores in the otherwise compact, closely knit mass by artificial means. For this, chopped straw or horse manure is mixed up with the loam sand.

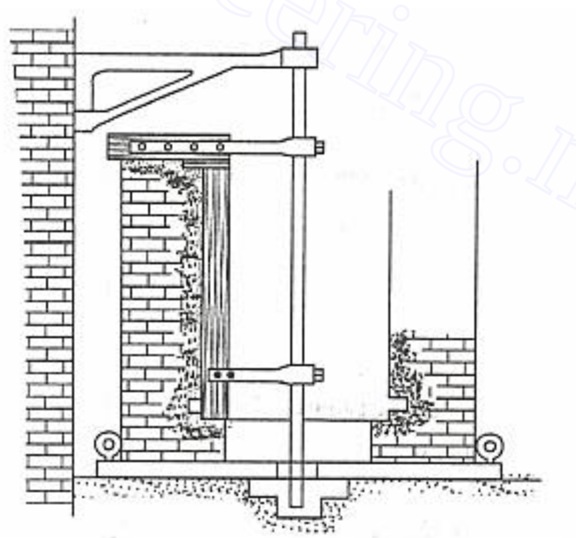


Fig.1.32 Loam Moulding with sweep pattern

Moulding machine.

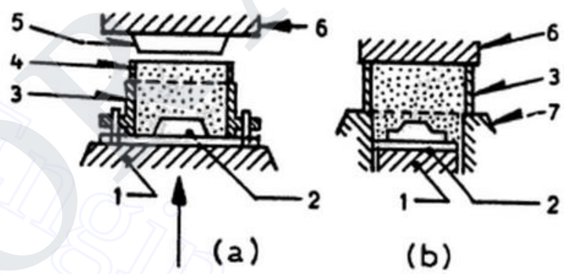
Moulding processes may be classified as hand moulding or machine moulding according to whether the mould is prepared by hand tools or with the aid of some moulding machine. Hand moulding is generally found to be ecoomical when the castings are required in a small number.

The main advantages of machine moulding are as follows.

- When the number of castings is substantial, the additional cost of metallic patterns and other equipment is compensated by the high rate of production, and the overall cost per piece works out lower than in the case of hand moulding.
- It affords great saving in time, especially when a large number of similar castings in small sizes are required.
- A semi-skilled worker can do the machine job whereas hand moulding requires skilled craftsmanship.
- The castings obtained are more uniform in size and shape and more accurate than those obtained by hand moulding due to steadier lift of the pattern.

Squeezing machine

A squeeze machine is very useful for shallow patterns. A squeezer (squeeze head), plate or presser board slides inside the flask to compress the sand above and around the pattern. For squeezing action the squeeze piston may by forced upward, pushing the flask up against the squeezer or presser board the presser board being forced into the flask



1) Table 2) Pattern 3) Flask 4) Sand Frame 5) Platen 6) Squeezer head 7) Frame

(a) Top Squeezer Machine (b) Bottom Squeezer machine

Fig.1.33 Squeeze moulding machine

The sand is rammed harder at the back of the mould and softer on the pattern face. In other words sand has greatest density at the surface where pressure is applied to sand and sand density decreases progressively towards the pattern.

Moulding force (M_f) = $P\left(\frac{\pi}{4}d^2\right) - W$

where

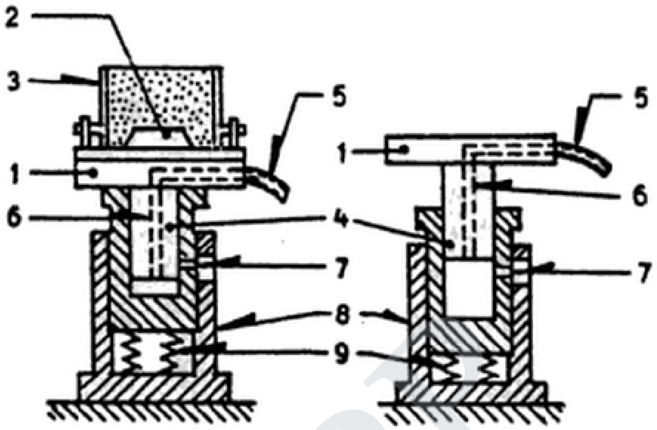
P - Pressure in squeeze cylinder

d - Piston diameter

W - Weight of flask pattern and sand

JOLT MACHINE

In jolt machine, the pattern and flask are mounted in the mould plate and the flask is filled with sand. The entire assembly is raised a small amount by means of an air cylinder and is then dropped against a fixed stop. The compacting of sand is achieved by the decelerating forces acting on it. The working of a jolt moulding machine is shown in figure. The table with moulding sand is lifted by plunger to a definite height, when compressed air is admitted through pipe and channel. Next the table drops since the air is released through pipe. In falling, the table strikes the stationary guiding cylinder and this impact packs the moulding sand in the flask. Springs by cushioning the table blows, reduced noise and prevent destruction of the mechanism and the foundation. About 20 to 50 drops are needed to compact the sand and the average machine operates at about 200 strokes per minute.



1) Table 2) Pattern 3) Moulding box
4) Plunger 5) Pipe 6) Channel
7) Through hole 8) Cylinder 9) Spring

Fig. 1.34 Jolt Moulding Machine

Drawback:

- Density of the sand is not uniform
- Noisy operation
- Impact load on foundation.

SAND SLINGER

The sand slinger consists of a base, a sand bin, a bucket elevator, a swinging or movable arm, a belt conveyor and the sand impeller. Prepared sand lying in the sand bin is picked up by the elevator buckets and is dropped on to the belt conveyor which takes the same to the impeller head. Inside the impeller head, rapidly rotating cup shaped blade picks up the sand and throws it downward into the moulding box as a continuous stream of sand with machine gun rapidity and great force. The sand is discharged into the moulding box at a rate of300 to 2000kg/minute.

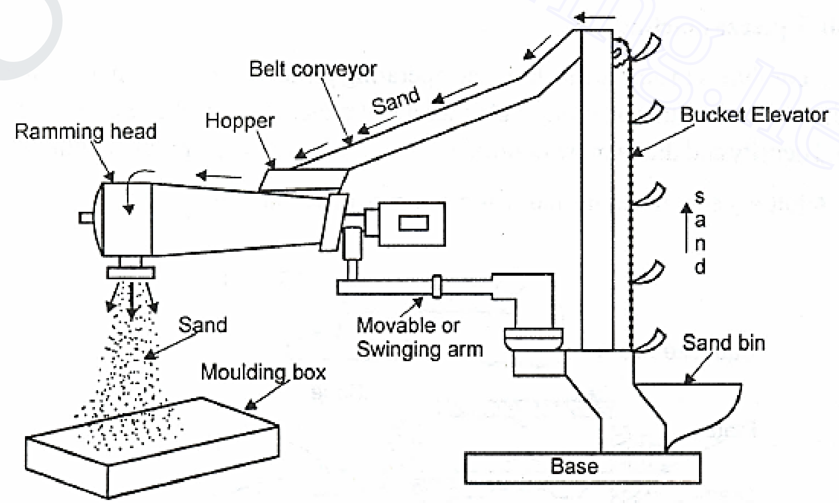


Fig. 1.35 Sand Slinger Machine

This force is great enough to ram the mould satisfactorily. In moulding boxes, sand is filled and rammed at the same time. The density of sand which is the result of sand's inertia is uniform throughout the mould.

STUCOR APP

MELTING FURNACE

Melting furnaces used in the foundry industry are of many diverse configurations. The selection of the melting unit is one of the most important decisions foundries must make with due consideration to several important factors including:

1. The temperature required to melt the alloy
2. The melting rate and quantity of molten metal required
3. The economy of installation and operation
4. Environmental and waste disposal requirements

Several types of furnaces are most commonly used in foundries:

For melting ferrous metal

- Cupola furnace
- Blast furnace

For melting ferrous metal

- Direct fuel-fired furnaces
- Crucible furnaces
- Electric-arc furnaces
- Induction furnaces

Cupola Furnace

A cupola is a vertical cylindrical furnace equipped with a tapping spout neat its base. Cupolas are used only for melting cast irons, and although other furnaces are also used the largest tonnage of cast iron is melted in cupolas.

General construction and operating features of the cupola are shown in figure 1.36.

It consists of a large shell of steel plate lined with refractory. The charge, consisting or iron, coke, flux and possible alloying elements, is loaded through a charging door located less than halfway up the height of the cupola. The iron is usually a mixture of pig iron and scrap (including risers, runners, and sprues left over from previous

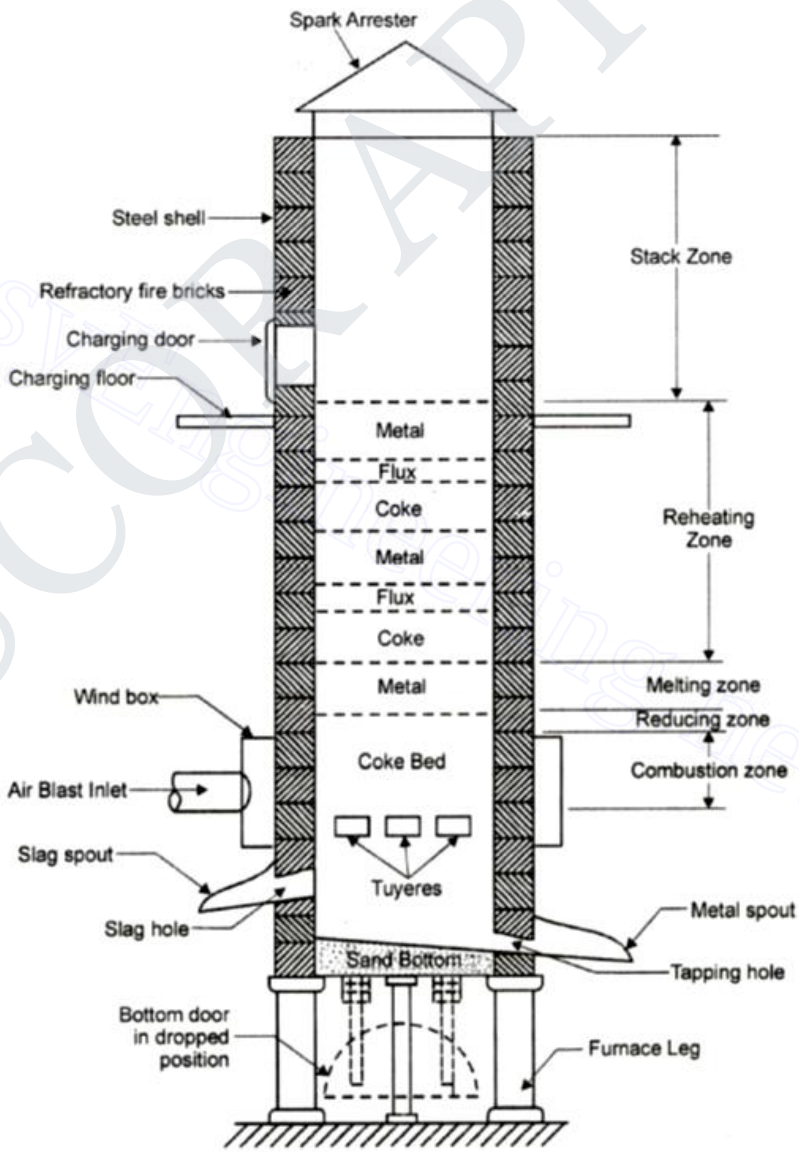


Fig.1.36 Cupola Furnace

castings). Coke is the fuel used to heat the furnace. Forced air is introduced through openings near the bottom of the shell for combustion of the coke. The flux is a basic compound such as limestone that reacts with coke ash and other impurities to form slag. The slag serves to cover the melt, protecting it from reaction with the environment inside the cupola and reducing heat loss. As the mixture is heated and melting of the iron occurs, the furnace is periodically tapped to provide liquid metal for the pour.

Cupola zones

Various zones of the cupola are illustrated in figure 1.36.

Combustion or Oxidizing zone

It is the zone where combustion takes place. It extends from the top of the tuyers to a surface boundary below which all the Oxygen of air is consumed by combustion.

Chemical reaction that takes place in the zone is

$C(coke) + O_2$ (from air) ~ CO_2 + Heat

The temperature in this zone is about 1800°C.

Reducing zone

It extends from the top of the combustion zone to the top of the initial coke bed. The CO_2 produced in the combustion zone moves up and is reduced to CO. The temperature also drops to 1650°C.

$CO_2 + C_2 \sim CO$ - Heat

Melting zone

It includes the first layer of pig iron above the initial coke bed. In this zone, the pig iron is melted. The following reaction takes place.

$3\ Fe + 2\ CO \sim Fe_3C + CO_2$

Pre heating zone

It includes all the layers of cupola charges placed above the melting zone to the top of the last charge. The layers of charges are heated by the out-going gases. The temperature in the zone may be upto 1050°C.

Stack

It is the zone beyond the pre-heating zone, through which the hot gases go to the atmosphere.

Cupola construction:

- The cupola essentially consists of a cylindrical steel shell lined on the inside with refractory bricks.
- The entire structure is supported on legs and is open at top and bottom when not in use.
- At the bottom, doors are provided which can be closed and propped to prepare a hearth for burning coke.
- About 100 mm above the bottom of the shell is an opening called the tap hole with a projecting spout for taking out the molten metal.
- On the rear of the tap hole is a slag hole to drain out slag. It is about 50 to 150 mm above the level of the tap hole.
- This height decides the amount of metal that can be stored in the cupola between taps.

- This height may be less if the cupola is fitted with a receiver and the metal IS continuously drained form the cupola.
- About 50 to 150 mm above the slag hole are openings through the shell into the cupola shaft called tuyers.
- These openings permit a blast of air from a wind box surrounding the cupola shell around the tuyers.
- These tuyers are provided around the shell in one or more rows to provide a balanced supply of air.
- Air is supplied into the wind box from a blower through pipes.
- The cupola shaft extends further up from the wind box to a charging platform.
- The height of the cupola from the tap hole to the charging platform is called the effective height.
- It is about 4 to 6 times the internal diameter of the cupola for small and medium size cupolas and about 3 to 5 metre for larger ones.
- At the height of the charging platform is a charging opening through which the cupola can be charged in operation.
- The cupola shaft extends further up by another 3 to 5 metre to give a chimney effect for natural draft.
- The other dimensions of the cupola are empirically fixed based on melting area.
- The total tuyers area is 15 to 25 percent of the cupola melting area. The wind belt section is about 30 percent of cupola melting area and so on.
- Commercial cupola sizes vary from 450m m to over 2000mrri in inside diameter with melting capacities ranging from 1.5 to 35 tonnes per hour.

The cupola furnace has several unique characteristics which are responsible for its widespread use as a melting unit for cast iron. The cupolas is one of the only methods of melting which is continuous in its operation

- High melt rates
- Relatively low operating costs
- Ease of operation

In more recent times, the use of the cupola has declined in favour of electric induction melting, which offers more precise control of melt chemistry and temperature, and much lower levels of emissions.

The construction of a conventional cupola consists of a vertical steel shell which is lined with a refractory brick. The charge is introduced into the furnace body by means of an opening approximately half way up the vertical shaft. The charge consists of alternate layers of the metal to be melted, coke fuel and limestone flux. The fuel is burnt in air which is introduced through tuyeres positioned above the hearth. The hot gases generated in the lower part of the shaft ascend and preheat the descending charge.

Most cupolas are of the drop bottom type with hinged doors under the hearth, which allows the bottom to drop away at the end of melting to aid cleaning and repaired. At the bottom front is a tap hole for the molten iron at the rear, positioned above the tap hole is a slag hole. The top of the stack is capped with a spark/fume arrester hood.

A typical operation cycle for a cupola would consist of closing and propping the bottom hinged doors and preparing a hearth bottom. The bottom is usually made from low strength moulding sand and slopes towards a tapping hole. A fire is started in the hearth using light weight timber; coke is charged on top of the fire and is burnt by increasing the air draught from the tuyers. Once the coke bed is ignited and of the required height, alternate layers of metal, flux and coke are added until the level reaches the charged doors. The metal charge would typically consist of pig iron, scrap steel and domestic returns.

An air blast is introduced through the wind box and tuyers located near the bottom of the cupola. The air reacts chemically with the carbonaceous fuel thus producing heat of combustion. Soon after the blast is turned on, molten metal collects on the hearth bottom where it is eventually tapped out into a waiting ladle or receiver. As the metal is melted and fuel consumed, additional charges are added to maintain a level at the charging door and provide a continuous supply of molten iron. At the end of the melting campaign, charging is stopped but the air blast is maintained until all of the metal is melted and tapped off. The air is then turned off and the bottom doors opened allowing the residual charge material to be dumped.

The Blast Furnace Process

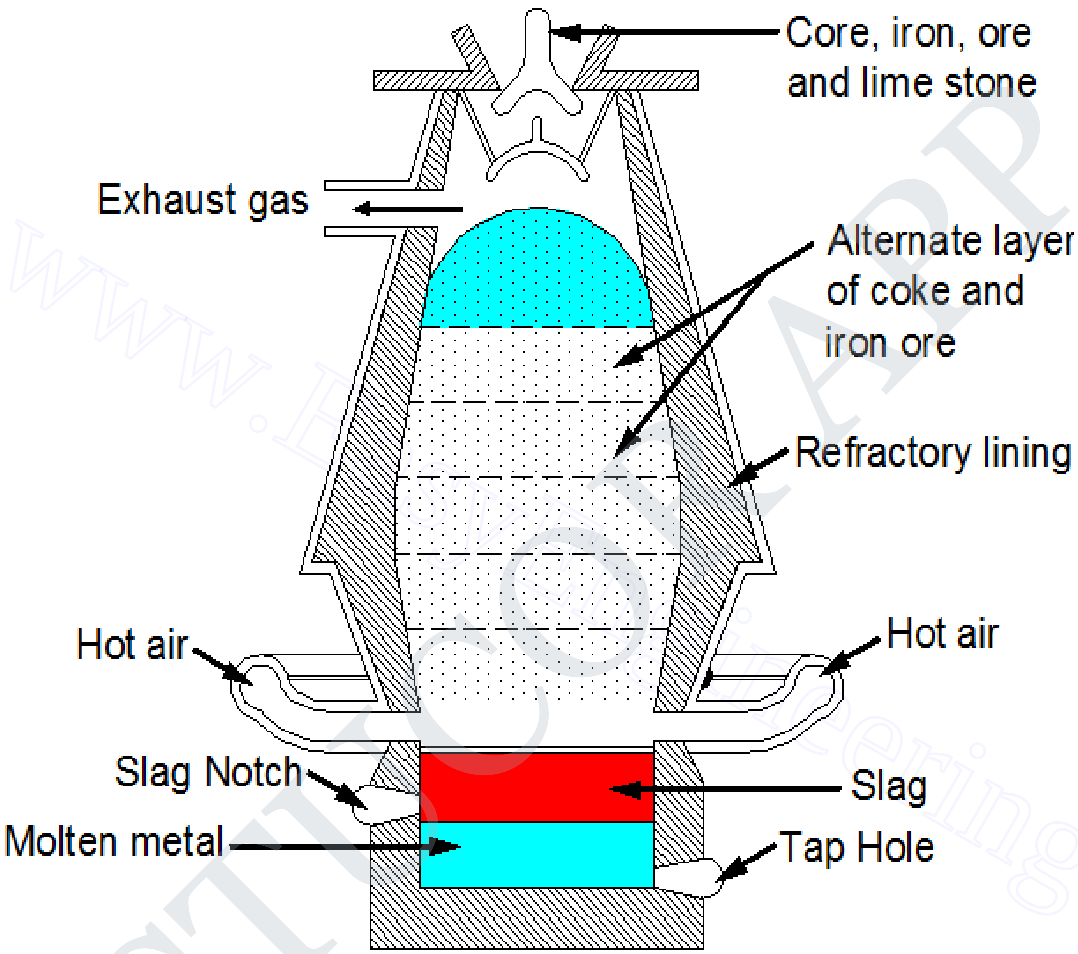


Fig. 1.37 : Blast Furnace

Working of Blast furnace

1. The Iron Ore, Coke and Limestone, (the Charge), is conveyed to the top of the Furnace.
2. The Charge is stored in Bells until the timing is right for the charge to be dropped into the Furnace.
3. Hot air is then blown through pipes called Tuyers, to fire the mixture.
4. The Coke burns to increase the temperature in the Furnace.
5. The Limestone attracts the impurities in the Iron Ore and forms Slag. This Slag is lighter than the molten Iron and so floats on top of it.
6. As the Furnace fills, the molten Iron is tapped off. The Slag is also tapped off at regular intervals. Most Iron is taken straight from the Blast Furnace to the Steel Mill, but some is poured into buckets called Pigs. This Iron is called Pig Iron and is used to make Cast Iron.

The Charge

The Charge consists of 3 parts:

- Iron Ore
- Coke
- Limestone

Iron Ore

The Iron Ore is first mined and then brought to the Blast Furnace. It contains impurities which have to be removed. Hematite and Magnetite are the most common ores. It takes about two tons of Iron Ore to produce one ton of iron, but this varies with different types of ores.

Coke

Coke is made by heating soft coal in the absence of air. As Coke is burned in the Blast Furnace it raises the temperature to about 2000°C which is enough to melt the Iron Ore. The Carbon in the Coke chemically reacts with the Oxygen in the Iron Ore to form Carbon di oxide (CO_2, and Carbon Monoxide (CO), which escapes through the Gas Outlet.

Limestone

The Limestone is mined then crushed before being brought to the Blast Furnace. It combines with the impurities in the Iron Ore to form Slag. A material which removes unwanted materials or cleans another material is called a Flux.

The Exhaust Gas Outlet

The Exhaust Gas Outlet collects any gaseous emissions from the chemical reactions that are taking place in the Furnace. As you know Carbon dioxide and Carbon monoxide are not exactly concussive towards healthy living and so they cannot be let to escape into the atmosphere as they are. Firstly because these gases are hot they are reused to save energy. They are piped to nearby Stoves in order to heat them. The gases are then 'cleaned' before being let into the atmosphere.

Charging Bells

You may notice that the Charging Bell system in the above diagram looks more complicated than those you see in books. The reason is that you are looking at a more accurate representation. You can understand that the manufacturers of Iron want to conserve as much energy as possible, not to do so would cost money and be mad! There are in fact two Bells in the system called, the Small Bell and the Large Bell. The Small Bell is filled directly from the Conveyor System, and when it is close to being full it is opened to allow the Charge drop into the Large Bell. The Large Bell is then opened when it is nearly full and the Charge can drop into the Furnace. Using this system greatly reduces the amount of heat that is lost to the atmosphere.

Gas Outlet

The Gas Outlet is simply an array of holes in the Furnace that allows the escaping gases to get to the Exhaust Gas Outlet.

Melting Iron Ore, Coke and Limestone

At the top of the Furnace the Iron Ore, Coke and Limestone is at a temperature of about 200°C. At this stage the materials are gone through the pre-heating stage. Close to the middle of the Furnace the temperature has increased to approximately 480°C, where the raw materials have started to melt. The temperature increases rapidly to about 2000°C at the bottom of the Furnace where the molten Iron is situated, waiting to be removed.

Tuyers

Strange word tuyers. (It's pronounced "2 ears"!). These are small pipes that permit hot air from the Bustle Pipe to enter the furnace. The hot air is necessary to keep the temperature in the furnace high. The tuyers are located all around the Furnace like spokes on the hub of a bicycle wheel. They also have valves so that nothing can escape from the Furnace. The diagram below shows the relationship between the tuyers, the Bustle Pipe and the Furnace. It is a view as if you were looking from the top of the Furnace.

Tap hole

The Tap hole is used to draw off the molten Iron at regular intervals of about 5 to 6 hours. You should notice that the Tap hole is located below the Slag hole. This is because the Slag is lighter than the molten Iron and so sits on top. The molten Iron leaves the Tap hole and is either poured into moulds called 'Pigs' or sent to other areas for further refining.

Slag Hole

The Slag hole, which is situated above the Tap hole, because Slag is lighter than molten Iron, is used to draw off the waste Slag. The Slag is scraped off every 3 or 4 hours and is then used for road beds, fertilizer or cement.

Bustle Pipe

The Bustle Pipe is a large diameter pipe that circles the base of the Furnace. It carries the hot air from the Stoves, where the air is heated, to the tuyers which allow the hot air to enter the Blast Furnace.

Refractory Lining

You might ask, that if the Blast Furnace is made from Steel and there is molten Iron inside the Furnace, how come the Furnace does not melt? That would be a good question, and the answer is quite simple. Inside the Steel shell of the Furnace there is a layer of Fire Brick called the Refractory Lining. This Refractory Lining reflects the heat back into the Furnace. You have seen a Refractory Lining before. If you look at the back of a fireplace, (preferably one that does not have a fire burning in it at the time), you will see a reddish cement. This is Fire Brick and causes the heat generated by the fire to be reflected back into the room, rather than be absorbed by the wall at the back of the fireplace.

Conveyor System

The Conveyor System takes the Charge from the area where it is maxed together to the top of the Blast Furnace. The Charge is carried in Skip Cars which run on a rail track.

Special Casting Processes:

- Casting in sand moulds is economical and gives good results for many applications where dimensional accuracy and surface finish requirements are not too stringent and the casting wall thicknesses are not too small.
- There are many applications in which it is desired to achieve better surface finish, finer details, thinner walls, better strength, and faster production rates or to eliminate further machining.
- Special casting processes have been developed to meet these requirements.
- Some of these special castings are discussed below.
  - Shell moulding
  - Investment casting
  - Centrifugal casting
  - Pressure die casting
  - Ceramic moulding
  - CO_2 process
  - Stir casting

Shell moulding

Shell mould casting process also known as Croning or C-process makes use of moulds (and cores) made of relatively thin shells about 6 mm thick for casting.

- The shells are made from clay free silica sand 60-140 AFS fineness mixed with 3 to 10 percent by weight of phenolic thermosetting resins like phenol formaldehyde or urea formaldehyde.
- The resin may be used in the powder form in the mixture or may be mixed in liquid form and then dried on the sand grains.
- The mixture should be dry and free flowing.
- Sometimes about 112percent kerosene is added in dry mixtures and mulled to avoid dusting and loss of binder during operation.

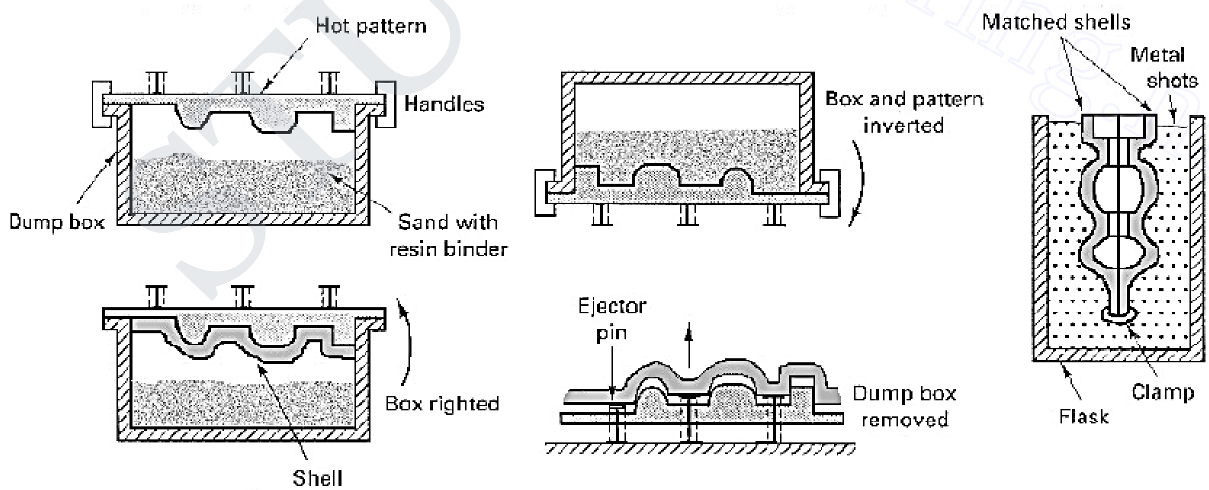


Fig.1.38 Step by step of shell moulding process

The main steps in the process are the following: (Fig. 1.38)

1. The sand resin mixture is invested on the pattern heated to a temperature of 200 to 400°C for a period of 15 to 45 seconds. During this period the sand mix around the pattern partially sets to a thickness of 6 to 15 mm depending on the dwell period and the type of mixture.
2. The unset sand is removed and the partially set shell sticking onto the pattern is cured at a temperature of 250° to 350°C for a period of 1 to 3 minutes depending on the pattern intricacy and shell thickness.
3. The cured shell is ejected from the pattern plate using ejector pins on the pattern. To aid in shell stripping a suitable releasing agent like silicon solution is applied on the heated pattern before investing the mould mixture.
4. The ejected mould parts are assembled with cores and clamped together for pouring. The assembled mould may be backed up by sand or shots if required.
5. The investment of the mould mixture is done either by blowing onto the pattern or by dumping the mixture on the pattern.
6. Blowing is more often used in the manufacture of shell cores and the dumping method in the manufacture of shell moulds.
7. In the dumping method, the heated pattern plate is placed inverted on a box" filled partially with the mould mixture.
8. The entire assembly of the pattern plate and the box is inverted to dump the mixture on the pattern plate.
9. After the dwell period, the box is brought back to the upright position to dump the unset mixture back into the box.
10. The pattern plate along with the sticking partially set shell is sent in for curing.
11. The steps in the dump method can be easily adapted to mechanization.
12. Modern shell moulding machines have been designed to complete a cycle of investment, dumping back of unset excess sand, curing and ejection automatically.

Advantages of shell moulding:

- Good surface finish of the order of 3 microns RMS and close dimensional tolerances of the order of ± 0.003 mm per mm.
- Dimensions across parting surfaces can be held to within 0.1 mm per mm.
- The moulds are highly permeable completely eliminating gas problems.
- The resin binder in the mould and core completely burns due to the heat of the poured metal leaving only loose sand with the casting which is easily cleaned. This simplifies shake out and cleaning operations.
- The process reduces the tendency for section variation in castings compared to green sand moulds.
- It also gives good surface finish and dimensional accuracy reducing machining allowance or eliminating machining in some cases.
- It is adaptable to mechanization and mass production.

Disadvantages of shell moulding

- High initial cost of the metal pattern plates,
- High cost of the binder
- Limitation of the size of the castings.

The process is used for manufacture of cams, pistons, piston rings, small pulleys, motor housings, fan blades etc.

Precision Investment Casting Methods:

Lost wax process:

- An age old process for the manufacture of precision castings with smooth surfaces makes use of disposable patterns of wax or polystyrene plastics.
- Patterns are made by injecting the pattern material in a die using a wax-injection machine.
- The injected patterns are joined together by wax welding or by suitable glue. Gates, runners and risers are added the same way.
- Several smaller patterns-may be assembled to a common gatting system so that a number of pattern can be placed in the same mould and poured simultaneously.
- The pattern assembly is sometimes given a primary investment coat of 300 mesh refractory grains made into a slurry in a suitable binder. The fineness of the grains in this coating determines the smoothness of the final casting.
- When the primary coat on the pattern is dried sufficiently the mould is invested around the pattern in a flask. Investment means the layer of refractory materials with which the pattern is covered to make the mould. Castings are produced by pouring the molten metal in these moulds.
- The injection pressure may vary from 4 to 35 bars depending upon the melting temperature of the injected material.
- The mould material is slurry of refractory silica with a suitable binder.
- For pouring temperatures upto 1000°C plaster binders may be used but for temperatures beyond 1000°C it is necessary to use a high temperature binder such as ethyl silicate.

Another method of investment used is to make a shell mould.

- In this method the pattern assembly is dipped in a series of slurries to build up a shell 3 to 6 mm thick of successively coarser grains.
- The invested moulds are allowed to set for a period of a few minutes to several hours depending upon the material.
- The flasks may also be vibrated to settle the investment material and drive out the air bubbles from the pattern surface.
- The moulds are then inverted and heat is applied to melt out the wax.
- Wax may also be removed by placing the mould in a solvent vapour bath such as a trichloroethylene bath.
- The vapour bath method removes wax more completely
- Vapour bath method is particularly suitable for shell type moulds.
- The completed moulds are preheated to temperatures ranging from 500 to 1000°C depending upon the metal to be cast.

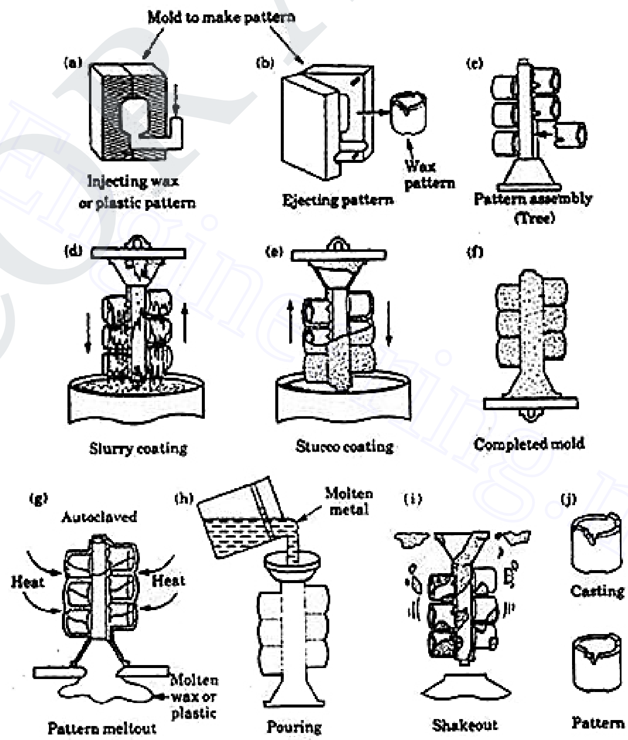


Fig. 1.39 Investment Casting Process

- This helps in removing any remaining wax and assures easy flow of the metal poured so that all cavities are filled properly. Moulds should be poured immediately after being preheated.
- Moulds with high permeability are poured under gravity but low permeability moulds may be poured under pressure or vacuum.

Mercast process:

In Mercast process or investment casting frozen mercury is used as a pattern material in place of wax.

- Mercury at room temperature is filled in the pattern dies which are then immersed in a bath maintained at - 60 to - 80°C.
- After the pattern has solidified the parts are joined by contact in a cold air atmosphere at - 60 to 75°C.
- The mercury patterns are then dipped in a series of ceramic baths maintained well below the freezing temperature of mercury.
- This produces a shell around the pattern.
- After the shell is built up and dried the mercury pattern is melted and flushed out at room temperature.
- The shell moulds are then fired at 1000°C for about 2 hours producing a porous mould resembling unglazed porcelain with a smooth finish in the cavity.
- The moulds are backed up in a flask with sand or shots and poured under gravity or pressure.

Advantages of investment casting:

- Since in investment-casting process patterns are melted out and not removed in the usual way, there is no parting line in the moulds and no draft is necessary on patterns. This results in better dimensional accuracies in castings produced by this method.
- Tolerances of the order of ± 0.05 mm per mm are readily obtained. Closer tolerances of upto ± 0.025 mm / mm can be possible.
- Surface finishes obtained range from 1 to 5 microns RMS.
- No machining operations are necessary in many cases.
- Intricate shapes in practically any ferrous or non-ferrous metal can be cast.
- Small diameter holes can be cast in thin sections.
- The process can also be made automatic.
- However, because of the number of steps involved investment casting usually cannot compete in cost with sand casting and other casting methods except where very small tolerances and fine finish are required.
- This process also becomes economical for casting of very high temperature melting alloys and in the production of complicated shapes that cannot be easily machined.
- The weight of castings made by investment process varies from a few gram to around 2.5 kg although 10 kg castings have been produced.

Disadvantages of investment casting:

- This process is expensive, is usually limited to small casting, and presents some difficulties where cores are involved.
- Holes cannot be smaller than 1/16 in. (1.6mm) and should be no deeper than about 1.5 times the diameter.
- Investment castings require very long production-cycle times versus other casting processes.
- This process is practically infeasible for high-volume manufacturing, due to its high cost and long cycle times.

Applications

Typical products include blades and, vanes, slides for cloth-cutting machines, camera and projector components, fuel parts for aviation carburetors etc.

Centrifugal Casting:

In centrifugal casting process, the molten metal poured at the center of a rotating mold or die. Because of the centrifugal force, the lighter impurities are crowded towards the center of the case. For producing a hollow part, the axis of rotation is placed at the center of the desired casting. The speed of rotation is maintained high so as to produce a centripetal acceleration of the order of 60g to 75g. The centrifuge action segregates the less dense nonmetallic inclusions near to the center of rotation that can be removed by machining a thin layer. No cores are therefore required in casting of hollow parts although solid parts can also be cast by this process.

The centrifugal casting is very suitable for axisymmetric parts. Very high strength of the casting can be obtained. Since the molten metal is fed by the centrifugal action, the need for complex metal feeding system is eliminated. Both horizontal and vertical centrifugal castings are widely used in the industry. Figure 1.40 schematically shows a set-up for horizontal centrifugal casting process.

Types of centrifugal casting:

Centrifugal casting can be divided into three categories namely

1. True centrifugal casting,
2. Semi centrifugal casting
3. Centrifuging.

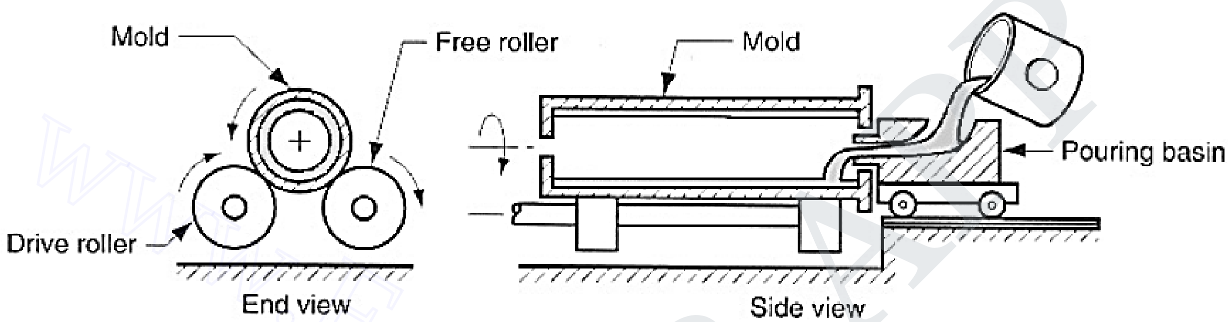


Fig. 1.40 Centrifugal casting

True centrifugal casting:

- The true centrifugal method of casting is used to produce hollow castings with a round hole.
- The characteristic feature of this process is that the hole is produced by the centrifugal force alone and no cores are used.
- The mould is rotated about the axis of the hole with the axis held horizontal, inclined or vertical.
- The outside surface of the job may be round, square, hexagonal etc. and should be symmetrical with the hole axis.
- The central hole should be round to be formed without cores.
- Long castings like cast iron soil pipes are cast with the moulds rotated about a horizontal axis.
- Castings with relatively short lengths are poured with moulds rotated about an inclined or vertical axis.
- Rotation about the vertical or inclined axis is convenient but the central hole produced will be slightly paraboloid with smaller diameter at the bottom because the metal has a tendency to settle down due to gravity.
- Fig. 1.40 gives a schematic diagram for a true centrifugal casting process.
- The speed of rotation for true centrifugal casting should be high enough to hold the metal on to the mould wall till it solidifies.
- A low speed of rotation would result in raining or slipping of the metal inside the mould.
- Too large a speed of rotation on the other hand may result in internal stresses and possible hot tears.
- A speed which would provide a centrifugal force of 60 to 75 times the force of gravity on horizontal moulds and 100 times force of gravity for vertical moulds is found to be suitable.
- The moulds used for the process may be metal moulds or refractory or sand lined moulds.

Applications:

Common products produced by true centrifugal casting include pipes, oil engine cylinders, piston ring stock, gear blank stock, bearing bushes and the like.

Semi centrifugal casting

- In semi-centrifugal casting process no attempt is made to produce a hole without a core.
- The centrifugal force resulting from rotation of the mould is used to properly feed the casting to produce a close grained clean casting.
- The process is suitable for large axis-symmetrical castings like gear blanks, fly wheels and track wheels.
- Any hole round or otherwise is made with the use of a core. The mould is clamped to a turn table with casting axis along the axis of rotation.
- The metal is poured along or near the axis to feed the points farthest from the axis of rotation under pressure.
- If made solid the central portion tends to be porous and with inclusion which are removed in subsequent machining.
- Fig. 1.42 shows a typical semi-centrifugal casting setup for the production of track wheels.

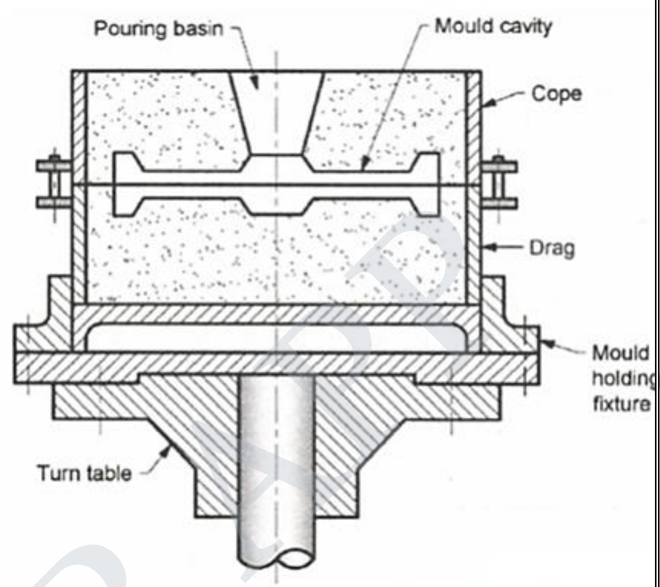


Fig. 1.41 Semi - centrifugal casting

Centrifuging:

- Centrifuging or centrifuge casting is employed to force metal under pressure into moulds of small castings or castings not symmetrical about any axis of rotation.
- The moulds are made around a central axis of rotation, to balance each other.
- The metal is poured along this axis of rotation through a central sprue and made to flow into mould cavities through radial ingates cut on the mould interface.
- Centrifuging helps in proper feeding of castings resulting in clean, close grained castings.
- Stack moulds can be used to advantage in centrifuging of castings required in very large numbers.
- A schematic diagram of a centrifuge casting set-up with stack moulds is given in Fig. 1.42.

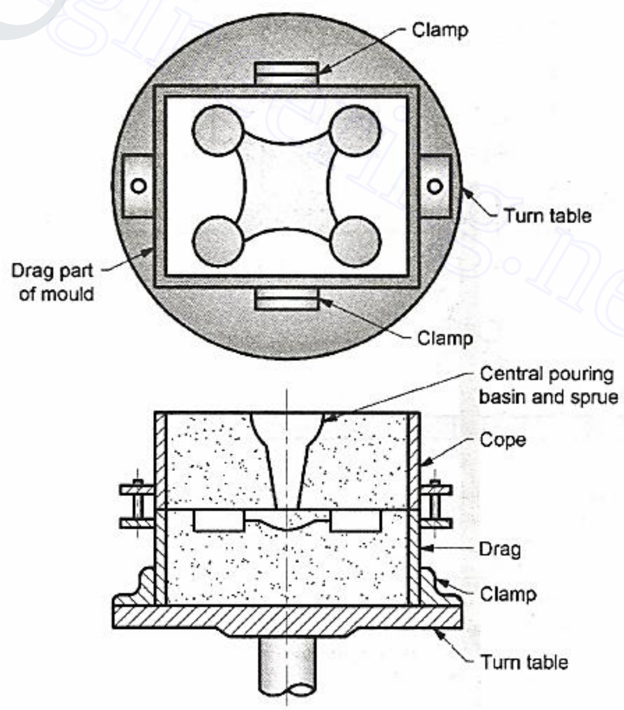


Fig.1.42 Centrifuge casting

Ceramic Mould Casting:

- Ceramic mould casting method uses a ceramic slurry prepared by mixing fine grained refractory powders of Zircon ($ZrSiO_4$), alumina (Al_2O_3), fused silica (SiO_2) and a patented liquid chemical binder (alcohol based silicon ester) for making the mould.
- The patterns used are split gated metal patterns usually mounted on a match plate.
- Unlike the patterns in investment casting these patterns are reusable.
- The slurry is applied over the patterns surfaces to form a thin coating around it. The slurry fills up all cavities and recesses by it and no ramming or vibration of the mould is required.
- The pattern is withdrawn after it sets in about 3 to 5 minutes.
- The mould is removed from the flasks, treated with a hardener to promote chemical stabilization and transferred to an oven for heating to about 100°C.
- The mould is ready to take molten metal.

The advantages of the process include:

1. High precision and very good surface finish.
2. The process does not require any risering, venting or chilling because the rate of cooling is very slow.
3. Any patterns made of wood, metal or plastic can be used.
4. The process can be used for all types of metals including highly reactive titanium or uranium.

The method can be used for producing precision parts like dies for drawing, extrusion, casting, forging etc., pump impellers, components of nuclear reactors and air craft.

The main short comings of the process are its high cost and the difficulty in controlling dimensional tolerances across the parting line.

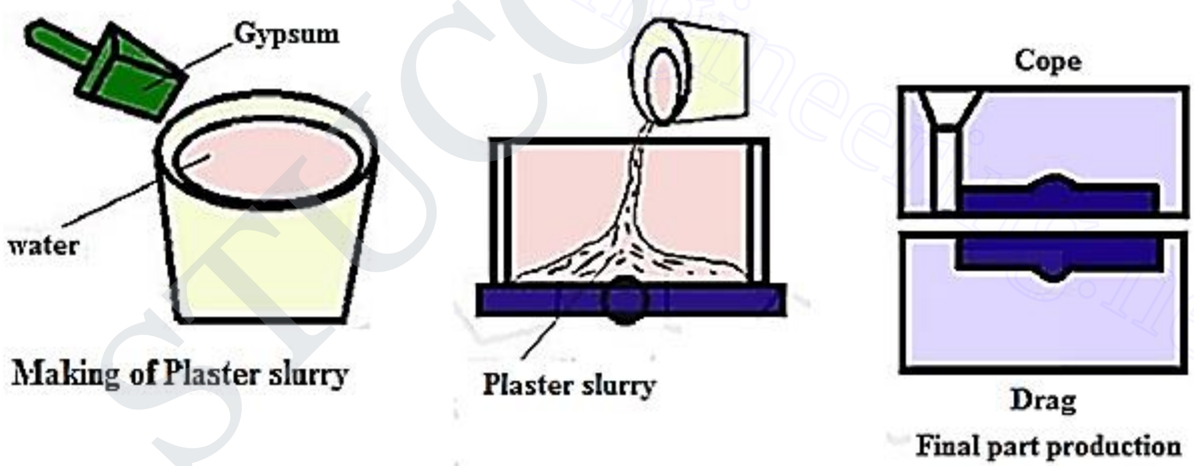


Fig.1.43 : Ceramic mould making

Pressure die casting

The pressure die casting process is the most common for Al, Zn and Mg castings (low melting point). The liquid metal is injected into the mold under high pressure and allowed to solidify at the high pressure. The solidified cast is then taken out of the mold or the die which is ready for the next cast. Pressure die casting is suitable for large batch size production.

Two types of pressure die casting are generally common in the industry –

- High pressure die casting (Hot chamber die casting)

- Low pressure die casting (Cold chamber die casting)

Very high production rates can be achieved in pressure die casting process with close dimensional control of the casting. However, the process is not suitable for casting of high melting temperature materials as the die material has to withstand the melting (or superheated) temperature of the casting. Pressure die castings also contain porosity due to the entrapped air. Furthermore, the dies in the pressure die casting process are usually very costly.

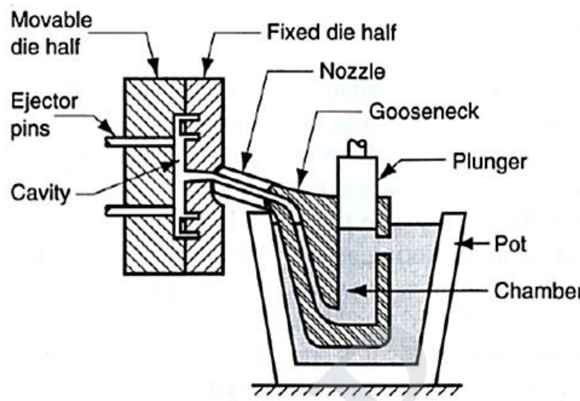


Fig. 1.44 : Hot chamber die casting

Figure 3.2.6 schematically presents the hot-chamber and the cold-chamber die casting processes. In the hot-chamber die casting process, the furnace to melt material is part of the die itself and hence, this process is suitable primarily for low-melting point temperature materials such as aluminum, magnesium etc.

Hot-chamber die-casting

In hot chamber die-casting, the metal is melted in a container attached to the machine, and a piston is used to inject the liquid metal under high pressure into the die.

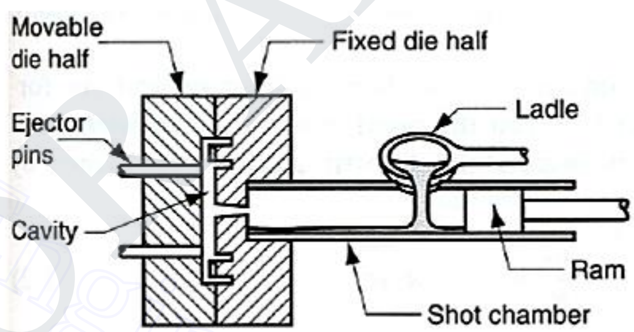


Fig. 1.45 : Cold chamber die casting

Advantages:

1. High productivity (up to 500 parts per hour)
2. Close tolerances
3. Good surface finish

Disadvantages:

1. The injection system is submerged in the molten metal
2. Only simple shapes

Area of application:

Mass production of non-ferrous alloys with very low melting point (zinc, tin, lead)

Cold-chamber die-casting

In cold-chamber die-casting, molten metal is poured into the chamber from an external melting container, and a piston is used to inject the metal under high pressure into the die cavity.

Advantages:

Same as in hot chamber die-casting, but less productivity.

Disadvantages:

Only simple shapes

Area of application:

Mass production of aluminium and magnesium alloys, and brass

Stir Casting:

Stir casting is a liquid state method of composite materials fabrication in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Among the variety of manufacturing processes available for discontinuous metal matrix composites, stir casting is generally accepted and currently practiced commercially.

Process

In general, the metal matrix composites of stir casting involves production of molten metal of selected matrix material followed by the introduction of a reinforcing material in to the molten metal, obtaining a suitable dispersion through stirring.

Solidification containing suspended particles to obtain the desired distribution of the dispersed phase in the cast matrix. The schematic diagram of this process is shown in figure 1.46

Particle distribution changes significantly depending on process parameters during the melting and solidification stages of the process.

The addition of particles to the melt drastically changes the viscosity of the molten metal and this has implications for casting processes. It is important that solidification occurs before appreciable settling is allowed to take place.

Benefits:

Simplicity, flexibility and applicability to large scale production.

Able to sustain high productivity due to liquid metallurgy technique.

Cheaper 1/3 to ½ than the other method of special casting process.

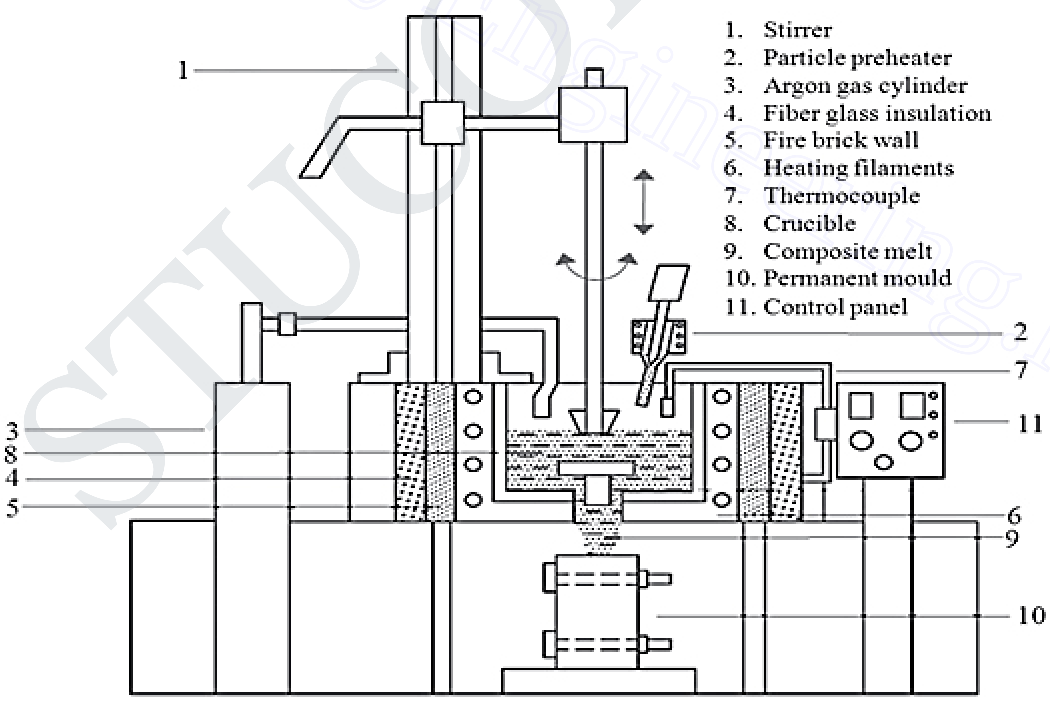


Fig. 1.46: Stir Casting

CO_2 Molding

Introduction: CO_2 Casting is a kind of sand casting process. In this process the sand molding mixture is hardened by blowing gas over the mold. This process is favoured by hobby metal casters because a lot of cost cutting can be done. In addition, one can be sure of getting dimensionally accurate castings with fine surface finish. But, this process is not economical than green sand casting process.

Process: The Mold for CO_2 Casting is made of a mixture of sand and liquid silicate binder which is hardened by passing CO_2 gas over the mold. The equipment of the molding process includes CO_2 cylinder, regulator, hoses and hand held applicator gun or nozzle. Carbon di oxide molding delivers great accuracy in production.

Any existing pattern can be used for the molding purpose which can be placed in the mold before the mold is hardened. This method helps in producing strong mold and cores that can be used for high end applications. If the process is carefully executed then casting can be as precise as produced by the shell casting method.

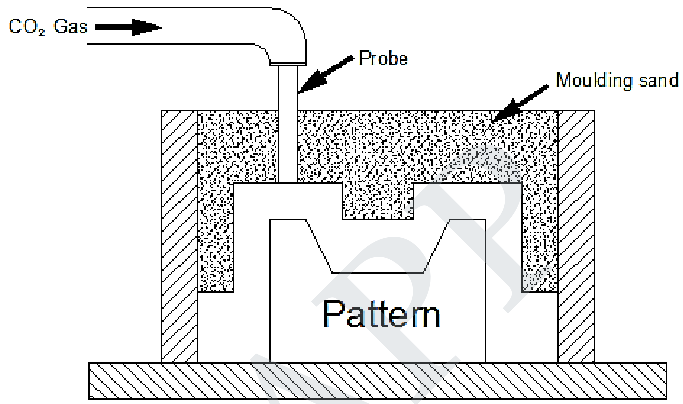


Fig. 1.47 Carbon - di - Oxide Processess

Carbon di oxide casting is favored both by the commercial foundry men and hobbyist for a number of reasons. In commercial operations, foundry men can assure customers of affordable castings which require less machining. The molding process which can be fully automated is generally used for casting process that require speed, high production runs and flexibility. In home foundries this is one of the simplest process that improves the casting quality.

Applications:

CO_2 casting process is ideal where speed and flexibility is the prime requirement. Molds and cores of a varied sizes and shapes can be molded by this process.

Advantages:

This process has many advantages in comparison to other forms of castings some of them are as follows:

a. Compared to other casting methods cores and molds are strong
b. Reduces fuel cost since gas is used instead of to other costly heating generating elements
c. Reduces large requirement for number of mold boxes and core dryers
d. Provides great dimensional tolerance and accuracy in production
e. Moisture is completely eliminated from the molding sand
f. This process can be fully automated.

Casting Defects

Casting defects are classified as below:

Casting Defects

- Surface defects
  1. Blow
  2. Scar
  3. Blister
  4. Drop
  5. Scab
  6. Penetration
  7. Buckle
- Internal Defects
  1. Blow holes
  2. Porosity
  3. Pin holes
  4. Inclusions dross
- Visible Defects
  1. Wash
  2. Rat tail
  3. Swell
  4. Mis run
  5. Cold shut
  6. Hot tear
  7. shrinkage

Scar

It is usually found on the flat casting surface. It is a shallow blow.

Blow

Blow is relatively large cavity produced by gases which displace molten metal from convex surface.

Blister

This is a scar covered by the thin layers of the metal.

Drop

Sometimes sand particles dropping out of the cope get embedded on the top surface of a casting. When removed, these leave small angular holes is known as dirts

Penetration

This defect appears as an uneven and rough external surface of the casting. It may be caused when the sand has too high permeability, large grain size, and low strength. Soft ramming may also cause metal penetration.

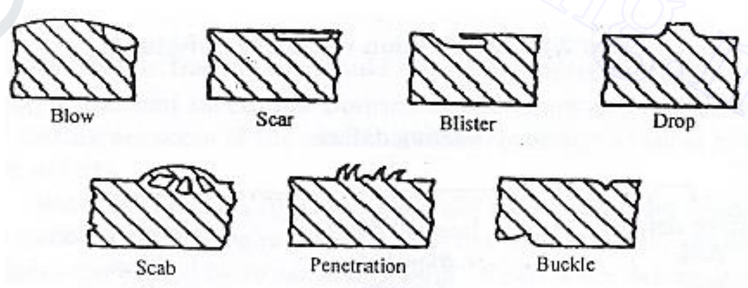


Fig. 1.48(a) Surface Defects

Buckle

It refers to a long fairly shallow broad depression at the surface of a casting of a high temperature metal. Due to very high temperature of the molten metal, expansion of the thin layered of the sand at the mold face takes place. As this expansion is obstructed by the flux, the mold tends to bulge out forming a V shape..

Porosity

Porosity occurs in materials, especially castings, as they change state from liquid to solid during the manufacturing process. Casting porosity has the form of surface and core imperfections which either effects the surface finish or as a leak path for gases and liquids.

The poring temperature should be maintained properly to reduce porosity.

Adequate fluxing of metal and controlling the amount of gas-producing materials in the molding and core making sand mixes can help in minimizing this defect.

Blowhole

Blowholes are smooth round holes that are clearly perceptible on the surface of the casting. To prevent blowholes, moisture content in sand must be well adjusted, sand of proper grain size should be used, ramming should not be too hard and venting should be adequate.

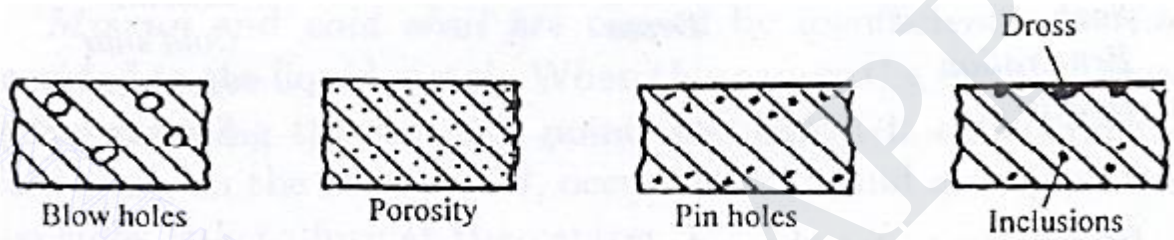


Fig. 1.48(b) Internal Defects

Dross

The lighter impurities are appearing on the top of the cast surface is called the dross. It can be taken care of at the pouring stage by using items such as a strainer and a skim bob.

Pin holes

Pin holes are tiny blow holes appearing just below the casting surface.

Inclusions

Inclusions are the non-metallic particles in the metal matrix,

Shrinkage

Shrinkage of molten metal as it solidifies is an important issue in casting. It can reduce the 5-10% volume of the cast. Need to design part and mold to take this amount into consideration. Shrinkage defect can be reduced by decreasing the number of walls and increasing the draft angle.

Wash

It is a low projection on the drag surface of a casting commencing near the gate. It is caused by the erosion of sand due to high velocity liquid metal.

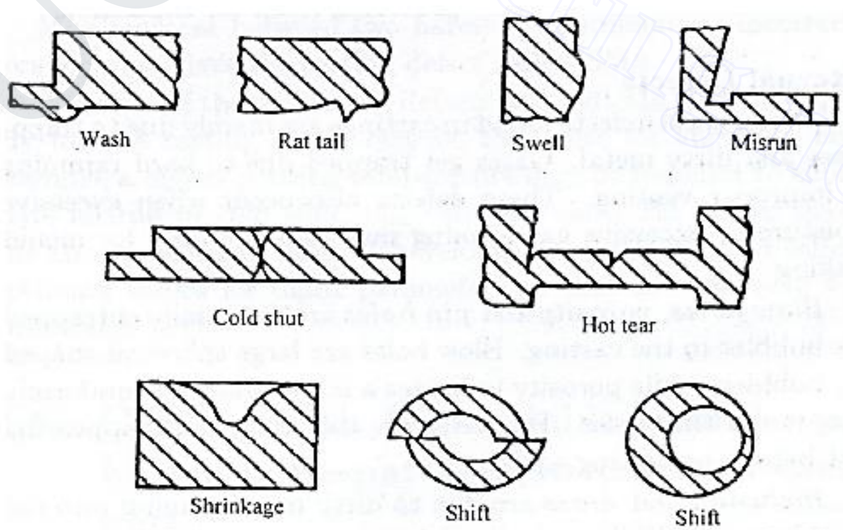


Fig.1.48 (c) Visible Defects

Rat tail

It is a long shallow angular depression found in a thin casting. The cause is similar to buckle.

Swell

Swell is the deformation of vertical mould surface due to hydrostatic pressure caused by moisture in the sand.

Cold Shut and Mis-Run

A cold shut is a defect in which a discontinuity is formed due to the imperfect fusion of two streams of metal in the mold cavity. The reasons for cold shut or mis-run may be too thin sections and wall thickness, improper gating system, damaged patterns, slow and intermittent pouring , poor fluidity of metal caused by low pouring temperature, improper alloy composition, etc.

Hot tear

Hot tears are internal or external ragged discontinuities or crack on the casting surface, caused by rapid contraction occurring immediately after the metal solidified. Hot tear may be caused when the mold and core have poor collapsibility or when the mold is too hard causing the casting to undergo severe strain during cooling. Incorrect pouring temperature and improper placement of gates and risers can also create hot tears.

Shift

A shift results in a mismatch of the sections of a casting usually as a parting line. Misalignment is common cause of shift. This defect can be prevented by ensuring proper alignment of the pattern for die parts, molding boxes, and checking of pattern flux locating pins before use.

UNIT – II

JOINING PROCESSES

SYLLABUS

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

The process of joining takes place by means of welding, riveting or by fastening nut and bolts. If a joint can be disassembled then joining method is called temporary joining method. If the same, cannot be disassembled without breaking it then the joint is called permanent joint. Normally in welding operation joining of metal pieces is done by raising their temperature to the fusion point so that they form a sort of pool of molten metal at the ends to the joined, sometimes, the pool is supplemented with a filler metal (wire or rod) which normally has almost same compositions as that of the work pieces. This way the pool forms a homogeneous mixture. It is allowed to get solidify to have a permanent joint. There is wide diversity in welding technology so its conventional definition can be modified as "welding is a technique of joining similar and dissimilar metals and plastics by adopting ways which do not include adhesives and fasteners."

Selection of type of joints:

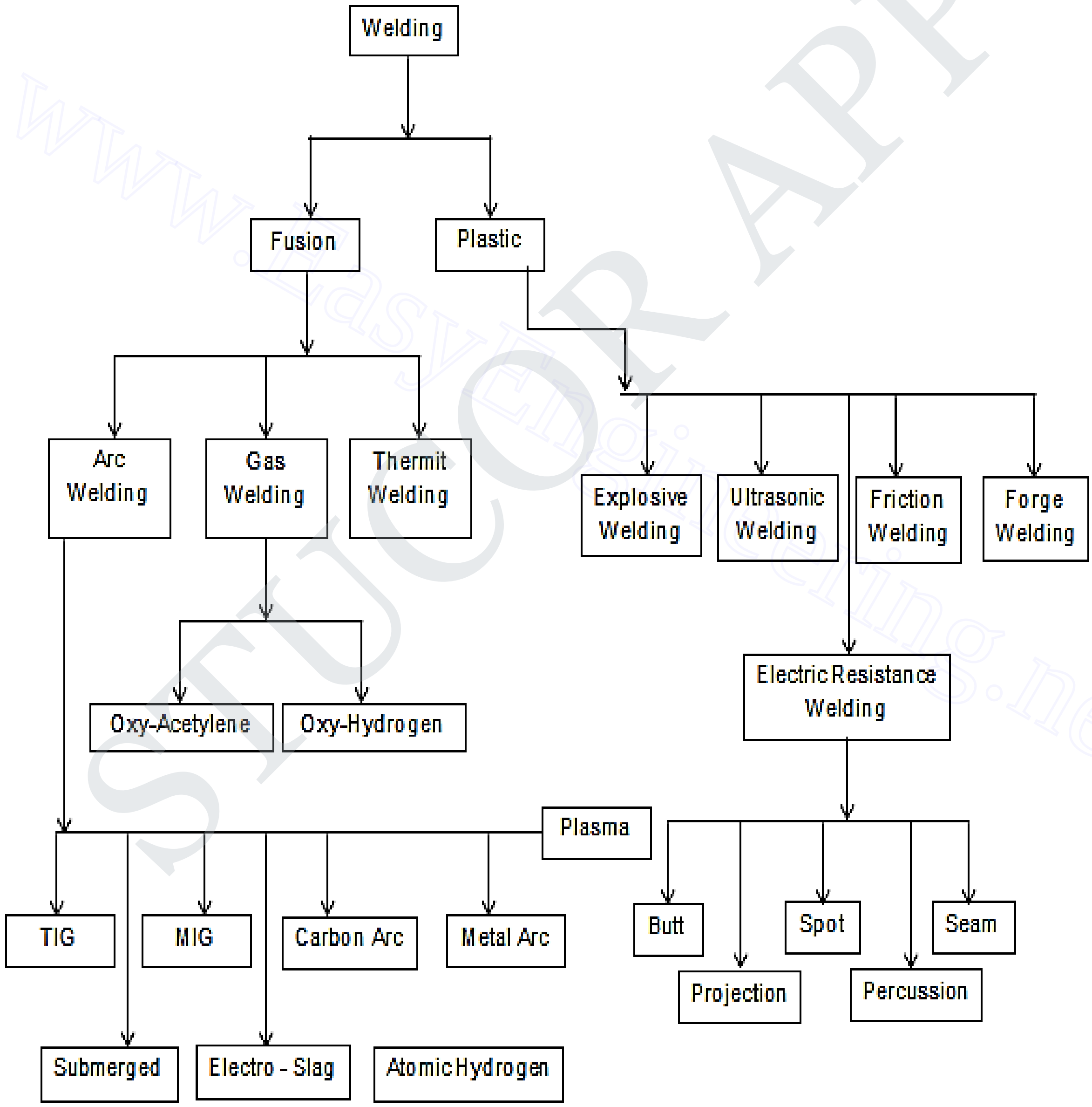
a) Type of joint required for an application is temporary or permanent.
b) Whether similar or dissimilar materials are to be joined in order to take care of the compatibility aspect as metallurgical incompatibility can be disastrous for performance of the joints
c) Physical, chemical metallurgical properties of materials to be joined.
d) Requirements of the service from the joint under special conditions of temperature, corrosion, environment, and reliability.
e) Type and nature of loading conditions (static and dynamic loading under tension, shear, compression, bending etc.)

f) Economy or cost effectiveness is one most important factors influencing the selection of joint for manufacturing an engineering component

2.2 CLASSIFIATION OF WELDING PROCESSES

Welding process can be classified into different categories depending upon the following criteria:

(a) Liquid state welding (Fusion welding)
(b) Solid state welding (Pressure welding)



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Welding process can be also classified as:

Autogeneous	:	During welding process, no filler metal is added to the joint interface. For example: solid welding process and electric resistance welding
Homogeneous	:	During welding process, filler metal is added and is of the same type as the parent metal. For Example: Arc welding
Heterogeneous	:	During welding process, filler metal is added and is of a different type from the parent metal. Example: Brazing and soldering

Advantages and Limitation of Welding

Advantages of welding are enlisted below:

1. Permanent joint is produced, which becomes an integral part of work piece.
2. Joints can be stronger than the base metal if good quality filler metal is used.
3. Economical method of joining.
4. It is not restricted to the factory environment.

Disadvantages of welding are enlisted also below:

1. Labour cost is high as only skilled welder can produce sound and quality weld joint.
2. It produces a permanent joint which in turn creates the problem in dissembling if of sub-component required.
3. Hazardous fumes and vapours are generated during welding. This demands proper ventilation of welding area.
4. Weld joint itself is considered as a discontinuity owing to variation in its structure, composition and mechanical properties; therefore welding is not commonly recommended for critical application where there is a danger of life.

Applications of welding

The welding is widely used for fabrication of pressure vessels, bridges, building structures, aircraft and space crafts, railway coaches and general applications besides shipbuilding, automobile, electrical, electronic and defense industries, laying of pipe lines and railway tracks and nuclear installations.

Specific components need welding for fabrication includes

(a) Transport tankers for transporting oil, water, milk etc.
(b) Welding of tubes and pipes, chains, LPG cylinders and other items.
(c) Fabrication of Steel furniture, gates, doors and door frames, and body

(d) Manufacturing white goods such as refrigerators, washing machines, microwave ovens and many other items of general applications

Electric Arc Welding

Electric arc welding is one of the fusion welding processes in which coalescence of the metal is achieved by the heat from an electric arc between an electrode and work piece. A line diagram indicating the whole process is shown in Figure 2.1.

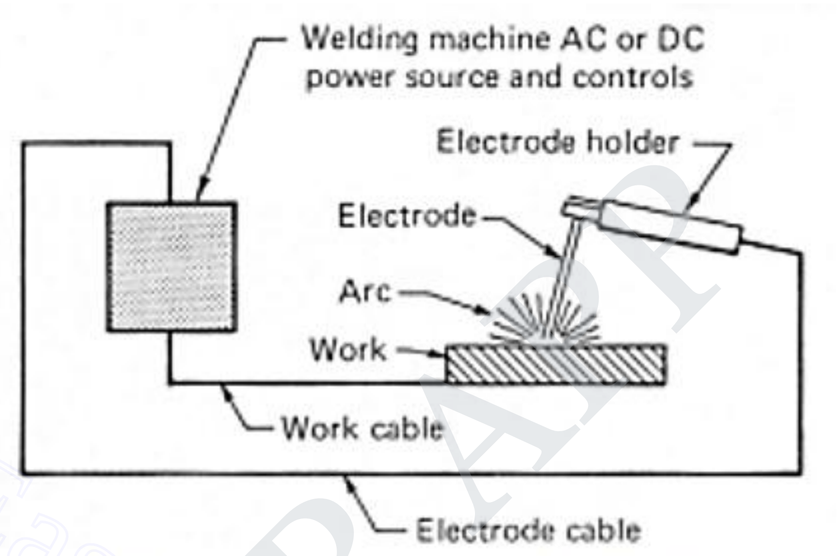

Fig.2.1 Process of Electric Arc Welding

Electric arc is generated when electrode is brought into contact with the work and is then quickly separated by a short distance approximately 2 mm. The circuit operates at low voltage and high current so arc is established in the gap due to thermo ionic emission from electrode (Cathode) to work piece (Anode). The arc is sustained due to continuous presence of a thermally ionized column of gas. This arc produces at temperature of the order of 5500°C or higher. In this way a pool of molten metal consisting of work piece metal and filler metal is formed in the welding zone. The electrode is moved along the joint with perpendicular zig-zag motion. The solidified molten weld pool makes the strong welded joint. Movement of the electrode relative to work piece is accomplished by either manually or by mechanical means in case of automatic welding machines. Better uniformity and good quality weldments are possible in case of automatic welding process.

Arc welding equipments are listed below. The equipments are categorized as facilitator, consumable and protecting equipments. Some of the equipment of arc welding is same as that are used in gas welding like flux, protecting devices and cleaning devices, etc.

Facilitator Equipment Welding

a) Power source (welding machine)
b) Electrode holder
c) Work table

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d) Cables (for connection)
e) Finishing devices like chipping, hammer, wire brush, etc.

Consumable Equipment

a) Electrode
b) Flux
c) Work piece
d) Filler metal

Protecting Equipment

a) Welding shields
b) Goggles
c) Screens
d) Gloves
e) Apron

Arc welding equipments are described below.

a) Power Source

Both AC (Alternative Current) and DC (Direct Current) can be used for welding. AC machines are recommended for ferrous metal and DC machines are recommended for other metals for better result. Main constituent of welding machine is transformer which converts the supply to low voltage and high current. For AC welding power is required at 80 to 110 volt and 50 to 80 ampere. For sustaining the established are power factor is kept low. In case of DC welding power is required at 8 to 25 volts and 50 ampere. Polarity is also are significant factor. Two types of polarities are possible in case of DC welding.

Straight Polarity

Electrode is made negative pole and work piece is made positive pole. It is also called as electrode negative.

Reversed Polarity

Electrode is made positive pole and work piece is made negative pole. It is called electrode positive too. As we know that two third of the total heat is generated at positive pole and only one third at negative pole. Polarity is decided according to the requirement of heat at either pole.

b) Welding Electrodes

These are also called welding rods. Two types of welding electrodes are generally used.

1) Consumable electrodes

2) Non-consumable electrodes.

Consumable electrodes

Consumable electrodes are the source of filler metal in case of arc welding. Consumable electrodes can further be classified into two categories

a. Coated electrodes
   - Light coated electrode
   - Heavily coated electrode

b. Bare electrodes.

Light coated electrode

Light coated welding electrodes have a definite composition. A light coating has been applied on the surface by washing, dipping, brushing, spraying, tumbling, or wiping. The coatings improve the characteristics of the arc stream. They are listed under the E45 series in the electrode identification system.

The coating generally serves the functions described below:

- It dissolves or reduces impurities such as oxides, sulfur, and phosphorus.
- It changes the surface tension of the molten metal so that the globules of metal leaving the end of the electrode are smaller and more frequent. This helps make flow of molten metal more uniform.
- It increases the arc stability by introducing materials readily ionized (i.e., changed into small particles with an electric charge) into the arc stream.
- Some of the light coatings may produce a slag. The slag is quite thin and does not act in the same manner as the shielded arc electrode type slag.

Heavily coated electrode

Heavy coated welding electrodes have a definite composition on which a coating has been applied by dipping or extrusion. The electrodes are manufactured in three general types: those with cellulose coatings; those with mineral coatings; and those whose coatings are combinations of mineral and cellulose. The cellulose coatings are composed of soluble cotton or other forms of cellulose with small amounts of potassium, sodium, or titanium, and in some cases added minerals. The mineral coatings consist of sodium silicate, metallic oxides clay, and other inorganic substances or combinations thereof. Cellulose coated electrodes protect the molten metal with a gaseous zone around the arc as well as the weld zone. The mineral coated electrode forms a slag deposit. The shielded arc or heavy coated electrodes are used for welding steels, cast iron, and hard surfacing.

Bare Electrodes

Bare welding electrodes are made of wire compositions required for specific applications. These electrodes have no coatings other than those required in wire drawing. These wire drawing coatings have some slight stabilizing effect on the arc but are otherwise of no consequence. Bare electrodes are used for welding manganese steel and other purposes where a coated electrode is not required or is undesirable.

Non-consumable Electrodes

They are made of tungsten or carbon. These do not melt in the process of welding and so called non-consumable electrodes. Their depletion rate is very low. In case of non-consumable electrodes metal and flux is supplied additionally. Generally non-consumable electrodes are used in MIG and TIG welding processes.

Electrode Coding

According to ISI coding system an electrode is specified six digits with a prefix letter 'M' which is indicative of its suitability for metal arc welding. Explanation of six digits is given below.

E 70 1 8 -X

E	:	Indicates that this is an electrode
70	:	Indicates how strong this electrode is when welded. Measured in thousands of pounds per square inch.
1	:	Indicates in what welding positions it can be used
8	:	Indicates the coating, penetration, and current type used.
X		Indicates that there are more requirements.

WELDING POSITIONS

1 : Flat, Horizontal, Vertical (up), Overhead

2 : Flat, Horizontal

4 : Flat, Horizontal, Overhead, Vertical (down)

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ADDITIONAL REQUIREMENTS

Suffix		Additional Requirement
1	:	Increased toughness (impact strength) for E7018 electrodes. Also increased ductility in E7024 electrodes.
M	:	Meets most military requirements - greater toughness, lower moisture content as received after exposure, diffusible hydrogen limits for weld metal.
-H4	:	Indicates the maximum diffusible hydrogen limit measured in millimeters per 100 grams (mL/100g).

Example: H4 = 4mL per 100 grams

The important functions Electrode coating are as follows:

1. Improve the electric conductivity in the arc region to improve the arc ignition and stabilization of the arc.
2. Formation of slag, which;
   (a) Influences size of droplet.
   (b) Protects the droplet during transfer and molten weld pool from atmospheric gases.
   (c) Protects solidified hot metal from atmospheric gases.
   (d) Reduces the cooling rate of weld seam.
3. Formation of shielding gas to protect molten metal.
4. Provide deoxidizers like Si and Mn in form of FeSi and FeMn.
5. Alloying with certain elements such as Cr, Ni, Mo to improve weld metal properties.
6. Improve deposition rate with addition of iron powder in coating.

Various constituents of electrode coating are cellulose, calcium fluoride, calcium carbonate, titanium dioxide, clay, talc, iron oxide, asbestos, potassium / sodium silicate, iron powder, ferro-maganese, powdered alloys, silica etc. Each constituent performs either one or more than one functions.

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Electrode metallic core wire is the same but the coating constituents give the different characteristics to the welds. Based on the coating constituents, structural steel electrodes can be classified in the following classes;

Cellulosic Electrodes

Coating consists of high cellulosic content more than 30% and TiO_2 up to 20%. These are all position electrodes and produce deep penetration because of extra heat generated during burning of cellulosic materials. However, high spatter losses are associated with these electrodes.

Rutile Electrodes

Coating consists of TiO_2 up to 45% and SiO_2 around 20%. These electrodes are widely used for general work and are called general purpose electrodes.

Acidic Electrodes

Coating consists of iron oxide more than 20%. Sometimes it may be up to 40%, other constituents may be TiO_2 10% and $CaCO_3$ 10%. Such electrodes produce self-detaching slag and smooth weld finish and are used normally in flat position.

Basic Electrodes

Coating consist of $CaCO_3$ around 40% and CaF_2 15-20%. These electrodes normally require baking at temperature of approximately 250°C for 1-2 hours or as per manufacturer's instructions. Such electrodes produce high quality weld deposits which has high resistance to cracking. This is because hydrogen is removed from weld metal by the action of fluorine i.e. forming HF acid as CaF_2 generates fluorine on dissociation in the heat of arc.

Table 2.1: Coating Constituents and Their Functions

Coating Constituent	Functions	
	Main Functions	Other Functions
Cellulose	Gas former	Coating Strength and Reducing agent
Calcium Fluoride (CaF_2)	Slag basicity and metal fluidity, H_2 removal	Slag former
Clay (Aluminum	Slag former	Coating strength

Silicate)		
Talc (Magnesium Silicate)	Slag former	Arc stabilizer
Rutile (TiO_2)	Arc stabilizer, Slag former, Fluidity	Slag removal and bead appearance
Iron Oxides	Fluidity, Slag former	Arc Stabilizer, improved metal transfer,
Calcium Carbonate	Gas former, Arc stabilizer	Slag basicity, Slag former
Asbestos	Coating strength	Slag former
Quartz (SiO_2)	Slag fluidity, Slag former	Increase in current carrying capacity.

Sodium Silicate / Potassium Silicate	Binder, Arc stabilizer	Slag former
FeMn / FeSi	Deoxidizer	
Iron Powder	Deposition Rate	
Powdered Alloys	Alloying	

COMPARISON OF AC and DC WELDING MACHINES

Sl.No.	Category	A.C Transformer	D.C.Transformer
1	Efficiency range	80-85%	30-60%
2	Power consumption	Less	More
3	Cost	Low	High
4	Terminal connection	Positive and Negative are	Positive to work piece and

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		changed	Negative to electrode
5	Operation	Noiseless	Noisy
6	Safely operation	No	Yes
7	Work piece	Only for ferrous material	Suitable for ferrous and non-ferrous
8	Electrode	Only coated electrode can be used	coated and bare electrode can be used
9	Maintenance	High	Low
10	Power factor	High	Low

GAS WELDING

It is a fusion welding in which strong gas flame is used to generate heat and raise temperature of metal pieces localized at the place where joint is to be made. In this welding metal pieces to be joined are heated. The metal thus melted starts flowing along the edges where joint is to be made. A filler metal may also be added to the flowing molten metal to fill up the cavity at the edges. The cavity filed with molten metal is allowed to solidify to get the strong joint. Different combinations of gases can be used to obtain a heating flame. The popular gas combinations are oxy-hydrogen mixture, oxygen-acetylene, etc. different mixing proportion of two gases in a mixture can generate different types of flames with different characteristics.

Oxy-Acetylene Welding

Oxy-acetylene welding can use for welding of wide range of metals and alloys. Acetylene mixed with oxygen when burnt under a controlled environment produces large amount of heat giving higher temperature rise. This burning also produces carbon dioxide which helps in preventing oxidation of metals being welded. Highest temperature that can be produced by this welding is 3200oC. The chemical reaction involved in burning of acetylene is

$$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O + Heat$$

On the basis of supply pressure of gases oxy-acetylene welding is categorized as high pressure welding in this system both gases oxygen and acetylene supplied to welding zone are high pressure from their respective high pressure cylinders. The other one is low pressure welding in which oxygen is supplied from high pressure cylinder but acetylene is generated by the action of water on calcium carbide and supplied at low pressure. In this case high pressure supply of oxygen pulls acetylene at the welding zone.

A comparison can be drawn between low pressure and high pressure welding. High pressure welding equipment is handy, supplies pure acetylene at constant pressure, with better control and low expenses as compared to low pressure welding.

Characteristics of the oxy-acetylene welding process include:

- The use dual oxygen and acetylene gases stored under pressure in steel cylinders,
- Its ability to switch quickly to a cutting process, by changing the welding tip to a cutting tip,
- The high temperature the gas mixture attains,
- The use of regulators to control gas flow and reduce pressure on both the oxygen and acetylene tanks,
- The use of double line rubber hoses to conduct the gas from the tanks to the torch,
- Melting the materials to be welded together,
- The ability to regulate temperature by adjusting gas flow.

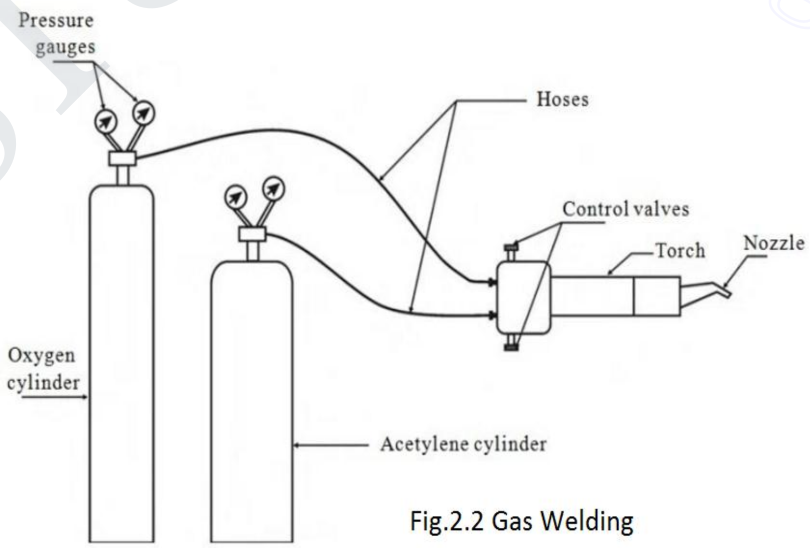

Fig.2.2 Gas Welding

Gas Welding Equipments

The following equipments are necessary for gas welding

1. Gas cylinders
2. Regulators
3. Pressure gauges
4. Rubber hoses
5. Welding torch
6. Safety goggles
7. Gloves
8. Spark lighter
9. Wire brush

1. Gas Cylinders

Oxygen and acetylene gases are stored in separate cylinders and used for gas welding. The colour of oxygen cylinder is black and the acetylene gas is stored in maroon cylinders. Oxygen is stored at a pressure of 125Kg/cm^2. Acetylene gas is stored at a pressure of 16 Kg/cm^2 in the cylinder.

2. Regulators

Separate regulators are fitted on both the cylinders. A regulator is used to control the working pressure of the gases. The working pressure of oxygen is 1Kg/cm^2 and acetylene is 0.15Kg/cm^2. Working pressure of these gases is altered according to the thickness of the metal parts of the joint.

3. Pressure Gauges

Two pressure gauges are fitted each on the oxygen cylinder and on the acetylene cylinder. One of the pressure gauges indicates the pressure of the cylinder and the other gauge indicates the working pressure of the specific gas.

4. Hoses

Separate hoses are used to connect the two cylinders with the welding torch through regulators. The colour of the hose from the oxygen cylinder is black and the one from the acetylene cylinder is red. These hoses carry the gases to the welding torch.

5. Welding Torch

Oxygen and acetylene reach the welding torch through the passages of hoses from the respective cylinders. These gases are mixed in the mixing chamber of the welding torch. Flame is produced at the tip of the torch when the gases are ignited. There are two control valves present in the torch to control the quantity of oxygen and acetylene. By this control, the grade of the flame can be altered. The size of the flame is altered to suit the thickness of the metal parts.

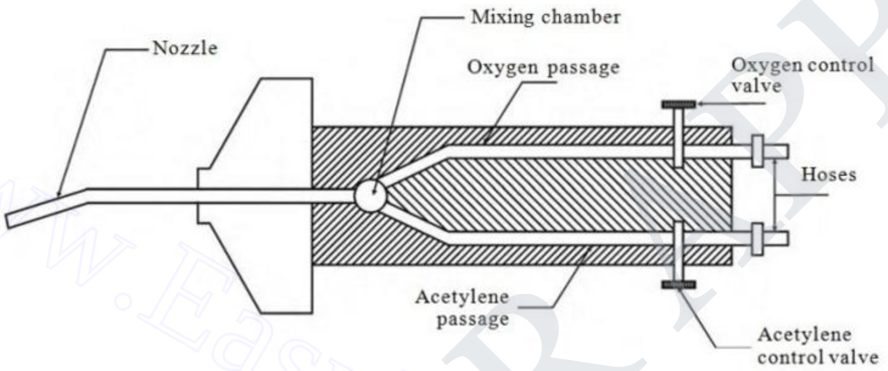

Fig.2.3 Welding Torch

6. Welding Gloves

Protective hand gloves are used by the operator to prevent possible damages that may be caused by high temperatures and metal splashes during welding.

7. Spark Lighter

Spark lighter is used to ignite the oxy-acetylene gas at the tip of the welding torch.

8. Wire Brush

Wire brushes are useful in cleaning the weld before and after the welding process.

Filler Rods Used in Gas Welding

Filler rods used in gas welding supply the additional metal in making joints. These rods are melted by the gas flame and deposited over the parts of the joint. Generally the filler rods are made of the same metal as that of the parts of the joint.

The diameter of the filler rod depends upon the thickness of the parts to be welded. The strength of the welding joint is increased by adding Nickel or Chromium in filler rods. A thin coat of copper is provided on the filler rods to prevent the molten metal from reacting with atmospheric oxygen. Flux may be applied either in powdered form or liquid form.

Advantages of Gas Welding

1. Applied for different classes of work
2. Welding temperature is controlled easily
3. The quantity of filler metal added in the joint can easily be controlled
4. The cost of the welding unit is less
5. The cost of maintenance is less
6. Both welding and cutting can be done

Limitations of Gas Welding

1. Intended for welding thin work pieces only
2. The process of welding is slow
3. The time taken by the gas flame to heat the metal is more when compared with electric arc
4. The strength of the joint is less
5. Great care should be taken in handling and storing gas cylinders

FLAME FORMATION AND ITS DIFFERENT TYPES

Flame is established by burning (controlled) of the two gases mixture at the outlet of blow pipe or torch. The proportion of gasses in the mixture is controlled by controlling the flow rate of each of the two gasses. Here, it should be clear that burning of acetylene generates heat and oxygen only supports acetylene in burning. Insufficient supply of oxygen leaves acetylene un burnt in atmosphere creating pollution and adding cost of waste acetylene. A general nomenclature of the flame established in oxy-acetylene welding is given in Figure 2.5. The flame can be divided in to three zones.

Zone '1' is very near to the outlet of torch, where oxygen reacts with acetylene and burning of two gases takes place.

Zone '2' produces carbon monoxide and hydrogen in ratio 2 : 1 by 45 volume. This zone gives the highest temperature of the flame. This zone is supposed to Welding consume the oxygen available here and contribute reducing properly to the flame.

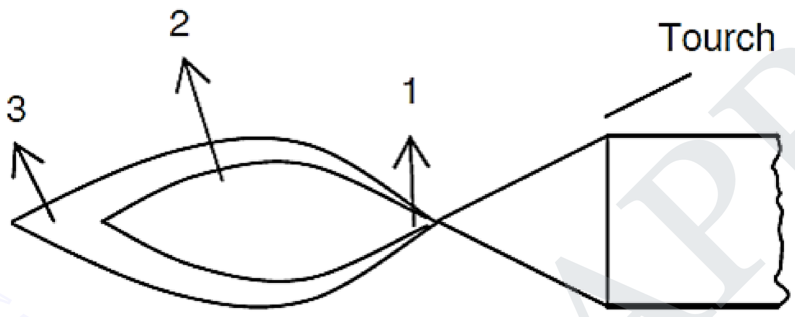

Fig.2.4 Flame establishment in oxy-acetylene welding

Zone '3' is the outermost zone of the flame. Temperature of this zone is comparatively low. This zone converts CO to CO_2 and H_2O vapours. On the basis of supply proportion of acetylene and oxygen, flames can be divided into three categories, neutral flame, carburizing flame and oxidizing flame. These are described here.

Neutral Flame

A neutral flame is obtained when amount of O_2 equal and C_2H_2 are mixed and burnt at the outlet of welding torch. The flame consists of two sharply defined zones inner white flame cone outer envelope of blue colour as shown in Figure 2.5. In this flame none of two gasses is supplied in excess. This flame is of white cone and has the maximum use for successful welding of many metals.

Carburizing Flame

This flame is obtained when excess of acetylene is supplied than which is theoretically required. This flame is identified by three zones the inner cone which is not sharply defined, an outer envelope as same in case of neutral flamed and middle zone surrounds inner one extended to outer envelope. It is white in colour due to excess acetylene. Larger the excess of acetylene larger will be its length. To get a neutral flame a systematic procedure is to make carburizing flame first and then increase oxygen supply gradually till the excess acetylene zone disappears. The resulting flame wills a carburizing flame. Its temperature generation range is 3100oC to 3300oC. It is used for the welding of metals where risk of oxidation at elevated temperature is more like aluminium, its alloys and lead and its alloys. The metals which have tendency to absorb carbon should not be welded by carburizing flame as they become brittle localized.

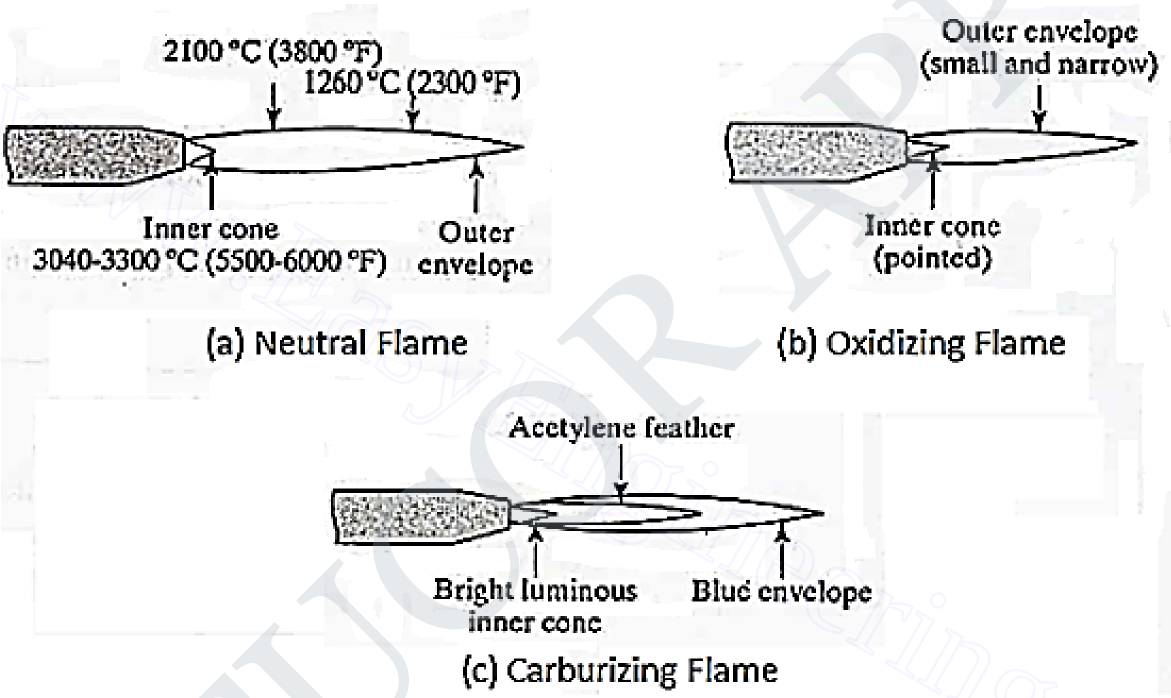

Fig.2.5 Various flame formation in Gas welding

Oxidizing Flame

This flame as an excess of oxygen over that required for a neutral flame. The ratio $O_2 : C_2H_2 = 1.15$ to 1.50. To have this flame set carburizing flame first convert it to neutral flame and then reduce the supply of acetylene to get oxidizing flame. Its inner cone is relatively shorter and excess oxygen turns the flame to light blue colour. It burns with a harsh sound. It is used for metals which are not oxidized readily like brasses and bronzes.

COMPARISON OF ARC WELDING AND GAS WELDING

Sl.No.	Arc welding	Gas welding
1	Electric arc is the source of heat.	Gas is the source of heat.
2	The arc temperature is about 4000℃.	The gas temperature is about 3200℃.
3	Filler rod functions as electrodes.	Filler rod is introduced separately.
4	Risk due to electric shock.	Risk due to gas pressure.
5	Arc welded joints have very high strength.	Gas welded joints have not much strength.
6	Brazing and soldering cannot be done using electric arc.	Brazing and soldering are done using gas.
7	Filler metal should be same as or an alloy of parent metal.	Filler metal need not be same as the parent metal.
8	This is a non-pressure fusion welding method.	This is also a non-pressure fusion welding method.
9	The filler rod metal should be selected as the same metal as that of the parts of the joint.	The filler rod metal can be different from that of the parts of the joint.

GAS TUNGSTEN ARC WELDING

Tungsten Inert Gas (TIG) or Gas Tungsten Arc (GTA) welding is the arc welding process in which arc is generated between non consumable tungsten electrode and work piece. The tungsten electrode and the weld pool are shielded by an inert gas normally argon and helium. Figures 2.6 show the principle of tungsten inert gas welding process.

The tungsten arc process is being employed widely for the precision joining of critical components which require controlled heat input. The small intense heat source provided by the tungsten arc is ideally suited to the controlled melting of the material. Since the electrode is not consumed during the process, welding without filler material can be done without the need for continual compromise between the heat input from the arc and the melting of the filler metal. As the filler metal, when required, can be added directly to the weld pool from a separate wire feed system or manually, all aspects of the process can be precisely and independently controlled i.e. the degree of melting of the parent metal is determined by the welding current with respect to the welding speed, whilst the degree of weld bead reinforcement is determined by the rate at which the filler wire is added to the weld pool.

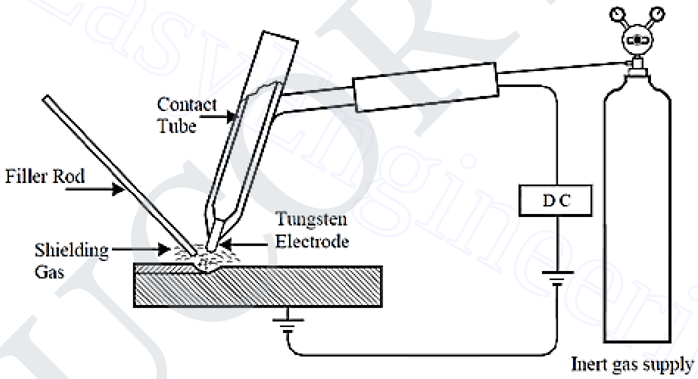

Fig.2.6 Gas Tungsten Arc Welding

In TIG torch the electrode is extended beyond the shielding gas nozzle. The arc is ignited by high voltage, high frequency (HF) pulses, or by touching the electrode to the work piece and withdrawing to initiate the arc at a preset level of current.

Selection of Electrode

D.C.Welding : 1 or 2 % of thoria

Thoria helps to improve electron emission which facilitates easy arc ignition

A.C.Welding : Pure tungsten or tungsten-zirconia

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Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of each size of electrode depends on whether it is connected to negative or positive terminal of DC power source. AC is used only in case of welding of aluminum and magnesium and their alloys.

The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the work piece, otherwise excessively high current shall flow, damaging the electrode. Open circuit voltage of power source ranges from 60 to 80 V.

Shielding Gases

- Argon
- Argon + Hydrogen
- Argon/Helium

Helium is generally added to increase heat input (increase welding speed or weld penetration). Hydrogen will result in cleaner looking welds and also increase heat input, however, Hydrogen may promote porosity or hydrogen cracking.

Argon or helium may be used successfully for most applications, with the possible exception of the welding of extremely thin material for which argon is essential. Argon generally provides an arc which operates more smoothly and quietly, is handled more easily and is less penetrating than the arc obtained by the use of helium. For these reasons argon is usually preferred for most applications, except where the higher heat and penetration characteristic of helium is required for welding metals of high heat conductivity in larger thicknesses. Aluminum and copper are metals of high heat conductivity and are examples of the type of material for which helium is advantageous in welding relatively thick sections.

Pure argon can be used for welding of structural steels, low alloyed steels, stainless steels, aluminum, copper, titanium and magnesium. Argon hydrogen mixture is used for welding of some grades of stainless steels and nickel alloys. Pure helium may be used for aluminum and copper. Helium argon mixtures may be used for low alloy steels, aluminum and copper.

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Application

TIG welding can be used in all positions. It is normally used for root pass(es) during welding of thick pipes but is widely being used for welding of thin walled pipes and tubes. This process can be easily mechanised i.e. movement of torch and feeding of filler wire, so it can be used for precision welding in nuclear, aircraft, chemical, petroleum, automobile and space craft industries. Aircraft frames and its skin, rocket body and engine casing are few examples where TIG welding is very popular.

Benefits

- Superior quality welds
- Welds can be made with or without filler metal
- Precise control of welding variables (heat)
- Free of spatter
- Low distortion

Limitations

- Requires greater welder dexterity than MIG or stick welding
- Lower deposition rates
- More costly for welding thick sections

GAS METAL ARC WELDING (MIG WELDING)

This process also known as Shielded Inert Gas Metal Arc (SIGMA) welding, Metal Inert Gas (MIG) welding or Gas Metal Arc Welding (GMAW) uses a shielded arc struck between a bare metal electrode and the work piece. The metal electrode is provided in the form of a wire reel.

This process is based on the principle of developing weld by melting faying surfaces of the base metal using heat produced by a welding arc established between base metal and a consumable electrode. Welding arc and weld pool are well protected by a jet of shielding inactive gas coming out of the nozzle and forming a shroud around the arc and weld. MIG and TIG welding is primarily attributed to the variation in effectiveness of shielding gas to protect the weld pool in case of above two processes. Effectiveness of shielding in two processes is mainly determined by

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two characteristics of the welding arc namely stability of the welding arc and length of arc besides other welding related parameters such as type of shielding gas, flow rate of shielding gas, distance between nozzle and work-price. Consumption of the electrode during welding slightly decreases the stability of the arc.

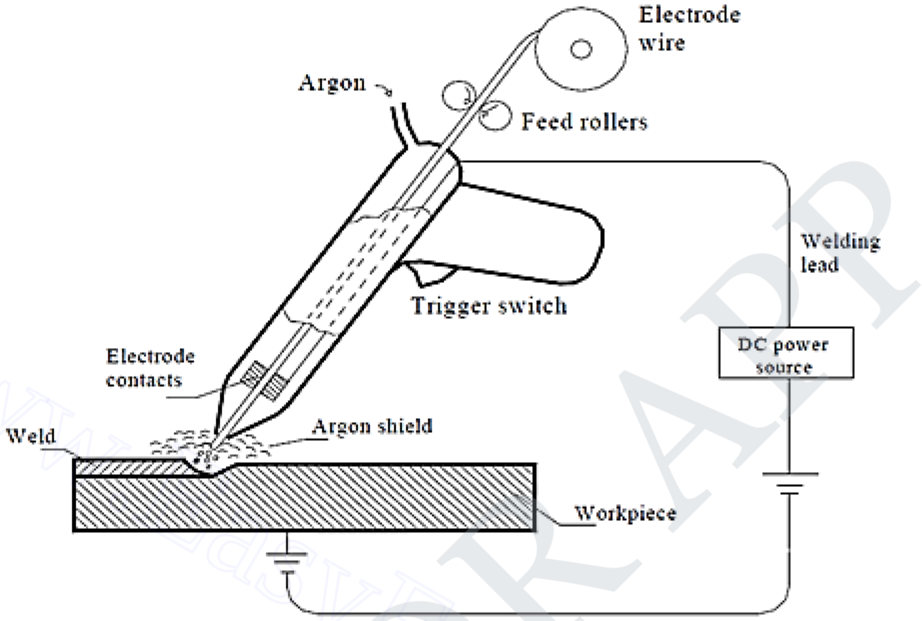

Fig.2.7 Metal Inert Gas (MIG) Welding

Metal inert gas process is similar to TIG welding except that it uses the automatically fed consumable electrode therefore it offers high deposition rate and so it suits for good quality weld joints required for industrial fabrication (Fig. 17.1). Consumable electrode is fed automatically while torch is controlled either manual or automatically. Therefore, this process is found more suitable for welding of comparatively thicker plates of reactive metals (Al, Mg, Stainless steel). The quality of weld joints of these metals otherwise is adversely affected by atmospheric gases at high temperature.

Characteristics of the MIG welding process

- Uses a consumable wire electrode during the welding process that is fed from a spool,
- Provides a uniform weld bead,
- Produces a slag-free weld bead,

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- Uses a shielding gas, usually – argon, argon - 1 to 5% oxygen, argon - 3 to 25% CO2 and a combination argon/helium gas,
- Is considered a semi-automatic welding process,
- Allows welding in all positions,
- Requires less operator skill than TIG welding,
- Allows long welds to be made without starts or stops,
- Needs little cleanup.

Shielding Gas

The shielding gas, forms the arc plasma, stabilizes the arc on the metal being welded, shields the arc and molten weld pool, and allows smooth transfer of metal from the weld wire to the molten weld pool.

The primary shielding gasses used are:

- Argon
- Argon - 1 to 5% Oxygen
- Argon - 3 to 25% CO2
- Argon/Helium

CO_2 is also used in its pure form in some MIG welding processes. However, in some applications the presence of CO_2 in the shielding gas may adversely affect the mechanical properties of the weld.

Benefits

- All position capability
- Higher deposition rates than SMAW
- Less operator skill required
- Long welds can be made without starts and stops
- Minimal post weld cleaning is required
- MIG weld is not considered as clean as TIG weld
- The MIG arc is relatively longer and less stable than TIG arc

MIG Welding Problems

- Heavily oxidized weld deposit
- Irregular wire feed

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- Burn back
- Porosity
- Unstable arc
- Difficult arc starting

Comparison on TIG welding and MIG welding

Sl.No.	TIG Welding	MIG Welding
1	Suitable to weld any metal.	Suitable to weld on Non-ferrous metal
2	Argon gas is used as primary shielding gas, Helium is Occasionally use.	Argon gas is used as primary shielding gas, Argon mixture with CO_2 is frequently used for dissimilar metal
3	Due to usage of non-consumable electrode, filler material is separately added	Filler metal is act as electrode
4	Difficult in operation	Simple and easy of operation
5	Suitable to operate on A.C. and D.C. supply	It is operate on D.C. supply only

SUBMERGED ARC WELDING

Submerged arc welding (SAW) is an arc welding process that uses a continuous, consumable bare wire electrode. The arc shielding is provided by a cover of granular flux consisting of lime, silica, manganese oxide, calcium fluoride and other compounds. The flux is fed into the weld zone from a hopper by gravity

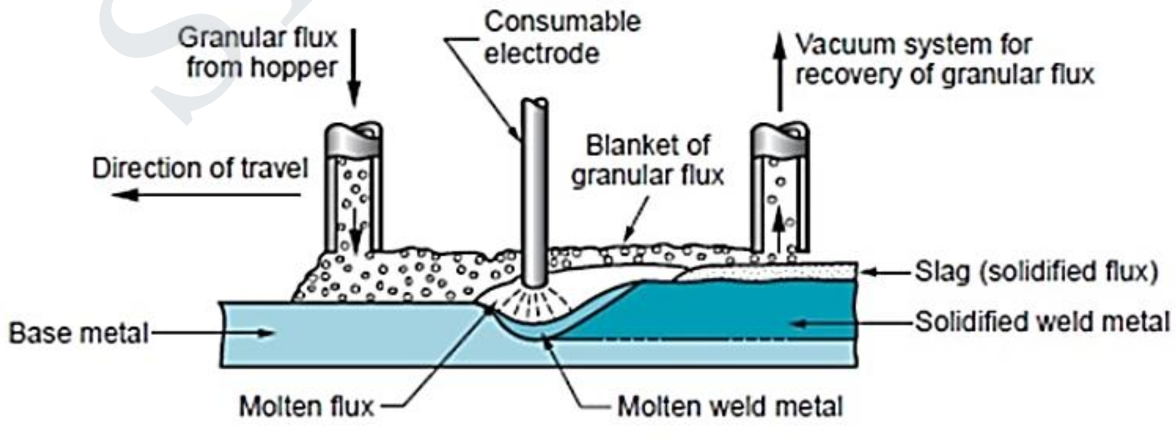

Fig.2.8 Submerged Arc Welding

flow through a nozzle. The thick layer of flux completely covers the molten metal. The electrode wire is fed automatically from a coil into the arc. The flux is introduced into the joint slightly ahead of the weld arc by gravity from a hopper, as shown in the figure.

The blanket of granular flux completely submerges the arc welding operation, preventing sparks, spatter and radiation that are so hazardous in other arc welding processes. The portion of the flux closest to the arc is melted, mixing with the molten weld metal to remove impurities and then solidifying on top of the weld joint to form a glasslike slag. The slag and infused flux granules on top provide good protection from the atmosphere and good thermal insulation for the weld area. This result in relatively slow cooling and a high-quality weld joint. The infused flux remaining after welding can be recovered and reused. The solid slag covering the weld must be chipped away usually by manual means. This process is widely used for automated welding of structural shapes, longitudinal and circumferential seams for large-diameter pipes, tanks, and pressure vessels. Because of the gravity feed of the granular flux, the parts must always be in a horizontal orientation.

The consumable electrode is a coil of bare round wire 1.5 to 10 mm in diameter, consumable electrode is fed automatically through a tube. Electric currents typically range from 300 to 2000A. The power supplies usually are connected to standard single-phase or three-phase power lines with a primary rating up to 440V.

Characteristics of submerged-arc welding

- The flux is fed into the weld zone from a hopper by gravity through a nozzle
- Prevents spatter and sparks;
- Suppresses the intense ultraviolet radiation and fumes characteristics of the SMAW.
- It acts as a thermal insulator by promoting deep penetration of heat into the work piece.
- The unused flux can be recovered, treated and reused.

Applications:

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The weld made by Submerged-arc welding have high strength and ductility with low Hydrogen and Nitrogen content. It is suitable for welding low alloy steel, high tensile steel, LC and MC steels, high resisting steel, corrosion resistant steel, high strength steel and many of non-ferrous alloys.

Advantages:

- Smooth welds of high strength and ductility with low H2 and N2 content.
- Because of high current, high metal deposition, high welding speeds and good penetration are achieved.
- Due to high speeds less distortion will occur.
- Elimination of fumes and spatter.
- Absence of visible arc and ease of penetration.

Limitations:

- During welding process arc is not visible, judging the welding progress is difficult and so tools like jigs, fixtures and guides are required.
- Pre-placing of flux may not always possible.
- This welding process is limited to flat position.
- Flux is subjected to contamination that may cause weld porosity.
- Chlorine, Aluminium, Magnesium, Lead, Zinc cannot be welded.

ELECTROSLAG WELDING

Electro slag Welding is a welding process, in which the heat is generated by an electric current passing between the consumable electrode (filler metal) and the work piece through a molten slag covering the weld surface.

Prior to welding the gap between the two work pieces is filled with a welding flux. Electroslag Welding is initiated by an arc between the electrode and the work piece (or starting plate). Heat, generated by the arc, melts the fluxing powder and forms molten slag. The slag, having low electric conductivity, is maintained in liquid state due to heat produced by the electric current.

The slag reaches a temperature of about 3500°F (1930°C). This temperature is sufficient for melting the consumable electrode and work piece edges. Metal

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droplets fall to the weld pool and join the work pieces. The weld pool is contained within this space and—due to contact with the copper blocks—it cools, solidifies, and is shaped. Electro-Slag welds are started and finished on run-off plates. This is known as starting or finishing tabs—they improve the quality of the weld metal.

Circumferential seams can be welded by the electro-slag process, using special devices to overcome the difficulty of joining the start and finish of a weld. The bead on the reverse side can be moulded by a water-cooled copper chill-ring, a permanent steel-ring, or a travelling shoe. Pieces of variable cross-sections can be electro-slag welded using consumable electrode guides.

An A.C. or D.C. power source in the range 300-800 amps is suitable, as used for automatic and MMA processes.

Electroslag welding is capable of welding plates with thicknesses ranging from 50 mm to more than 900 mm and welding is done in one pass. The current required is about 600 A at 40 to 50 Volts although higher currents are used for thick plates. The travel speed of the weld is in the range from 12 to 36 mm/min. Weld quality is high. This process is used for large structural-steel sections, such as heavy machinery, bridges, ships and nuclear-reactor vessels.

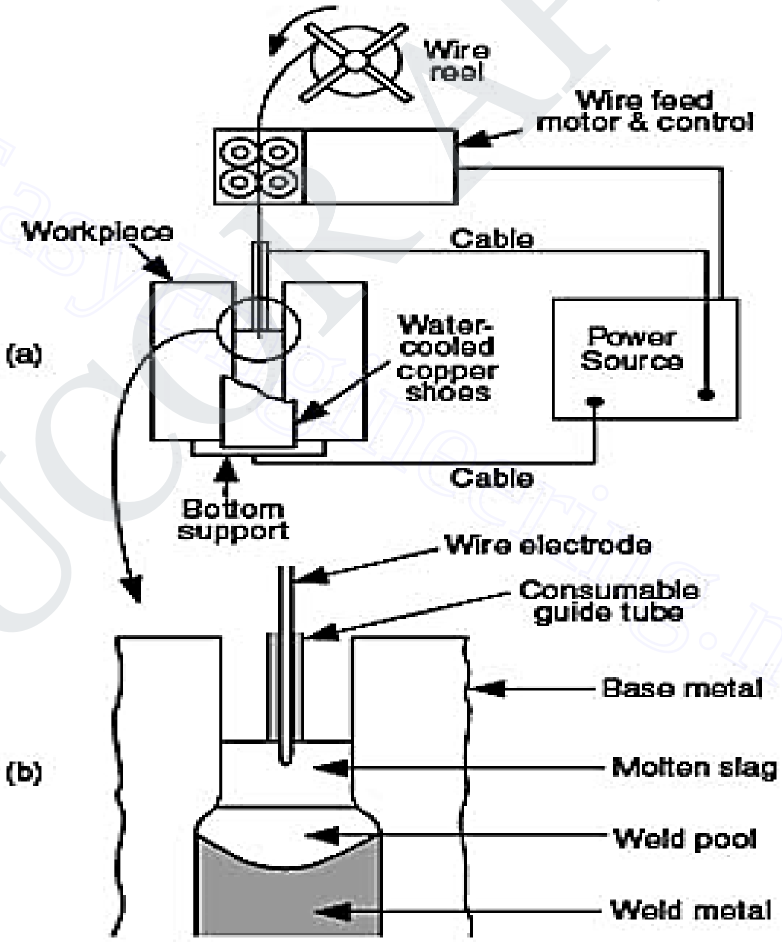

Fig.2.9 Electroslag welding

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Advantages:

- High deposition rate - up to 20 kg/h
- Low slag consumption (about 5% of the deposited metal weight);
- Low distortion;
- Unlimited thickness of work piece.

Disadvantages

- Coarse grain structure of the weld;
- Low toughness of the weld;
- Only vertical position is possible.

RESISTANCE WELDING

Resistance Welding is a welding process in which work pieces are welded due to a combination of a pressure applied to them and a localized heat generated by a high electric current flowing through the contact area of the weld.

Different metals and alloys such as low carbon steels, aluminium alloys, alloy steels, medium carbon and high carbon steels can be welded by resistance welding. However, for high carbon contained steels, the weld bed can be harder (less brittle).

Resistance Welding (RW) is used for joining vehicle body parts, fuel tanks, and domestic radiators, pipes of gas oil and water pipelines, wire ends, turbine blades, railway tracks.

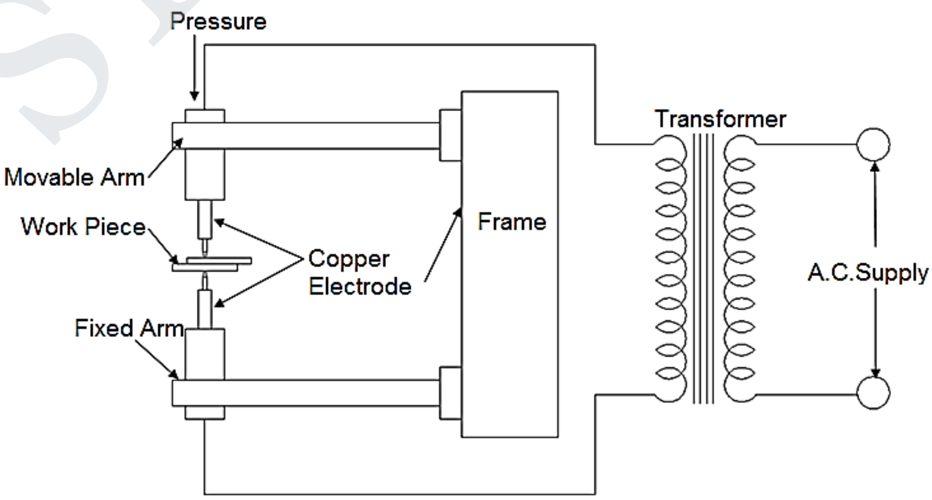

Fig. 2.10 : Resistance welding

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Required heat is generated at the junction due to flowing current through it and resistance offered. The amount of heat generated is

$$H = i^2 Rt$$

$where$

$H = heat\ generated\ w - sec$

$i = the\ current\ flowing$

$R = Resistance\ of\ junction$

$t = time\ taken\ for\ flow\ of\ current$

Principle of resistance welding can be explained with the help of diagram shown in Figure. It consists of work piece to be welded, two opposing electrodes a mechanism to apply pressure to squeeze the work pieces, AC power supply to maintain the current, and a circuit breaker with times to stop the flowing current after a preset time.

Heat produced by the current is sufficient for local melting of the work piece at the contact point and formation of small weld pool (”nugget”). The molten metal is then solidifies under a pressure and joins the pieces.

Advantages:

- High welding rates;
- Low fumes;
- Cost effectiveness;
- Easy automation;
- No filler materials are required;
- Low distortions.

Disadvantages:

- High equipment cost;

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- Low strength of discontinuous welds;
- Thickness of welded sheets is limited - up to 6 mm

TYPES OF RESISTANCE WELDING

- Butt welding
- Spot welding
- Seam welding
- Projection welding
- Percussion
- Stud welding

BUTT WELDING

Resistance butt welding is the simplest form of a group of resistance welding processes that involve the joining of two or more metal parts together in a localised area by the application of heat and pressure. The heat is generated within the material being joined by resistance to the passage of a high current through the metal parts, which are held under a pre-set pressure.

The process is used predominantly to make butt joints in wires and rods up to about 16mm diameter, including small diameter chain. The faces of the pieces to be joined may be flat and parallel or profiled in the case of larger sections. This reduces the initial contact area and further concentrates the heating at the interface. The components are clamped in opposing copper dies, with a small amount of stick-out, and abutted under pressure. Current is passed between the dies causing resistance heating of the weld area. The heat generated during welding depends on the current, the duration of the current, and the resistance. As the resistance is highest at the joint interface, heating is most intense in this area. When the material softens, it deforms under the applied load, giving a solid phase forge weld. No melting occurs. The current is terminated once a pre-set upset length has occurred, or the duration of the current is pre-set.

The joint is then allowed to cool slightly under pressure, before the clamps are opened to release the welded component. The weld upset may be left in place or removed, by shearing while still hot or by grinding, depending on the requirements.

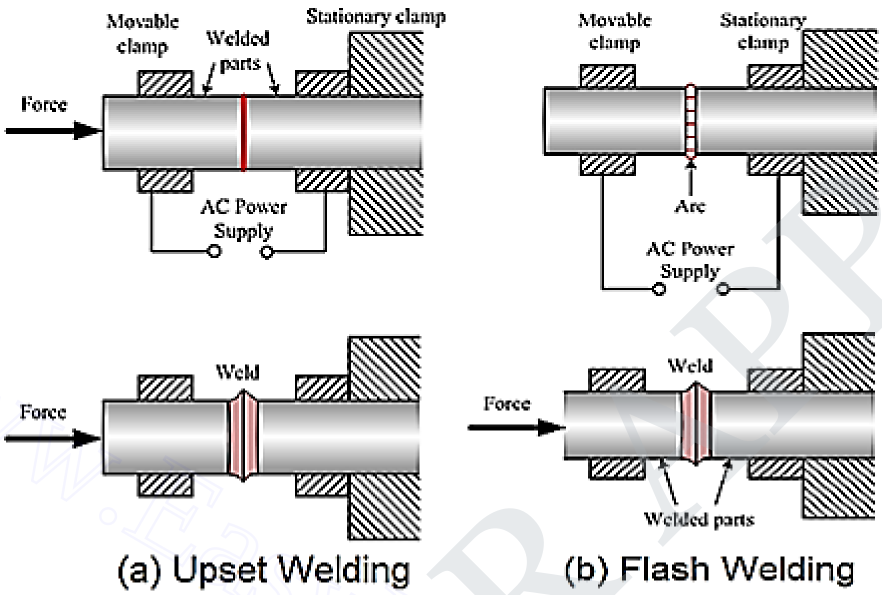

Fig. 2.11 : Butt Welding

Benefits

- Resistance butt welding is a high speed,
- It is clean process
- It is preferred to flash welding for many small components.

Drawbacks

There are some limitations on component size and geometry:

- Very thin or large sections are unsuitable.
- The risk of crushing fingers or hands
- Burns or eye damage from splash metal.

SPOT WELDING

Spot welding is one of the oldest welding processes. It can be used on very thin foils or thick sections but is rarely used above about 6mm thickness. It is used in a wide range of industries but notably for the assembly of sheet steel vehicle bodies. High quality welds can also be made in stainless steels, nickel alloys, aluminium alloys and titanium for aerospace application.

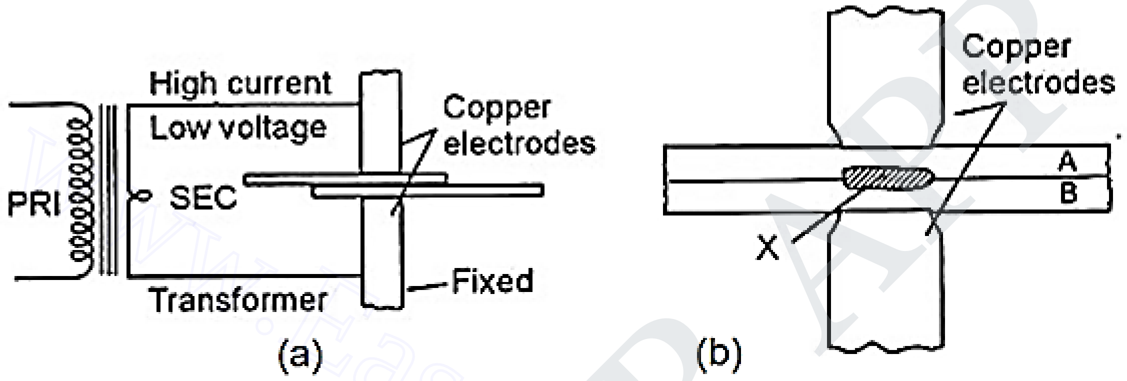

Fig. 2.12 : Spot Welding

Spot welding is one of a group of resistance welding processes that involve the joining of two or more metal parts together in a localised area by the application of heat and pressure. The heat is generated within the material being joined by the resistance to the passage of a high current through the metal parts, which are held under a pre-set pressure.

The process is used for joining sheet materials and uses shaped copper alloy electrodes to apply pressure and convey the electrical current through the work pieces. Heat is developed mainly at the interface between two sheets, eventually causing the material being welded to melt, forming a molten pool, the weld nugget. The molten pool is contained by the pressure applied by the electrode tip and the surrounding solid metal.

Benefits

Spot welding offers a number of advantages over other techniques, including high speed, ease of automation and energy efficiency.

Drawbacks:

There are some limitations on material weldability but attention to correct setting up and good process control can solve most production problems. The main hazards are (i) the risk of crushing fingers or hands and (ii) burns or eye damage from splash metal. Little fume is produced but may need attention when welding coated steels or when oils or organic materials are present.

SEAM WELDING

In Resistance Seam Welding (RSEW), the electrodes are two rotating wheels as shown in the figure:

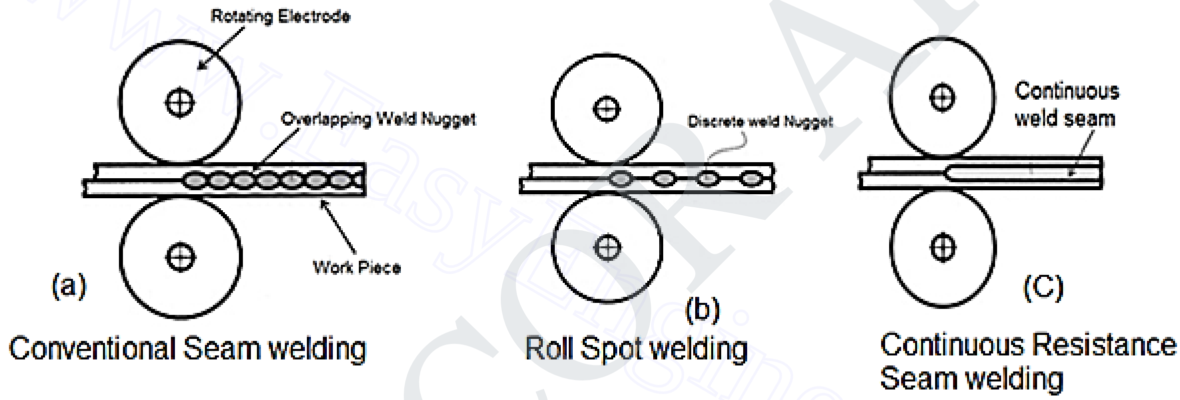

Fig.2.13 : Seam Welding

In the process of welding, a series of overlapping spot welds is made along the lap joint. The process is capable of producing airtight joints, and its industrial applications include the production of gasoline tanks, automobile mufflers, and various others fabricated sheet-metal containers.

The spacing between the weld nuggets in resistance seam welding depends on the motion of the electrode wheels relative to the application of the weld current. In the usual method of operation, called continuous motion welding, the wheel is rotated continuously at a constant velocity, and current is turned on at timing intervals consistent with the desired spacing between spot welds along the seam so that overlapping weld spots are produced. But if the frequency of current switching is reduced sufficiently, there will be spacing between the weld spots, and this method is termed roll spot welding. In another variation, the welding current remains on at a constant level so that a truly continuous welding seam is produced. These variations are depicted in the figure: Since the operation is usually carried out continuously, rather than discretely, the seams should be along a straight or uniformly curved line. Sharp comers and similar discontinuities should be avoided.

Advantages

- Gas tight as well as liquid tight joints can be made.
- The Overlap is less than spot or projection welding.
- The production of single seam weld and parallel seams can be got simultaneously.

Disadvantages

- The welding process is restricted to a straight line or uniformly curved line.
- The metals sheets having thickness more than 3mm can cause problems while welding.
- The design of the electrodes may be needed to change to weld metal sheets having obstructions.

Applications of RSEW

- Girth weld is possible in rectangular or square or even in circular shapes.
- Most of the metals can be welded (Except copper and some high percentage copper alloys)
- Butt welding can be done.

PROJECTION WELDING

In resistance projection welding (RPW), small projections are formed on one or both pieces of the base metal to obtain contact at a point which localize the current flow and concentrate the heat. Under pressure, the heated and softened projections collapse and a weld is formed. Projection on the upper component is

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pressed against the lower component by electrode force. The projection collapses and a fused weld nugget are formed with the application of current. This technique is of special value in mounting attachments to surfaces of which the back side is inaccessible to a welding operator.

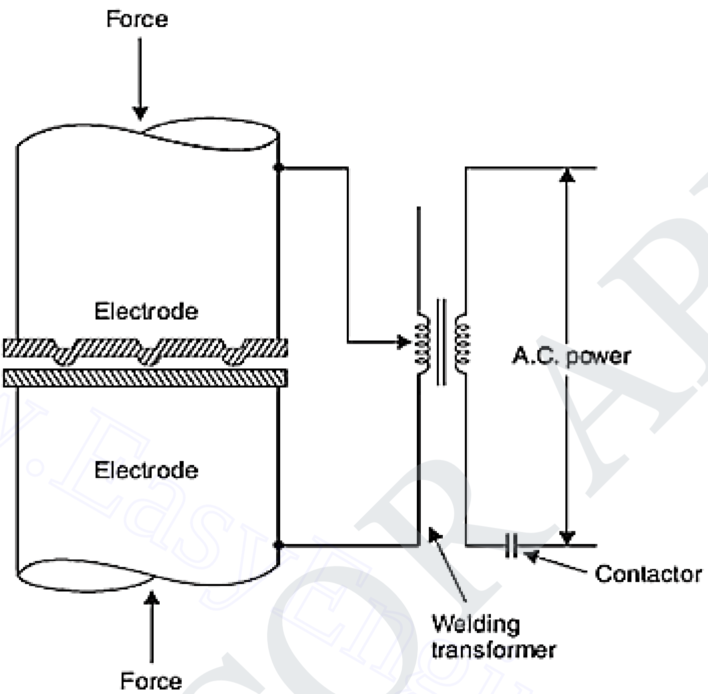

Fig.2.14 Projection Welding

Types of Projection Designs

There are typically three types of projection designs which are used for projection welding:

1) Embossed Projections
2) Stud-to-Plate Projections
3) Annular Projections

Advantages

- Simultaneous operation can be done i.e. more than one welds can be made.
- Projection welding has this advantage that it can weld metals of thickness which is not suitable for spot welding.

- Projection welding electrodes have a longer life when compared to spot welding electrodes.
- Resistance projection welding is not limited to sheet to sheet joints.
- Projection welding can be done in specific points which are desired to be welded.
- In difficult welding work projection welding gives a better heat balance.
- Projection welding saves electricity because it needs less current to produce heat. So it reduces the shrinkage and distortion defects.

Disadvantages

- All types of metals cannot be welded using projection method. Metal thickness and composition is a big question.
- All the metals are not strong enough to support the projections. Some brasses and coppers cannot be welded satisfactorily using projection welding.
- There is an extra operation which is called forming of projection.
- Projections need to have same heights for a appropriate welding.

Applications

- Resistance Projection welding is used in Automobile sector.
- Projection welding is used in refrigeration works (mass production of condensers, gratings, racks etc.)

PERCUSSION WELDING

Percussion welding is a variation or version of resistance welding, which is characterized by extremely short welding times and high welding currents. During this procedure, a joint is produced by a rapidly ignited arc and by the force which is generated by an electromagnet. Since only one 50 Hz half wave is used for the actual welding process, the welding time is always in the range of about 10 milliseconds. The weld current can reach values of about 100 kA.

The short welding time and the high welding current allow the combination of materials with high electrical and thermal conductivity. Also, large cross-section and thickness differences in the work pieces to be welded are no problem.

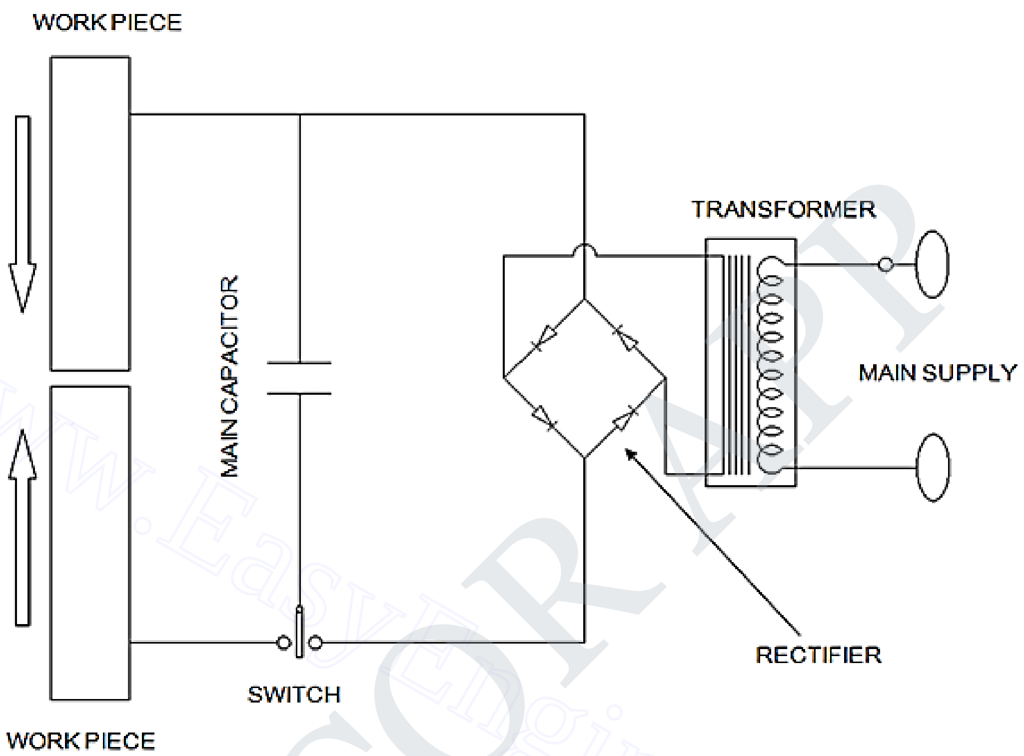

Fig.2.15 : Percussion welding

Process steps in Percussion Welding

1) The two materials to be welded are positioned with a preset air gap between them
2) A burst of RF energy ionizes the air gap.
3) Capacitor banks discharge, creating an arc that heats the two materials to a weldable temperature.
4) When the materials reach the proper welding state, electromagnetic actuators accelerate them together. The molten masses combine, metal to metal, and are forged together. As the weld cools, a complete alloy bond is formed.

In addition to the materials that can be processed on conventional resistance welding machines, the method is particularly suitable for the following combinations of materials and applications:

- Copper, tungsten, silver, molybdenum, nickel and their alloys
- Work pieces produced by powder metallurgy
- High-melting materials for high-voltage switchgear and control gear as well as power and heavy-duty switching devices

The components frequently used in power and high power switching devices in the field of electrical engineering can be made without the use of solder, flux or other welding and soldering consumables.

The main features of the method are

- The short welding time results in a very narrow heat affected zone
- A joint is created which is free from weld upset and nearly free from spatter
- Since the parts do not distort during the welding process and since there is nearly no material loss, minimum post weld machining or dressing is required, only.

STUD WELDING

Stud welding is an economical, rapid fixing method of metals used both in engineering and construction work in heavy sections. Stud means a protecting know-pin or a large-headed nails which can apply the fixing or fastening method of a variety of shapes and diameters to the parent plate.

The studs may be of circular or rectangular cross-section, plain or threaded (internally or externally) and vary from heavy support pins to clips or attachments used in component assembly.

Types of Stud welding:

(1) Drawn arc; and

(2) Capacitor discharge.

The Drawn arc method is generally used for heavier studs and plates. The Capacitor discharge method is for light gauge sheets. The operation depends upon the size, shape, and material of the stud and the composition and thickness of the metal parts.

Drawn arc process is used in both engineering and heavy construction work. The equipment consists of a D.C. power source controller and a hand-operated gun or holder. The hand-operated gun has an operating solenoid and return-spring within the gun-body which carries the operating adjustment switch. Studs are fluxed on the contact end, which is slightly pointed, and are supplied with ferrules. To operate the equipment, the welding current and time for the diameter of the stud are selected,

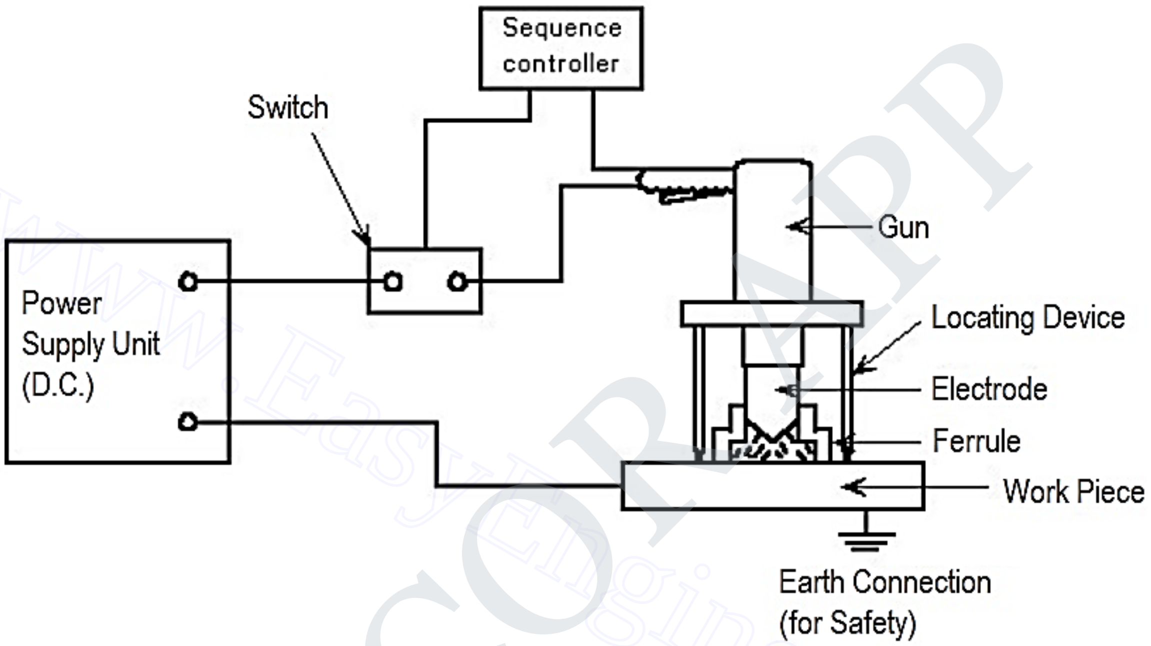

Fig.2.16 : Stude welding process

the stud is loaded into the proper chuck, the legs adjusted for length and the stud positioned on the plate. When the gun switch is pressed a low current flows between the pointed stud end and the work-piece and immediately the stud is raised, drawing an arc and ionizing the gap.

Studs from 3.3-20 mm and above in diameter can be used on the plate thicker than 1.6 mm and above. The rate of welding varies with the type of work, jigging, location, etc. In circular and rectangular cross-section for engineering and construction industries the weld can be made in mild steel, austenitic stainless steel, aluminium, and its alloys, etc.

In the capacitor process, a small projection on the end of the stud makes contact with the work-piece and the energy from a bank of charged capacitors is discharged across the contact. This melts the stud projection and produces a molten

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end of the stud and a shallow molten pool in the base metal. This completes the work-piece under controlled spring pressure.

Advantages:

- Fast attachment.
- No reverse marking.
- The welded joint is stronger than the parent material or the stud.
- Access is only required from one side.
- No holes hence no leaking or weakening of the sheet.
- Tamper proof.
- Pre-coated or painted material can be welded

Disadvantages

- It lacks the near-instant speed that the CD stud welding process offers. This factor could serve as a drawback for arc stud welding, resulting in a slight effect on productivity in certain fast-paced projects.
- Arc stud welds aren't ideal for use on thin metals,
- The amount of heat and current could leave behind discoloration on thinner work pieces.
- It is not suitable for smaller length of fasteners

PLASMA ARC WELDING (PAW)

It is a fusion welding process wherein the coalescence is produced by heating the work with a constricted arc established between a non-consumable tungsten electrode and work piece or between a non-consumable electrode and constricted nozzle. The shielding of the weld pool is obtained by the hot ionized gas produced by passing inert gas through the arc and constricted nozzle. Filler material may or may not be applied.

Principles of Operation:

In the PAW process, the work piece is cleaned and edges are prepared. An arc is established between a non-consumable tungsten electrode and work piece or between a non-consumable electrode and constricted nozzle. An inert gas is passed through the inner orifice surrounding the tungsten electrode and subsequently the gas is ionized and conducts electricity. This state of ionized gas is known as plasma. The plasma arc is allowed to pass through the constricted nozzle causing high energy and current density. Subsequently high concentrate heat and very high temperatures are reached. The low flow rate (0.25 to 5 l/min) of the orifice gas is maintained as excessive flow rate may cause turbulence in the weld pool. However the orifice gas at this flow rate is insufficient to shield the weld pool effectively. Therefore inert gas at higher flow rate (10- 30 l/min) is required to pass through outer gas nozzle surrounding the inner gas nozzle to protect the weld pool. A typical manual torch used in PAW is as shown in Fig. 4.5.2.

Plasma arc welding is of two types:

1) Non-transferred plasma arc welding process and
2) Transferred arc welding process.

In the former, the arc is established between the electrode and the nozzle and in the latter process the arc is established between the electrode and the work piece. The differences between these two processes are presented in the Table 2.1.

Operation:

In this process, arc cannot be initiated by touching the work piece as electrode is recessed in the inner constricted nozzle. Therefore, a low current pilot arc established in the constricted inner nozzle ad electrode. The pilot arc is generally initiated by the use of high frequency. AC or high voltage DC pulse superimposed on the main welding current. It cause the ionization of the orifice gas and high temperature which contributes to easy initiation of the main arc between the electrode and the work piece. After the initiation of the main arc, the pilot arc may be extinguished. This is followed by adding the filler material as in TIC welding process. Next, the welding torch is moved manually or automatically in the direction of welding. There are two techniques

1) Key hole technique
2) Non key hole techniques

In the key hole technique, due to constricted arc, high temperature and high gas flow, small weld pool with high penetration (up to 100%) width is obtained, resulting in complete melting of the base material beneath the arc. As the arc move forward, the material is melted and fills the hole produced due to arc force. The

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power supply and gas flow rate are turned off once the key hole is filled appropriately in the end of welding. The work piece is suitably cleaned after cooling

Table 2.1: Difference between the transferred and non-transferred arc welding processes

Sl.No.	Transferred plasma arc welding	Non-transferred plasma arc welding
1	Arc is established between electrode and Work piece	Arc is established between electrode and nozzle.
2	The work piece is part of the electrical circuit and heat is obtained from the anode spot and the plasma jet. Therefore, higher amount of energy is transferred to work. This is useful for welding.	The work piece is not part of the electrical circuit and heat is obtained from the plasma jet. Therefore, less energy is transferred to work. This is useful in cutting.
3	Higher penetration is obtained, so thicker sheets can be welded.	Less penetration is obtained, so thin sheets can be welded.
4	Higher process efficiency	Less process efficiency.

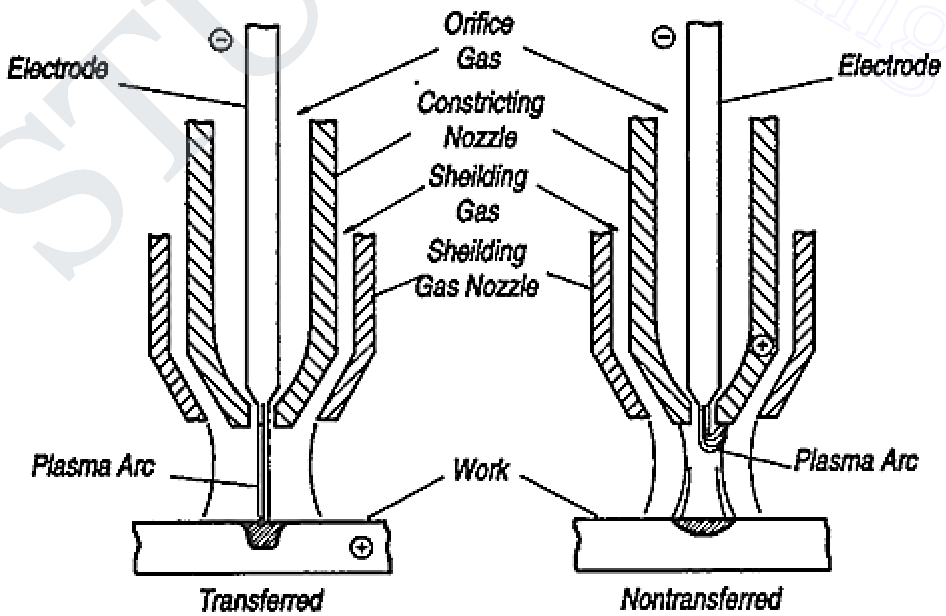

Fig. 2.17 : Plasma Arc welding

Equipment and Consumables:

Power source: A conventional DC current power supply with drooping V-I characteristics is required. Both rectifier or generator type power source may be used; however, rectifier type power source is preferred. The general range of the open-circuit voltage and current is 60-80V and 50-300A respectively.

Plasma torch: It consists of non consumable tungsten electrode, inner nozzle (constricting nozzle) and outer gas nozzle. The torch is water cooled to avoid heating of the nozzle. It is of two types: transferred arc and non transferred arc welding torch.

Filler material and shielding gases: Filler material used in this process is the same as those used in the TIG and MIG welding processes. The selection of the gases depends upon the martial to be welded. The orifice gas must be an inert gas to avoid contamination of the electrode material. Active gas can be used for shielding provided it does not affect the weld quality. In general, the orifice gas is the same as the shielding gas.

Applications of PAW:

This process is comparatively new and hence the potential of the process is yet to be understood/ accepted. This process can be used to join all the materials those can be welded by welding TIG process. Present applications of the process include:

- Piping and tubing of stainless and titanium,
- Submarine, aeronautical industry and jet engine manufacturing,
- Electronic components.

Advantages of PAW:

- Welding speed is higher.
- Penetration is more.
- Higher arc stability.
- The distance between torch and work piece does not affect heat concentration on the work up to some extent.

- Addition of filler material is easier than that of TIG welding process.
- Thicker job can be welded.
- Higher depth to width ratio is obtained resulting in less distortion.

Disadvantages of PAW:

- Higher radiations.
- Noise during welding.
- Process is complicated and requires skilled manpower.
- Gas consumption is high.
- Higher equipment and running cost.
- Higher open circuit voltage requiring higher safety measures to take.

ELECTRON-BEAM WELDING

Electron Beam Welding (EBW) is a fusion welding in which coalescence is produced by heating the work piece due to impingement of the concentrated electron beam of high kinetic energy on the work piece. As the electron beam impinges the work piece, kinetic energy of the electron beams converts into thermal energy resulting in melting and even evaporation of the work material.

Principles:

In general, electron beam welding process is carried out in vacuum. In this process, electrons are emitted from the heated filament called electrode. These electrons are accelerated by applying high potential difference (30 kV to 175 kV) between cathode and anode. The higher the potential difference, the higher would be the acceleration of the electrons. The electrons get the speed in the range of 50,000 to 200,000 km/s. The electron beam is focused by means of electromagnetic lenses. When this high kinetic energy electron beam strikes on the work piece, high heat is generated on the work piece resulting in melting of the work material. Molten metal fills into the gap between parts to be joined and subsequently it gets solidified and forms the weld joint.

Equipment:

An Electron Beam Welding set up consists of the following major equipment:

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1) Electron gun,
2) Power supply,
3) Vacuum Chamber, and
4) Work piece handling device

Electron Gun: An electron gun generates, accelerates and aligns the electron beam in required direction and spots on the work piece. The gun is of two types:

(1) Self-accelerated
(2) Work accelerated.

The work accelerated gun accelerates the electron by providing potential difference between the work piece and cathode. In the self-accelerate gun, electrons are accelerated by applying potential difference between the cathode and the anode. The anode and cathode are enclosed within the gun itself. The control of electron density is better in this type of electron gun. A schematic diagram of an Electron Beam Welding is shown in figure. The major parts of a gun are briefly introduced in the following section.

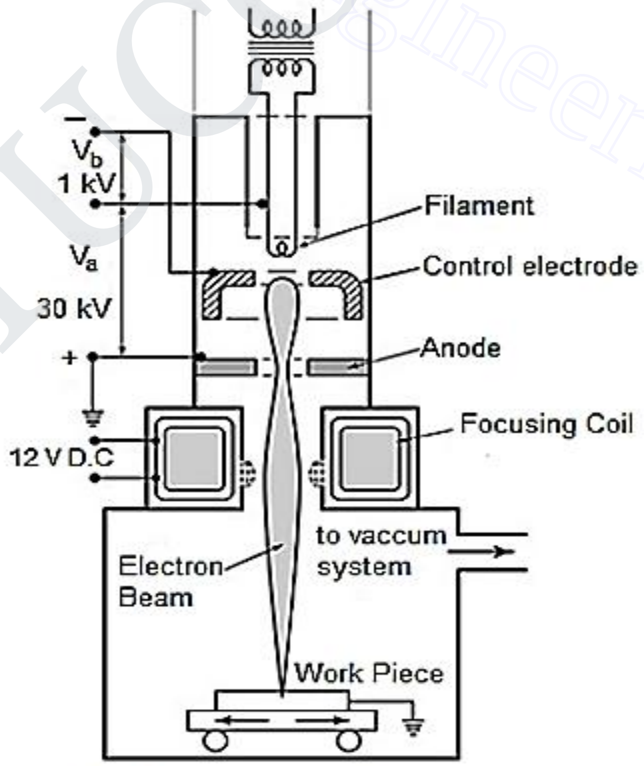

Fig. 2.18 : Electron Beam welding

Emitter / Filament:

It generates the electron on direct or indirect heating.

Anode:

It is a positively charged element near cathode, across which the high voltage is applied to accelerate the electrons. The potential difference for high voltage equipment ranges from 70-150 kV and for low voltage equipment from 15-30kV.

Grid cup:

Grid cup is a part of triode type electron gun. A negative voltage with respect to cathode is applied to the grid. The grid controls the beam.

Focusing unit:

It has two parts: Electron focusing lens and deflection coil. Electron focusing lens focuses the beam into work area. The focusing of the electrons can be carried out by deflection of beams. The electromagnetic lens contains a coil encased in iron. As the electrons enter into the magnetic field, the electron beam path is rotated and refracted into a convergent beam. The extent of spread of the beam can be controlled by controlling the amount of DC voltage applied across the deflection plates.

Electron gun power supply:

It consists of mainly the high voltage DC power supply source, emitter power supply source, electromagnetic lens and deflection coil source. In the high voltage DC power supply source the required load varies within 3-100 kW. It provides power supply for acceleration of the electrons. The current level ranges from 50-1000 mA.

In emitter power supply, AC or DC current is required to heat the filament for emission of electrons. However DC current is preferred as it affects the direction of the beam. The amount of current depends upon the diameter and type of the filament. The current and voltage varies from 25-70 A and 5-30 V respectively. The

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power to the electromagnetic lens and deflection coil is supplied through a solid state device.

Vacuum Chamber:

In the vacuum chamber pressure is reduced by the vacuum pump. It consists of a roughing mechanical pump and a diffusion pump. The pressure ranges from 100 kPa for open atmosphere to 0.13-13 Pa for partial vacuum and 0.13-133 mPa for hard vacuum. As the extent of vacuum increases, the scattering of the electrons in the beam increases. It causes the increase in penetration.

Work Piece Handling Device:

Quality and precision of the weld profile depends upon the accuracy of the movement of work piece. There is also provision for the movement of the work piece to control the welding speed. The movements of the work piece are easily adaptable to computer numerical control.

Advantages of EBW:

- High penetration to width can be obtained, which is difficult with other welding processes.
- High welding speed is obtained.
- Material of high melting temperature can be welded.
- Superior weld quality due to welding in vacuum.
- High precision of the welding is obtained.
- Distortion is less due to less heat affected zone.
- Dissimilar materials can be welded.
- Low operating cost.
- Cleaning cost is negligible.
- Reactive materials like beryllium, titanium etc. can be welded.
- Materials of high melting point like columbium, tungsten etc. can be welded.

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- Inaccessible joints can be made.
- Very wide range of sheet thickness can be joined (0.025 mm to 100 mm)

Disadvantages of EBW:

- Very high equipment cost.
- High vacuum is required.
- High safety measures are required.
- Large jobs are difficult to weld.
- Skilled man power is required

Applications of EBW:

a. Electron beam welding process is mostly used in joining of refractive materials like columbium, tungsten, ceramic etc. which are used in missiles.
b. In space shuttle applications wherein reactive materials like beryllium, zirconium, titanium etc. are used.
c. In high precession welding for electronic components, nuclear fuel elements, special alloy jet engine components and pressure vessels for rocket plants.
d. Dissimilar material can be welded like invar with stainless steel.

THERMIT WELDING

The energy in the form of heat is liberated by a chemical reaction the reaction is called "Exothermic" — which is the chemical reaction of Thermit welding.

Thermit is a chemical process welding which was previously termed "Alumino -Thermit" because the chemical mixture was of iron oxide and powdered aluminium. Aluminium is a strong reducing agent—it combines with the oxygen from the iron oxide, reducing it to iron.

The Thermit consists of about five parts of aluminium to eight parts of iron oxide. If this mixture is placed in a fireclay crucible and ignited by means of a special

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powder, the action starts and continues throughout the mass of the mixture, giving out great heat.

The intense heat that results due to the chemical action not only melts the iron but raises the temperature to about 3,000°C. The high temperature of the iron results in excellent fusion of the parts to be welded. Good steel scrap, or a small percentage of manganese or other alloying elements may be added, thereby producing a good quality Thermit steel.

$$Fe_2O_3 + 2\ Al \longrightarrow 2\ Fe + Al_2O_3$$

$$3Cu_2O + 2\ Al \longrightarrow 6\ Cu + Al_2O_3$$

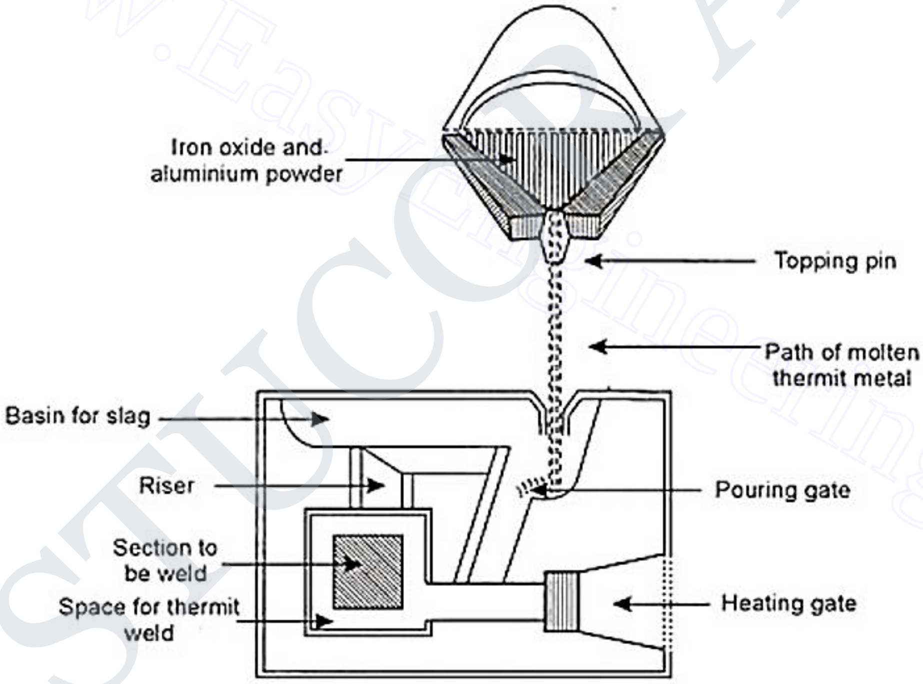

Fig.2.19 : Thermit welding process

Preparation of the Weld:

1. The edges of the work piece are cut flat and cleaned to remove dirt, grease and other impurities to obtain a sound weld. A gap of about 1.5-6mm is left between the edges of the two work pieces.

2. A wax heated to its plastic state is poured in the gap between the work pieces to be joined and allowed to solidify. Excess wax solidified around the joint is removed.
3. A mould box is placed around the joint and packed with sand providing necessary gates and risers. A hole or heating gate is made in the mould connecting to the joint.
4. The wax material is melted out by means of flame directed into the heating gate, so that it leaves a cavity at the joint which will later be occupied by the molten metal. The heating gate is then closed with a sand core or iron plug.
5. Exothermic reaction occurs to form molten iron and slag which floats at the top. The temperature resulting from this reaction is approximately 3000°C. The plug at the bottom of the crucible is opened and the molten metal is poured into the cavity. The molten metal acts as a filler metal, melts the edges of the joint and fuses to form a weld.
6. After the weld joint cools and solidifies, the mould is broken, risers are cut and the joint is finished by machining and grinding.

Fig. 2.11 illustrates the weld process.

Types of Thermit welding

1. Wabbler Thermit
2. Plain Thermit
3. Cast iron Thermit
4. Forging Thermit

Wabbler Thermit

Wabbler thermit which is particularly alloyed to make a solid, wear resistant, Machinable Steel use for produce rolls and pinions within rolling mills.

Plain Thermit

Plain Thermit is a combination of Aluminium with Iron Oxide and is the base for every other Thermits

Cast Iron Thermit:

Beside by Ferro-Silicon, Plain Thermit with Mild Steel are add as a combination and is use for welding iron works

Forging Thermit

Beside by Nickel, Manganese, Plain Thermit with mild steel are other as a mixture and is use for welding iron works.

Advantages:

- Intended for finish welding of strengthens bars to be use in concrete construction.
- For welding new necks to rolling mill rolls with pinions.
- Used for welding large broken crankshafts
- Used for building up damaged wobblers
- For welding busted frames of machines
- For restore broken teeth on big gears

Disadvantages:

- Low deposition rate with operating factor
- Its cannot weld low melting point
- It has slag inclusion
- It is high skill factor
- Extremely high level of fumes

Application:

The process is especially useful in welding together large-sections such as locomotive frames, stem posts of ship and rudders, railway lines, and tramlines.

FRICTION WELDING

Friction Welding (FRW) is a solid state welding process which produces welds due to the compressive force contact of work pieces which are either rotating or moving relative to one another. Heat is produced due to the friction which displaces material plastically from the faying surfaces. The basic steps explaining the friction welding process are shown in Fig.4.4.1. In friction welding the heat required to produce the joint is generated by friction heating at the interface. The components to be joined are first prepared to have smooth, square cut surfaces. One piece is held stationary while the other is mounted in a motor driven chuck or collet and rotated against it at high speed. A low contact pressure may be applied initially to permit cleaning of the surfaces by a burnishing action. This pressure is then increased and contacting friction quickly generates enough heat to raise the abutting surfaces to the welding temperature.

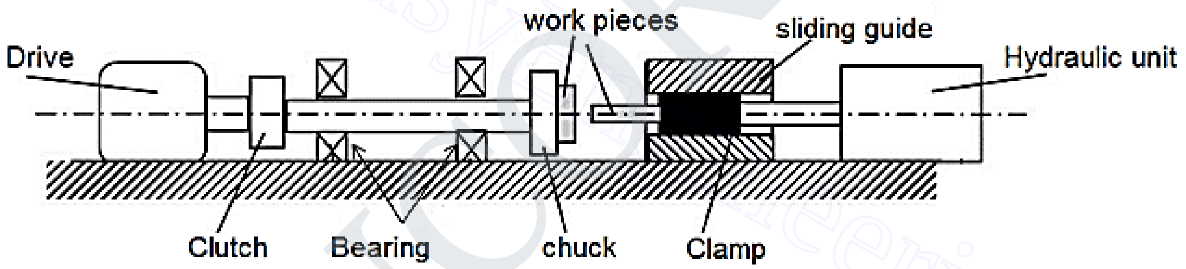

Fig.2.20 : Friction Welding

As soon as this temperature is reached, rotation is stopped and the pressure is maintained or increased to complete the weld. The softened material is squeezed out to form a flash. A forged structure is formed in the joint. If desired, the flash can be removed by subsequent machining action. Friction welding has been used to join steel bars upto 100 mms in diameter and tubes with outer diameter up to 100 mm. Inertia welding is a modified form of friction welding, where the moving piece is attached to a rotating flywheel. The flywheel is brought to a specified rotational speed and is then separated from the driving motor. The rotating assembly is then pressed against the stationary member and the kinetic energy of the flywheel is converted in to frictional heat. The weld is formed, when the flywheel stop its motion and the pieces remain pressed together. Since the conditions of the inertia welding are easily duplicated, welds of consistent quality can be produce and the process can be easily automated. The heat affected zones are usually narrow, since the time period is very short for heating and cooling. The radial and orbital FRW are shown in figure.

Advantages

1. No filler metal, flux or shielded gases are needed
2. It is an environment-friendly process with generation of smoke, fumes or gases.
3. No material is melted so the process is in solid state with narrow HAZ
4. Oxides can be removed after the welding process.
5. The process is very efficient and comparatively very rapid welds are made.
6. The weld is strength is stronger than the weaker of the two materials being joined

Disadvantages

1. The process is restricted to joining round bars or tubes of same diameter
2. Dry bearing and non-forgeable materials cannot be welded. (i.e. one of the material must be ductile)
3. Preparation and alignment of the work piece may be critical for developing uniform rubbing and heating
4. Equipment and tooling cost are high
5. Free machining alloys are difficult to weld.

Application

- Tongs hold to critical aircraft engine components
- Automotive parts like engine valve and shock absorber
- Hydraulic piston rod and track roller in agricultural equipment.
- Friction welded assemblies are often used to replace expensive casting and forgings

FRICTION STIR WELDING

Friction-stir welding (FSW) is a solid-state joining process (the metal is not melted) that uses a third body tool to join two facing surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool. It then mechanically intermixes the two pieces of metal at the place of the joint, then the softened metal (due to the elevated temperature) can be joined using mechanical pressure (which is applied by the tool), much like joining clay, or dough. It is primarily used on aluminium, and most often on extruded aluminium (non-heat treatable alloys), and on structures which need superior weld strength without a post weld heat treatment.

A constantly rotated non-consumable cylindrical-shouldered tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface.

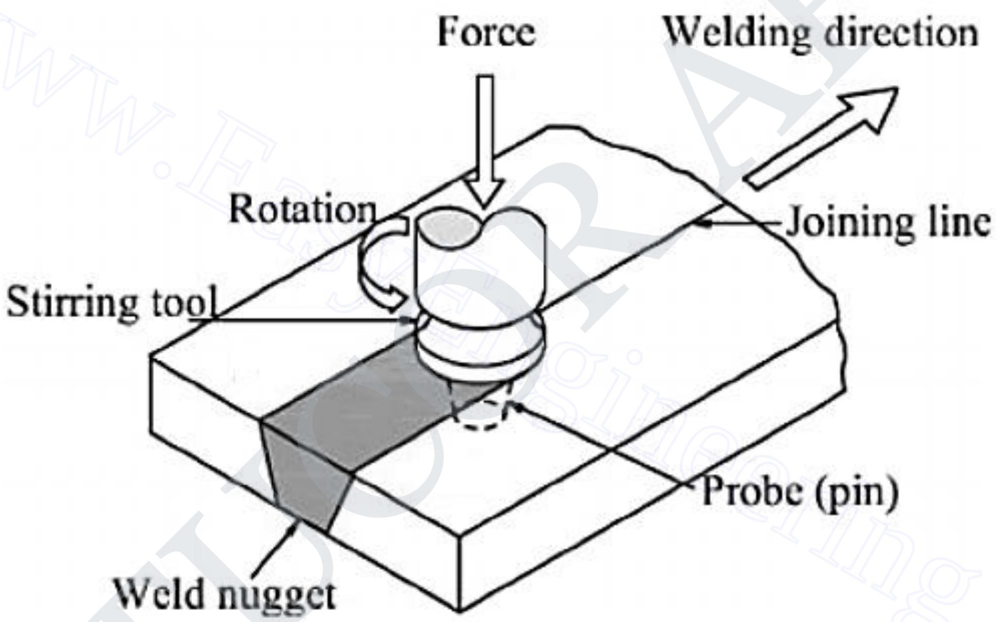

Fig. 2.21 Friction stir welding

Frictional heat is generated between the wear-resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticized material to the rear where clamping force assists in a forged consolidation of the weld.

This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material.

Advantages:

- Good mechanical properties in the as-welded condition
- Improved safety due to the absence of toxic fumes or the spatter of molten material.
- No consumables — no filler or gas shield is required for aluminium.
- Easily automated on simple milling machines — lower setup costs and less training.
- Can operate in all positions (horizontal, vertical, etc.), as there is no weld pool.
- Generally good weld appearance and minimal thickness under/over-matching, thus reducing the need for expensive machining after welding.
- Can use thinner materials with same joint strength.
- Low environmental impact.
- General performance and cost benefits from switching from fusion to friction.

Disadvantage

- Exit hole left when tool is withdrawn.
- Large down forces required with heavy-duty clamping necessary to hold the plates together.
- Less flexible than manual and arc processes (difficulties with thickness variations and non-linear welds).
- Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required.

BRAZING

The filler material cools down and solidifies forming a strong metallurgical joint, which is usually stronger than the parent (work piece) materials. The parent materials are not fused in the process.

Brazing is similar to Soldering. The difference is in the melting point of the filler alloy: brazing filler materials melt at temperatures above 840°F (450°C); soldering filler materials (solders) melt at temperatures below this point.

The difference between brazing and welding processes is more sufficient: in the welding processes edges of the work pieces are either fused (with or without a filler metal) or pressed to each other without any filler material; brazing joins two parts without melting them but through a fused filler metal.

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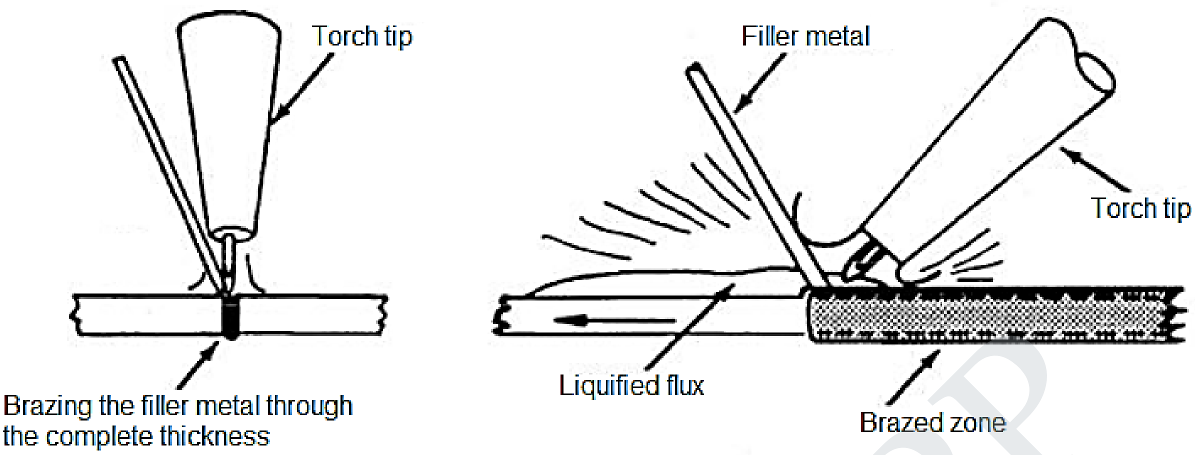

Fig.2.22 Brazing Process

Surface Cleaning and Brazing Fluxes

- Capillary effect is achieved by both: a proper Surface preparation and use of a flux for wetting and cleaning the surfaces to be bonded.
- Contaminants to be removed from the part surface are: mineral oils, miscellaneous organic soils, polishing and buffing compounds, miscellaneous solid particles, oxides, scale, smut, rust.
- The work pieces are cleaned by means of mechanical methods, soaking cleaning and chemical cleaning (acid etching).
- A brazing flux has a melting point below the melting point of the filler metal, it melts during the heating stage and spreads over the joint area, wetting it and protecting the surface from oxidation.
- It also cleans the surface, dissolving the metal oxides.
- It is important that the surface tension of the flux is: 1. Low enough for wetting the work piece surface; 2. Higher than the surface tension of the molten filler metal in order to provide displacement of the flux by the fused brazing filler. The latter eliminates the flux entrapment in the joint.
- The flux is applied onto the metal surface by brushing, dipping or spraying.

The more common types of filler metals used are

- Aluminum-silicon
- Copper
- Copper-silver
- Copper-zinc (brass)
- Copper-tin (bronze)
- Gold-silver
- Nickel alloy
- Silver
- Amorphous brazing foil using nickel, iron, copper, silicon, boron, phosphorus, etc.

Brazing methods

Torch brazing utilizes a heat of the flame from a torch. The torch mixes a fuel gas with Oxygen or air in the proper ratio and flow rate, providing combustion process at a required temperature.

The torch flame is directed to the work pieces with a flux applied on their surfaces. When the work pieces are heated to a required temperature, filler alloy is fed into the flame. The filler material melts and flows to the gap between the joined parts.

Torch brazing is the most popular brazing method.

Torch brazing equipment:

- Fuel gas cylinder with pressure regulator;
- Oxygen cylinder with pressure regulator;
- Welding torch;
- Blue oxygen hose;
- Red fuel gas hose;
- Trolley for transportation of the gas cylinders.

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Furnace brazing	:	It uses a furnace for heating the work pieces.
Vacuum brazing	:	It is a type of furnace brazing, in which heating is performed in vacuum.
Induction brazing	:	Induction brazing utilizes alternating electro-magnetic field of high frequency for heating the work pieces together with the flux and the filler metal placed in the joint region.
Resistance brazing	:	Resistance brazing uses a heat generated by an electric current flowing through the work pieces.
Dip brazing	:	Dip brazing is a brazing method, in which the work pieces together with the filler metal are immersed into a bath with a molten salt. The filler material melts and flows into the joint.
Infrared brazing	:	Infrared brazing utilizes a heat of a high power infrared lamp.

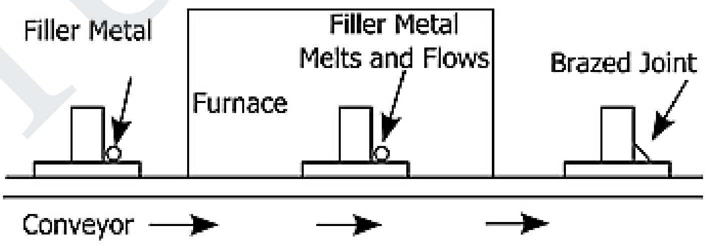

Fig.2.23 Furnace Brazing

Advantages of brazing

1. Low thermal distortions and residual stresses in the joint parts;
2. Microstructure is not affected by heat;
3. Easily automated process;

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4. Dissimilar materials and thin wall parts may be joined;
5. High variety of materials may be joined;
6. Moderate skill of the operator is required.

Disadvantages of brazing

1. Careful removal of the flux residuals is required in order to prevent corrosion;
2. No gas shielding may cause porosity of the joint;
3. Large sections cannot be joined;
4. Fluxes and filler materials may contain toxic components;
5. Relatively expensive filler materials.

SOLDERING

Soldering is a method of joining two metal work pieces by means of a third metal (solder) at a relatively low temperature, which is above the melting point of the solder but below the melting point of either of the materials being joined. Flow of the molten solder into the gap between the work pieces is driven by the capillary force. The solder cools down and solidifies forming a joint. The parent materials are not fused in the process.

Soldering is similar to Brazing. The difference is in the melting point of the filler alloy: solders melt at temperatures below 840°F (450°C); brazing filler materials melt at temperatures above this point.

The difference between soldering and welding processes is more sufficient: in the welding processes edges of the work pieces are either fused (with or without a filler metal) or pressed to each other without any filler material; soldering joins two parts without melting them but through a soft low melting point solder.

Fluxes:

The function of fluxes is to remove the non-metallic oxide film from the metal surface during the heating and soldering operations, so that clean metals may make mutual metallic contact.

The flux does not constitute a part of the soldered joint. Commonly used fluxes in soldering joining process are Zinc chloride (Zncl2), ammonium chloride (NH4cl and hydrochloric acid (Hcl).

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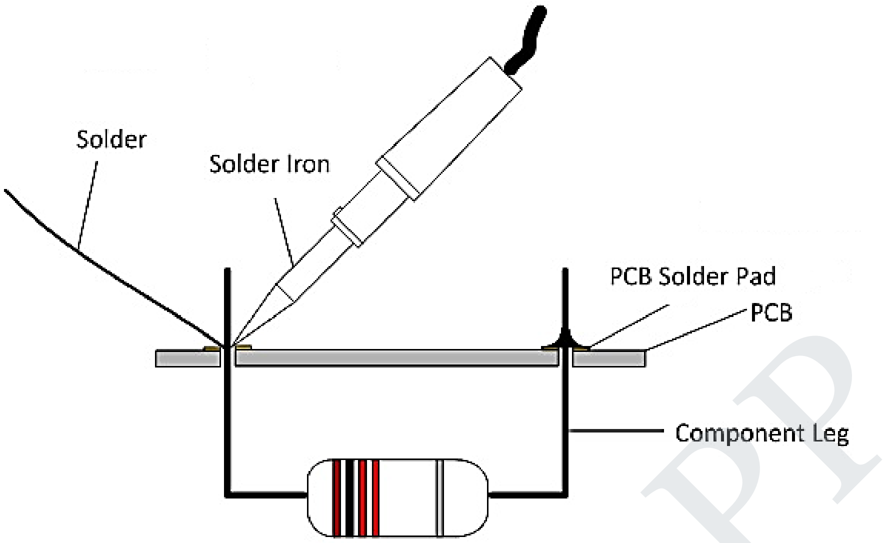

Fig. 2.24 Soldering Process

Soldering Methods

Hand soldering

Iron soldering utilizes a heat generated by a soldering iron.

Torch soldering utilizes a heat of the flame from a torch. The torch mixes a fuel gas with oxygen or air in the proper ratio and flow rate, providing combustion process at a required temperature.

The torch flame is directed to the work pieces with a flux applied on their surfaces. When the work pieces are heated to a required temperature, solder is fed into the joint region. The solder melts and flows to the gap between the joined parts. Hand soldering is used in repair works and for low volume production.

Wave soldering

The method uses a tank full with a molten solder. The solder is pumped, and its flow forms a wave of a predetermined height. The printed circuit boards pass over the wave touching it with their lower sides. The method is used for soldering through-hole components on printed circuit boards.

Reflow soldering

In this method a solder paste (a mix of solder and flux particles) is applied onto the surface of the parts to be joined and then are heated to a temperature above the melting point of the solder. The process is conducted in a continuous furnace, having different zones: preheating, soaking, reflow and cooling. The joint forms when the solder cools down and solidifies in the cooling zone of the furnace.

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Advantages of soldering

1. Low power is required;
2. Low process temperature;
3. No thermal distortions and residual stresses in the joint parts;
4. Microstructure is not affected by heat;
5. Easily automated process;
6. Dissimilar materials may be joined;
7. High variety of materials may be joined;
8. Thin wall parts may be joined;
9. Moderate skill of the operator is required.

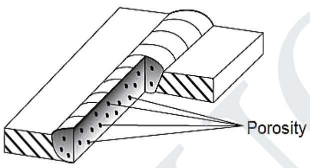
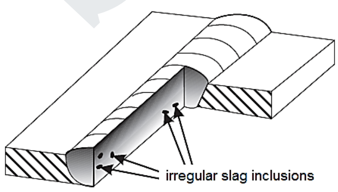
Disadvantages of soldering

1. Careful removal of the flux residuals is required in order to prevent corrosion;
2. Large sections cannot be joined;
3. Fluxes may contain toxic components;
4. Soldering joints cannot be used in high temperature applications;
5. Low strength of joints.

Comparison of welding soldering and brazing

Sl.No.	Welding	Soldering	Brazing
1	Welding joints are strongest joints used to bear the load. Strength of the welded portion of joint is usually more than the strength of base metal.	Soldering joints are weakest joints out of three. Not meant to bear the load. Use to make electrical contacts generally.	Brazing joints are weaker than welding joints but stronger than soldering joints. This can be used to bear the load up to some extent.
2	Temperature required is 3800°C in welding joints.	Temperature requirement is up to 450°C in soldering joints.	Temperature may go to 600°C in brazing joints.
3	To join work pieces need to be heated till their melting point.	Heating of the work pieces is not required.	Work pieces are heated but below their melting point.

4	Mechanical properties of base metal may change at the joint due to heating and cooling.	No change in mechanical properties after joining.	May change in mechanical properties of joint but it is almost negligible.
5	Heat cost is involved and high skill level is required.	Cost involved and skill requirements are very low.	Cost involved and sill required are in between other two.
6	Heat treatment is generally required to eliminate undesirable effects of welding.	No heat treatment is required.	No heat treatment is required after brazing.
7	No preheating of workpiece is required before welding as it is carried out at high temperature.	Preheating of workpieces before soldering is good for making good quality joint.	Preheating is desirable to make strong joint as brazing is carried out at relatively low temperature.

Sl.No	Defects	Causes	Remedies
1	Porosity  (a)	• Porosity is the entrapment of small volumes of gas in solidifying weld metal • It may arise from damp consumables or metal or, from dirt, particularly oil or grease, on the metal	• Drying consumables • Cleaning, degreasing material being welded • Electrode or filler metals with higher level of deoxidants • Sealing air leaks, reducing excess shielding gas flow
2	Slag inclusions  (e) Slag Inclusion	• These are irregularly shaped, not spherical like porosity	• Position work and/or change electrode/flux to increase slag control • Better slag removal between passes • Dress weld surface smooth if it is likely to cause slag traps • Remove heavy mill scale on plate

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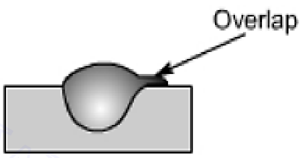
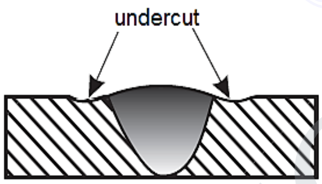
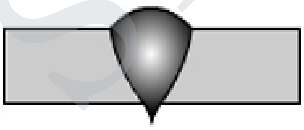
3	Lack of Fusion  lack of fusion between weld and base metal	• Lack of fusion is caused by incorrect welding conditions	• Procedure for complete fusion should be verified by testing • Increased energy input • Correct electrode angle and work position
4	Overlap  	• Overlap is an imperfection at the weld toe or root caused by metal flowing onto the surface of the base metal without fusing to it	• Adjust electrode manipulation to ensure fusion of base metal • Limit size of fillet to 9-mm leg length
5	Undercut  (c) Undercut	Undercut is an irregular groove at the weld toe in the parent metal or previous pass caused by • excessive weaving • melting of top edge of fillet weld with high current	• Weld in flat position • Change shielding gas to one which produces better wetting • Terminate welds so they don't finish at a free edge
6	Excessive penetration  Excessive Root Penetration	Excessive penetration is caused by • Incorrect assembly or preparation Edge preparation too thin to support weld under bead Excessive root gap • Energy input too high • Lack of operator skill	• Control of preparation • backing bars

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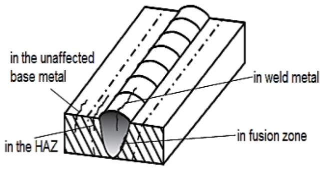
7	Crack  (b) Crack	These are developed due to shrinkage during solidification of weld metal , high arc travel speeds fast cooling rates, too concave or convex weld bead	Avoid producing too large a depth to width ratio Avoid high welding speeds Provide sufficient time for cooling

UNIT – III

METAL FORMING PROCESSES

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.

FUNDAMENTALS OF METAL FORMING

There are four basic production processes for producing desired shape of a product. These are casting, machining, joining (welding, mechanical fasteners, epoxy, etc.), and deformation processes.

- Casting process
- Machining processes
- Joining processes
- Deformation processes

To understand the forming (by deformation process) of metal, it is important to know the structure of metals. Metals are crystalline in nature and consist of irregularly shaped grains of various sizes. Each grain is made up of atoms in an orderly arrangement, known as a lattice. When a force is applied to deform it or change its shape, a lot of changes occur in the grain structure. These include grain fragmentation, movement of atoms, and lattice distortion.

To deform the metal permanently, the stress must exceed the elastic limit. At room temperature, the metal is in a more rigid state than when at higher temperature. Thus, to deform the metal greater pressures are needed when it is in cold state than when in hot state.

The amount of deformation that a metal can undergo at room temperature depends on its ductility. The higher the ductility of a metal, the more the deformation it can undergo. Metals having large grains are more ductile than those having smaller grains.

The deformation of metal can be achieved by following methods, namely

- Cold working
- Warm working
- Hot working

Cold Working:

Plastic deformation of metals below the recrystallization temperature is known as cold working. It is generally performed at room temperature. In some cases, slightly elevated temperatures may be used to provide increased ductility and reduced strength.

Benefits of cold working are

1. No heating is required
2. Better surface finish is obtained
3. Better dimensional control is achieved; therefore no secondary machining is generally needed.
4. Products possess better reproducibility and interchangeability.
5. Better strength, fatigue, and wear properties of material.
6. Directional properties can be imparted.
7. Contamination problems are almost negligible

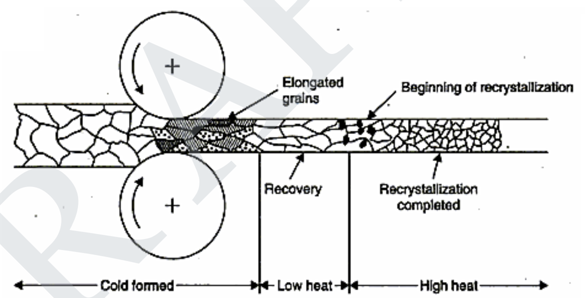


Fig. 3.1: Cold working Processes

Drawbacks of cold-working processes are:

1. Higher forces are required for deformation.
2. Heavier and more powerful equipment is required.
3. Less ductility is available.
4. Metal surfaces must be clean and scale-free.
5. Strain hardening occurs (may require intermediate annealing).
6. Undesirable residual stresses may be produced

Cold forming processes, in general, are better suited to large-scale production of parts because of the cost of the required equipment and tooling.

Warm Working:

Metal deformation carried out at temperatures intermediate to hot and cold forming is called Warm Forming. Compared to cold forming, warm forming offers several advantages. These include:

- Lesser loads on tooling and equipment

- Greater metal ductility
- Fewer number of annealing operation (because of less strain hardening)

Advantages.

1. Lesser amount of heat energy requirement
2. Better precision of components
3. Lesser scaling on parts
4. Lesser decarburization of parts
5. Better dimensional control
6. Better surface finish
7. Lesser thermal shock on tooling
8. Lesser thermal fatigue to tooling, and so greater life of tooling.

Hot Working:

Plastic deformation of metal carried out at 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 deformed by previously carried out mechanical working no longer exist, instead new crystals which are strain-free are formed.

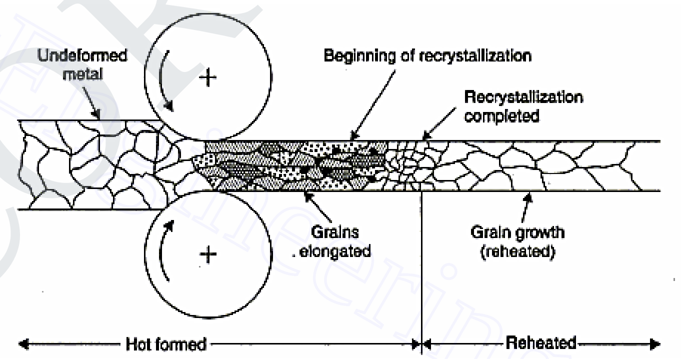


Fig. 3.2 : Hot working Processes

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 material.

The advantages of hot working are

1. No strain hardening
2. Lesser forces are required for deformation
3. Greater ductility of material is available, and therefore more deformation is possible.

4. Favorable grain size is obtained leading to better mechanical properties of material
5. Equipment of lesser power is needed
6. No residual stresses in the material.

Disadvantages of hot-working of metals are:

1. Heat energy is needed
2. Poor surface finish of material due to scaling of surface
3. Poor accuracy and dimensional control of parts
4. Poor reproducibility and interchangeability of parts
5. Handling and maintaining of hot metal is di
6. fficult and troublesome
7. Lower life of tooling and equipment.

Recrystallization temperature

Recrystallization temperature can be defined as the process, the temperature in which grains of a crystal structure are come in new structure or new crystal shape. Recrystallization is usually accompanied by a reduction in the strength and hardness of a material and a simultaneously increase in the ductility.

Comparison of hot working and cold working

Sl.No.	Hot working	Cold working
1	Working temperature is above the re crystallization temperature. Therefore, it can be regarded as a simultaneous process of deformation and recovery.	Cold working temperature is below the crystallization temperature. So no appreciable recovery can take place during deformation.
2	Coefficient of friction in hot forming is as high as 0.6.	The coefficient of friction in cold forming i generally of the order of 0.1.

3	Hardening due to plastic deformation is completely eliminated by recovery and re crystallization, only if the rate of recrystallization is higher than deformation.	Harding is not eliminated in this case. This is always accompanied by work hardening.
4	Refinement of crystal occurs.	Grains are only elongated and distorted.
5	Internal and residual stresses are not developing in the metal.	Internal and residual stresses are developed.
6	Surface finishing is not good.	Better surface finishing is obtained.
7	It promotes uniformity of materials.	Uniformity of material is lost.
8	Cracks and blow holes are welded up.	Possibility of crack formation and its propagation is great.
9	Mechanical properties such as elongation, reduction of area, and impact value are improved	Cold working decreases elongation, reduction of area, and impact value.

Classification of hot working and cold working processes

Hot working processes

- Rolling
- Forging
- Drawing
- Spinning
- Piercing
- Extruding

Cold working processes

- Drawing
- Squeezing
- Bending
- Shearing
- Hobbing
- Shot peening
- Extruding

Forging

Forging is a manufacturing process involving the shaping of metal using localized compressive force. The blows are delivered with a hammer (often a power hammer) or a die. Forging is often classified according to the temperature at which it is performed:

- Cold forging (performed at room temperature)
- Warm forging (performed at elevated room temperature)
- Hot forging (a type of hot working)

Application:

- Crankshaft and Connecting rod for I.C. Engines
- Turbine disc, gear wheel, bold head, hand tools
- Many types of structural components

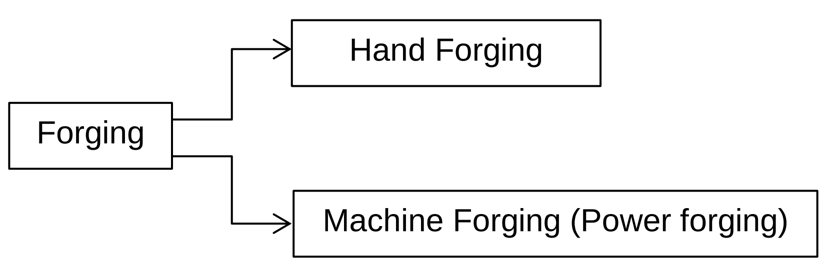
Benefits of forging:

1. It improves the structure as well as mechanical properties of the metallic parts.
2. Forged components can withstand unpredictable load.
3. Forged parts are consistent in shape with the minimum presence of voids and porosities.
4. Forging can produce parts with high strength to weight ratio.
5. Forging processes are very economical for moderate to high volume productions.

Drawbacks of forging:

1. Initial cost of dies and the maintenance cost are high
2. In hot forging, due to high temperature, there is rapid oxidation on the surface resulting poor finish
3. Forging are usually costlier than casting
4. Forging operations are limited to simple shape

Classification of forging



- Drop forging
- Press forging
- Open – die forging
- Closed – die forging
- Impression die forging
- Flashless forging
- Upset forging
- Roll forging

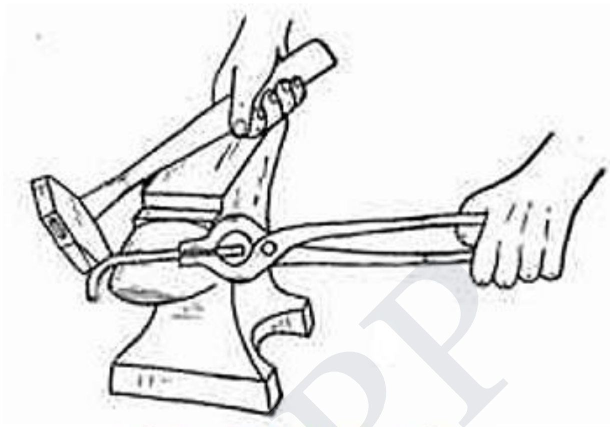


Fig. 3.3 : Hand Forging

Hand forging

The hand forging process is an ancient one that has been utilized for many centuries by professionals who are generally referred to as blacksmiths. Basically, they shape the metal by heating and hammering with varying pressure to the metal in order to manipulate it into a desired to achieve. This method of forging metal requires a lot of labour and strength.

Benefits of hand forging are the fact the metal produced through this method is usually stronger than metal produced by other techniques, such as casting or welding. The main reason is that the repeated blows from the blacksmith and the careful monitoring of the process results in a less porous material that is better refined than most tactics.

Hand forging can be done by two methods: open die forging and closed die forging

Hand Forging → Open Die Forging
Hand Forging → Closed Die Forging

Drop forging

Hammer forging (drop forging) is forming a preheated work piece by using impact energy of the falling hammer by a mechanical force, forcing the metal to fill the space between the punch (a part attached to the hammer) and the forging die (a part attached to the anvil).

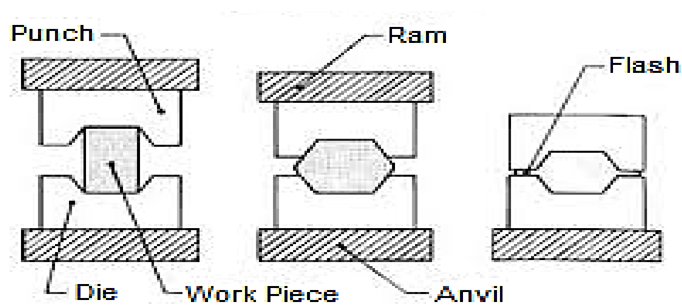


Fig. 3.4 Drop Forging (Closed - Die - Forging)

Press Forging (closed die

forging)

Press forging, which is mostly used for forging of large sections of metal, uses hydraulic press to obtain slow and squeezing action instead of a series of blows as in drop forging. The continuous action of the hydraulic press helps to obtain uniform deformation throughout the entire depth of the work piece. Therefore, the impressions obtained in press forging are cleaner.

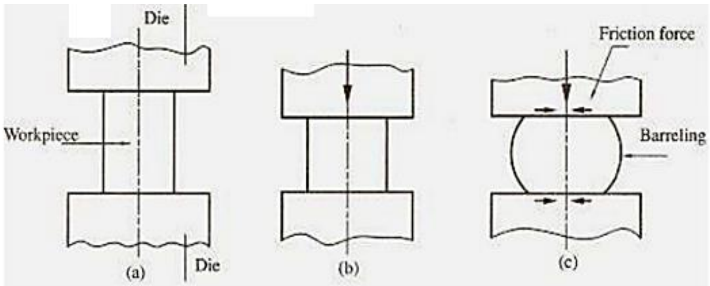


Fig. 3.5 Drop Forging (Open - Die - Forging)

Press forgings generally need smaller draft than drop forgings and have greater dimensional accuracy. Dies are generally heated during press forging to reduce heat loss, promote more uniform metal flow and production of finer details.

Hydraulic presses are available in the capacity range of 5 MN to 500 MN but 10 MN to 100MN capacity presses are more common.

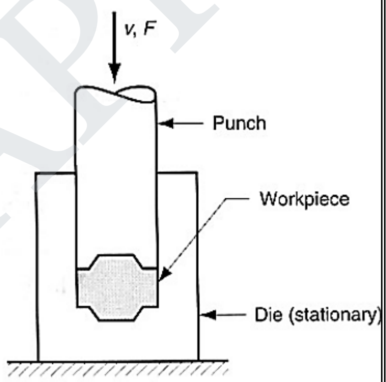


Fig. 3.4 Flashless forging

Upset Forging

Upset forging involves increasing the cross – section of a material at the expense of its corresponding length. Upset – forging was initially developed for making bolt heads in a continuous manner, but presently it is the most widely used of all forging processes. Parts can be upset – forged from bars or rods upto 200 mm in diameter in both hot and cold condition. Examples of upset forged parts are fasteners, valves, nails, and couplings.

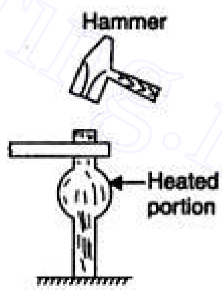


Fig. 3.6 Upset forging

The process uses split dies with one or several cavities in the die. Upon separation of split die, the heated bar is moved from one cavity to the next. The split dies are then forced together to grip the and a heading tool (or ram) advances axially against the bar, upsetting it to completely fill the die cavity. Upon completion of upsetting process the heading tool comes back and the movable split die releases the stock.

Upsetting machines, called up setters, are generally horizontal acting.

When designing parts for upset – forging, the following three rules must be followed.

- The length of unsupported bar that can be upset in one blow of heading tool should not exceed 3 times the diameter of bar. Otherwise bucking will occur.
- For upsetting length of stock greater than 3 times the diameter the cavity diameter must not exceed 1.5 times the diameter of bar.
- For upsetting length of stock greater than 3 times the diameter and when the diameter of the upset is less than 1.5 times the diameter of the bar, the length of un – supported stock beyond the face of die must not exceed diameter of the stock.

Roll Forging

This process is used to reduce the thickness of round or flat bar with the corresponding increase in length. Examples of products produced by this process include leaf springs, axles, and levers.

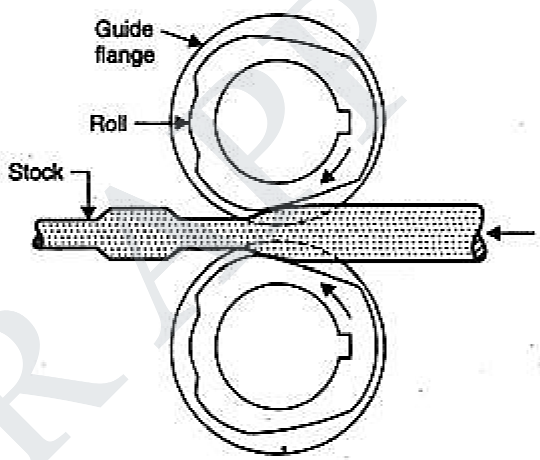


Fig. 3.7 : Roll Forging

The process is carried out on a rolling mill that has two semi cylindrical rolls that are slightly eccentric to the axis of rotation. Each roll has a series of shaped grooves on it. When the rolls are in open position, the heated bar stock is placed between the rolls. With the rotation of rolls through half a revolution, the bar is progressively squeezed and shaped. The bar is then inserted between the next set of smaller grooves and the process is repeated till the desired shape and size are achieved.

Forging operation

- Upsetting
- Drawing down
- Heading
- Fullering
- Edging

Upsetting

The process of shortening the length of the work piece or increasing the thickness and width (if the work piece is circular, then its diameter) on either side is named as upsetting

Heading

Heading operation is similar to upsetting operation, but the stock dimension is increased only on one end of the stock.

Fullering

It is the operation of reducing the stock between the two ends of the stock at a central place, so as to increase its length. The inclined surface of the die prevents material movement in the width direction, because there is a pressure component acting in the direction of material flow. Repeated strokes with the stock rotated around its axis between strokes, allow substantial material redistribution.

Edging

The process (edging or rolling operation) of distribute the metal longitudinally by moving the metal from the portion of the stock where it is in excess to the portion which is deficient in metal.

Drawing down or cogging

It is an operation similar to fullering with the difference that the stock is reduced at only one end (and its length increased) instead of at a central place as in fullering.

Bending

Bending operation makes the longitudinal axis of the stock in two or more places. This operation is done after the stock has been edged or fullered, so that the stock is brought into a proper relation with the shape of the finishing impression.

Flattening

This operation is used to flatten the stock so that it fits properly into the finishing impression of a closed die.

Blocking

This operation which imparts to the forging its general but not exact or final shape. This is done just prior to finishing operation.

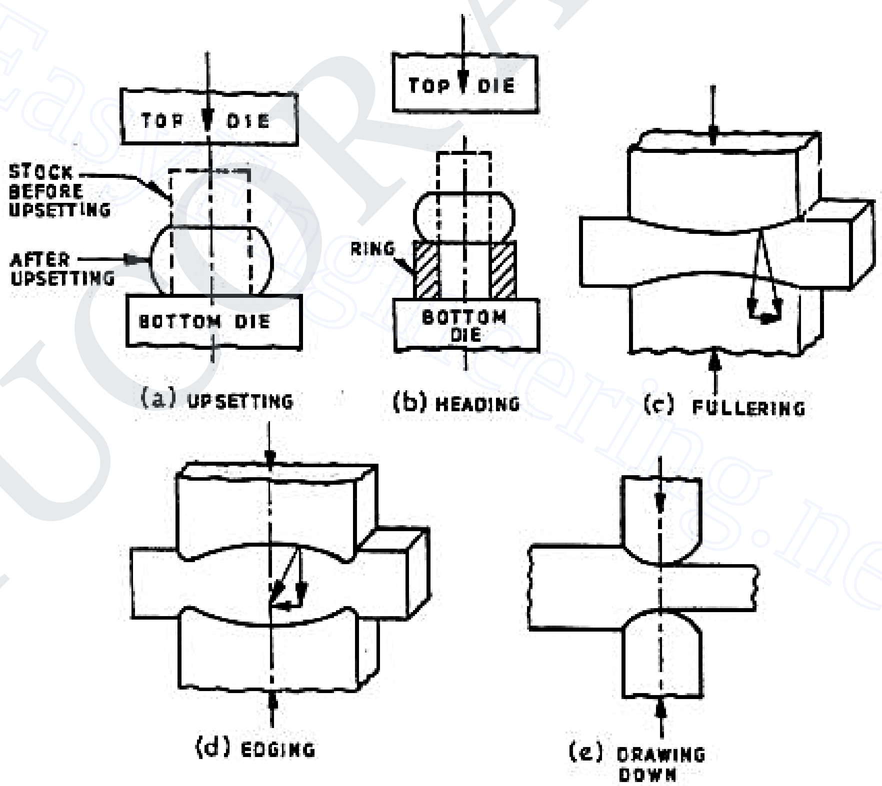


Fig. 3.8 Various forging operations

Cut-off

A pair of blade, either milled in the corner of a pair of forging dies, or inserted in the dies, used to cut away a forging from the bar after the finishing blow.

Piercing

It is the operation done with the help of a punch to obtain blind or through holes in the metal. The pierced billet is further processed.

Punching

This is the operation of shearing out a slug in a forging to produce a hole.

Swaging

It is the operation of reducing or changing the cross-section area of diameter by revolving the stock under fast impact blows.

Coining

It is a cold closed die forging operation (no flash) to obtain closer tolerances and smoother surfaces.

Hot Forging Vs. Cold Forging

Hot forging and **cold forging** are two different metal forming processes that deliver similar results. Forging is the process of deforming metal into a predetermined shape using certain tools and equipment—deformation is accomplished using hot, cold, or even warm forging processes. Ultimately, the manufacturer will look at a number of criteria before choosing which type of forging is best for a particular application.

Hot Forging Process

When a piece of metal is hot forged it must be heated significantly. The average temperatures necessary for hot forging are:

- Up to 1150 degrees Celsius for Steel
- 360 to 520 degrees Celsius for Al-Alloys
- 700 to 800 degrees Celsius for Cu-Alloys

During hot forging, the temperature reaches above the recrystallization point of the metal. This kind of extreme heat is necessary in avoiding strain hardening of the metal during deformation. In order to prevent the oxidation of certain metals, like super alloys, a type of hot forging called isothermal forging is a good choice. In isothermal forging, the metal deformation occurs within a highly controlled atmosphere, similar to that of a vacuum.

Factor to be consider for hot Forging

- Production of discrete parts
- Low to medium accuracy
- Scale Formation

- Low stresses or low work hardening
- Homogenized grain structure
- Increased ductility
- Elimination of chemical incongruities

Possible disadvantages of hot forging include:

- Less precise tolerances
- Possible warping of the material during the cooling process
- Varying metal grain structure
- Possible reactions between the surrounding atmosphere and the metal

Cold Forging

Cold forging deforms metal while it is below its recrystallization point. Cold forging is generally preferred when the metal is already a soft metal, like aluminum. This process is usually less expensive than hot forging and the end product requires little, if any, finishing work. Sometimes, when aluminum is cold forged into a desired shape, it is heat treated to strengthen the piece. This is called "tempering."

Cold Forging Process

Despite the word "cold," cold forging actually occurs at or near room temperature. The most common metals in cold forging applications are usually standard or carbon alloy steels. One of the most common types of cold forging is a process called impression-die forging, where the metal is placed into a die that is attached to an anvil. The metal is then hit by a descending hammer and forced into the die. Depending on the product, the hammer may actually be dropped on the metal numerous times in a very rapid sequence.

Advantages:

- Easier to impart directional properties
- Improved interchangeability
- Improved reproducibility
- Increased dimensional control
- Handles high stress and high die loads
- Produces net shape or near-net shape parts

Disadvantages:

- Easier to impart directional properties
- Improved interchangeability
- Improved reproducibility
- Increased dimensional control

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- Handles high stress and high die loads
- Produces net shape or near-net shape parts
- The metal surfaces must be clean and free of scale before forging occurs
- The metal is less ductile
- Residual stress may occur
- Heavier and more powerful equipment is needed
- Stronger tooling is required

Comparison of press forging and drop forging

Sl. No.	Press forging	Drop forging
1	Faster process	Slow process
2	Alignment of dies is easier	Alignment of dies is difficult
3	Quite operation	Noisy operation
4	Structural quality of the product is superior	Structural quality is fair
5	Easy to maintenance	Difficult to maintenance
6	High productivity	Moderate productivity
7	No need for skilled operator	Required skilled operator
8	One stroke is enough to complete an operation	More than one stroke is needed to complete an operation
9	Stroke and ram speed is high	Slow speed is recommended

Comparison of open die forging and closed die forging

Sl. No.	Open forging	Closed forging
1	The process is completed in between the flat surface of the two die.	The upper die fitted with ram and the lower die is fitted with anvil and the process is completed.

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2	The process is finished by repeated blowing	The process is finished by single blowing
3	It is simple and flexible	This is complex and rigid
4	Pressure is limited	Pressure can be varies depends on the material
5	'U' Bolt, chisels, polygonal shaped components are example of the product.	Spanner, automobile parts and machine parts are made by closed die forging process.

Types of forging (hammer) machines or press

Forging press

- Mechanical press
- Power press
    1. Pneumatic (50 to 1000 Kg)
    2. Hydraulic (100 tonne)
    3. Steam (400 to 8000 Kg)

Board Drop Hammer

This type is commonly used type. The ram carrying the upper die is fastened to the hardwood board which passes between a pair of steel roll which rotate continuously. These rolls are moving together, pressure of the rolls against the board raise the ram. The ram is continuously lifted until the release lever is actuated by a pin on the ram. This cause the roll to move outward, releasing the board and allowing the ram to fall freely by gravity. The blowing force is depends on the weight of falling ram and the height to which it is lifted. The size of drop hammer is varies from 900Kn to 45000KN. The height range is 0.75m to 1.5m.

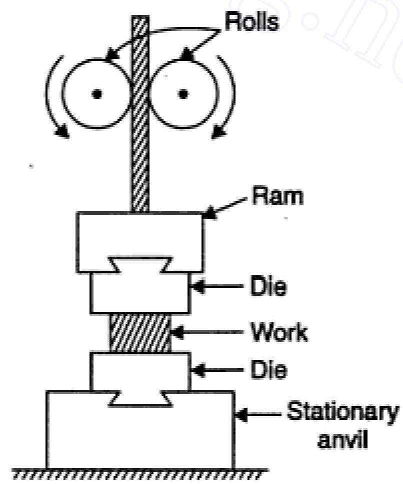


Fig. 3.9 Board Hammer

Mechanical Press

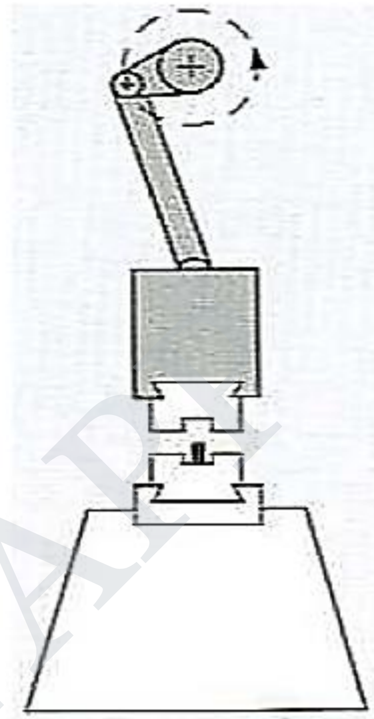


Fig. 3.10: Crank Press

Mechanical presses belong to a class of machine tools that encompass a wide range of different machine types. Primarily, the mechanical press transforms the rotational force of a motor into a translational force vector that performs the pressing action. Therefore, the energy in a mechanical press comes from the motor. These types of presses are generally faster than hydraulic or screw presses, (actually the screw press may also be classified as a mechanical press). Unlike some presses, in a mechanical press, the application of force varies in both speed and magnitude throughout the distance of the stroke. When performing a manufacturing operation using a mechanical press, the correct range of the stroke is essential.

These presses are basically of either crank, knuckle, screw or the eccentric type. The energy in a mechanical press is generated by a large flywheel powered by an electric motor. The clutch engaged the flywheel to an eccentric shaft. A connecting rod translates the rotary motion to reciprocating motion. The capacity range of the mechanical press varies from 900KN to 110MN.

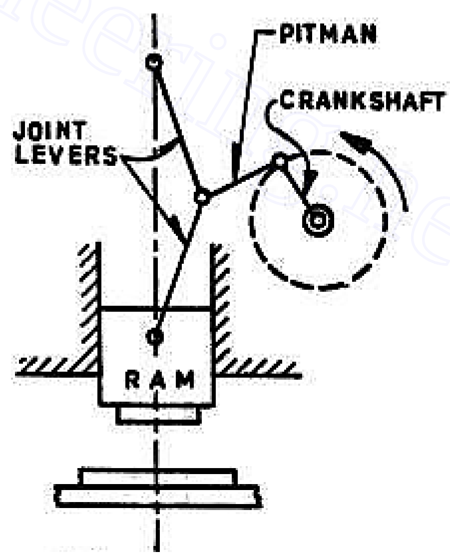


Fig.3.11: Knuckle Press

Presses are chosen based on the characteristics of the manufacturing process. Mechanical press machine tools are commonly used in metal forging manufacture, and sheet metal working. The desired application of force will dictate the type of machine required.

Crank press:

The crank press uses a crank link attached to a drive shaft. The crank link rotates with the drive shaft and is attached to a connecting rod by a rotational joint. The connecting rod rocks back and forth during the motion of the crank. The connecting rod is, in turn, attached to a ram by a rotational joint. The ram operates in a slider joint and travels a one dimensional path in both directions. It is through this path that the crank press delivers its force. The crank press does allow for a stoke of a relatively long distance.

Knuckle press:

The knuckle joint press translates the energy of a motor through a powerful linkage design, and is capable of delivering a tremendous amount of force. The drive shaft crank rotates completely. The links are well grounded to support such pressure.

Eccentric press

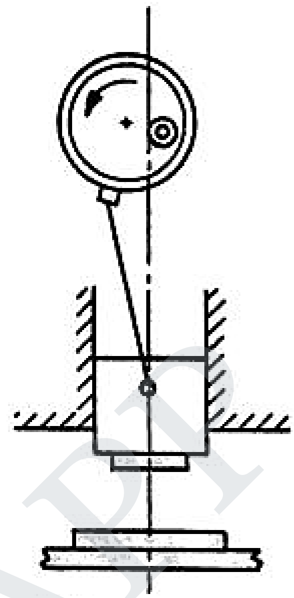


Fig. 3.12 Eccentric Press

The eccentric press uses a motor to drive an eccentric shaft, rotating in a connecting rod. The connecting rod moves a ram in a slider joint one dimensionally. The eccentric shaft itself is round; therefore it may completely rotate within the connecting rod. The center of the drive is not the center of the overall shaft. As the motor rotates, the center of the drive remains stable but the overall center of the shaft changes. This causes the shaft to change position, providing motion. The actual principle of an eccentric press is very similar to a crank press.

Screw Press

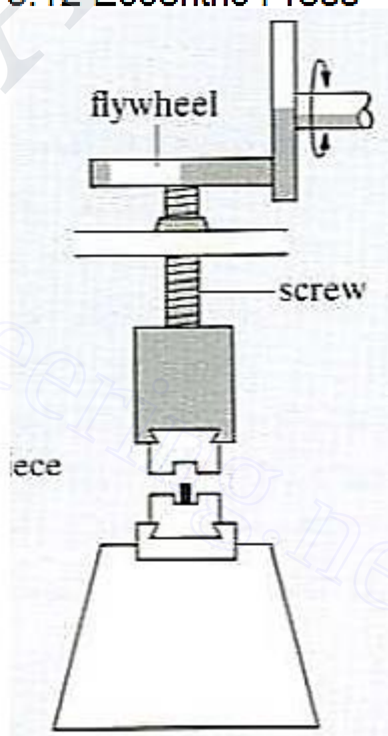


Fig. 3.13 Screw Press

Screw presses use the rotational energy of a motor to turn a large screw. Typically, a friction disk is used to translate the force from the drive shaft to the screw's head. The screw pushes a ram with great mechanical advantage. Screw presses are similar to hydraulic presses in that they are relatively slow and require a longer contact with the work. Screw presses are also similar to hydraulic presses in that they can produce a constant amount of force over a long stroke. Some screw press machine tools in modern industry can produce 31,000 tons of force.

Rack and Pinion Press

The rack and pinion press delivers the motors energy from a gear directly connected to the drive shaft. The rack is actually a round gear of infinite radius. A rotating gear (pinion) provides force through the rack. This gives the one dimensional, translational motion desired of press machines.

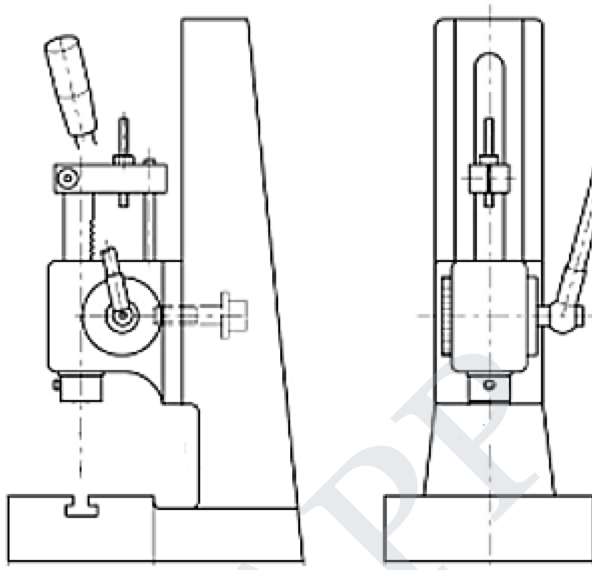


Fig. 3.14 Rack and Pinion Press

Hydraulic presses

Hydraulic presses are a powerful class of machine tools, they derive the energy they deliver through hydraulic pressure. Fluid pressure, in a particular chamber, can be increased or decreased by the use of pumps, and valves. Sometimes devices and systems may be used to increase the capacity of the pumps in more powerful presses. These presses can operate over a long distance and at a constant speed. Hydraulic presses are generally slower relative to other press machine types. This involves longer contact with the work, therefore the cooling of the work can be an issue when hot forming a part with hydraulic force. Hydraulic presses are capable of being the most powerful class of presses. Some may be as large as buildings, and can deliver awesome pressure. The largest hydraulic presses are capable of applying 75,000 tons of force. The hydraulic press shown is being used to manufacture a metal forging.

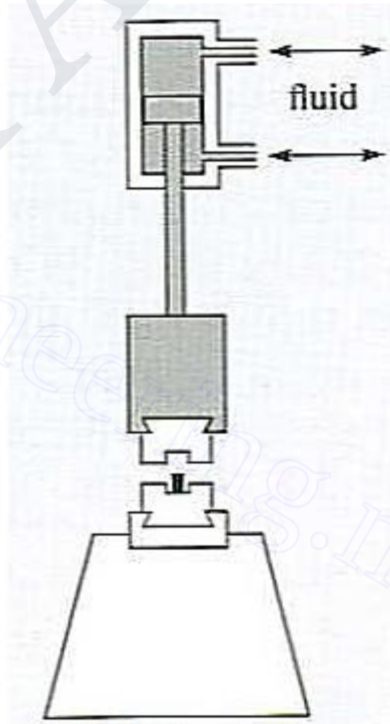


Fig. 3.15 Hydraulic Press

The basic working principles of the hydraulic press are simple, and trust on differences in fluid pressure. Fluid is pumped into the cylinder below the piston; this causes the fluid pressure under the piston to increase. Simultaneously, fluid is pumped out of the top channel, causing the fluid pressure above the piston to decrease. A higher pressure of the fluid below the piston than the fluid above it causes the piston to rise. In the next step, fluid is pumped out from below the piston, causing the pressure under the piston to decrease. Simultaneously, fluid is pumped into the cylinder from the top; this increases the fluid pressure above the piston. A higher pressure of the fluid above the piston, than the fluid below it, moves the piston downward.

Pneumatic press

Pneumatic presses are used to forge small parts. In this press, the weight of anvil is equal to 15 to 20 times of falling weight. The operating principle is similar to hydraulic press. There are two cylinder namely; compressor cylinder and ram cylinder. The air is compressed in a compressor cylinder for the upward stroke and downward stroke and is delivering to the ram cylinder, where it actuates the ram, delivering the forging blow to the work. The reciprocation of the compressor piston is obtained from a crank drive which is powered from an electric motor through reducing gear. The distribution of air between compressor cylinder and ram cylinder is controlled by means of two valves with port through which air passes in to the ram cylinder, up and down the ram alternately. The valves are actuated by depressing foot treadle or operating by a hand lever.

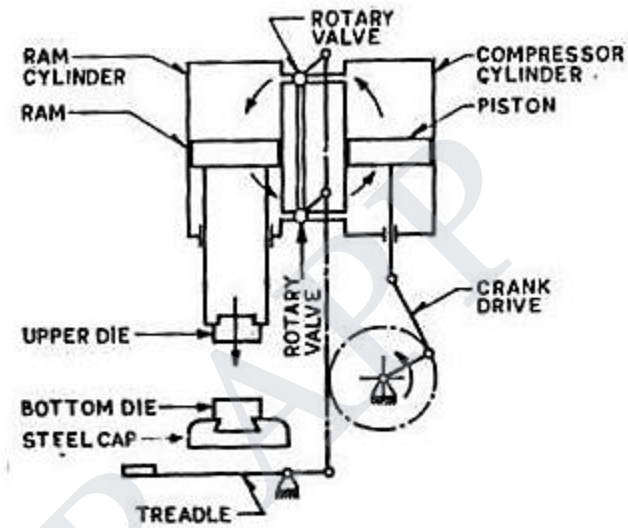
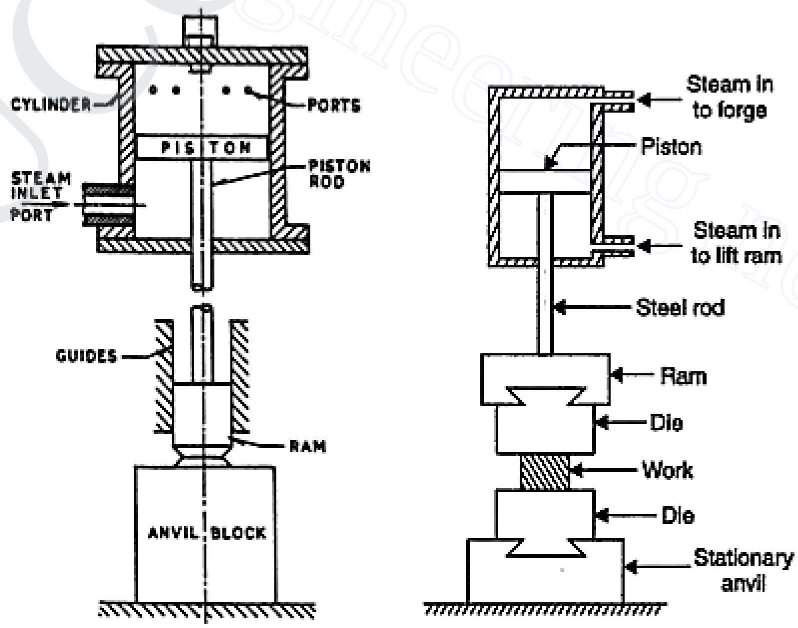


Fig. 3.16 Pneumatic Press

By controlling the air distribution, the required ram movement can be attained: either continuous blow or to hold the ram in upper or lower position.

The size of pneumatic press varies from 0.5 to 10KN. The operating speed is 80 to 200 blows per minute.



(a) Single acting
(b) Double acting

Fig. 3.17 Steam Hammer

Steam hammer

In this type of hammer, there is no in-built air compressor. Separate high pressure steam is required. There are two types of steam hammer are employed namely (1) single acting (2) double acting.

In single acting steam hammer, the high pressure steam enters in to the cylinder port employed at lower portion of the cylinder. Due to this, the ram fitted with upper die allow to move up, meanwhile the steam or air present in the upper portion of the cylinder is exhaust through port provided at top most portion of the cylinder. The ram will move downward by self-weight of ram and also due to gravitational force. Now the compressive action is happen and the forging process is completed.

Similarly, the double acting steam hammer also have same working principle, but the lowering movement of ram is occurred due to steam inlet through the port provided in the upper portion of the cylinder. The capacity of this type of hammer is in the range of 400Kg to 8000Kg.

Forging defects

Sl.No.	Types of crack		Causes
1	Cold shuts or laps	:	Short crack occur at corner
2	Pitting	:	Due to scale formation
3	Die shift	:	Misalignment of die
4	Dents	:	Result of careless work
5	Burnt and overheated metal	:	Improper heating condition
6	Cracks	:	Improper heating
7	Hair crack	:	Too rapid cooling
8	Internal crack	:	Drastic changes in material properties
9	Fins and rags	:	Loose metal is driven in to the surface.
10	Ruptured fiber structure	:	Due to inadequate stock size

Rolling

Rolling is a forming operation where cylindrical rolls are used to reduce the cross sectional area of a bar or plate with a corresponding increase in the length. Rolling process is widely used because of high productivity. **Figure 3.3.2 depicts schematic set-up of rolling process**. Rolling processes are broadly classified by the geometry of the final rolled shape of the work piece material such as flat rolling that is used to reduce thickness of a rectangular cross-section, and shape rolling that is used to produce shaped sections such as I-Beam from a square or rectangular cross-section

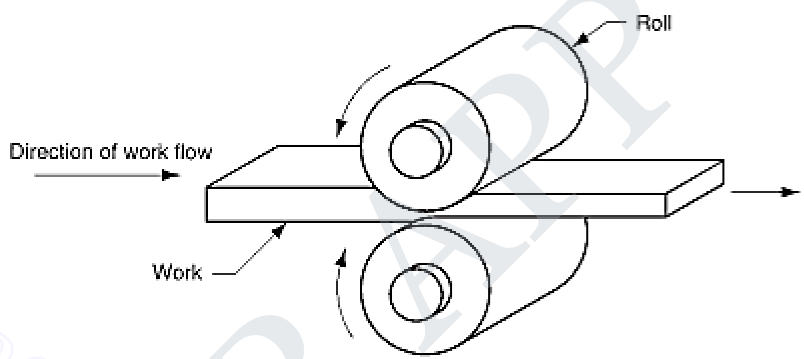


Fig. 3.18 : Rolling of metal

Rolling processes are performed both at high temperature (above the recrystallization temperature), which is referred to as Hot Rolling, as well as at room temperature that is referred to as Cold Rolling. Hot Rolling is usually performed when large amount of deformation is required while Cold Rolling is performed for finished sheet and plate stock. Various structural members, plates and sheets as well as pipes are produced by rolling at very high productivity although due to high tooling cost, it is economical for large batch size only

Comparison of hot rolling and cold rolling

Sl.No.	Hot Rolling	Cold Rolling
1	Metal is fed to the rolls after being heated above the recrystallization temperature.	Metal is fed to the rolls when it is below the recrystallization temperature.
2	In general rolled metal does not show work hardening effect.	The metal shows the working hardening effect after being cold rolled.
3	Co-efficient of friction between two rolls and the stock is higher	Co-efficient of friction between two rolls and the stock is comparatively lower.

	Experiment measurements are difficult to make.	Experiment measurement can be carried out easily in cold rolling.
4	Heavy reduction in area of the work piece can be obtained.	Heavy reduction is not possible.
5	Mechanical properties are improved by breaking cast structure are refining grain sizes below holes and others,	Cold rolling increased the tensile strength and yield strength of the steel.
6	Rolls radius is generally larger in size	Rolls radius is smaller.
7	Very thin sections are not obtained.	Thin sections are obtained.
8	Hot roll surface has (metal oxide) on it, this surface finish is not good.	The cold rolled surface is smooth and oxide free.
9	Hot rolling is used for ferrous as well as non-ferrous metals such as industries for steel, aluminum, copper, brass, bronze, alloy to change ingot into slabs.	Cold rolling is equally applicable to both plain and alloys steels and non-ferrous metals and their alloys.
10	Hot rolling is the father of the cold rolling.	Cold rolling follows the hot rolling.

Classification of rolling mill

- Classification based on the mill product

  This classification is usually done in three ways.

  1. By the type of the product. These are:

     Flat mills – These mills rolls plates, sheets and strips.

Long product mills – These mills rolls rounds, rods and shapes.

2. Based on the nature of the product. These are

   Finishing mills – These mills produced saleable products.

   Semi finishing mills – These mills produce semi-finished products which need further rolling in the finishing mills.

3. based on products

   Blooming, cogging and slabbing mills – These are the preparatory mills to roll blooms and slabs from ingots. With the wide spread acceptance of slab and bloom continuous castings these mills are no more required.

   Billet mills – These mills produce billets from the blooms.

   Beam mills – These mills are used for the production of heavy beams and large channels.

   Rail mills – As the name suggest rails mills are used for rolling of rails from the blooms.

   Shape or structure mills – In these mills medium and smaller sizes of beams and channels and other structural shapes are rolled usually from billets.

   Merchant bar mills – These mills rolls merchant grades of rounds and reinforcement bars.

   SBQ mills – These mills are used for rolling special bar quality rounds.

   Wire rod mills – These mills produces wire rods from billets. Usually these mills are provided with no twist rolling in the blocks and controlled cooling of the rods after rolling.

   Plate mills – These are flat mills to produce heavy plates.

   Hot strip mill – These are also flat mills and rolls hot strips from slabs.

   Cold strip mills – These mills rolls cold strips from hot strips by cold rolling.

   Universal mills – These mills are for the production of various wide flanged shapes by a system of vertical and horizontal rolls.

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Classification based on rolling process

Under this classification, the rolling mills can be classified as follows:

Reversing mills – In this type of mills the rolling direction changes after each pass. In these mills the rolls are stopped, reversed, and then brought back up to rolling speed after each pass. In these materials the material being rolled moves in to and fro directions.

Continuous mills – In this type of mills the material to be rolled moves only in one direction and all the mill rolls rotates only in single direction. There are number of stands provided in the mill for giving total reduction to the material being rolled and for giving final shape to the rolled product.

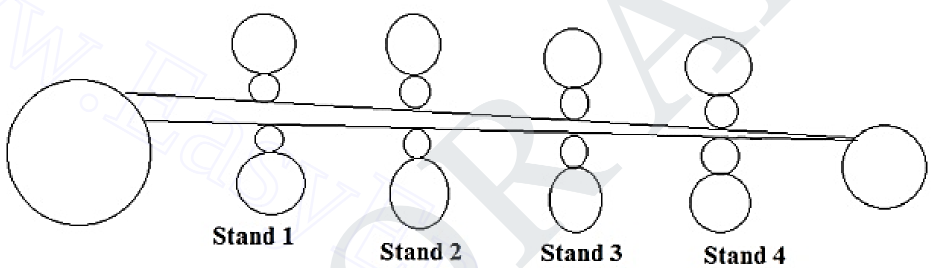

Fig. 3.19 Continuous rolling mill

Semi continuous mills – In this type of mills some roll stands (usually roughing stands) are reversing type while other rolling stands (usually finishing stands) constitutes continuous rolling.

Tandem mills – A tandem mill is a type of rolling mill where rolling is done in one pass. In a traditional rolling mill rolling is done in several passes, but in tandem mill there are several stands (>/=2 stands) and reductions take place successively. The number of stands ranges from 2 to 18. Tandem mills can be either of hot or cold rolling mill types.

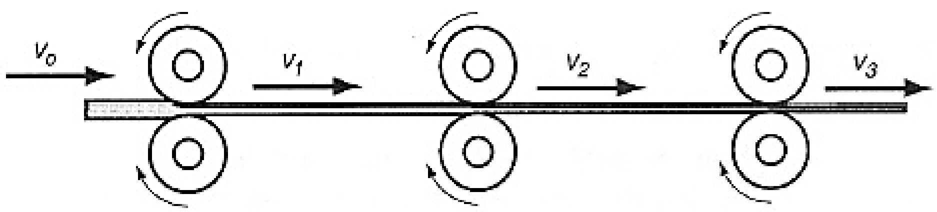

Fig. 3.20 Tandem Rolling Mill

Classification based on stand arrangements

Under this classification there are two types of rolling mills as given below.

Cross country mills – In these types of the mills the centre lines of initial rolling stands are parallel to each other and the material being rolled is shifted perpendicular to the rolling directions. Most of the cross country mills are reversing mills.

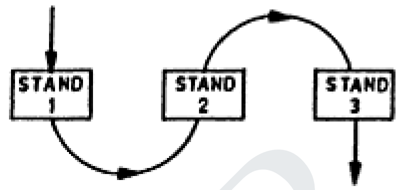

Fig. 3.21 Cross country Mill

Straight line mills – In these mills all the roll stands have a common centre line and material being rolled moves only in forward or forward/backward direction.

Classification based on roll configuration

Rolling mills are also classified based on the roll configurations. The types of mills based on roll configurations are given below.

Two high rolling mills may further classified as

- Reversing mill
- Non reversing mill

A two high rolling mill has two rolls only.

Two high reversing mill:

In two high reversing rolling mills the rolls rotate ist in one direction and then in the other, so that rolled metal may pass back and forth through the rolls several times. This type is used in pluming and slabing mills and for roughing work in plate , rail , structural and other mills.

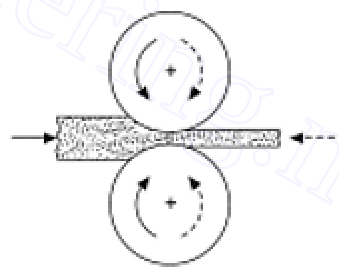

Fig. 3.22 Two roll Mill

Three high rolling mill:

It consists of a roll stand with three parallel rolls one above the other. Adjacent rolls rotates in opposite direction. So that the material may be passed between the top and the middle roll in one direction and the bottom and middle rolls in opposite one.In three high rolling mills the work piece is rolled on both the forward and return passes. First of all the work piece passes through the bottom and middle rolls and the returning between the middle and the top rolls.

So that thickness is reduced at each pass. Mechanically operated lifted tables are used which move vertically or either side of the stand. So that the work piece fed automatically into the roll gap.

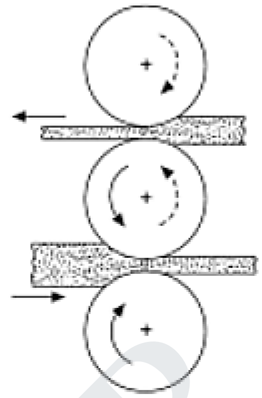

Fig. 3.23 Three roll mill

Since the rolls run in one direction only a much less powerful motor and transmission system is required. The rolls of a three high rolling mills may be either plain or grooved to produce plate or sections respectively.

Four-High Rolling Mill

It is essentially a two-high rolling mill, but with small sized rolls. Practically, it consists of four horizontal rolls, the two middle rolls are smaller in size than the top and bottom rolls as shown in Figure 2(d). The smaller size rolls are known as working rolls which concentrate the total rolling pressure over the workpiece. The larger diameter rolls are called back-up rolls and their main function is to prevent the deflection of the smaller rolls, which otherwise would result in thickening of rolled plates or sheets at the centre. The common products of these mills are hot or cold rolled plates and sheets.

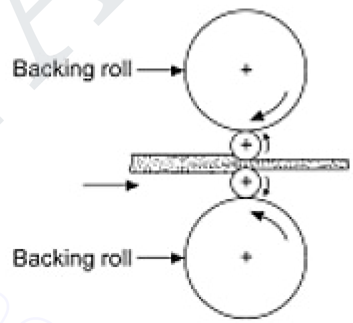

Fig. 3.24 Four roll mill

Cluster Mill

It is a special type of four-high rolling mill in which each of the two smaller working rolls are backed up by two or more of the larger back-up rolls as shown in Figure 2(e). For rolling hard thin materials, it may be necessary to employ work rolls of very small diameter but of considerable length. In such cases adequate support of the working rolls can be obtained by using a cluster-mill. This type of mill is generally used for cold rolling work.

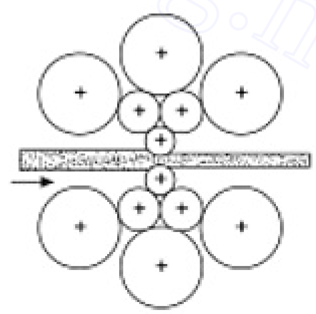

Fig. 3.25 Cluster mill

Planetary mill

This mill consists of a pair of heavy back up rolls surrounded by a large number of planetary rolls. Each planetary roll gives an almost constant reduction to the feed material as it sweeps out of a circular path between the backup roll and the feed material. As each pair of planetary rolls ceases to have contact with the work piece, another pair of rolls makes contact and repeat the reduction.

Flat strip rolling

Flat strip rolling utilizes a series of rolls to gradually change the shape of the metal. As the fast moving continuous strip passes between the rolls, the cross sectional shape is changed to the desired form.

The work is squeezed between two rolls so that it thickness is reduced by an amount called the draft. If the draft is expressed as a fraction of the starting block thickness, it is called reduction. Rolling increases the work width and this is called spreading.

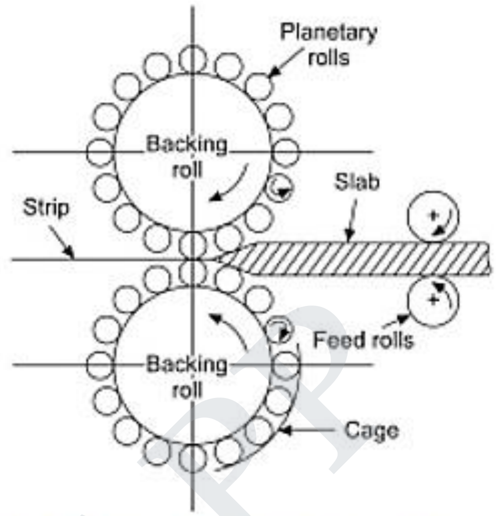

Fig. 3.26 Planetary rolling mill

The inlet and outlet volume rates of material flow must be the same

The entering and exiting velocities of the work. The point where roll velocity equals work velocity is known as the no-slip point or the neutral point.

The true strain and the mean flow stress are defined by true strain, and mean flow stress

Friction occurs with a certain coefficient of friction μ on either sides of no-slip point. Both friction forces act in opposite directions and are not equal. The entrance force is bigger so that the resulting

force pulls the work through the rolls. The maximum possible draft depends on μ and roll radius R.

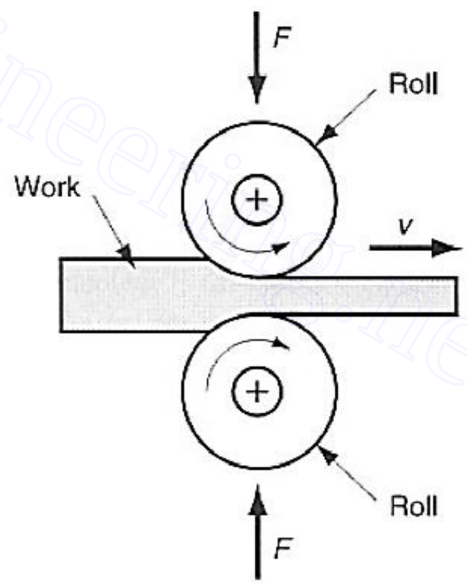

Fig. 3.27 Flat strip rolling

The rolling force F is estimated as

$$F = L\,w\,Y_{avg}$$

$$where, \quad L = \text{Roll strip contact length}$$

$$w = \text{Width of strip}$$

$$Y_{avg} = \text{Average true stress}$$

The power P required to drive each roll is $P = \frac{2\,\pi\,F\,L\,N}{60\times1000}\ kW$

Where N = speed of roll in rpm and F = Force in N.

Shape rolling is a broad term for a range of metal rolling operations that involve forming the work with rolls of certain geometry. The rolls form the part to a specific shape. Most shape rolling involves passing the material through several steps. Two very common examples of continuous shape rolled product are the I beam for structural purposes and the rail for railroad track.

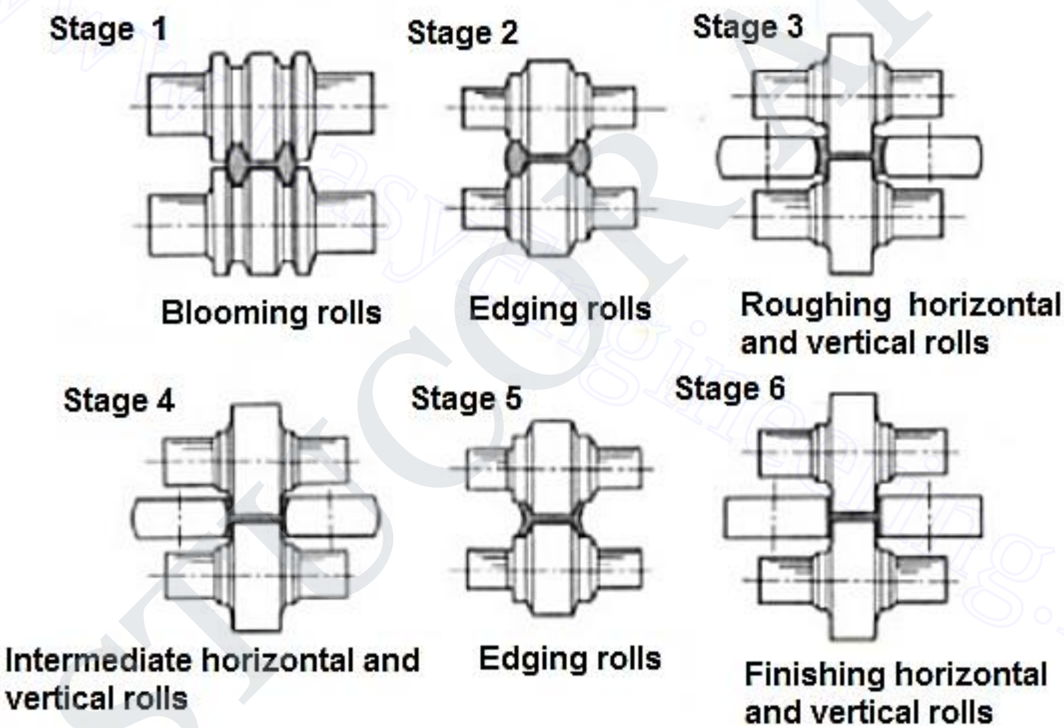

Fig. 3.28 Shape Rolling operation

Designing a proper series of shape changes in a work will involve more deformation in some areas than others. As mentioned earlier, excessive shape change in some parts of the cross section is a serious cause of defects in shape rolling production. The rolling engineer must design a system of passes in such a way as to achieve the shape change through several steps, mitigating any excessive deformations at any particular area of the work's cross section.

Many different shapes can be shape rolled in metal rolling industry today. Here is an example of a possible roll pass design for the production of a H- section roll shape rolling.

Ring rolling

Ring rolling is a particular category of metal rolling, in which a ring of smaller diameter is rolled into a precise ring of larger diameter and a reduced cross section. This is accomplished by the use of two rollers; one driven and one idle, acting on either side of the ring's cross section. Edging rollers are typically used during industrial metal rolling manufacture, to ensure that the part will maintain a constant width throughout the forming operation. The work will essentially retain the same volume; therefore the geometric reduction in thickness will be compensated for entirely by an increase in the ring's diameter. Rings manufactured by ring rolling are seamless. This forming process can be used to manufacture not only flat rings, but rings of differently shaped cross sections as well, producing very precise parts with little waste of material.

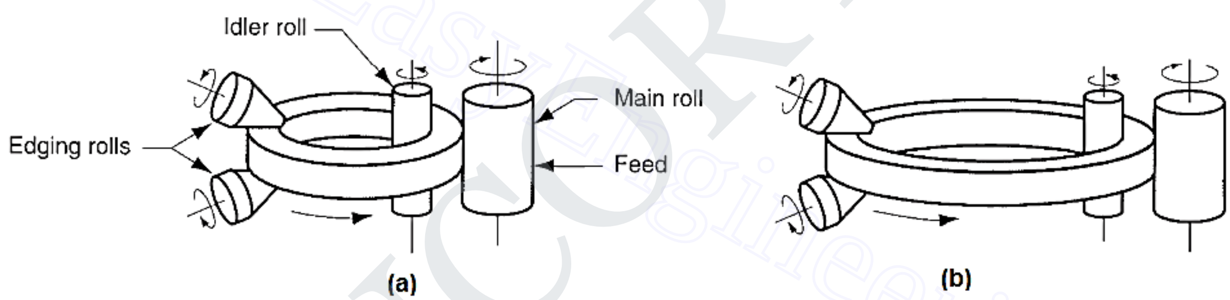

Fig. 3.29 Ring rolling process

A significant advantage of parts produced by this metal rolling process is that the forming of the material will impart the ring with a grain orientation that gives it enhanced strength relative to most applications. Common items produced by this process in manufacturing industry today include rings for machinery, aerospace applications, turbines, pipes, pressure vessels, roller and ball bearing races. The following shows the sequence of events of the ring rolling process, the part is commonly started as a metal bar cut to a certain length.

Thread rolling

Thread rolling is a metal rolling process used extensively in manufacturing industry to produce screws, bolts and other fasteners. A common thread rolling process, used in industry to manufacture threaded parts, involves forming the threads into the metal of a blank by a pressing and rolling action between two die. The die surfaces hold the shape and the force of the action forms the threads into the material. A similar metal forming process has been developed for the production of gears.

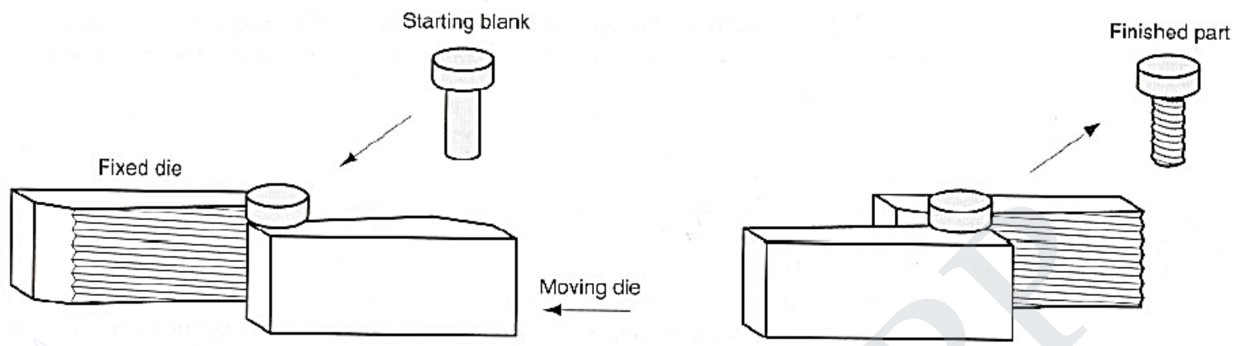

Fig. 3.30 Threading rolling with flat die

Thread rolling, in modern manufacturing, has an extremely high productivity rate, significantly higher than producing threaded parts by machining. Machining is the alternative method to industrial manufacturing of threaded parts. Producing threads by this method has several other benefits over machining. Forming will harden the metal through cold working, does not waste material by cutting, and produces a favorable grain structure to strengthen the part with respect to its function.

Rolling defects

There are two types of defects which can be observed in rolled products.

1) Surface defects
2) Internal surface defects.
    a) Wavy edges
    b) Zipper cracks
    c) Edge cracks
    d) Alligatoring
    e) Folds
    f) Laminations.

Defects due to bending on rolls:

Types of defects occur due to this reason

a) Wavy edges
b) Zipper cracks

Zipper crack also occur due to poor material ductility at the rolling temperature. The remedy is to provide a camber to the rolls, (i.e.) their diameter is made slightly larger at the centre than at the edges.

Inhomogeneous deformation of elements across the width.

During rolling process, the thickness of metal is reduced and the length is increase, due to this the elements near the edges will be under tension and the element near the centre will be under compression. Such a situation can lead to **edge cracks** (fig. (c)).

Another interesting defect that can occur in flat rolling is **alligatoring**, where the work being rolled actually splits in two during the process. The two parts of the work material travel in opposite directions relative to their respective rolls.

Folds: these defects are encountered during plate rolling if the reduction per pass is very small.

Laminations: during rolling process, due to incomplete welding, defects like longitudinal strings of non-metallic inclusions are introduced at the time of ingot productions. Under severe reduction, these defects can results in to small crack called laminations along the thickness direction. Due to this the strength along the thickness direction can get drastically reduced.

Fig. 3.31 Rolling defects

Process variable in rolling process are:

- Roll diameter
- Angel of bite
- Temperature
- Strength of work material
- Speed of rolling roll gap
- Coefficient of friction
- Dimensions of sheet

Metal Drawing

Metal drawing is a manufacturing process that forms metal work stock by reducing its cross section. This is accomplished by forcing the work through a mold, (die), of smaller cross sectional area than the work. This process is very similar to metal extrusion, the difference being in the application of force. In extrusion the work is pushed through the die opening, where in drawing it is pulled through.

- Rod (bar) drawing
- Wire drawing
- Tube drawing

Rod (bar) drawing

Rod or bar drawing is a term used to denote one of two categories of metal drawing. Rod or bar drawing refers to the drawing of work of larger cross sections, while wire drawing refers to the forming of work of a relatively smaller profile. Due to the size of the work, rod and bar drawing involves much more finite lengths of material than wire drawing. This type of process is carried out as a discrete manufacturing operation.

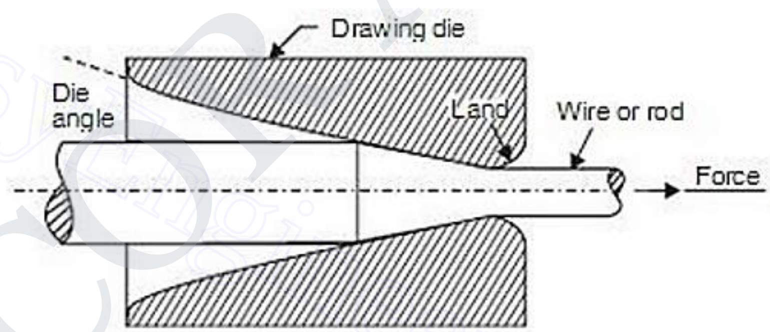

Fig. 3.32 Rod or bar drawing

It is usually performed on a draw bench. A draw bench consists of a long table, a die stand containing the mold and a carriage used to grip and draw the work. The die stand may contain two or more molds; multiple dies allow more than one part to be drawn with each operation. Draw benches vary in size and can be up to 100 feet in length. Force used to draw the metal is exerted through hydraulic or mechanical means. Pulling force as high as 150 tons has been used during industrial production.

Wire drawing

Wire drawing is the second major category of metal drawing operations. While rod and bar drawing refer to the drawing of larger cross sections, wire drawing refers to the drawing of relatively smaller cross sections. The enormous amount of electrical wire and cable produced by this manufacturing method makes wire drawing a major modern industrial process. Some wire must be manufactured to tremendously small cross sectional areas, such as those used in electromagnets. Wire may be drawn to diameters as low as .0001 inch. Diamond die inserts are often used in the production of extremely fine wire.

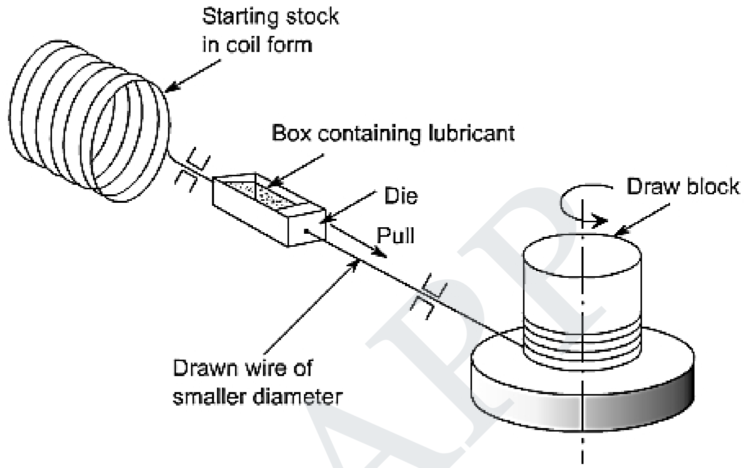

Fig. 3.33 Wire drawing

Metal work stock in wire drawing will usually undergo several reductions in diameter, since the mechanics of the process limit the amount of reduction in a single draw. This is accomplished by drawing the work through several die in series, each producing an incremental reduction in the work's diameter. Between dies the wire stock is wrapped several times around a motor driven rotating drum called a capstan, before proceeding to the next die in series. Annealing of the metal may be performed between groups of operations. The capstans provide the force for the manufacturing process. As the diameter is reduced, the speed of the wire is increased. Velocity of wire leaving the last mold in a series can be significantly higher than the velocity of the work entering the first mold. Typically drawing speeds may be 20-100 feet per minute, but in some cases wire may be drawn at 10,000 feet per minute. Pieces of stock can be end welded together as they are fed into the system of capstans and die so that the process will be completely continuous. Industrial wire drawing operations can manufacture miles of wire at a time.

TUBE DRAWING

Tubes and pipes are required in large quantities by industries all over the world. Tubes are basically of two types. They are either seamless (i.e., without any joint) or with joint all along the length of the tube. Seamless tubes are made by processes such as casting, extrusion or rolling. Tubes with joint are made by welding. Usually, the weld joint is made by electric resistance welding process; such tubes are referred to as ERW tubes. The size of a tube or pipe is indicated by the size of its bore in mm. Since the requirement of tubes is so large, a special rolling process called Mannesmann rotary piercing process has been developed. In this process, a heated round billet with its leading end, in the centre of which a short guide hole has been punched or drilled, is pushed longitudinally between two large tapered rolls as shown in Fig. 3.33.

The rolls revolve in the same direction and their axes are inclined at opposite angles of approx 6°from the axis of the billet. As the billet is caught by the rolls and is rotated, their inclination causes the material to be drawn forward. The small clearance between the rolls forces the material to deform into an elliptical shape. Due to compressive forces, secondary tensile stresses start acting in a direction perpendicular to the direction of the compressive stresses. The guide hole drilled/punched at centre of billet tears open. This action is assisted by a suitably placed mandrel. As the billet mores forward and keeps rotating the tearing action is propagated throughout the length of the billet. End result is a roughly formed seamless tube of elliptical cross-section. This roughly formed seamless tube is further rolled in a “plug rolling mill”. The final operations of “reeling” and “sizing” are further conducted on cooled tube to improves size and finish of tube.

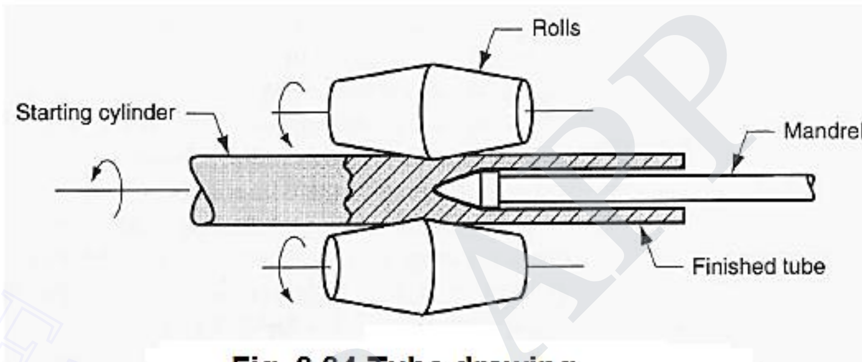

Fig. 3.34 Tube drawing
(or)
Tube Piercing
(or)
seemless tube drawing

TUBE DRAWING METHOD

- Tube drawing with fixed plug
- Tube drawing with floated plug
- Tube drawing with moving mandrel
- Tube sinking

The ‘drawing’ process can also be used for tube drawing. Tube drawing does not mean manufacturing a tube from solid raw material. It means lengthening a tube reducing its diameter. Various arrangements used for tube drawing are shown in Fig. 3.33

The method shown in Fig. 3.33 (a) is the most common method used for tube drawing. A conventional tube drawing bench is used. Method shown in Fig. 3.33 (b) employs a floating mandrel. Method shown in Fig. 3.33 (c) uses a long circular rod to control the size of tube-bore. Method shown inFig.3.33 (d) uses neither a mandrel nor a bar and controlling size of bore is difficult.

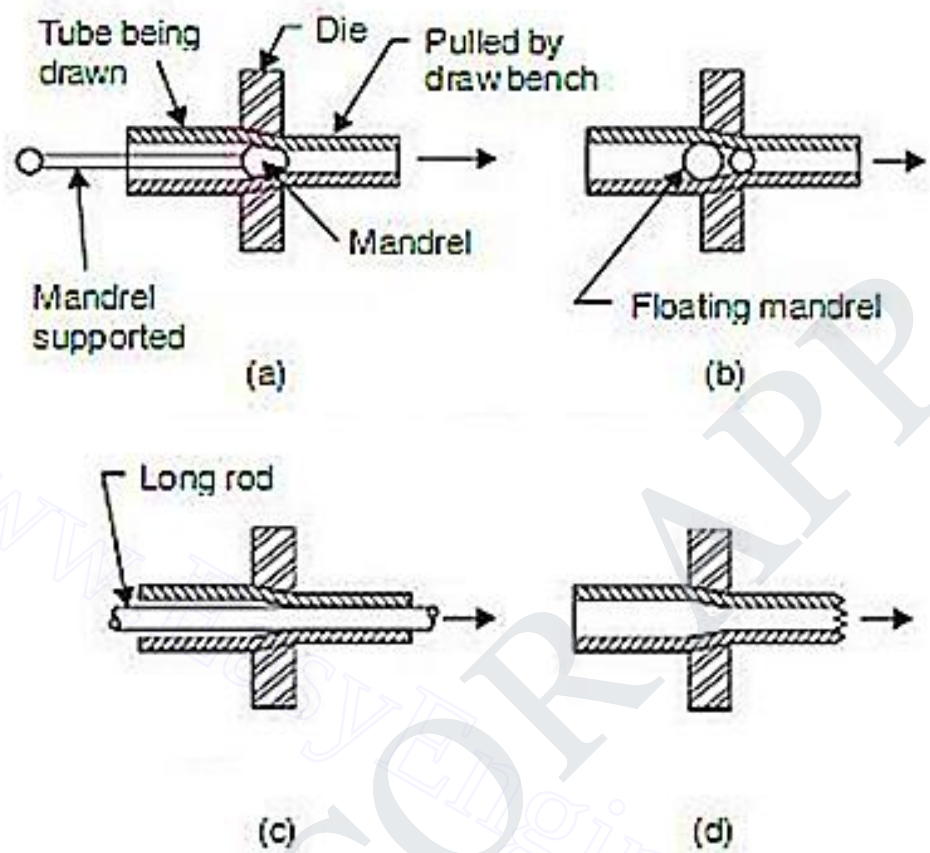

Fig. 3.35 Tube drawing method

EXTRUSION

"Extrusion is a process in which the metal is subjected to plastic flow by enclosing the metal in a closed chamber in which the only opening provided is through a die". The material is usually treated so that it can undergo plastic deformation at a sufficiently rapid rate and may be squeezed out of the hole in the die. In the process the metal assumes the opening provided in the die and comes out as a long strip with the same cross-section as the die-opening. Incidentally, the metal strip produced will have a longitudinal grain flow.

The process of extrusion is most commonly used for the manufacture of solid and hollow sections of nonferrous metals and alloys. Aluminum is an extremely good material for metal extrusion. Copper, magnesium, zinc, tin and some softer low carbon steels, can also be extruded with little complication due to the material. High carbon steels, titanium and various refractory alloys, can be difficult to extrude.

Advantages of extrusion processes.

- Extrusion can produce variety of shapes with uniform cross-section.
- The grain structure and mechanical strength of work piece material are improved in cold and warm extrusion processes.
- Cold extrusion can provide close tolerances.
- Wastage of material is the minimum in extrusion processes.
- Extrusion can be performed even for relatively brittle materials.

Type of extrusion

- Hot extrusion
- Cold extrusion
- Direct extrusion
- Indirect extrusion
- Hydrostatic extrusion
- Impact extrusion

Hot Extrusion

Hot extrusion is done at fairly high temperatures, approximately 50 to 75 % of the melting point of the metal. The pressures can range from 35-700 MPa. Due to the high temperatures and pressures and its detrimental effect on the die life as well as other components, good lubrication is necessary. Oil and graphite work at lower temperatures, whereas at higher temperatures glass powder is used.

Typical parts produced by extrusions are trim parts used in automotive and construction applications, window frame members, railings, aircraft structural parts.

Advantages of hot extrusion

- Improvement of the mechanical properties
- This ratio can be very large while still producing quality parts.
- Improved physical characteristics of the metal
- Easy to extrude for larger parts,
- It has more extreme changes in shape
- Possible for extruding more complex geometry.

Disadvantages

- Results in a layer of oxide scale build up on the external surfaces of the work piece.
- Scale can affect surface finish
- Affect the accuracy of the part

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- wear at die metal interfaces.
- High maintenance cost
- decreased tolerances, and
- increased die wear

Cold Extrusion

Cold extrusion is the process done at room temperature or slightly elevated temperatures. This process can be used for most materials-subject to designing robust enough tooling that can withstand the stresses created by extrusion. Examples of the metals that can be extruded are lead, tin, aluminum alloys, copper, titanium, molybdenum, vanadium, steel. Examples of parts that are cold extruded are collapsible tubes, aluminum cans, cylinders, gear blanks.

Advantages of cold extrusion over hot extrusion include,

- Process not having to heat the work,
- Higher production rate,
- No oxidation and scale form on surfaces,
- Greater geometric accuracy,
- Better surface finish
- Ability to strengthen the part by way of strain hardening.

DIRECT or FORWARD EXTRUSION

In manufacturing industry, extrusion processes can be classified into two main categories, direct and indirect. Hollow extrusions, as well as cross sections, can be manufactured by both methods. Each method, however, differs in its application of force and is subject to different operational factors.

In Direct or forward extrusion, the work billet is contained in a chamber. The ram exerts force on one side of the work piece, while the forming die, through which the material is extruded, is located on the opposite side of the chamber. The length of extruded metal product flows in the same direction that the force is applied.

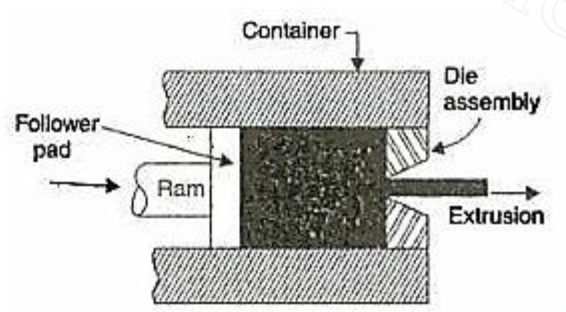

Fig. 3.36 Forward or Direct extrusion

During direct extrusion, metal flow and forces required are affected by the friction between the work piece and the chamber walls. Particularly in hot working, oxide scale build up on the outer surfaces of the work piece can negatively influence the operation.

For these reasons, it is common manufacturing practice to place a dummy block (follower pad) ahead of the ram. The dummy block is of slightly smaller diameter than the chamber and work piece. As the metal extrusion proceeds, the outermost surface of the work is not extruded and remains in the chamber. This material will form a thin shell, (called skull), that will later be removed. Much of the skull will be comprised on the surface layer of oxidized scale from the work metal.

BACKWARD or INDIRECT EXTRUSION

Indirect extrusion is a particular type of metal extrusion process in which the work piece is located in a chamber that is completely closed off at one side. The metal extrusion die are located on the ram, which exerts force from the open end of the chamber. As the manufacturing process proceeds, the extruded product flows in the opposite direction that the ram is moving. For this purpose the ram is made hollow, so that the extruded section travels through the ram itself. This manufacturing process is advantageous in that there are no frictional forces between the work piece and the chamber walls. Indirect extrusion does present limitations. Tooling and machine set up are more complicated, hollow rams are not as strong and less ridged and support of the length of the metal extrusion's profile, as it travels out of the mold, is more difficult.

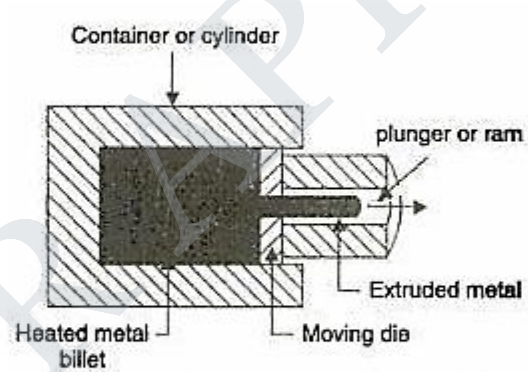

Fig. 3.37 Backward or Indirect extrusion

Indirect extrusion can also be used to produce hollow parts. In this process, a ram is forced into the work material. The ram gives the internal geometry to the tubular part, while the material is formed around it. Difficulties in supporting the ram limit this process and the length of tubular metal extrusions that may be manufactured.

IMPACT EXTRUSION

Impact extrusion is a discrete manufacturing process, in which a metal part is extruded through the impact of a die with the work stock. The part is formed at a high speed and over a relatively short stroke. In impact extrusions, mechanical presses are most often employed. The force used to form in standard extrusions is usually delivered over a horizontal vector, producing a long continuous product. But in this method, Force used to form is usually delivered over a vertical vector, producing a single part with each impact of the punch. Impact extrusion is most often performed cold. Occasionally with some metals and thicker walled structures, the work is heated before impact forming it.

This process is best suited for softer metals, aluminum is a great material for forming by impacting.

In manufacturing operation of impact extrusion, a work piece is placed in a mold and struck with great force, causing the metal to flow into position in an instant. The forces acting on the machinery are extreme, particularly on the punch and die. Tooling must have sufficient impact resistance, fatigue resistance and strength, for extruding metal by impact. There are three basic types of impact extrusion processes, forward, reverse and combination. The different categories are based on the kind of metal flow that occurs during the process. In forward impact extrusion, metal flows in the same direction that the force is delivered. In backward impact extrusion, the metal flows in the opposite direction that the force is delivered. In combination, the metal flows in both directions.

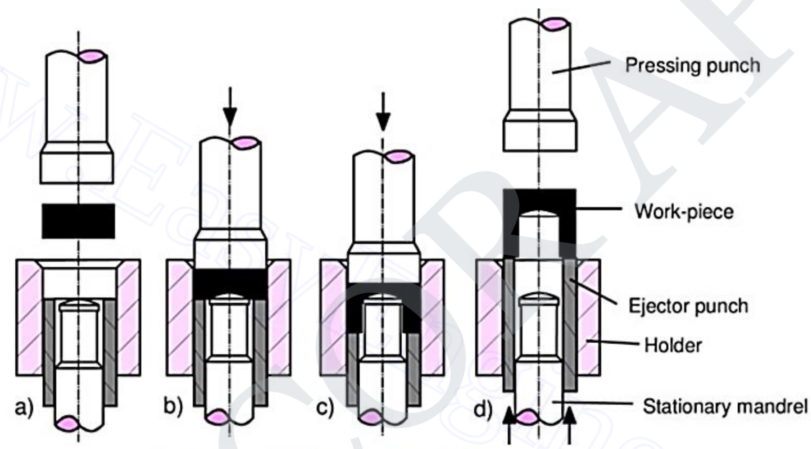

Fig. 3.38 Impact Extrusion (forward method)

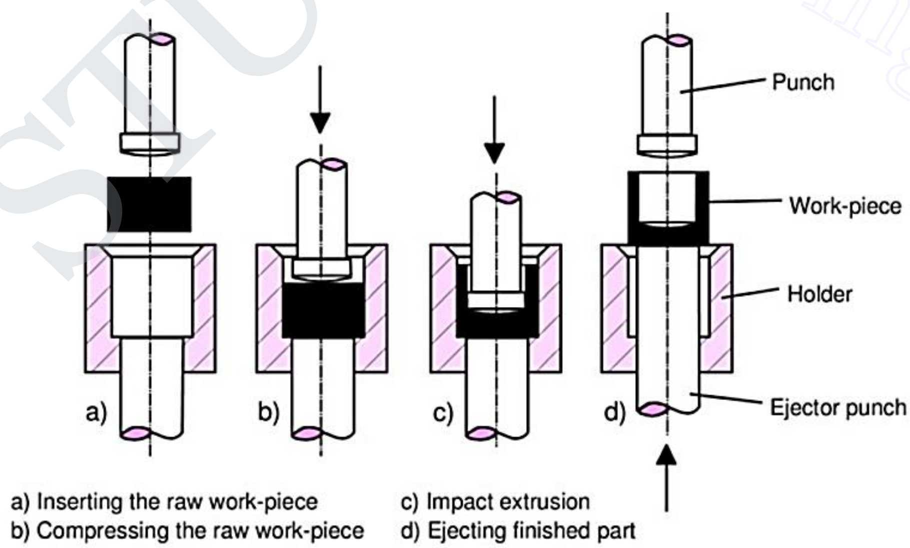

Fig. 3.39 Impact Extrusion (Backward method)

Benefits of impact extrusion compared to conventional extrusion

- Raw material savings of up to 90%
- Reduced machining times up to 75%
- Elimination of secondary machining operations
- Reduction in multi-part assemblies
- Improved mechanical properties for material strength and machining due to cold working of the material
- Significantly reduced total part costs up to 50%

HYDROSTATIC EXTRUSION

In hydrostatic extrusion the work piece is held in a sealed chamber surrounded by pressurized liquid. Hydrostatic extrusion is actually a form of direct extrusion. The force delivered through the ram is what pressurizes the liquid. The liquid applies pressure to all surfaces of the work billet. When the ram moves forward, it is the force from the incompressible fluid that pushes the work through the die, extruding the metal part.

A critical aspect of manufacturing by this process is setup. The metal work billet must first be tapered to fit through the die opening, thus creating a seal. This is done before adding the liquid, in order to prevent leaking. Since the liquid is under great pressure, this taper must be precise to create a robust bond. Many different shapes may be manufactured by this process, using a variety of materials.

Liquid pressure from all directions also greatly decreases the chances of buckling of the work.

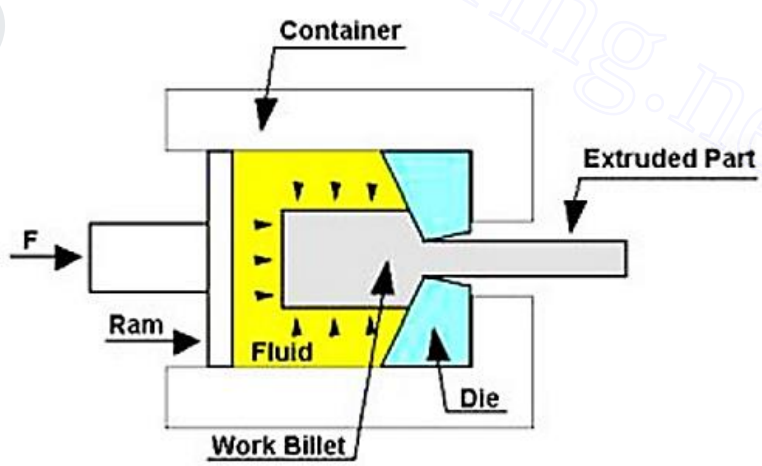

Fig. 3.40 Hydrostatic extrusion

Hydrostatic extrusion may be performed at room or elevated temperatures, depending upon the manufacturing process. When performed hot, the liquid will insulate the work from thermal gradients between the container and work material. An advanced variation of this process is called fluid to fluid extrusion. This process is basically the same, except that the part is extruded into a second chamber also containing pressurized liquid. The liquid in the second chamber is of a lower pressure than the first. Several different kinds of liquids are used when manufacturing by hydrostatic extrusion, including oils, waxes, melted polymers and molten glass. Hydrostatic extrusion has not had much use in manufacturing industry, due to the complicated equipment and procedures, work preparation, long cycle times and dangers of working with hot, high pressure liquid.

Advantages of Hydrostatic Extrusion

- No friction amidst the container and billet. This minimizes the force requirements, allowing higher reduction ratios, faster speeds, & lower billet temperatures.
- Friction of the die can be largely reduced by a film of pressurized lubricant amidst the die surface and deforming metal.
- On applying high pressures, the ductility of material increases.
- Even flow of material.
- Large billets & large cross-sections are extruded.
- Uniform hydrostatic pressure inside the container eliminates the requirement of billets being straightened and extrusion of coiled wire.
- No billet residue is left on the walls of container.

Limitations of Hydrostatic Extrusion

There are a number of limitations in the hydrostatic extrusion, especially when a large volume of fluid is used in comparison with the billet volume, which is to be extruded. These limitations are as follows:

- Increased handling for the injection and removal of the fluid for every extrusion cycle
- Decreased control of speed of the billet & stopping because of potential stick-slip and enormous stored energy in the compressed fluid
- Decreased process efficiency in terms of billet-to-container volume ratio
- Enhanced complications, when extrusion is done at elevated temperatures

Defects in Extrusion

Surface cracking

Surface cracking occurs when the surface of an extrusion splits, which is often caused by the extrusion temperature, friction, or speed being too high. It can also happen at lower temperatures if the extruded product temporarily sticks to the die.

Internal cracking

Internal cracking occurs when the centre of the extrusion develops cracks or voids. These cracks are attributed to a state of hydrostatic tensile stress at the center line in the deformation zone in the die.

Pipe

It is the flow pattern that draws the surface oxides and impurities to the centre of the product. Such a pattern is often caused by high friction or cooling of the outer regions of the billet.

Surface lines

These are the lines visible on the surface of the extruded profile. This depends heavily on the quality of the die production and how well the die is maintained, as some residues of the material extruded can stick to the die surface and produce the embossed lines.

UNIT – IV

SHEET METAL PROCESSES

SYLLABUS

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

INTRODUCTION

Sheet metal is metal formed by an industrial process into thin, flat pieces. It is one of the fundamental forms used in metalworking and it can be cut and bent into a variety of shapes. Countless everyday objects are constructed with sheet metal. Thicknesses can vary significantly; extremely thin thicknesses are considered foil or leaf, and pieces thicker than 6 mm (0.25 in) are considered plate.

Sheet metal is available in flat pieces or coiled strips. The coils are formed by running a continuous sheet of metal through a roll slitter.

The thickness of sheet metal is commonly specified by a traditional, non-linear measure known as its gauge. The larger the gauge number, the thinner the metal. Commonly used steel sheet metal ranges from 30 gauges to about 7 gauges. Gauge differs between ferrous (iron based) metals and a nonferrous metal such as aluminum or copper; copper thickness, for example is measured in ounces (and represents the thickness of 1 ounce of copper rolled out to an area of 1 square foot).

There are many different metals that can be made into sheet metal, such as aluminum, brass, copper, steel, tin, nickel and titanium. For decorative uses, important sheet metals include silver, gold, and platinum (platinum sheet metal is also utilized as a catalyst.)

Sheet metal is used for car bodies, airplane wings, medical tables, roofs for buildings (architecture) and many other applications. Sheet metal of iron and other materials with high magnetic permeability, also known as laminated steel cores, has applications in transformersand electric machines. Historically, an important use of sheet metal was in plate armor worn by cavalry, and sheet metal continues to have many decorative uses, including in horse tack. Sheet metal workers are also known as "tin bashers" (or "tin knockers")

Sheet Metal Characteristics

TABLE 4.1

Characteristic		Description
Elongation	:	The capability of the sheet metal to stretch without necking and failure are determined; 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 flame like 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 non-uniform deformation during forming; causes part distortion when sectioned and can lead to stress-corrosion cracking; reduced or eliminated by stress relieving.
Spring back	:	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 over bending and bottoming of the punch.
Wrinkling	:	Caused by compressive stresses in the plane of the sheet; can be objectionable or can be useful in

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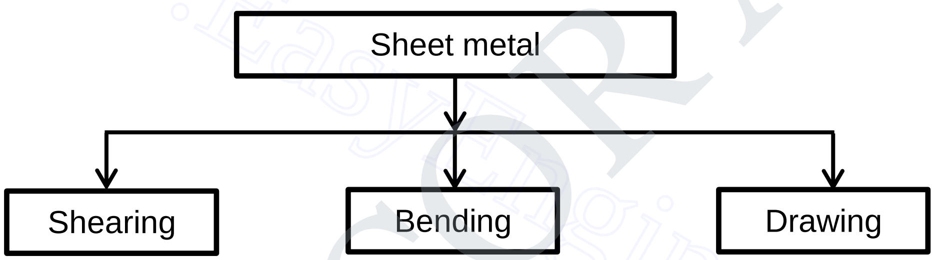
		imparting stiffness to parts; can be controlled by proper tool and die design.
Quality of sheared edges	:	Depends on process used; edges can be rough, not square, and contain cracks, residual stresses, and a work-hardened layer, which are all detrimental to the formability of the sheet; quality can be 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

Classification of sheet metal working processes



The term "shearing or cutting process" is refers to a specific cutting process that produces straight line cuts to separate a piece of sheet metal. Most commonly, shearing is used to cut a sheet parallel to an existing edge which is held square, but angled cuts can be made as well. For this reason, shearing is primarily used to cut sheet stock into smaller sizes in preparation for other processes. Shearing has the following capabilities:

- Sheet thickness: 0.005-0.25 inches
- Tolerance: ±0.1 inches (±0.005 inches feasible)
- Surface finish: 250-1000 µin (125-2000 µin feasible)

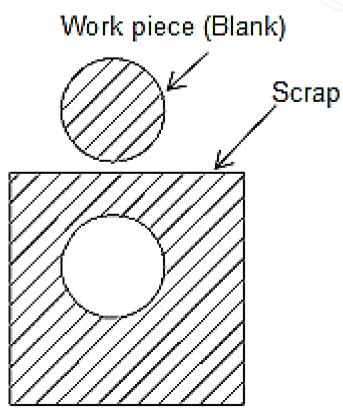
The shearing process is performed on a shear machine, often called a squaring shear or power shear, that can be operated manually (by hand or foot) or by hydraulic, pneumatic, or electric power.

A variety of cutting processes that utilize shearing forces exist to separate or remove material from a piece of sheet stock in different ways. Each process is capable of forming a specific type of cut, some with an open path to separate a portion of material and some with a closed path to cutout and remove that material. By using many of these processes together, sheet metal parts can be fabricated with cutouts and profiles of any 2D geometry. Such cutting processes include the following:

- Shearing - Separating material into two parts
- Blanking - Removing material to use for parts
  - Conventional blanking
  - Fine blanking
- Punching - Removing material as scrap
  - Piercing
  - Slotting
  - Perforating
  - Notching
  - Nibbling
  - Lancing
  - Slitting
  - Parting
  - Cutoff
  - Trimming
  - Shaving
  - Dinking

Blanking

Blanking is a cutting process in which a piece of sheet metal is removed from a larger piece of stock by applying a great enough shearing force. In this process, the piece removed, called theblank, is not scrap but rather the desired part. Blanking can be used to cutout parts in almost any 2D shape, but is most commonly used to cut workpieces with simple geometries that will be further shaped in subsequent processes.



Final parts that are produced using blanking include gears, jewelry, and watch or clock components. Blanked parts typically require secondary finishing smoothing out

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burrs along the bottom edge.

The hydraulic press drives the punch downward at high speed into the sheet. A small clearance, typically 10-20% of the material thickness, exists between the punch and die. When the punch impacts the sheet, the metal in this clearance quickly bends and then fractures. The blank which has been sheared from the stock now falls freely into the gap in the die. This process is extremely fast, with some blanking presses capable of performing over 1000 strokes per minute.

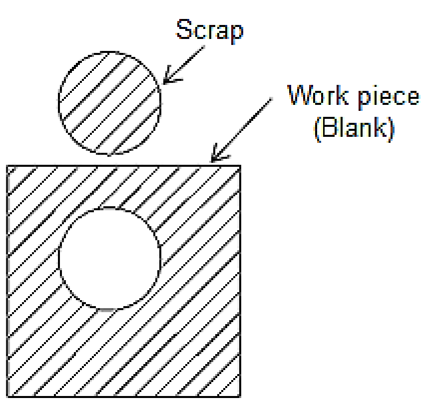
Fine blanking

Fine blanking is a specialized type of blanking in which the blank is sheared from the sheet stock by applying 3 separate forces. This technique produces a part with better flatness, a smoother edge with minimal burrs, and tolerances as tight as ±0.0003. As a result, high quality parts can be blanked that do not require any secondary operations. However, the additional equipment and tooling does add to the initial cost and makes fine blanking better suited to high volume production. Parts made with fine blanking include automotive parts, electronic components, cutlery, and power tools.

In fine blanking, the clearance between the punch and the die is smaller, around 0.001 inches, and the blanking is performed at slower speeds. As a result, instead of the material fracturing to free the blank, the blank flows and is extruded from the sheet, providing a smoother edge.

Punching

Punching is a cutting process in which material is removed from a piece of sheet metal by applying a great enough shearing force. Punching is very similar to blanking except that the removed material, called the slug, is scrap and leaves behind the desired internal feature in the sheet, such as a hole or slot. Punching can be used to produce holes and cutouts of various shapes and sizes. The most common punched holes are simple geometric shapes (circle, square, rectangle, etc.) or combinations thereof. The edges of these punched features will have some burrs from being sheared but are of fairly good quality. Secondary finishing operations are typically performed to attain smoother edges.



The punching process requires a punch press, sheet metal stock, punch, and die. The punch press

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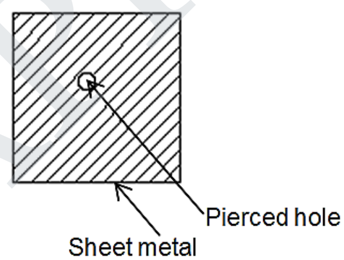
drives the punch downward at high speed through the sheet and into the die below. There is a small clearance between the edge of the punch and the die, causing the material to quickly bend and fracture. The slug that is punched out of the sheet falls freely through the tapered opening in the die. This process can be performed on a manual punch press, the punch press can be hydraulically, pneumatically, or electrically powered and deliver around 600 punches per minute.

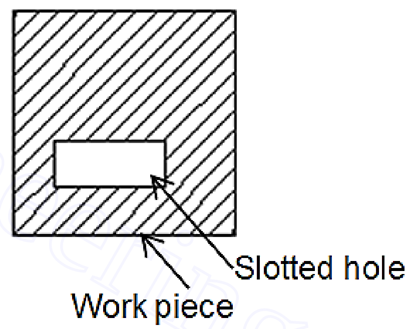
Typical punching operation is one in which a cylindrical punch tool pierces the sheet metal, forming a single hole. However, a variety of operations are possible to form different features. These operations include the following:

Piercing



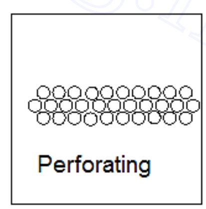
The typical punching operation, in which a cylindrical punch pierces a hole into the sheet. The size of hole is very small (i.e. less than 1mm)

Slotting



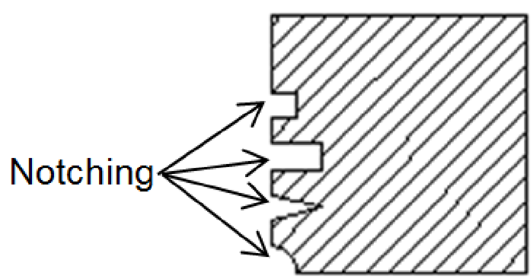
A punching operation that forms rectangular holes or any polygonal shape in the sheet. Sometimes described as piercing despite the different shape

Perforating



Punching a close arrangement of a large number of holes in a single operation

Notching



Punching the edge of a sheet, forming a notch in the shape of a portion of the punch

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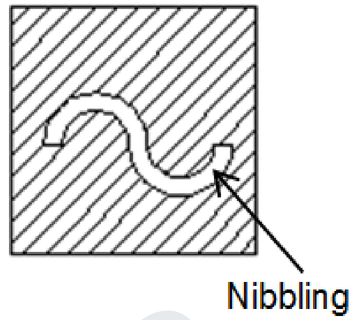
Nibbling

Punching a series of small overlapping slits or holes along a path to cutout a larger contoured shape. This eliminates the need for a custom punch and die but will require secondary operations to improve the accuracy and finish of the feature.



Lancing

Creating a partial cut in the sheet, so that no material is removed. The material is left attached to be bent and form a shape, such as a tab, vent, or louver.

Slitting

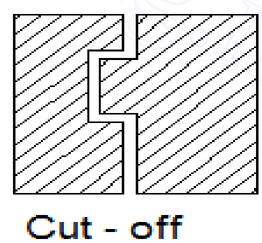
Cutting straight lines in the sheet. No scrap material is produced.

Parting

Separating a part from the remaining sheet, by punching away the material between parts.

Cutoff

Separating a part from the remaining sheet, without producing any scrap. The punch will produce a cut line that may be straight, angled, or curved.



Trimming

Punching away excess material from the perimeter of a part, such as trimming the flange from a drawn cup.

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Shaving

Shearing away minimal material from the edges of a feature or part, using a small die clearance.Used to improve accuracy or finish. Tolerances of ±0.001 inches are possible.

Before shaving

After Shaving

Types of dies used for shearing operation

A typical die and punch set used for blanking operation is shown in Figure. The sheet metal used is called strip or stock. The punch which is held in the punch holder is bolted to the press ram while die is bolted on the press table. During the working stroke, the punch penetrates the strip, and on the return stroke of the press ram the strip is lifted with the punch, but it is removed from the punch by the stripper plate. The stop pin is a gage and it sets the advance of the strip stock within the punch and die. The strip stock is butted against the back stop acting as a datum location for the centre of the blank.

The die opening is given angular clearance to permit escape of good part (blank). The waste skeleton of stock strip, from which blanks have been cut, is recovered as salvaged material.

The clearance angle provided on the diedepends on the material of stock, as well as its thickness. For thicker and softer materials generally higher angular clearance is given. In most cases, 2 degree of angular clearance is sufficient. The height of cutting land of about 3 mm is generally sufficient.

Clearance

In *blanking operation*, the die size is taken as the blank size and the punch is made smaller giving the necessary clearance between the die and the punch.

Die size = blank size

Punch size = blank size – 2 x clearance

Clearance = k .t . τ

where t = shear strength of material, t = thickness of sheet metal stock, and k is a constant whose value may be taken as 0.003.

In a *piercing operation* , the following equations hold.

Punch size = blank size

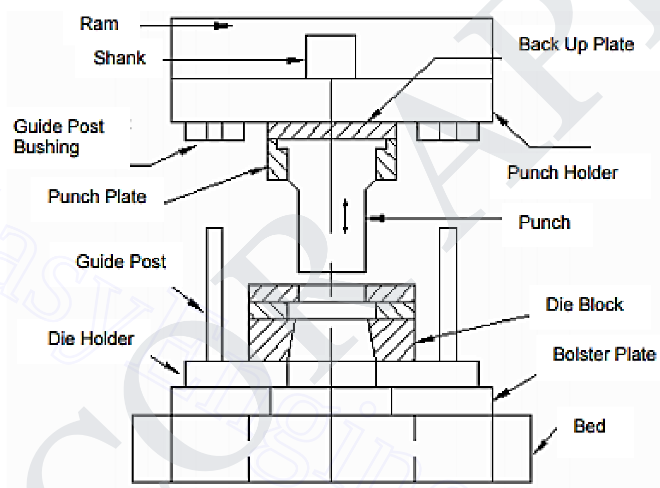
Die size = blank size + 2 x clearance

Clearance = k .t . τ

Types of dies

Simple die

A simple cutting die is shown in Figure



Simple Die

Description

Bed : The bed is lower part of press frame that serves as a table on which a bolster plate is mounted.

Bolster Plate : Bolster plate is a thick plate secured to the press bed, which is used for locating and supporting the die assembly. Its thickness is usually 5 to 12.5 cm.

Die set : Die set is unit assembly which incorporates a lower and upper shoe, two or more guide posts and guide post bushings.

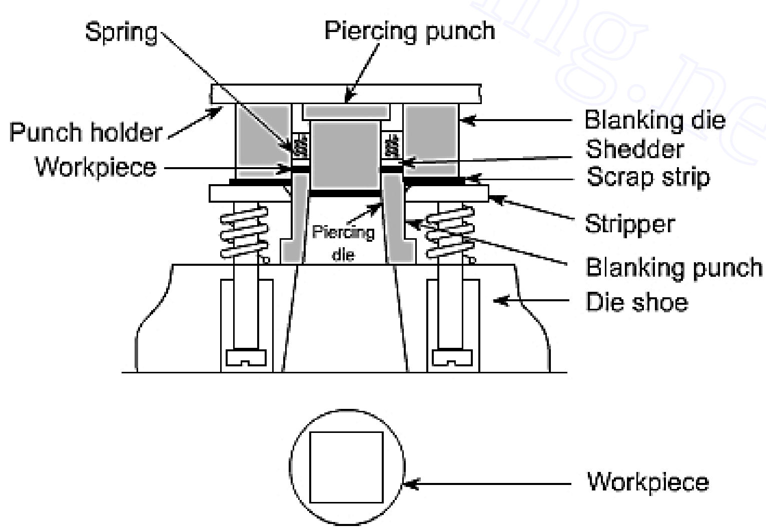
Die : Die is the female part of a complete tool for producing work in a press. It is also referred to a complete tool consisting of pair of mating members for producing work in press.

Die Block : It is the block or a plate which contains the die cavity.

Lower Shoe	:	The lower shoe of a die set is generally mounted on the upper plate of a press. The die block is mounted on the lower shoe. The guide posts are also mounted in it.
Punch	:	Punch is the male component of the die assembly which is directly or indirectly moved by or fastened to the press ram or slide.
Upper Shoe	:	It is the upper part of the die set which contain die post bushings
Punch Plate	:	The punch plate or punch retainer fits closely over the body of the punch and holds it in proper relative position.
Back Up Plate	:	It is also called pressure plate. It is placed so that the intensity of pressure does not become excessive on punch holder. The plate distributes the pressure over a wide area and intensity of pressure on the punch holder is reduced to avoid crushing.
Stripper	:	Stripper is a plate which is used to strip the metal strip from a cutting or non-cutting punch or die. It may also guide the strip.
Knock Out	:	Knock out mechanism is used to remove the workpiece from a die. It is connected to and operated by the press ram.
Pitman	:	Pitman is a connecting rod which is used to transmit the motion from the main drive shaft to the press slide.

Compound die

Compound die combines the principles of the conventional and inverted dies in one station. This type of die may produce a workpiece which is pierced and blanked in one operation at one station. The piercing punch is fastened in the conventional position to the punch holder. Its matching die opening for piercing is machined into the blanking punch. The blanking punch and blanking die opening are mounted in an inverted position. The blanking punch is fastened to the die shoe and the blanking die opening is



Compound Die

fastened to the punch holder.

It is used for producing washer which is piercing and blanked at one station in one operation.

Advantages

- Accuracy is more
- Large parts can be blanked in a smaller press
- Shorter length of strip material can be used.
- The cost of production is very less.

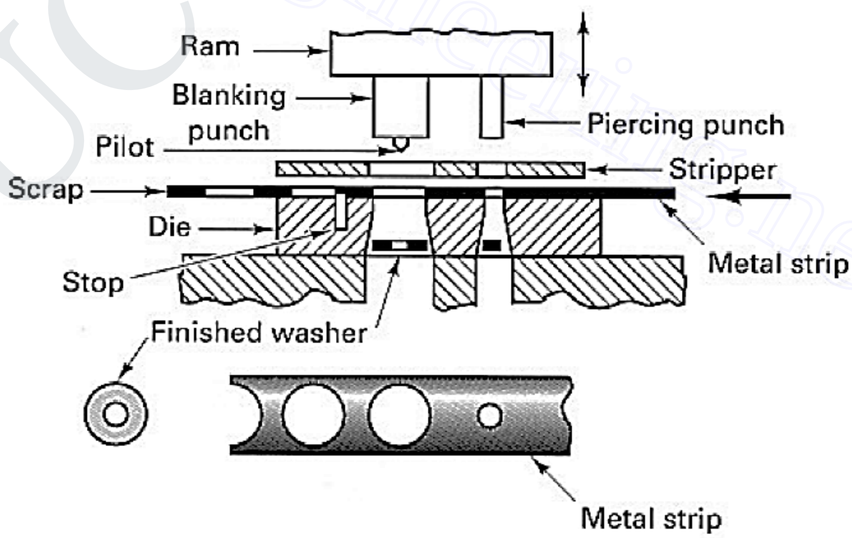
Disadvantages

- More expensive to construct and repair
- Slower in operation as compared with progressive die
- Heaviest construction.
- Complicated design.

Progressive die

It is also called a follow on die. The progressive die is shown in Figure. It performs two or more operations in one stroke of a ram at different stages. First operation is punching, which is followed by blanking. The metal strip is transferred to the next station in between the stroke to produce a complete workpiece.

When the piercing punch cuts a hole in the strip, the blanking punch draws out a portion of the metal strip in which a hole had been pierced at a previous station. The metal strip is fed into the die mechanically or manually. The primary stop is pushed in by hand and lead end is then made to contact with it. The press is now made to operate to pierce a hole at station 1.



Progressive die

As the primary stop is released, the strip is transferred to the station 2. The strip contacts with automatic button die stop at station 2.

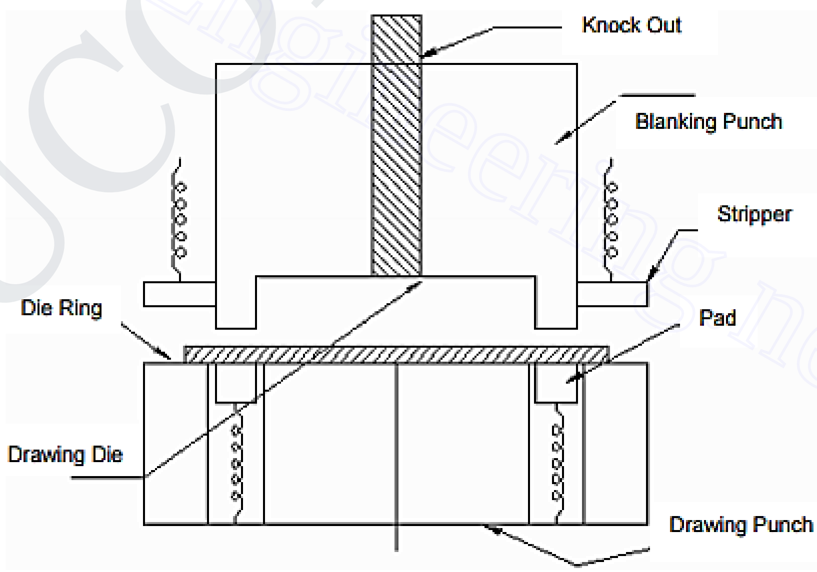
During the next stroke, the pilot on blanking punch enters the previously pierced hole which ensures the exact alignment of the strip to be blanked next. The die stop activation pin pushes the die stop pin below the edge of the blank. Hence the strip is transferred to next station on return stroke of the ram. The button die stop pin returns to its normal position and holds the strip on the inside wall of the blanked hole. During the third stroke, another complete part is produced and thereafter parts are produced at each stroke of the ram. In a progressive die, force required is reduced to a large extent due to the staggering of punches. The disadvantage of progressive die is that it makes balancing of the punches difficult.

Transfer die

Transfers dies are same as progressive dies, the only difference being that the already cut blanks are fed manually or automatically from station to station. First operation is blanking, which is followed by piercing.

Combination Dies

In a combination die, cutting action is combined with non-cutting actions, i.e. forming. Non-cutting actions may be bending, drawing, extrusion or embossing. More than one operation is possible in one stroke at a single stage, but the die is more useful for two operations only. The principle of working of a combination dies is shown in Figure



Combination die

The die ring is mounted on the die shoe. The die ring is counter bored at the bottom to allow the flange of a pad to travel up and down. This pad is held flush with the face of die by a spring. The drawing punch of required shape is attached to the die shoe. The blanking punch is placed in the punch holder. The stripper (spring operated) strips the skeleton from the blanking punch. As the workpiece comes in contact with the knock out bar during the return stroke, knock out removes the part attached to the punch. As the part is blanked, the blank holding comes down. Then the drawing punch contacts and forces the blank into the drawing die which is made into the blanking punch.

Bending

Bending is a manufacturing process; it is defined as the straining of the sheet metal around a straight edge. It produces a V-shape, U-shape, or channel shape along a straight axis in ductilematerials called sheet metal.

Bending induces plastic deformation in the material, so the part retains its shape after the bending force is released.

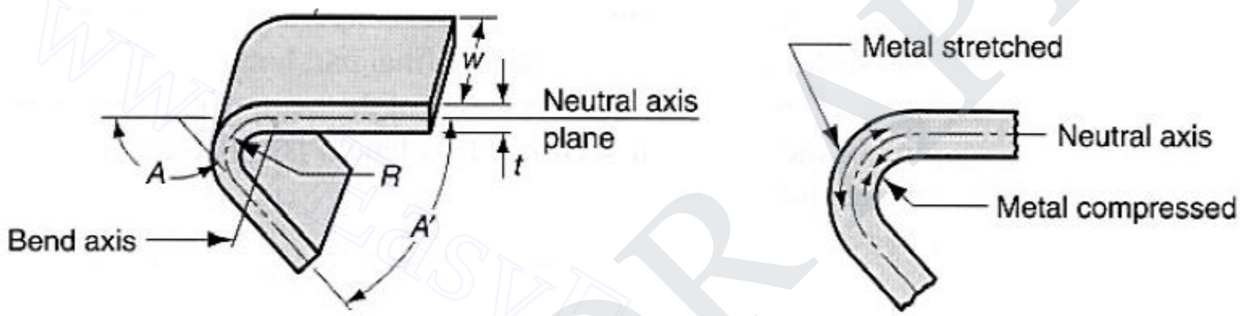


Figure (a) Bending of sheet metal

Figure (a) shows a simple bend on a rectangular blank. The top profile of the blank undergoes extension – a thin element along the top surface will be longer after the bending than the initial length; likewise, the bottom portion experiences compression. Thus, as we travel from the bottom to the top, there is some layer in the middle which retains its original length – this forms the neutral axis. The location of the neutral axis, and therefore its length, determines the length of the blank we must begin with, in order to get the final part with the correct geometry.

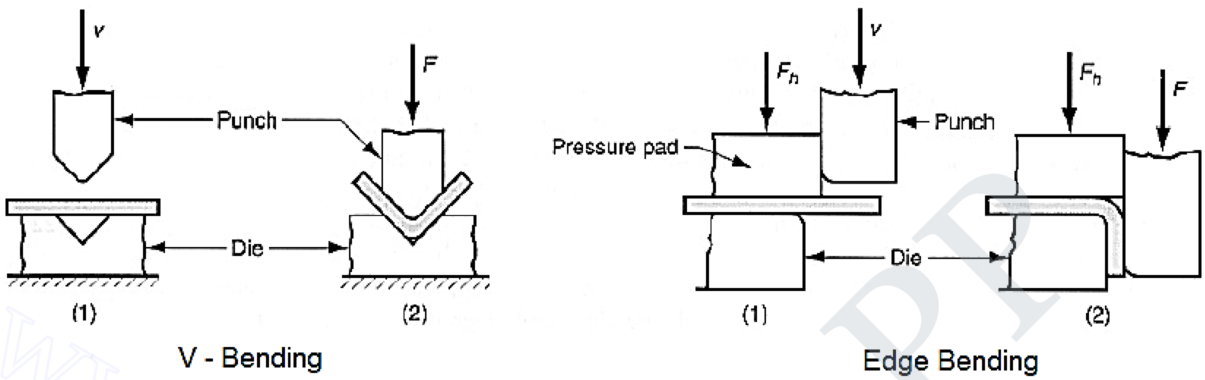
Types of bending

- V – Bending

  One of the most common types of sheet metal manufacturing processes is V bending. The V shaped punch forces the work into the V shaped die and hence bends it. This type of process can bend both very acute and very obtuse angles, also anything in between, including 90°.

- Edge Bending (wiping)

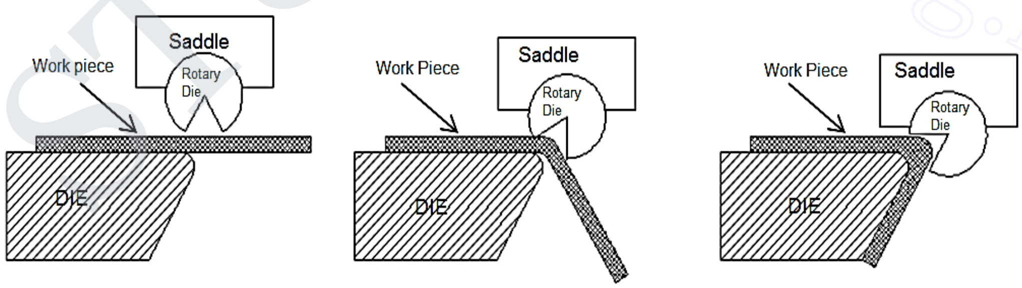
Edge bending is another very common sheet metal process and is performed with a wiping die. Edge bending gives a good mechanical advantage when forming a bend. However, angles greater than 90 degrees will require more complex equipment, capable of some horizontal force delivery.



(1) Before bending (2) After Bending

- Rotary bending

Rotary bending forms the work by a similar mechanism as edge bending. However, rotary bending uses a different design than the wiping die. A cylinder, with the desired angle cut out, serves as the punch. The cylinder can rotate about one axis and is securely constrained in all other degrees of motion by its attachment to the saddle. The sheet metal is placed cantilevered over the edge of the lower die, similar to the setup in edge bending.



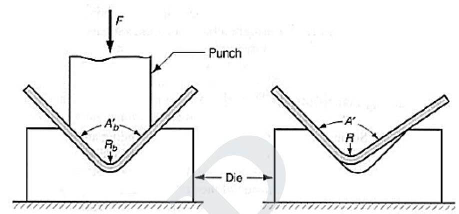
Rotary bending of sheet metal

Spring Back

At the end of the bending operation, when the pressure on the metal is released, there is an elastic recovery of the material. This cause a decrease in the bend angle and this phenomenon is called as spring back.

Table 4.1 Spring back value for various materials

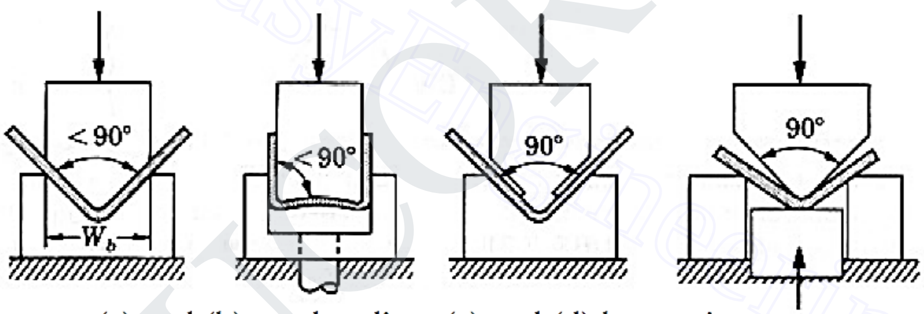
Material	Angle value
Low carbon steel	1° to 2°
Medium carbon steel	3° to 4°
Phosphor bronze and spring steel	10° to 15°



Springback in bending

To compensate for springback two methods are commonly used:

- Œ Over bending–the punch angle and radius are smaller than the final ones.
- • Bottoming–squeezing the part at the end of the stroke.

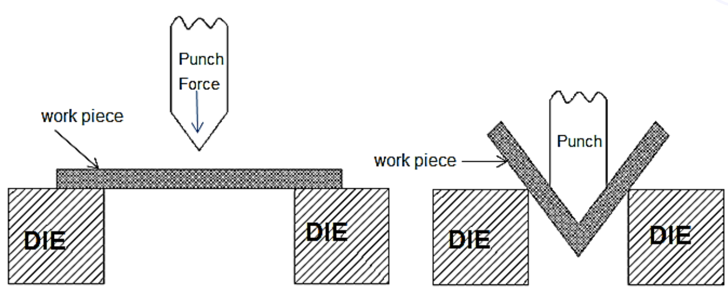


(a) and (b) overbending; (c) and (d) bottoming

Other types of bending

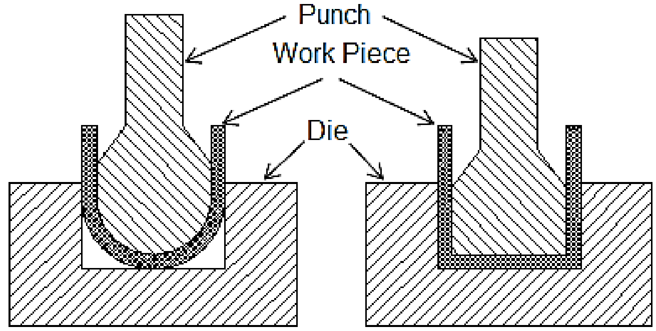
- Air Bending

  Air Bending is the most common type of bending process used in sheet metal shops today. In this process the work piece is only in contact with the edge of the Die and the tip of the Punch. The punch is them forced the top of the die into the v-opening without coming into contact with the bottom of the V.

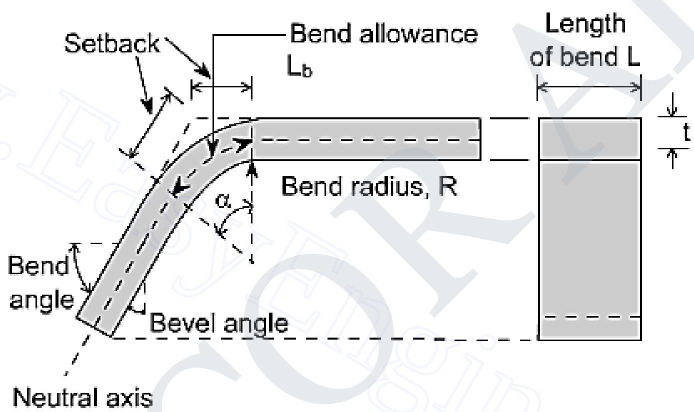


Air Bending

STUCOR APP



U - Bending   Channel Bending



Bending Terminology

BEND ALLOWANCE

This is the stretching length that occurs duringbending. It must be accounted to determine thelength of the blank

$$BA = \alpha\ (R + kt)$$

Where,

BA = bend allowance (mm)

α = bend angle (radian)

R = bend radius (mm)

t = thickness of sheet (mm), and

k = constant,

whose value may be taken as 1/3 when R < 2t, and as 1/2 when R ³ 2t.

Example

A 20 mm wide and 4 mm thick C 20 steel sheet is required to be bent at 600 at bend radius 10 mm. determine the bend allowance.

Solution.

Here, bend radius R = 10 mm   Sheet thickness t = 4 mm

$$\alpha = 2\pi \times \frac{60}{360}$$

Since R > 2t, k = 0.5

Bend allowance

$$= \left(2 \times \pi \times \frac{60}{360}\right)(10 + 0.5 \times 4) = 12.56\, mm$$

Bending Force :

The bending force is required to perform bending depends on the geometry of the punch and die, strength, thickness and width of the sheet metal. The bending force can be estimated from the following simple relation.

$$F = \frac{K_{bf} TS \omega t^2}{D}$$

Where

F = Bending force

TS = tensile strength of sheet metal

w = width of the part in the direction of the bend axis

t = thickness of sheet metal

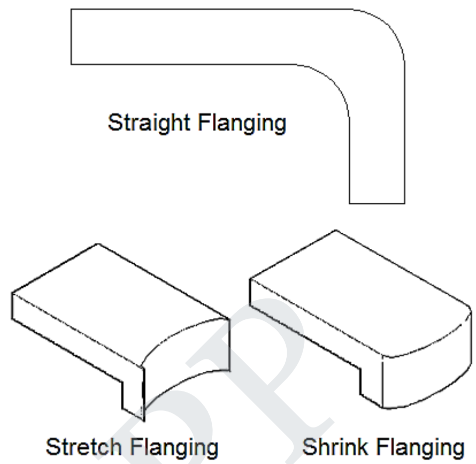
D = Die opening dimension

K_{bf} = bending factor   1.33 = V-Bending

Bending Operation

- Flanging

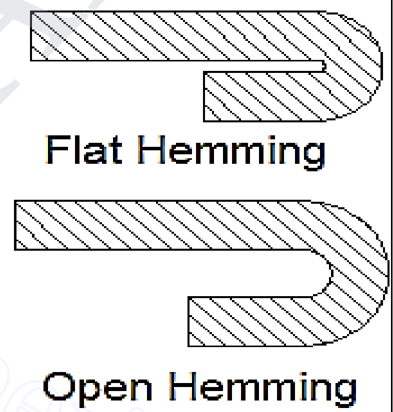
Flanging is one kind of bending operation in which the edge of the sheet metal part is bending at 90^{o} angle to form a rim or flange. It is often used to strengthen or stiffen the sheet metal part. There are three type of flanging, they are:



  - Straight
  - Stretch
  - Shrink

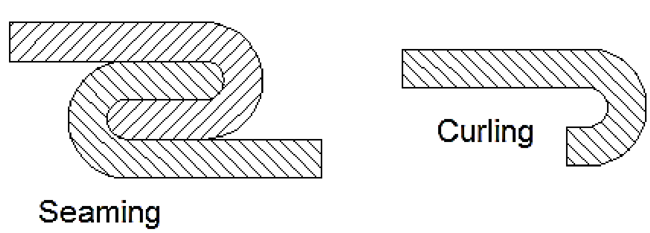
- Hemming

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 of the piece, to increase stiffness and to improve appearance. There are two type of hemming, namely as:



  - Flat
  - Open

- Seaming – two sheet metal edges are assembled
- Curling – form the edges of the part in to a roll or curl as shown in figure



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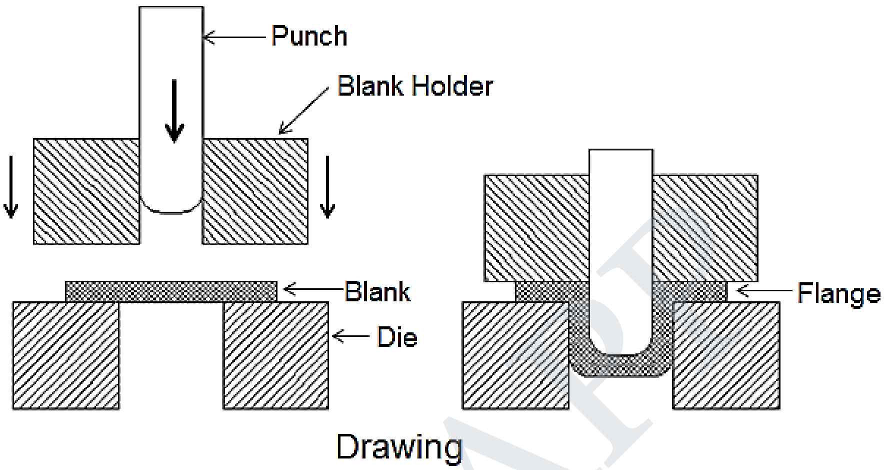
Drawing

Drawing is sheet-metal forming operation used to make cup-shaped, box shaped or other more complex-curved, hollow shaped parts. It is performed by placing a sheet metal blank over die cavity and then pushing the metal into the opening with a punch, as shown in figure



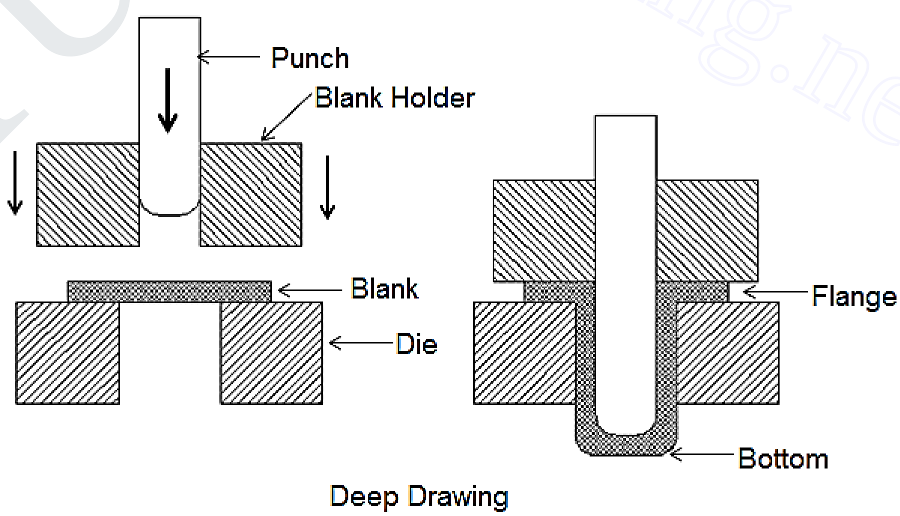
Drawing

The blank must usually be held down flat against the die by a blank holder.

Applications: beverage cans, cooking pots and automobile body panels.

DEEP DRAWING

Deep drawing is a sheet metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. The process is considered "deep" drawing when the depth of the drawn part exceeds its diameter. This is achieved by redrawing the part through a series of dies. The flange region (sheet metal in the die shoulder area) experiences a radial drawing stress and a tangential compressive stress due to



Deep Drawing

the material retention property. These compressive stresses (hoop stresses) result in flange wrinkles (wrinkles of the first order). Wrinkles can be prevented by using a blank holder, the function of which is to facilitate controlled material flow into the die radius.

Deep drawing is always accompanied by other forming techniques within the press. These other forming methods include:

- Beading: Material is displaced to create a larger, or smaller, diameter ring of material beyond the original body diameter of a part, often used to create O-ring seats.
- Bottom Piercing: A round or shaped portion of metal is cut from the drawn part.
- Bulging: In the bulging process a portion of the part's diameter is forced to protrude from the surrounding geometry.
- Coining: Material is displaced to form specific shapes in the part. Typically coining should not exceed a depth of 30% of the material thickness.
- Curling: Metal is rolled under a curling die to create a rolled edge.
- Extruding: After a pilot hole is pierced, a larger diameter punch is pushed through, causing the metal to expand and grow in length.
- Ironing / Wall Thinning: Ironing is a process to reduce the wall thickness of parts. Typically ironing should not exceed a depth of 30% of the material thickness.
- Necking: A portion of the part is reduced in diameter to less than the major diameter.
- Rib Forming: Rib forming involves creating an inward or outward protruding rib during the drawing process.
- Stamping / Marking: This process is typically used to put identification on a part, such as a part number or supplier identification.
- Threading: Using a wheel and arbor, threads are formed into a part. In this way threaded parts can be produced within the stamping press.

FORMABILITY OF SHEET METAL

Formability may be defined as the ease with which material may be forced into a permanent change of shape.

The formability of a material depends on several factors. The important one concerns the properties of material like yield strength, strain hardening rate, and ductility. These are greatly temperature - dependent. As the temperature of material is increased, the yield strength and rate of strain hardening progressively reduce and ductility increases. The hot working of metal, therefore, permits relatively very large amount of deformation before cracking.

There are several methods of predicting formability. A brief description of some important methods follows.

Cup or Radial Drawing:

Cup drawing test uses a circular blank from the metal to be tested. It is inserted in a die, and the severity of the draw it is able to withstand without tearing called the drawing ratio, is noted. The drawing ratio is the ratio of the cup diameter to the blank diameter.

$$R_d = \frac{D - d}{D}$$

Where R_d = drawing ratio

D = blank diameter

d = punch diameter

A drawing ratio of 50 % is considered excellent. As shown in Fig 4.1(a), either a flat bottom punch with lubricated blank may be used to draw the cup, or as shown in Fig 4.1(b) a blank may be drawn by a lubricated hemi – spherical punch. In the first case, the action is principally that of drawing in which cylindrical stretching of material takes place. In the second case, there will be bi – axial stretching of the material. For drawing, the clamping force is just sufficient to prevent buckling of the material at the draw radius as it enters the die. The deformation takes place in the flange and over the draw radius.

Fukui Conical – Cup Test:

It utilizes a hemispherical, smoothly polished punch. No blank holder is required. In each test, a drawing ratio which will result in a broken cup is determined. Formation of wrinkles is avoided by using a fixed ratio between the thickness of the sheet, the size of the blank, and the punch and die diameters. Under these conditions, the test produces a known amount of stretching, drawing, and bending under tension.

Normal Anisotropy Coefficient:

The material is subjected to uni-axial tensile test. The anisotropy coefficient is derived from the ratio of the plastic width strain e_W to the thickness strain e_t . A material with a high plastic anisotropy also has a greater "thinning resistance." In general, the higher the anisotropy coefficient the better the material deforms in drawing operations.

Strain-Hardening Coefficient:

Strain hardening refers to the fact that as a metal deforms in some area, dislocations occur in the microstructure. As these dislocations pile up, they tend to strengthen the metal against further deformation in that area. Thus the strain is spread throughout the sheet. However, at some point in the deformations, the strain suddenly localizes and necking, or localized thinning, develops. When this occurs, little further overall deformation of the sheet can be obtained without it fracturing in the necked region.

The strain – hardening coefficient therefore reflects how well the metal distributes the strain throughout the sheet, avoiding or delaying localized necking. The higher the strain – hardening coefficient, the move the material will harden as it is being stretched and the greater will be the resistance to localized necking. Necks in the metal harm surface appearance and affect structural integrity.

For many stamping operations, stretching of the metal is the critical factor and is dependent on the strain – hardening coefficient. Therefore, stampings that need much drawing should be made from metal having high average strain – hardening coefficients. Yield strength should be low to avoid wrinkles or buckling

Forming Limit Curve:

The forming – limit curve is a good index of determining the formability of sheet metal. Essentially, it requires to draw a curve that shows a boundary line between acceptable strain levels in forming and those that may cause failure, Fig 4.2.

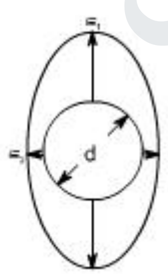
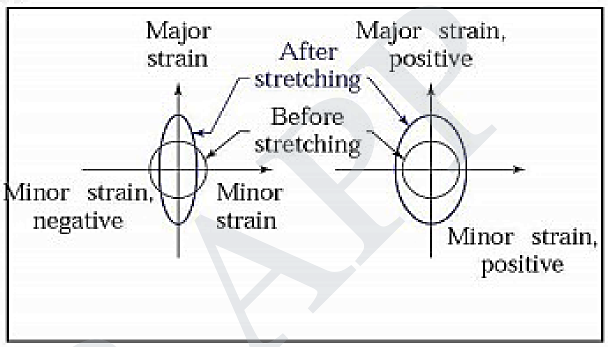


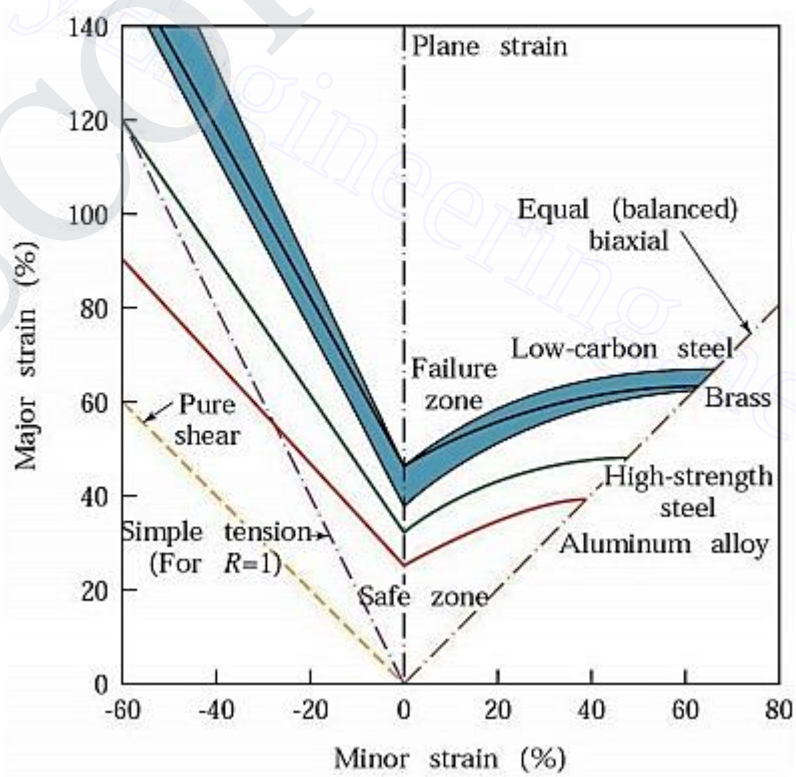
Fig 4.2 The relationship of major, e_1 , and minor, e_2 , strains is established by measurement after forming.

The curve indicates the relation between major and minor strains that are perpendicular to the plane of the sheet. To determine these strains, a grid of circles is marked on the sheet metal, say by an electrolytic stencil – etching process. After the metal is deformed, the circles are measured to obtain the major strain e1 and the minor strain e2 , as shown in Fig 4.2 Typically, ten to fifteen data points are obtained from a test specimen in the region of fracture. Ellipses lying both in the failed region and just outside of it are measured. The forming – limit curve is then drawn to fall below the strains in the necked and fractured zones, and above the strains found just outside these zones (Fig 4.3)



With controlled variation in specimen size it is possible to plot an entire forming – limit curve from one test setup. A reasonably accurate forming limit curve may be obtained with four specimens while a precision curve may be obtained with eight specimens.

In may be noted that "local" ductility varies for different metals, so no universal forming – limit curve can be developed. For example, two metals may have peak local ductilities of 20% and 50% at a given minor strain. The metal with the 20 % local ductility (high strain – hardening coefficient) may turn out to be the best choice because the strain will then have a better distribution throughout, allowing the entire sheet to be stretched 20%. If the other sheet showed little strain hardening, it might stretch by 50% in local area, but leave the rest of the sheet relatively unstrained.

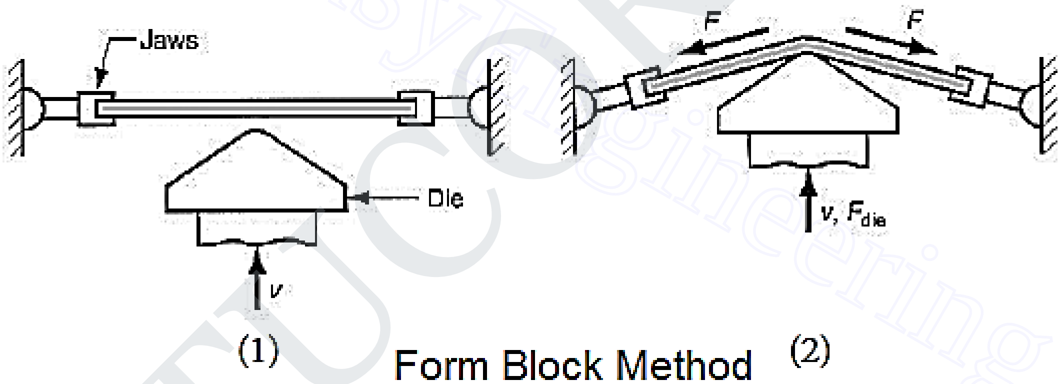


Through the use of formability – prediction techniques. Designers and fabricators are able to make a wider choice of metals and obtain date quickly on newer metals. The essential data can be obtained before the die is designed. Also metal suppliers will be able to establish whether a material possesses required formability before it is shipped from the plant.

Stretch forming

Stretch forming is a very accurate and precise method for forming metal shapes, economically. The level of precision is so high that even intricate multi-components and snap-together curtainwall components can be formed without loss of section properties or original design function. Stretch forming capabilities include portions of circles, ellipses, parabolas and arched shapes. These shapes can be formed with straight leg sections at one or both ends of the curve. This eliminates several conventional fabrication steps and welding.

The stretch forming process involves stretch forming a metal piece over a male stretch form block (STFB) using a pneumatic and hydraulic stretch press. Stretch forming is widely used in producing automotive body panels. Unlike deep drawing, the sheet is gripped by a blank holder to prevent it from being drawn into the die. It is important that the sheet can deform by elongation and uniform thinning.



Form Block Method

The variety of shapes and cross sections that can be stretch formed is almost unlimited. Window systems, skylights, store fronts, signs, flashings, curtainwalls, walkway enclosures, and hand railings can be accurately and precisely formed to the desired profiles.

Benefits

- Close and consistent tolerances,
- No surface defacing,
- No distortion or ripples,

- No surface misalignment of complex profiles
- smooth and even surface results

This process is ideally suited for the manufacture of large parts made from aluminum, but does just as well with stainless steel and commercially pure titanium. It is quick, efficient, and has a high degree of repeatability.

Stretch forming method

- Form block Method
- Mating Die Method

Hydroforming

Hydroforming, sometimes referred to as fluid forming or rubber diaphragm forming, was developed during the late 1940's and early 1950's in response to a need for a lower cost method of producing relatively small quantities of deep drawn parts.

Hydroforming, in simple terms, replaces the punch in traditional stamping with liquid--usually water--to provide shaping force. Hydroforming refers to the manufacture, via fluid pressure, of hollow parts with complex geometries. Hydroforming can be used to shape tubes or extrusions—where it finds its greatest use--or to shape sheet blanks.

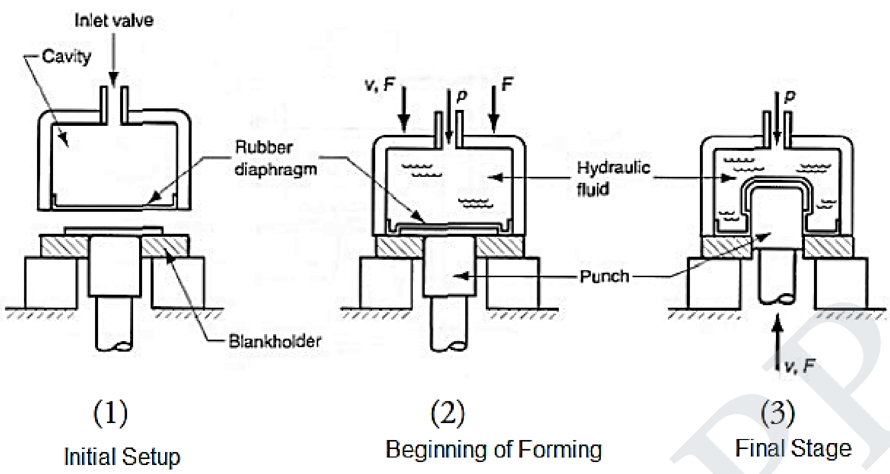
In tube and extrusion hydroforming, the workpiece is inflated by introducing fluid into the cavity while the tube undergoes axial or radial compression. The tube then expands where permitted by the tooling to the die wall. Such hydroforming in many cases is preceded by forming steps such as bending the tube to distribute where it's needed—corner radii, usually--for final hydroforming, or bent in order to fit into the die. Hydroforming dies used for tubes or extrusions consist of upper and lower blocks and plates as well as axial units used for sealing and end-feeding of the part.

A sheet blank can be formed via fluid applied directly or through a bladder system to force the sheet to assume the shape of the die wall or punch end. Here, the punch may provide additional pressure to assist in the process.

The hydroforming process requires specialized presses—or specially fitted hydraulic presses--and tooling as well as fluid delivery, storage, disposal and reclamation capability. Fluid pressure can range from the about 3,000 to nearly 100,000 psi.

Competitive processes

Deep-draw stamping, tube bending, fabrication.



Hydro Forming

Applications -

In automotive, the process delivers hollow parts such as radiator frames, engine cradles, exhaust manifolds, roof and frame rails and instrument-panel supports. Various rails, manifolds and supports find use in aircraft and appliance applications. Parts made through sheet hydroforming, currently a low-volume specialty process, include automotive deep-drawn fuel-tank trays and body panels as well as appliance parts such as panels and sink basins. The process also works well with smaller parts such as fittings and fuel filler necks

Benefits -

- Lighterweight parts in applications where it has replaced traditional stamping, fabrication and assembly methods.
- One-piecehydro formed parts can replace assemblies, thus increasing structural integrity while saving on material costs and reducing scrap.
- Hydroforming is better suited in producing parts from high-strength steel and aluminum than competing processes.

Recently, technology has allowed inclusion of operations such as piercing during hydroforming.

Capacities:

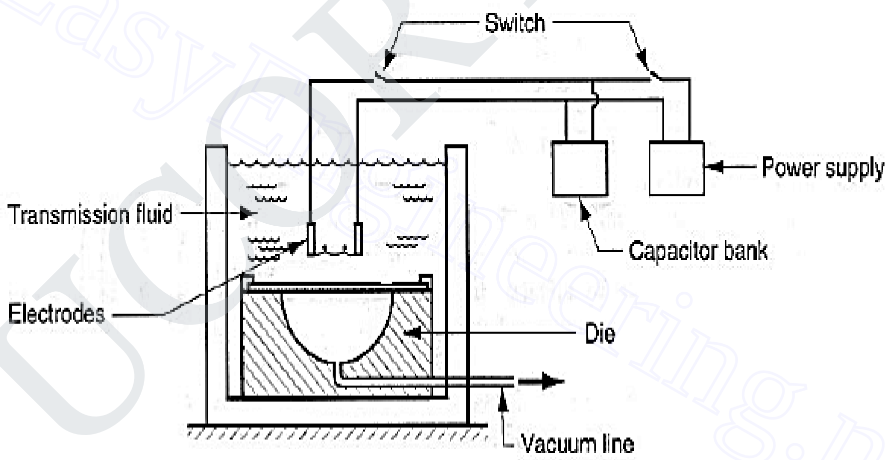
Part size is dependent on press size. Currently, the largest hydroforming press available can churn out parts to nearly 20 ft. long, but typical parts are less than half that size, and can be produced in sizes down to a few inches. Cycle times are slower than traditional stamping methods.

Materials:

High-strength steel and aluminum are the materials of choice in hydroforming parts for automotive use. But any sheet material that can be cold formed is a candidate for hydroforming.

Electrohydraulic Forming

In electrohydraulic forming, an electric arc discharge is used to convert electrical energy to mechanical energy. A capacitor bank delivers a pulse of high current across two electrodes, which are positioned a short distance apart while submerged in a fluid (water or oil). The electric arc discharge rapidly vaporizes the surrounding fluid creating a shock wave. The workpiece, which is kept in contact with the fluid, is deformed into an evacuated die.



Electro Hydraulic forming

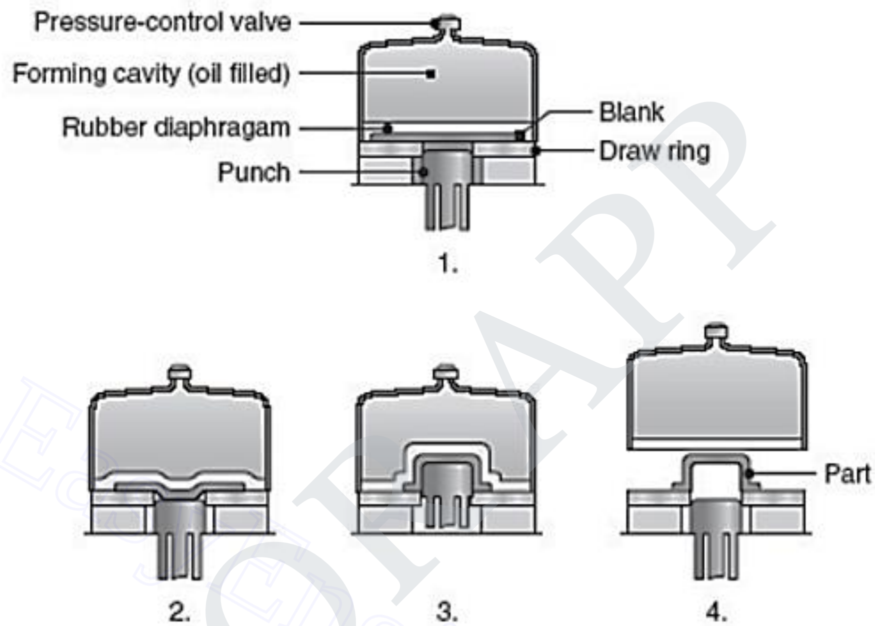
The potential forming capabilities of submerged arc discharge processes were recognized as early as the middle of 1940s. During the 1950s and early 1960s, the basic process was developed into production systems. This work principally was by and for the aerospace industries. By 1970, forming machines based on submerged arc discharge, were available from machine tool builders. A few of the larger aerospace fabricators built machines of their own design to meet specific part fabrication requirements.

Electrohydraulic forming is a variation of the older, more general, explosive forming method. The only fundamental difference between these two techniques is the energy source, and subsequently, the practical size of the forming event.

Very large capacitor banks are needed to produce the same amount of energy as a modest mass of high explosives. This makes electrohydraulic forming very capital intensive for large parts. On the other hand, the electrohydraulic method was seen as better suited to automation because of the fine control of multiple, sequential energy discharges and the relative compactness of the electrode-media containment system.

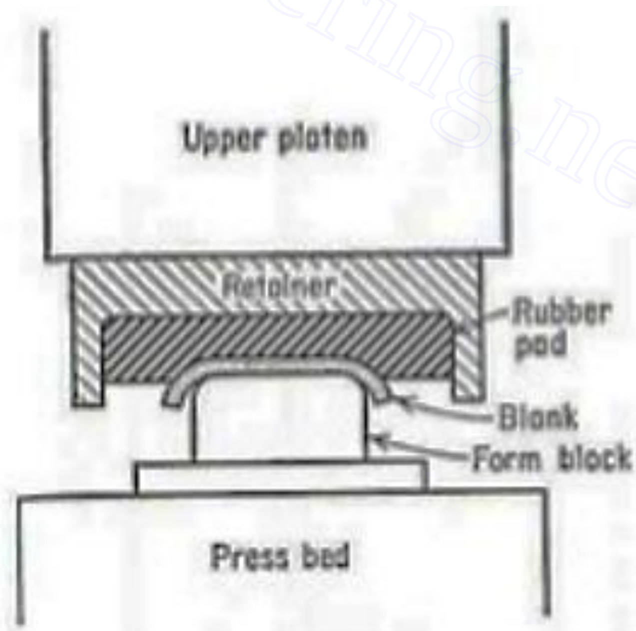
RUBBER PAD FORMING

The name of rubber pad forming is also called as Guerin Process.



Rubber Pad Forming

Rubber pad forming (RPF) is a metalworking process where sheet metal is pressed between a die and a rubber block, made of polyurethane. Under pressure, the rubber and sheet metal are driven into the die and conform to its shape, forming the part. The rubber pads can have a general purpose shape, like a membrane. Alternatively, they can be machined in the shape of die or punch.

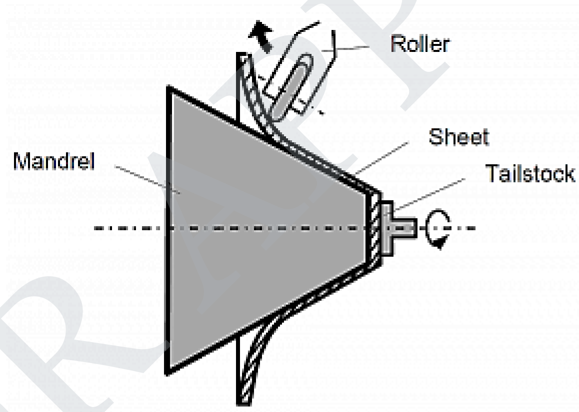


Rubber pad forming has been used in production lines for many years. Up to 60% of all sheet metal parts in the aerospace industry are fabricated using this process. The most relevant applications are indeed in the aerospace field.It is frequently used in prototyping shops and for the production of kitchenware.

METAL SPINNING PROCESS

The metal spinning process starts with special machinery that produces rotationally symmetrical (i.e. cone-shaped) hollow parts; usually from circular blanks. Shear forming, a related process where parts are formed over a rotating conical mandrel, can be used to produce not only cone-shaped parts but also elliptical or other concave or convex parts. Often, shear forming is used in conjunction with metal spinning. Metal spinning is used as a replacement for the stamping and deep drawing processes.

The metal spinning process starts with a sheet metal blank which rotates on a lathe. The metal disc is pressed against a tool (called a mandrel or a chuck) with a tailstock. The metal disc, tailstock and tool rotate in a circular motion and a roller presses against the metal to form the metal over the tool through a series of passes by the roller. The resulting part is a piece that duplicates the exterior portion of the tool it was formed on. The basic shapes in metal spinning are cones, flanged covers, hemispheres, cylindrical shells, venturis and parabolic nose shapes.



Metal Spinning

Metal spinning yields pots and pans, vases, lamp shades, musical-instrument parts and trophies. Automotive parts include wheel discs, rims, hubcaps and clutch drums. Other examples include radar reflectors, parabolic dishes, hoppers, concrete-mixer bodies, drums, pressure bottles, tank ends, compensator and centrifuge parts, pulleys, hydraulic cylinders, engine inlet rings and a variety of jet-engine and missile parts.

Some of the advantages of metal spinning include -

- Low capital-investment
- Low tooling and energy costs
- Short setup times
- Quick and inexpensive adaptation of tooling and methods to accommodate design changes
- Ability to carry out other operations such as beading, profiling, trimming and turning in the same production cycle with one setup.

- Forming forces are appreciably lower than competing processes due to localized working.
- Economical for one-off parts; prototypes; and small, medium and high volumes.
- Any sheet material that can be cold formed for metal spinning including - cold rolled steel, hot rolled steel, aluminum, stainless steel, brass, copper and exotic metals such as titanium, Inconel, and haste alloy.

Tooling for spinning is relatively inexpensive and simple to employ, translating to a short lead time for parts. Tight tolerancing requirements may require secondary operations, but the advent of automated spinning machines allows more precise forming than with manual spinning machines, with less reliance on operator skill.

Explosive Forming

Explosive forming has evolved as one of the most dramatic of the new metalworking techniques. Explosive forming is employed in aerospace and aircraft industries and has been successfully employed in the production of automotive-related components. Explosive Forming or HERF (High Energy Rate Forming) can be utilized to form a wide variety of metals, from aluminum to high strength alloys. In this process the punch is replaced by an explosive charge. The process derives its name from the fact that the energy liberated due to the detonation of an explosive is used to form the desired configuration. The charge used is very small, but is capable of exerting tremendous forces on the workpiece. In Explosive Forming chemical energy from the explosives is used to generate shock waves through a medium (mostly water), which are directed to deform the workpiece at very high velocities.

Methods of Explosive Forming

Explosive Forming Operations can be divided into two groups, depending on the position of the explosive charge relative to the workpiece.

Standoff Method

In this method, the explosive charge is located at some predetermined distance from the workpiece and the energy is transmitted through an intervening medium like air, oil, or water. Peak pressure at the workpiece may range from a few thousand psi to several hundred thousand psi depending on the parameters of the operation.

Contact Method

In this method, the explosive charge is held in direct contact with the workpiece while the detonation is initiated. The detonation produces interface pressures on the surface of the metal up to several million psi (35000 MPa).

The system used for Standoff Method consists of following parts: -

1) An explosive charge
2) An energy transmitted medium
3) A die assembly
4) The workpiece.

The die assembly is put together on the bottom of a tank. Workpiece is placed on the die and blankholder placed above. A vacuum is then created in the die cavity. The explosive charge is placed in position over the centre of the workpiece. The explosive charge is suspended over the blank at a predetermined distance. The complete assembly is immersed in a tank of water.

After the detonation of explosive, a pressure pulse of high intensity is produced. A gas bubble is also produced which expands spherically and then collapses until it vents at the surface of the water. When the pressure pulse impinges against the workpiece, the metal is displaced into the die cavity.

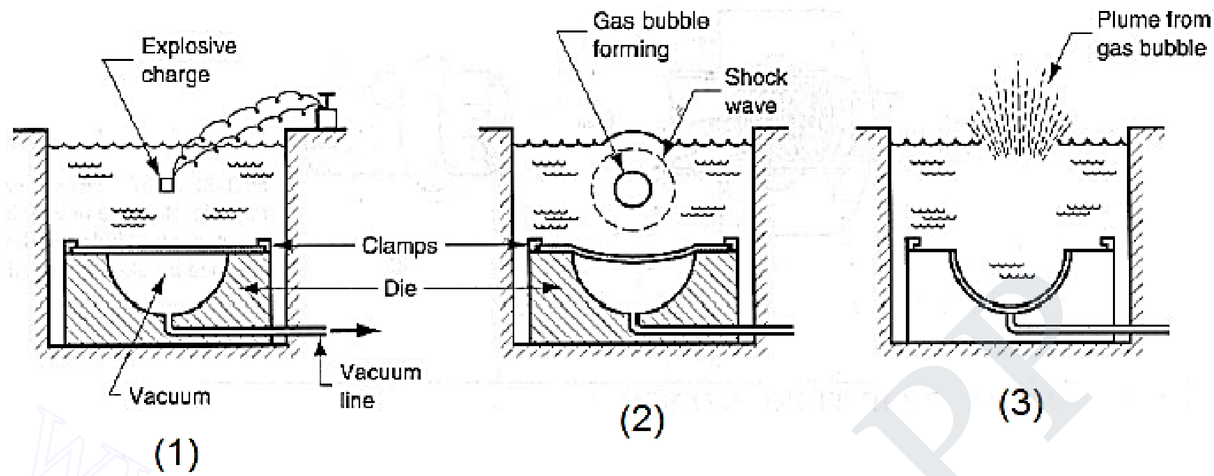
Explosives

Explosives are substances that undergo rapid chemical reaction during which heat and large quantities of gaseous products are evolved. Explosives can be solid (TNT-trinitro toluene), liquid (Nitroglycerine), or Gaseous (oxygen and acetylene mixtures). Explosives are divide into two classes; Low Explosives in which the ammunition burns rapidly rather than exploding, hence pressure build up is not large, and High Explosive which have a high rate of reaction with a large pressure build up. Low explosives are generally used as propellants in guns and in rockets for the propelling of missiles.

Advantages of Explosion Forming

1. Maintains precise tolerances
2. Eliminates costly welds.
3. Controls smoothness of contours.
4. Reduces tooling costs.

5. Less expensive alternative to super-plastic forming.



Die Materials

Different materials are used for the manufacture of dies for explosive working, for instance high strength tool steels, plastics, concrete. Relatively low strength dies are used for short run items and for parts where close tolerances are not critical, while for longer runs higher strength die materials are required. Kirksite and plastic faced dies are employed for light forming operations; tool steels, cast steels, and ductile iron for medium requirements.

Material of Die	Application Area
Kirksite	Low pressure and few parts
Fiberglass and Kirksite	Low pressure and few parts
Fiberglass and Concrete	Low pressure and large parts
Epoxy and Concrete	Low pressure and large parts
Ductile Iron	High pressure and many parts
Concrete	Medium pressure and large parts

Characteristics of Explosive Forming Process

- Very large sheets with relatively complex shapes, although usually axisymmetric.
- Low tooling costs, but high labor cost.
- Suitable for low-quantity production.
- Long cycle times.

Transmission Medium

Energy released by the explosive is transmitted through medium like air, water, oil, gelatin, liquid salts. Water is one of the best media for explosive forming since it is available readily, inexpensive and produces excellent results. The transmission medium is important regarding pressure magnitude at the workpiece. Water is more desirable medium than air for producing high peak pressures to the workpiece.

ADVANTAGE

1. It can simulate a variety of other conventional metal forming techniques such as stamp- or press-forming and spin-forming in a single operation.
2. Explosive hydro-forming can efficiently form large parts – up to 4' square or 10' in diameter.
3. It is particularly suitable for short production runs of a large parts such as occurs in aerospace applications.
4. It maintains precise tolerances and Eliminates costly welds.

DISADVANTAGES

1. Low tooling costs, but high labor cost.
2. Suitable for low-quantity production.
3. Due to shock waves and spillage of water it is not suitable to carry out indoor.
4. It should be done in open air.

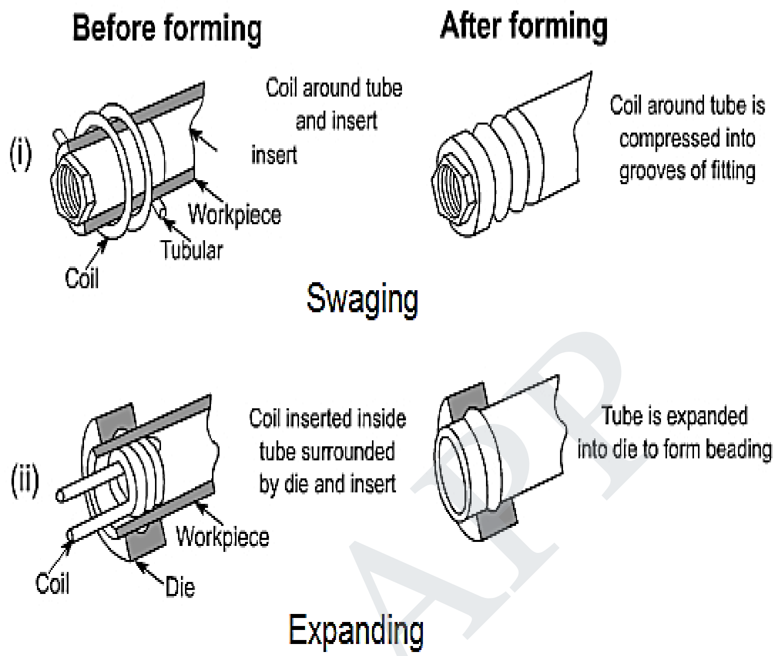
Electro Magnetic Forming

The process is also called magnetic pulse forming and is mainly used for swaging type operations, such as fastening fittings on the ends of tubes and crimping terminal ends of cables. Other applications are blanking, forming, embossing, and drawing. The work coils needed for different applications vary although the same power source may be used.

To illustrate the principle of electromagnetic forming, consider a tubular work piece. This work piece is placed in or near a coil, (Refer figure). A high charging voltage is supplied for a short time to a bank of capacitors connected in parallel. (The amount of electrical energy stored in the bank can be increased either by adding capacitors to the bank or by increasing the voltage). When the charging is complete, which takes very little time, a high voltage switch triggers the stored electrical energy through the coil. A high – intensity magnetic field is established which induces eddy currents into the conductive work piece, resulting in the establishment of another magnetic field. The forces produced by the two magnetic fields oppose each other with the consequence that there is a repelling force between the coil and the tubular work piece that causes permanent deformation of the work piece.

Either permanent or expandable coils may be used. Since the repelling force acts on the coil as well the work, the coil itself and the insulation on it must be capable of withstanding the force, or else they will be destroyed. The expandable coils are less costly and are also preferred when high energy level is needed.

Magnetic forming can be accomplished in any of the following ways, depending upon the requirements.



- Coil surrounding work piece. When a tube – like part x is to fit over another part y (shown as insert in Fig. (a)), coil is designed to surround x so that when energized, would force the material of x tightly around y to obtain necessary fit.
- Coil inside work piece. Consider fixing of a collar on a tube – like part, as shown in Fig. (b). The magnetic coil is placed inside the tube – like part, so that when energized would expand the material of the part into the collar.

In electromagnetic forming, the initial gap between the work piece and the die surface, called the *fly distance*, must be sufficient to permit the material to deform plastically. From energy considerations, the ideal pressure pulse should be of just enough magnitude that accelerates the part material to some maximum velocity and then let the part come to zero velocity by the time it covers the full fly distance. All forming coils fail, expendable coils fail sooner than durable coils, and because extremely high voltages and currents are involved, it is essential that proper safety precautions are observed by the production and maintenance personnel.

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 riveting.

Peen Forming

Shot peen forming is a dieless process performed at room temperature, whereby small round steel shot impact the surface of the work piece. Every piece of shot acts as a tiny peening hammer, producing elastic stretching of the upper surface and local plastic deformation that manifests itself as a residual compressive stress. The combination of elastic stretching and compressive stress generation causes the material to develop a compound, convex curvature on the peened side.

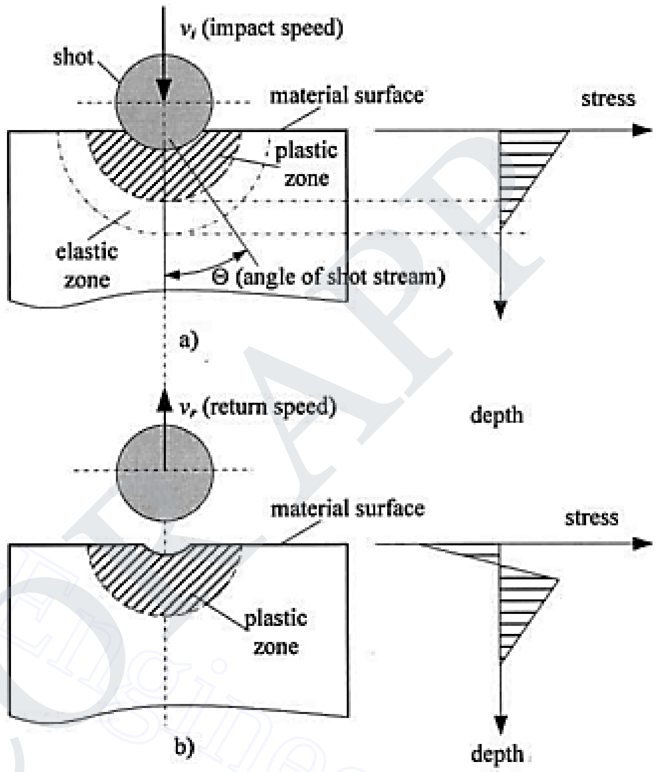
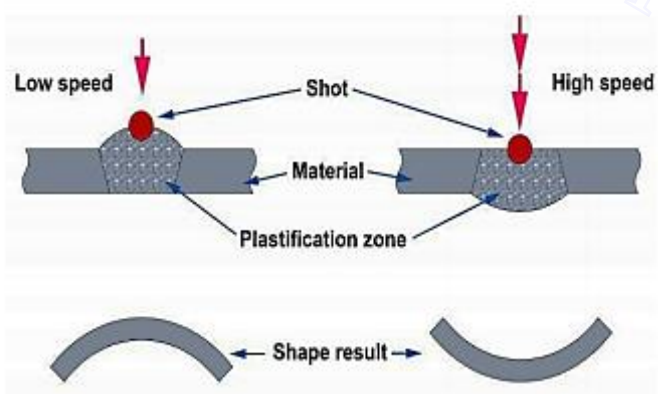


Figure 3 **The effect of shot impact on stress distribution: a) at the moment of impact; b) immediately after impact**

The shot peen forming process is ideal for forming large panel shapes where the bend radii are reasonably large and without abrupt changes in contour. Shot peen forming is best suited for forming curvatures where radii are within the metal's elastic range. Although no dies are required for shot peen forming, for severe forming applications, stress peen fixtures are sometimes used. Shot peen forming is effective on all metals, even honeycomb skins and ISO grid panels.



Mechanism of Peen forming

Shot peen forming is often more effective in developing curvatures than rolling, stretching or twisting of metal. Saddle-back shapes also are achievable. Because it is a dieless process, shot peen forming reduces material allowance from trimming and eliminates costly development and manufacturing time to fabricate hard dies. The shot peen forming process also is flexible to design changes, which may occur after initial design. Metal Improvement Company can make curvature changes by adjusting the shot peen forming process.

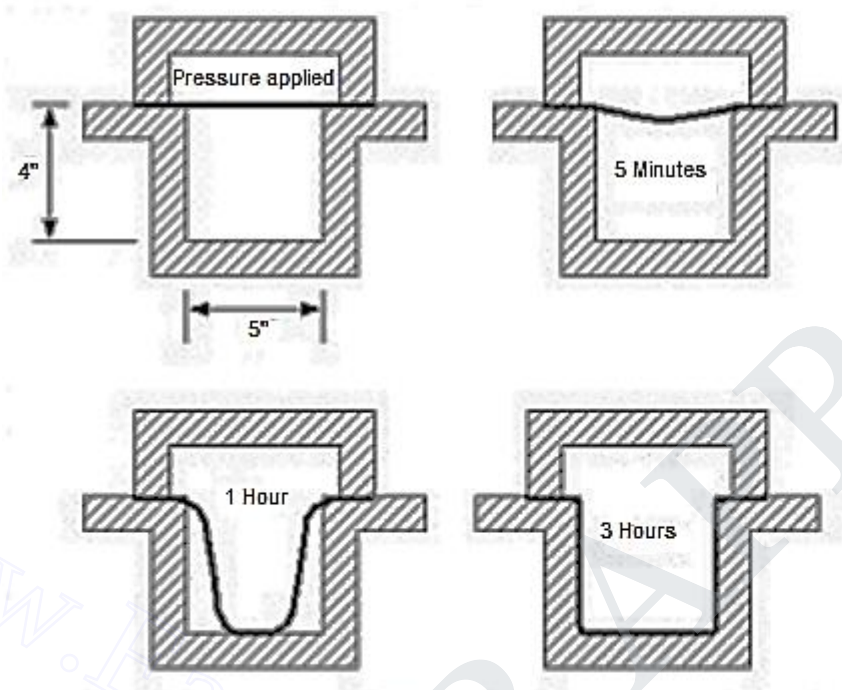
Parts formed by shot peen forming exhibit increased resistance to flexural bending fatigue. Unlike most other forming methods, all surface stresses generated by shot peen forming are of a compressive nature. Although shot peen formed pieces usually require shot peening on one side only, the result causes both sides to have compressive stress. These compressive stresses serve to inhibit stress corrosion cracking and to improve fatigue resistance. Some work pieces should be shot peened all over prior to or after shot peen forming to further improve fatigue and stress corrosion cracking resistance.

Shot peening of parts that have been cold formed by other processes overcomes the harmful surface tensile stresses set up by these other forming processes.

SUPERPLASTIC FORMING

The superplastic forming (SPF) operation is based on the fact that some alloys can be slowly stretched well beyond their normal limitations at elevated temperatures. The higher temperatures mean the flow stress of the sheet material is much lower than at normal temps. This characteristic allows very deep forming methods to be used that would normally rupture parts. Superplastic alloys can be stretched at higher temperatures by several times of their initial length without breaking. Superplastic forming can produce complex shapes with stiffening rims and other structural features as well.

The process begins by placing the sheet to be formed in an appropriate SPF die, which can have a simple to complex geometry, representative of the final part to be produced. The sheet and tooling are heated and then a gas pressure is applied, which plastically deforms the sheet into the shape of the die cavity.



Super Plastic Forming

Process Advantages --

- Reduced weight for high fuel efficiency
- Improved structural performance
- Increased metal formability and part complexity
- Near net shape forming of complex shapes reduces part count
- Cost/weight savings
- Low-cost tooling
- Low environmental impacts - non-lead die lubes, low noise

Materials used -

1) Titanium alloys
2) Aluminum alloys
3) Bismuth-tin alloys
4) Zinc-aluminum alloys
5) Stainless steel
6) Aluminum-lithium alloys

SYLLABUS

* Types and characteristics of Plastics
* Moulding of Thermoplastics
* Working principle and typical application
  ⇒ Injection moulding
    ✓ Plunger machine
    ✓ Screw machine
  ⇒ Blow moulding
  ⇒ Rotational moulding
  ⇒ Film blowing
  ⇒ Extrusion
  ⇒ Thermoforming
* Thermosetting plastics
  ⇒ Compression moulding
  ⇒ Transfer moulding
* Bonding of Thermoplastics

The word plastic is derived from the Greek word Plastikos which means it can be moulded and shaped.

Plastics are polymer material. Poly means many mers means parts. Polymer is an organic macro molecules, comprised of several repeating units called mers, linked together in a chain form.

Plastic is defined as an organic polymer. It can be moulded in to any required shape with the help of pressure or heat or both.

Polymerisation is refers to a particular segment is repeated in to number of times.

Liquid form of plastic is called resin, it contain carbon as a central element. oxygen, Nitrogen and chlorine linked to the carbon atom to form the molecules.

Polymerisation

Addition polymerisation

Condensation polymerisation

Addition Polymerisation

Similar monomers are added chemically one by one

Here, Vander wall's force is used as a basic principle for bonding

Example : Polyethylene

Polymerisation process is done by applying energy in the form of pressure and heat

If different monomers are joint together, then it is named as co-polymerisation process

Condensation polymerisation.

Two or more unlike ~~poly~~ monomers are linked

By-product are formed due to repitative elimination of smaller molecules

By-products are water ~~and~~ or ammonic

The formation of by-products is known as condensation

It require high pressure and 'n' number of hours or 'n' number of days to complete the process

Properties of plastics

* Elongation
* Heat Resistance
* High Rigidity
* Insensitive to tension cracks
* Surface hardness
* Maximum usage temperature
* High viscosity
* Density
* Ignition Temperature
* Humidity absorption
* General chemical resistance

The properties of plastic are modified by the addition of agents like additives and fillers

Additives

Plasticizers:

It is in the form of liquid with high boiling point

It act as an internal lubricant for increasing the toughness and flexibility

It helps to deform the molecules easier

Example: Water, organic solvent.

Catalyst

It is also named as accelerator or hardeners

It is usually added to promote faster and complete polymerisation.

Dyes and pigments:

These are added to impart a desired colour to the material.

Initiators

It is used to initiate the reaction of polymerisation

It stabilize the end reaction of the molecular chain

Example: H_2O_2 is a common initiator

Modifier

It is used to improve the mechanical properties of plastic like strength, toughness, plasticity, ductility, etc....

Lubricants:

It is used to reduce friction during process.

It helps to prevent parts from sticking to mould walls

It helps to prevent parts from sticking to each other

It prevent polymer film from sticking

Example: oil, soap and waxes.

Flame retardants

It is added to the plastic to enhance the non-inflammability of the plastics.

Example : Bromine, phosphorous and compound of chlorine

Solvents :

It is useful for dissolving certain fillers or plasticizers and helps to allow the processing in the fluid state

Example : Alcohol

Filler

It is used to economize the quantity of polymer required. It helps to improve the strength and stability of the plastics.

Example : Mica, cloth fiber

Mica and asbestos are used to improve the heat resistance capacity of the plastics.

Types of plastics

Thermosetting plastics

Thermo plastics.

Thermosetting plastics.

The plastics are hardened by heat effecting non reversible chemical change are called thermo-setting

They are made from chain which have been linked together referred to as cross-linked.

It has three dimensional network of molecules and will not soften when heated

They are practically insoluble, Fireproof and usually hard and brittle.

It cannot be reused.

Various types of thermosetting plastics (Resin or Polymers)

Phenol formal dehyde

It is also known as bakelite.

It is made by the reaction of Phenol with formaldehyde

It is generally produced in dark colour

It is excellant insulating quality

It can be easily laminated

Example products:

plug, knob, lavatory seat, printed circuit board

Polyster resin:

Good electrical resistance

Application: T.V parts and car bodies.

Draw back: High cost

Melamines

Excellant electrical and heat resistance

Good Stability

low moistore absorption

It is also named as Mel mac, catlin, plaskon

Application: Telephone set, circuit breaker, Switch panels

Phenol furfural:

Good resistance to Moisture and electricity

Good flowability at low Moulding temperature and

set quickly at correct temperatore

Application: Instrument cabinet, Brake lining

Epoxy Resin

Good chemical and electrical resistance

Available in the form of liquid

Good resistance to wear and impact

Quite expensive

Application: Tools and dies jigs and fixture

Housing of electrical parts

Silicones

High resistance to high temperature up to 260°C

In liquid form, it is used as liquid repellants

It can be compressed and rein forced

Application : Induction heating aparatus, laminates and coating

Amino resin (urea formaldehyde)

It is obtained by condensation of urea and aqueous formal dehyde

There two main groups

Urea formal dehyde

Melamine formal dehyde

It can with stand up to 77°C

Application : Dinnerware, Radio cabinets, clock cases.

Alkyds

It is also called as oil modifeed polyesters.

It is used in solid form where high electrical resistance and heat resistance are required

Application : Automobile ignition parts.

Polyurethanes :

It is mainly used for cushions in transporation seats for insulation

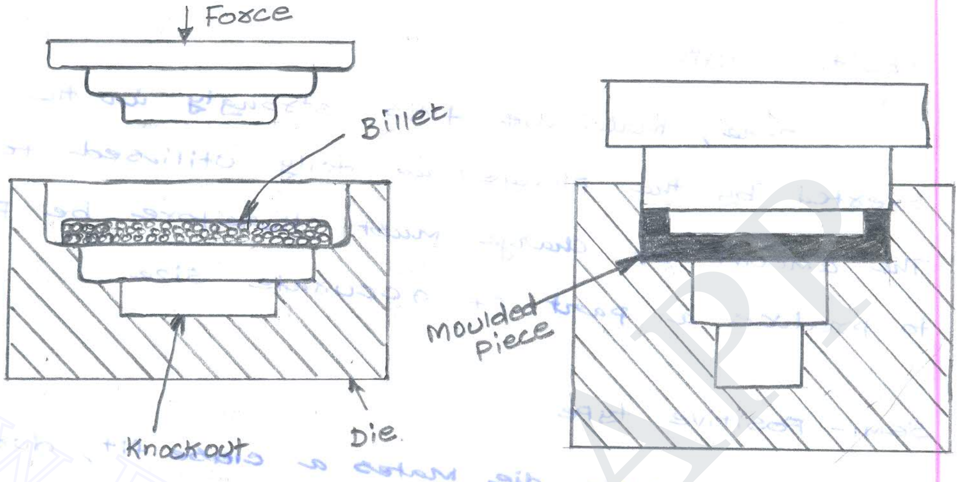
Electronic equipment as a packing material.

Processing of Thermosetting Plastics

Compression Moulding

Transfer Moulding

Compression Moulding



Compression moulding is one of the forming method for thermo setting plastics.

In this process, a measured quantity of charge (Power material in the form of semi solid or compressed pre-form of material) placed in a die cavity.

Now, the die cavity is closed, heat and pressure are applied through downward moving die to the material until it soften and is force filled in to the mould cavity.

Now, polymerisation process takes place and the material is hardened to the required shape. Curing is supplied through the walls of cavity by steam

The wall thickness of the parts produced by this method is not more than 3 mm

Pressure = 3·5 MPa for Polyester

Temperature = 1100°c to 2200°c

Cycle time = 10 sec

The compression moulding is also done in cold moulding also.

This method is not suitable for closed tolerance and good surface finish.

There are three types

1) Positive type

Semi - Positive type or Flash type

Positive type:

Here, Male die fits strongly in the mould. The force exerted by the plunger is fully utilised to fill the mould. The amount of charge must therefore be precisely controlled to produce a part of accurate size.

Semi - Positive type

Here, Male die mates a close fit, during last few millimeter of its travel only. Full pressure is exerted only during the final closing of the mould and excess material appear as a small flash.

Flash type

In this type, the male die closes the mould bearing on a narrow flash ridge. In this case, excess material is squeezed out around the cavity as flash. Then it is removed from the moulded article, after ejected from the mould.

This method is cheaper, because close fit of the plunger is not required.

Merits.

1 Moulded parts do not have high stresses
2 It produce fewer knit lines and less fibre length degradation
3 Higher production rate
4 Able to mould large, fairly intricate shape
5 Lower tooling cost
6 Simple process

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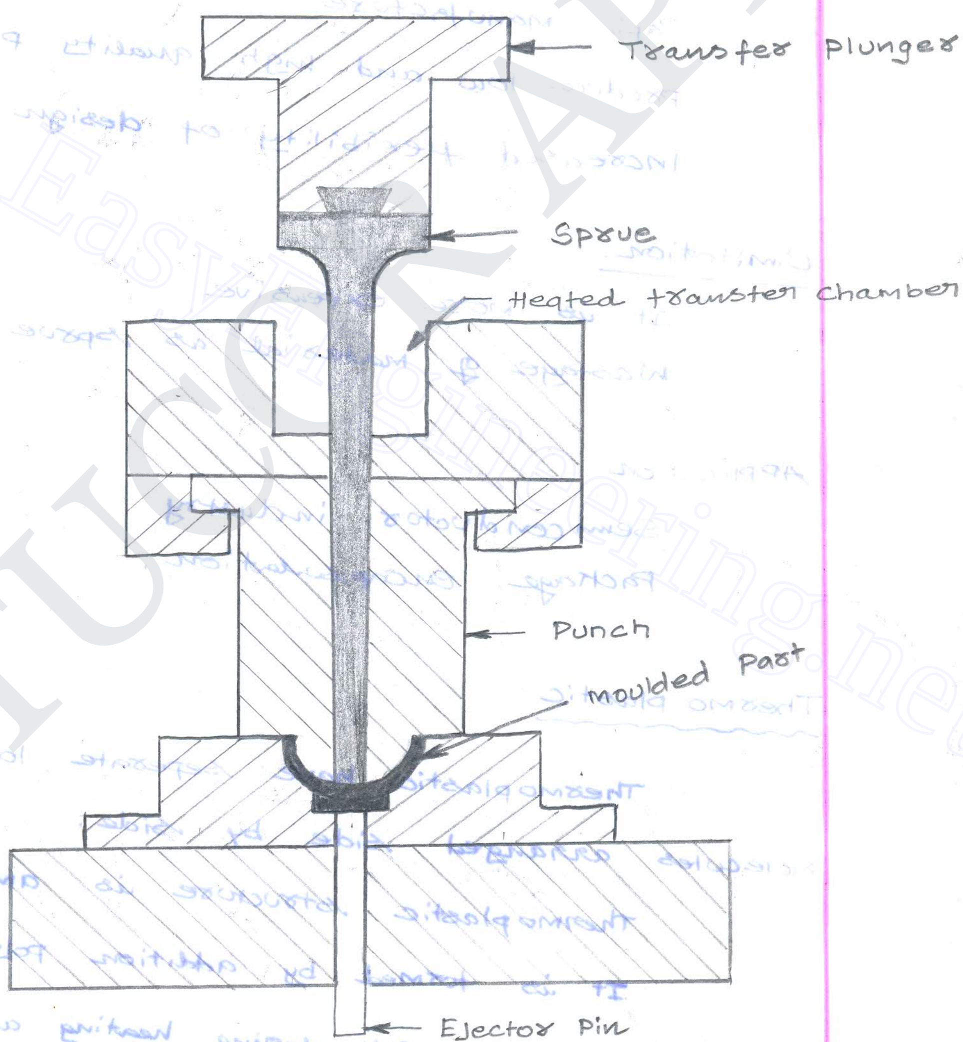
Demerits.

Compression moulding often results in turbulance and uneven flow of liquid plastic in the mould because of non-uniform pressure.

Application:

~~and~~ uni directional tapes
woven fabrics
Chopped strand.

Transfer moulding



Transfer moulding also named as resin transfer moulding.

A measured quantity of pre-heated moulding material is inserted in the chamber called pot.

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A plunger force the material through channel known as sprue in to the mould cavity.

The mould wall are heated to a temperature above the melting point of mould material. It helps to faster flow of material through cavities.

Ejector pins are used to remove the parts from the cavity, after solidification.

Advantages

It is good for making complex parts.
Larger structure can be moulded
Rapid manufacture
Produce low and high quality products.
Increased flexibility of design and lower cost.

Limitation.

It is more expensive
Wastage of material. as sprue and residual material.

Application

Semiconductor industry
Package encapsulation.

Thermo plastic

Thermoplastic have seperate long and large size molecules arranged side by side.

Thermoplastic structure is amorphous in nature.
It is formed by addition polymerization.
They are soft during heating and hard while cooling
Easy to remould and extrude to any shape

There are two major categories.

1 Cellulose derivatives
2 Synthetic resins.

Cellulose Derivatives.

1) Cellulose nitrate

It is obtained by treating the cellulose with a mixture of nitric and sulphuric acid

Benefits

High toughness
Good resistance to moisture
Highly inflammable

Application

Spectacle frames
Pen bodies
Table tennis balls

2) Cellulose acetate

It is obtained by treating the cellulose with acetic acid.

For better stability and mechanical strength, it can be injected and compressed in the mould

Benefits

lighter than cellulose
Tendency to absorb moisture

Application

Photographic film
Button
Toys

3) Ethyl cellulose

lightest of all cellulose derivatives.

Benefits

Good electrical properties
Chemical resistance
Surface hardness and strength

Application

Moulded article, Jigs and fixtures, Hose nozzles

Cellulose acetate - butyrate

obtained by treating cellulose with acetic acid and butoric acid.

Benefits

Good stability against light, heat and moisture absorption tendency.

Application

Insulation tapes, Handles

Radio cabinet

Cellophane :

It is available in extruded form. It has attractive appearance

Benefits

Good resistance to moisture, Fire and solvents

Application

Curtains

wrapping and packaging

Cellulose propionate.

Temperature withstand upto 93°C

Easy to mould

Low tendency for moisture absorption

Application

Fountain - pens, Telephones, Flash light cases.

Synthetic resins

Types	Description	Application
Polyethylenes	Very high resistance to acid, alkalizes Solvent can be made flexible tough and good Insulator low water absorption	Fabric Tray Corrosion resistance coating

Polystyrenes	Dimensional Stability Strain resistance Easy to mould Crack under load Easily Jointed by Cementing	Battery Boxes toys table ware radio Parts
Acrylic resins	High transparency tendency Resistance to Moisture Good strength	Tubes, Plates Display cases Helmet, lenses
Vinyles	Flexible or rigid Good electrical and weather resistance Trade name is PVC	Tarpaulin Rain coats water roofing insulation
Polytetra fluoroethylene	Trade name is Teflon Temperature withstand up to 288°C Cannot dissolved in any solvant low friction low adhesion	Gasket electrical insulator Chemical Containers
Polyamide	Trade name is Nylon High strength toughness and elasticity Good insulator and wear resistance	Yarn for cloth wire insulation Combs
Methyl Methacrylate	It can be formed at 120°C Trade name is Lucite and Plexiglass	Aircraft parts Contact lenses surgical instruments

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Thermoplasic	Thermosetting Plastic
It is soften by heating	It cannot be soften
Structure is made of linear chain molecules	Structure is made of cross linked molecules
It is produced by addition polymerization method	It is produced by condensation polymerization method
It can be reproduced	It cannot be reproduced
The temperature increase with increase in plasticity	Plasticity is stable at high temperature.
It can be remoulded	cannot be remoulded
Softer and less strong	Harder and strong
Scrap can be reused	Scrap cannot be reused

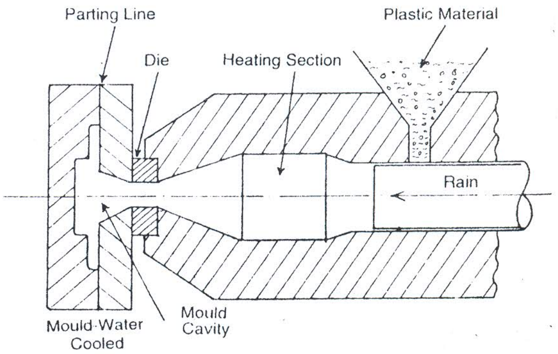
Moulding and typical Application of thermoplastics.

- Injection moulding
  - Plunger type
  - Screw type
- Blow moulding
- Rotational moulding
- Film blowing
- Extrusion
- Thermoforming
  - Vaccum forming
  - Pressure forming
  - Drape forming
  - Twin sheet forming
  - Simple sheet bending
  - free blowing

STUCOR APP

INJECTION MOULDING

Plunger type



Working principle:

The injection moulding is used to achive high speed moulding of thermoplastics.

The working principle of this process is that the molten thermoplastic is injected in to a mould under high pressure.

Injection moulding can be done by two method

1) Plunger type
2) Screw type

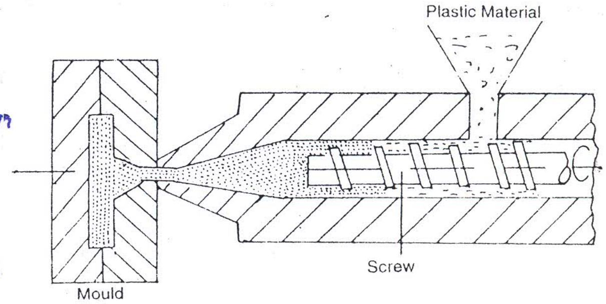
Plunger type

The moulding material is loaded into a hopper from which it is transfered to a heating section by a feeding device, where the temperature is raised to 150°C - 370°C and pressure is build up. The material melts and is forced by an injection ram at high pressure through a nozzle and sprue into a closed mould which form the part.

The mould is in at two section, so that the finished component can be ejected easily. For the process to be competitive, the mould must be fairly cool and consequently the mould must be cooled by circulating water.

Screw type

The improvement method to the ram type injection moulding is screw type injection moulding.



The rotation of the screw provides the plasticizing action by shearing and frictional effect and the axial motion of the screw provides the firing action.

Benefits

High production capacity

Suitable for making complex thread and intricate shape

Limitation

Equipment should be non corrosive

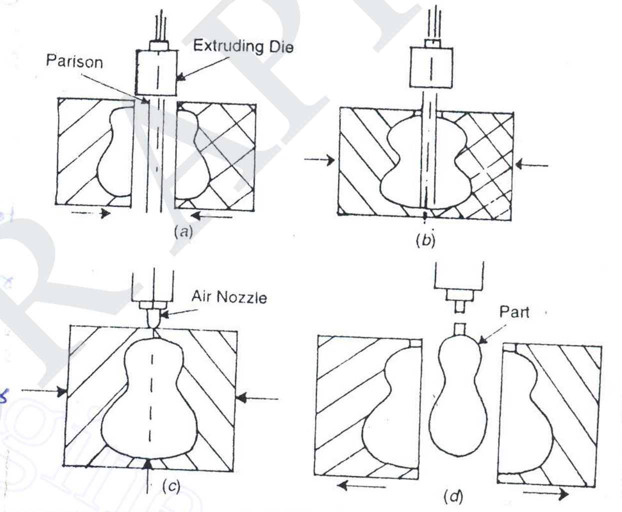
Reliable temperature controls are essential

Range of capacity : $12 \times 10^3\ mm^3 - 2.2 \times 10^6\ mm^3$

Force range = 0.1 MN – 8 MN

Pressure range = 100 Mpa – 150 Mpa

BLOW MOULDING



In this process, a hot extruded tube of plastic called a parison is placed between the two part open mould. The two halves of the mould move towards each other so that the mould closes over the tube. The tube gets pinched off and welded at the bottom by the closing mould. The tube is then expended by internal pressure usually by hot air, which force the tube against the wall of the mould. The component is cooled and the mould open to release the component

Types

Injection blow moulding

Extrusion blow moulding

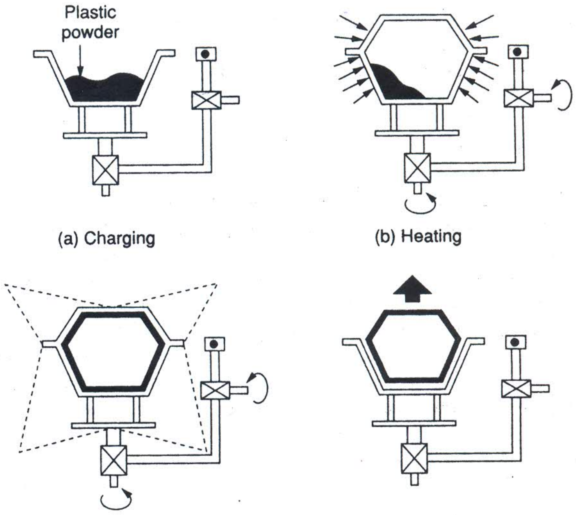
Multi layer blow moulding

Application

Plastic beverage bottle

Hollow container.

ROTATIONAL MOULDING



(a) Charging
(b) Heating
(c) Cooling
(d) Demoulding

This process is also called as roto-moulding

In this process, the product is formed inside a closed mould that is rotated about two mutual perpendicular axes, major and minor axis, as heat is applied.

The difference between the other moulding processes with rotational moulding is that only heat is required for the mould whereas in other processes heat and pressure are required to plasticise the material

working:

A Powdered plastic is poured into the mould and its halves are then clamped shut.

The loaded mould rotates the power melt and is distributed on mould cavity. walls by gravitational force, and not by centrifugal force.

The mould is then cooled and when the plastic has hardened sufficiently, the mould is opened and the article is removed

Process parameter

Rotational speed of major and minor axis are controlled by two seperate motor in the ratio of 3:1

Rotational speed of major axis motor is 18 rpm

The mould temperature range is 260°c - 370°c

Benefits

Low cost per unit produced

Excellant surface finish.

Low Initial investment

Draw back

Low production rate

Simple shape only can be produced.

Application

- Children toys
- Drum for food beverages
- Gasoline tanks
- Garbage container

THERMOFORMING

Thermoforming is the shaping of hot sheet or strip into 3D object either by Mechanical or pnematic Method

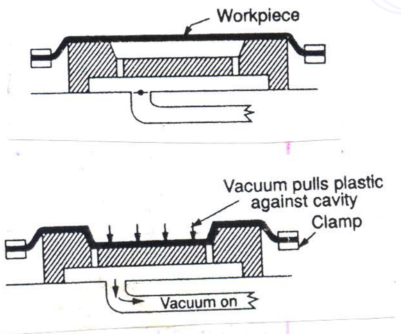
Thermoforming can be used to produce items smaller than a drinking cup and larger than a boat hull.

Different form of thermoforming techniques are

- Vacuum forming
- Pressure forming
- Twin sheet forming
- Drape forming
- Free blowing
- Simple Sheet bending

Each techniques is used to manufacture a product with slightly different characteristics.

Vacuum forming



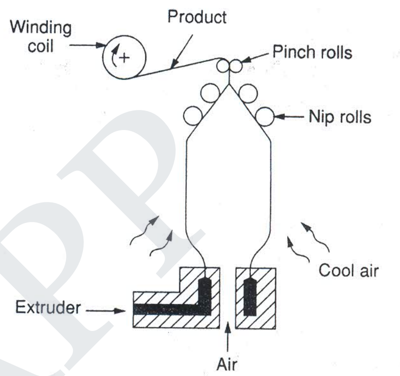
A piece of plastic sheet is clamped into a frame. The plastic is heated with electric heater, until it begin to sag. Air or mechanical Pressure is then applied through a small hole in the Mould and the plastic is rapidly Pulled tightly against the Mould creating close profile conformity. The frame is raised, the part is removed and then trimmed in a Punch press, The product produced will vary in thickness The Material touching the mould will be the thinnest. This is because of the material that has been stretching the largest and therefore has thinned the most. The mould may have several shapes for the small part or for different parts.

Application

useful for making tray
Refrigeration door lines
Panel for shower stall and advertising signs.

FILM BLOWING

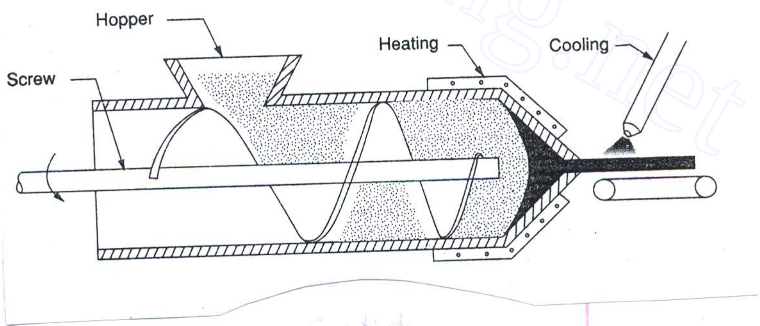
Film blowing is also called blown tubular extrusion. It produces plastic film by extruding a tube vertically through a ring die. Then it is blown with air in to a larger diameter cylinder. The blown cylinder is air cooled as it rises vertically, then it is flattened by driven rolls before it reach the winder.



This process is used to produce trash bags and packaging materials.

EXTRUSION

The operation of the extrusion process is similar to squeezing of tooth paste from a tube.



Extrusion is perform in extruder. It is simple in design and consist of a screw feed that advances the pre heated plastic material from the hopper and force it out through die opening.

Steam or hot oil is used to heat the material and also to heat the die to keep the material in plastic state throughout the operation

Working

The Starting Material (chiefly polyethylene, Polypropylene Poly vinyl chloride and poly styrene) which is usually in powder or pellet form is placed in a feed hopper.

It is then allowed to fall from the hopper into an extruder barrel. As the Screw extruder is rotated, the Material passes through a pre-heating zone, where it is heated homogenized and compressed, and is finally forced through the die.

The extruder Material comes on to a conveyor where it is cooled by air or water spray

It is used for producing long product of uniform cross section such as rods, tubes, channels.

Plastic coated wire and cables are also produced by this process.

Benefits.

wide tolerances

Simple in operation

Plastic film and tubing can be produced

High production rate

Limitation

Sharp corner in the die design should be avoided

Uneven wall thickness in the die results in non uniform plastic flow and tends to wrap the extrude

Application.

tubes

films

Bonding of thermoplastics

Bonding can be done by application of heat and pressure. The bonding of thermoplastic can be grouped in to two major categories

1) Chemical Bonding
2) Thermal welding

Chemical Bonding

It is an effective method for assembling plastic parts. This method produce clean looking joint with low weight and sufficient strong connection.

There are two method of chemical bonding

1) Solvent Bonding
2) Adhesive Bonding

Benefits

Sufficient ~~strong~~ connection

Suitable for heat sensitive plastics

Suited to leak tight applications

Limitation

Adhesives and Solvent are flammable

Preparation and curing time are long

Chemicals may be toxics

Thermal welding

It involves melting the bond line between the two parts to form a weld.

Benefits.

Fast, Economical and Safe

Types of thermal welding

1, Hot Gas welding

Hot tool welding

Ultrasonic welding

Induction welding

Chemical bonding

Solvent Bonding

In this process, the surface of the parts to be bonded are treated with a solvent. Due to this, the surface get soften and pressure is applied to the joint with the evaporation of the solvent. Adhesives are not used in this process. This process is used in amorphous thermoplastics.

Different solvent can be mixed to produce a mixture with optimal properties.

If two dissimilar materials are to be joined, a mixture of two miscible solvent specific to the different polymer can be used.

For example

A mixture of methylene chloride and ethylene dichloride is sometimes used for Xantar poly carbonate and poly carbonate blends. Because methylene chloride evaporates faster than ethylene chloride.

Procedure for solvent Bond

1. Clean the surface of the mating parts
2. Parts having a single joining surface are simply pressed against a sponge
3. The quantity of solvent must be kept minimum to avoid drip and crazing
4. It may be necessary to allow a few seconds to ensure sufficient swelling
5. The parts are then clamped together with a moderate pressure.
6. unclamp the parts, Heat can be used to accelerate the over all rate of evaporation and to reduce the cycle time

Advantages.

Homogeneous distribution of Mechanical load

Good aesthetics

Economic assembly

Good sealing and insulating properties.

Limitation

Stress cracking

No Disassemble possible

Assembly hazard such as fire or toxicity

Dissimilar material can only be joined

High solvent evaporation time.

Adhesive Bonding

In adhesive bonding, a third substance bond a plastic to another material like wood, metal, glass, ceramic, rubber

Types of Adhesive

1 Epoxy

2 Polyurethane

3 Acrylic

4 Cyano-acrylic

5 Silicone

Advantages

Applicable to various substrate like thermoplastics thermoset, elastomer and metal

Homogeneous distribution of Mechanical load

Economic assembly

No thermal stresses introduced

Limitation

Stress cracking

Not possible for disassemble

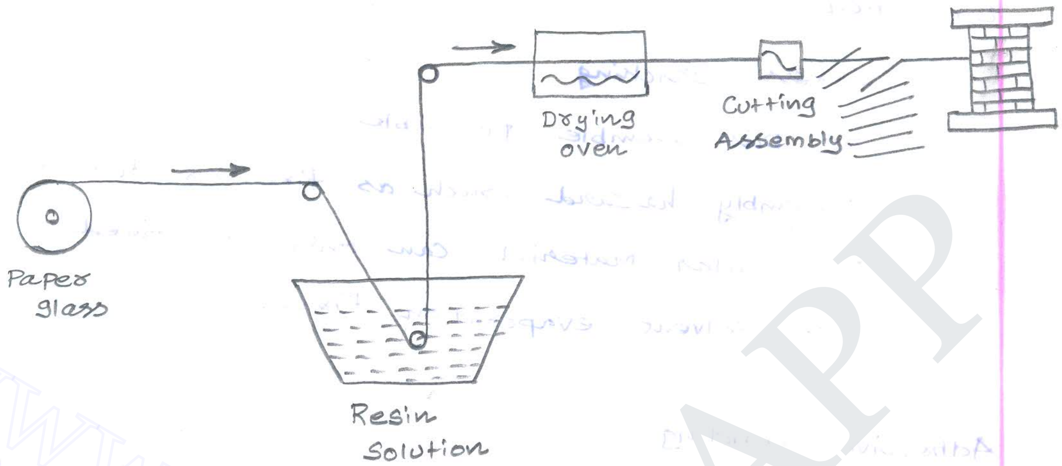
Assembly hazard such as fire or toxicity

Curing time is dependent on the adhesive

Lamination process

Two types

1) High pressure laminates
2) Low pressure laminates



In high pressure laminates, the pressure is applied upto 7 MPa and temperature of about 150°c.

In low pressure, laminates, the applied pressure is less than high pressure laminates

Material such as asbestas, cotton, fibre are fabricated by this process.

The low pressure laminates also called as Reinforced Plastics

Working

Paper and glass are immersed in the resin solution using roller and then resin mixed plastics are dried in the drying oven. The dried plastics are cutting section After cutting, it will be pressed by the press.

Process involved

Saturation of the base with the resin solution
wet drying
Size cutting
Pressing

Characteristics of reinforced plastics

Elastic stability

Less weight

Application

Storage bin

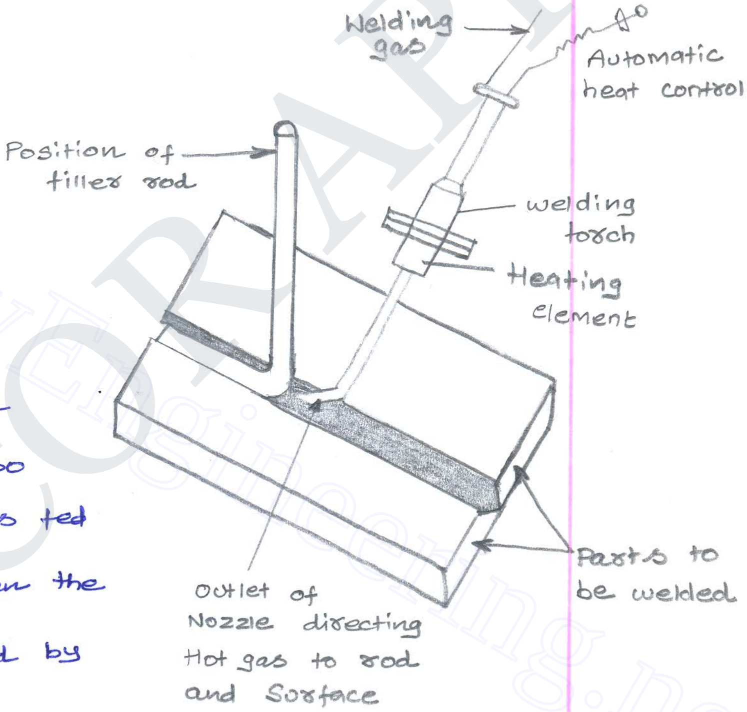
Horns

thin sheet

Aircraft panel

Thermal welding

Hot gas welding



A stream of Hot gas is directed towards the joint between the two thermoplastic parts to be joint.

The hot gas soften the polymer. A filler rod is also heated by the hot gas and is fed into a prepared joint between the two parts. A weld is formed by the fusion together of the thermoplastic parts and the filler rod.

Temperature of hot gas – 350°c for PC and PC blend
– 80°c – 100°c for Semi crystalline Material

Travel speed = 0.1 m/min to 0.3 m/min

Gas flow rate = 16 – 60 l/min

Advantages

Suitable for very large product

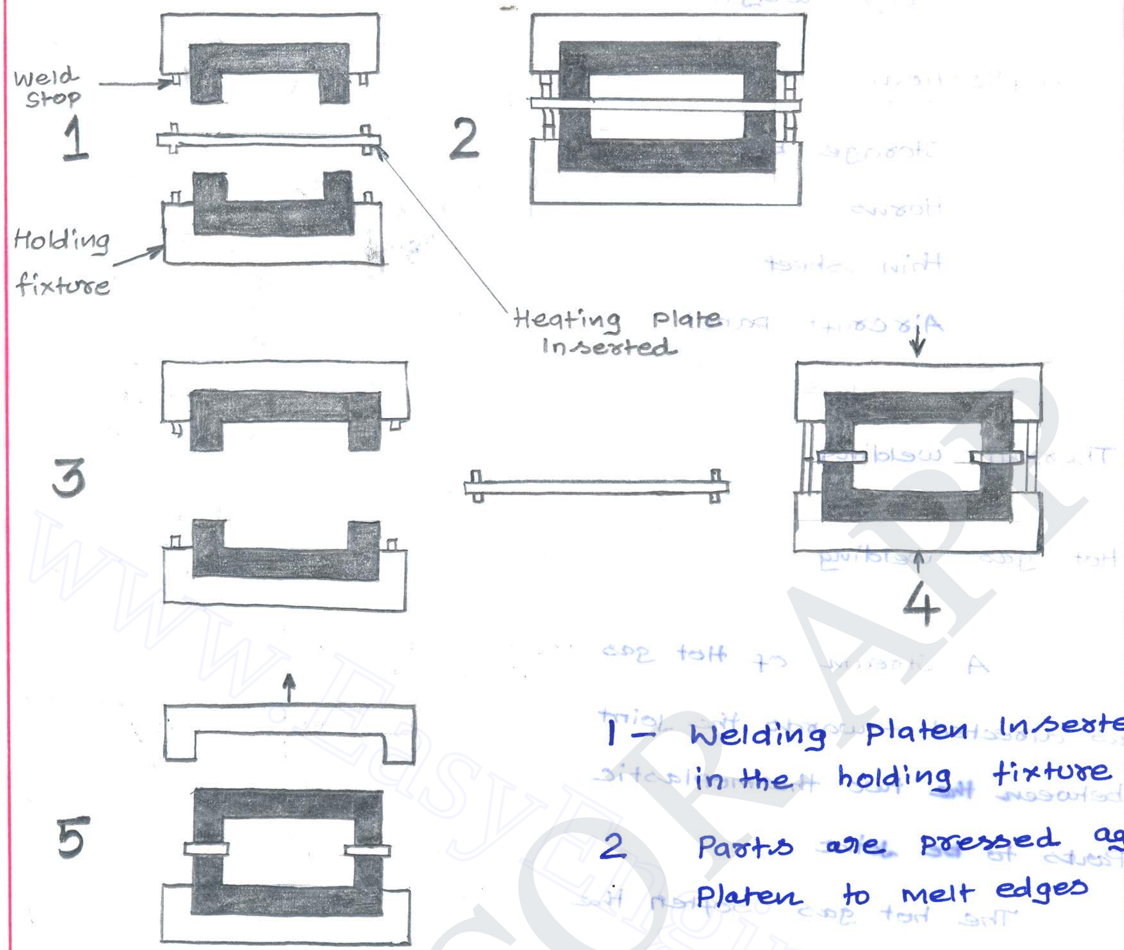
Suitable for field assembly, repair and prototypes

Simple equipment, Easily Portable

Hot tool welding

or

Hot plate plastic welding



1 — Welding platen inserted in the holding fixture

2 Parts are pressed against Platen to melt edges

3 Heating platen withdrawn

4 Parts are pressed against each other

5 Parts Removed from fixture

Working Process :

1 Prepare the work holding fixture and heating plate as shown in figure (1)

2 Heating plate are inserted between the work surface and pressed against each other, until the both surface get soften. Recommended pressure range is about 0.1 to 0.5 MPa

3, Then the heating plate is withdrawn from the works surface and ready to join the work piece against work surface

4 once again, the work surface are pressed together by applying mechanical pressure for 10 - 20 sec Now, the work surface are joined together

5 unclamp the fixture and remove the work piece from the fixture.

The cycle time for complete the operation is about 60 sec and the recommended plate temperature is about 100-160°c

Poly tetra fluroethylene coating is recommended for hot place, to avoid sticking of parts to it. Its working temperature is about 450°c

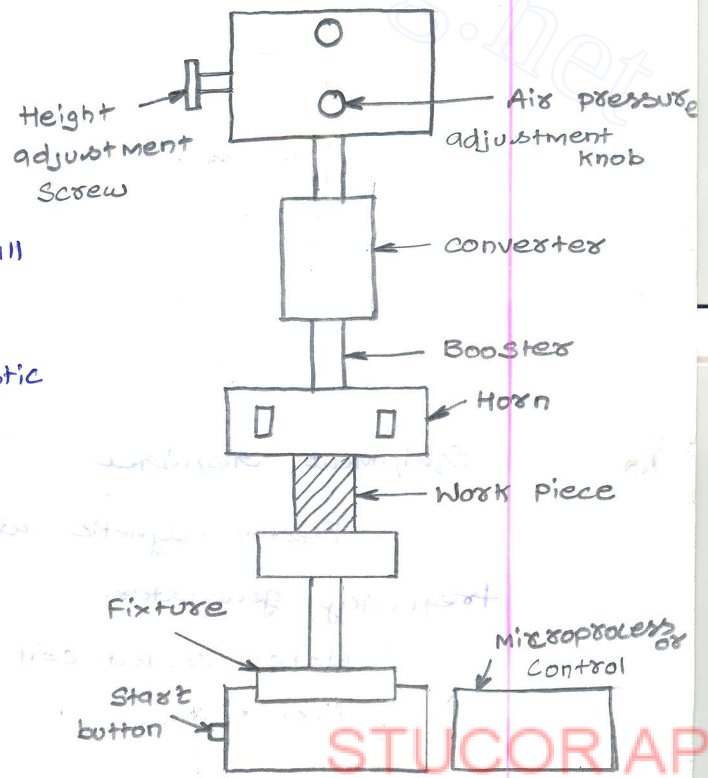
Advantage

Cost effective
Large batch size possible
Suited for soft materials
No electrical field, No mechanical vibration
Strong bond

Limitation

Long cycle time
Molten Polymer exposed to open air

ULTRASONIC WELDING



It is the most common fast and cost effective thermal method for joining small and medium sized parts of amorphous and crystalline plastic

It applied high frequency energy [20 - 40 KHZ] directly to the interface between parts.

As a result of the friction between the parts and the internal friction in the parts, heat is generated

This cause the polymer to melt at the interface. when vibration stops, the weld cool down and solidifies.

The process cycle time is very short [less than 2 sec] and forms a continuous leak proof joint that is often as strong as the base material.

Various phases of ultrasonic welding

Solid friction phase

Transient phase

Steady state phase

Cooling phase

Advantages

Cost effective

Very fast cycle time

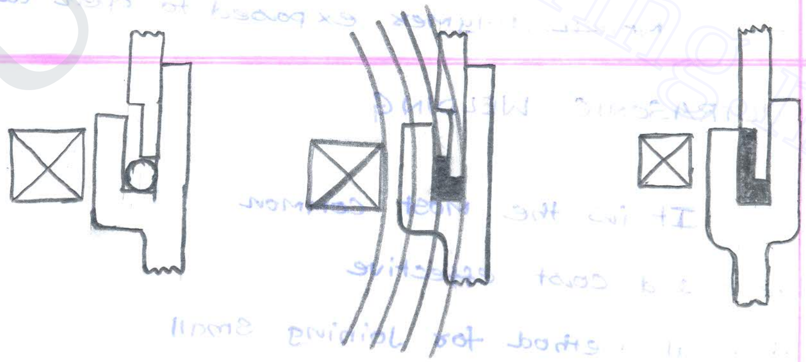
Large batch size possible

Limitation

Restricted to small and medium sized parts

Exposed to vibration during welding

Electromagnetic or Induction welding



Before welding | During welding | After welding

Equipment required

Electro magnetic welding equipment consists of a radio frequency generator.

Water cooled coil

fixture

The generator creates a high frequency current in the coil, producing an oscillating magnetic field in the joint area. The parts to be joined must be transparent to the magnetic field.

The high frequency magnetic field generates eddy current in the bonding material through induction and the hysteresis loss in this process is responsible for the heat generation.

The bonding material melts and the parts are joined under low pressure. The plastic solidifies again as soon as the magnetic field is switched off.

The bonding material can be supplied as extruded tape, strand or other profile or as a mould gasket for complex geometries or for ease of handling. It is normally produced from parts of the same polymer or from a compatible polymer.

The most commonly used joints are the tongue and groove joints and the step joints.

Advantages.

* Short cycle times
* 3D weld surface are possible
* Welding process is reversible (repairing & recycling)
* Tolerance on part dimensions are not tight

Limitation

* Electro Magnetic welding gasket materials is required
* Not well suited for parts containing electromagnetic sensitive items (metal inserts)