ME 2201 – MANUFACTURING TECHNOLOGY- I

Introduction

Manufacturing, in the broadest sense, is the process of converting raw materials into products; it includes

- Design of the product
- Selection of raw materials and
- The sequence of processes through which the product will be manufactured.

Manufacturing is extremely important for the national and global economies.

Manufacturing may produce discrete products, meaning individual parts or pieces, such as nails, rivets, gears, steel balls, and beverage cans. On the other hand, wire, sheet metal, tubing, and pipe are continuous products that may be cut into individual parts and thus become discrete products.

Manufacturing is generally a complex activity involving people who have a broad range of disciplines and skills, together with a wide variety of machinery, equipment, and tools with various levels of automation and controls, including computers, robots and material-handling equipment. Manufacturing activity must be responsive to several demands and trends:

i) A product must fully meet design requirements and specifications and standards.
ii) It must be manufactured economically and by environmental friendly methods.
iii) Production methods must be sufficiently flexible to respond to changes
iv) New materials, methods and integration with computers must be continuously evaluated and adopted.
v) Manufacturers should work with customers for timely feedback.
vi) Constantly strive for higher productivity.

Selecting Manufacturing Processes

Wide range of manufacturing processes is used to produce a variety of parts, shapes, and sizes. Also there is usually more than one method of manufacturing a part. Each of these processes has its own advantages, disadvantages, limitations, production rates and cost. The broad categories of processing methods for materials can be listed as follows:

- **Casting:** Expendable molding and permanent molding
- **Forming and Shaping:** Rolling, Forging, Extrusion, Drawing, Sheet Forming, Powder metallurgy, molding.
- **Machining:** Turing, Boring, Drilling, Milling, Planing, Shaping, Broaching, Grinding, Ultrasonic machining, chemical, electrical, and electro chemical machining, and high energy beam machining.

- **Joining:** Welding, Brazing, Diffusion Bonding, Adhesive bonding, and mechanical joining.
- **Micro-manufacturing and Nano-manufacturing:** Surface micromachining, dry and wet etching and electroforming.
- **Finishing:** Honing, Lapping, Polishing, Burnishing, Deburring, Surface Treating, Coating and plating.

It should be noted that no component can be produced entirely by one single category of manufacturing process For ex: Coin preparation: Ingots or plates are cast, rolled into sheets, and blanked in presses and coated, if necessary.

All manufacturing processes can be grouped into 2 major categories:

i. Primary manufacturing processes: Involved in the initial breakdown of the original material to shapes that can be processed into final products. Ex: Casting Rolling, Extrusion, etc
ii. Secondary manufacturing processes: These processes take the products of some primary process and change the geometry and properties to the semi-finished or finished stage. Ex: metal removing processes, metal forming processes.

The selection of a manufacturing process depends on

i. Type and nature of the starting material
ii. Volume of production
iii. Expected quality and properties of the material
iv. Technical viability of the process
v. Economy
vi. Geometrical shape, jigs, fixtures, gauges, equipment available
vii. Delivery dates

UNIT I

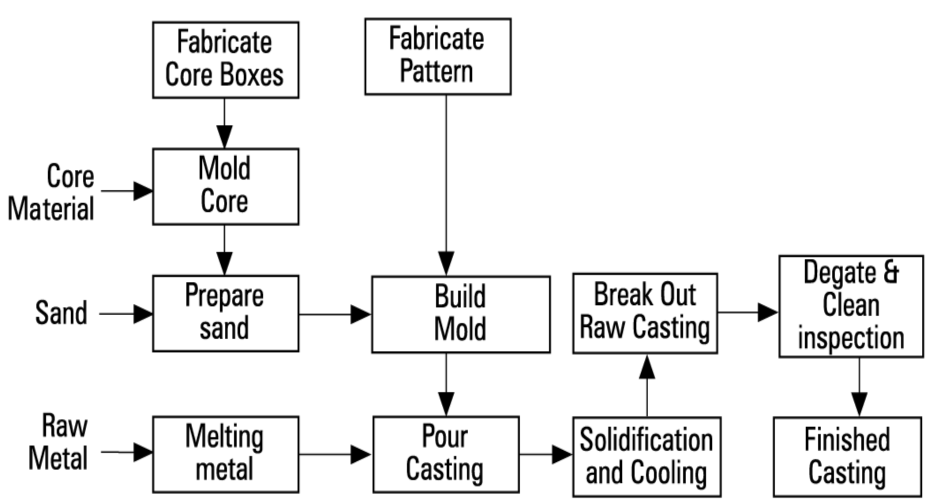
METAL CASTING PROCESSES

Sand casting – Sand moulds - Type of patterns – Pattern materials – Pattern allowances – Types of Moulding sand – Properties – Core making – Methods of Sand testing – Moulding machines – Types of moulding machines - Melting furnaces – Working principle of Special casting processes – Shell – investment casting – Ceramic mould – Lost Wax process – Pressure die casting – Centrifugal casting – CO2 process – Sand Casting defects.

Casting

Casting is one of the oldest methods and was first used around 4000 B.C. to make ornaments, arrowheads, and various other objects. Casting is the process of producing metal parts by pouring molten metal into the mould cavity of the required shape and allowing the metal to solidify. The solidified metal piece is called as “casting”. This process is capable of producing intricate shapes in a single piece, ranging in size from very large to very small, including those with internal cavities. Typical cast products are engine blocks, cylinder heads, transmission housings, pistons, turbine disks, railroad and automotive wheels etc. The steps in this process are :

1. Place a pattern, having the shape of the desired casting, in sand to create a mold.
2. Incorporate the pattern and sand in a gating system.
3. Remove the pattern.
4. Fill the mold cavity with molten metal.
5. Allow the metal to cool.
6. Break away the sand mold
7. Remove the casting and finishing it.
8. Inspect and testing
9. Removal of defects if any
10. Heat treatment for stress relief
11. Inspect the casting
12. Ready for use.

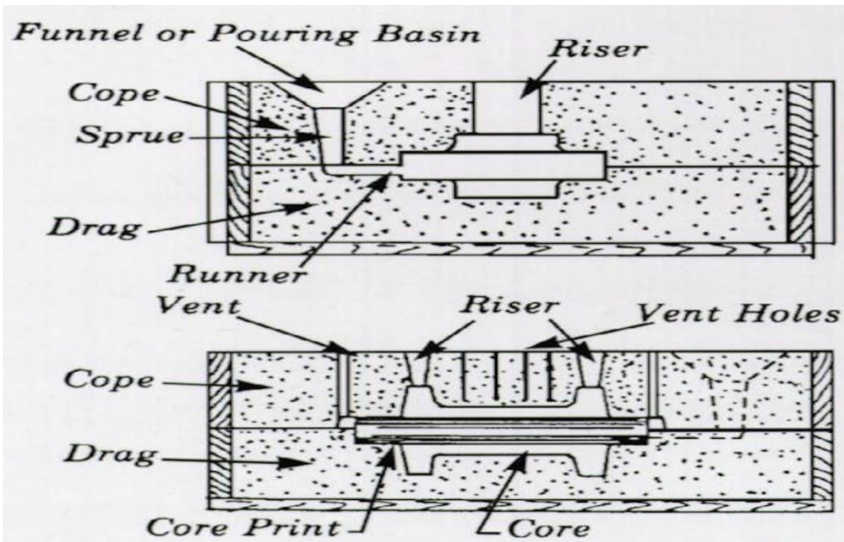


SAND CASTING

Types of Sand Mold Casting Process:

- Hand Molding:- Bench (small objects), Floor (Medium sized castings), and Pit molding (heavy)
- Machine Molding:

Example of hand molding operation- using two molding boxes



Casting Terms

1. **Flask**: A metal or wood frame, without fixed top or bottom, in which the mold is formed. Depending upon the position of the flask in the molding structure, it is referred to by various names such as drag - lower molding flask, cope - upper molding flask, cheek – intermediate molding flask used in three piece molding.
2. **Pattern**: It is the replica of the final object to be made. The mold cavity is made with the help of pattern.
3. **Parting Line**: This is the dividing line between the two molding flasks that makes up the mold.
4. **Bottom Board**: This is a board normally made of wood which is used at the start of the mould making. The pattern is first kept on the bottom board, sand is sprinkled on it and then the ramming is done in the drag.
5. **Molding Sand**: Sand, which binds strongly without losing its permeability to air or gases. It is a mixture of silica sand, clay and moisture in appropriate proportions.
6. **Facing Sand:** The small amount of carbonaceous material sprinkled on the inner surface of the mold cavity to give a better surface finish to the castings.
7. **Backing Sand**: it is what constitutes most of the refractory material found in the mould. This is made up of used and burnt sand.

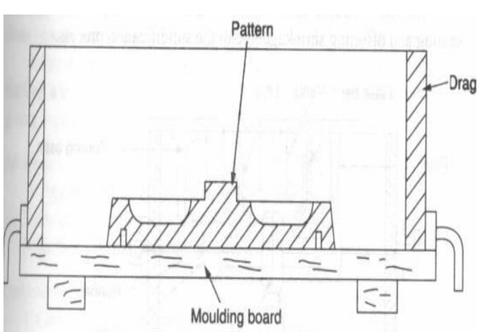
8. **Core**: A separate part of the mold, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.
9. **Pouring basin**: A small funnel shaped cavity at the top of the mold into which the molten metal is poured.
10. **Sprue**: The passage through which the molten metal, from the pouring basin, reaches the mold cavity. In many cases it controls the flow of metal into the mold.
11. **Runner**: The channel through which the molten metal is carried from the sprue to the gate.
12. **Gate**: A channel through which the molten metal enters the mold cavity.
13. **Chaplets**: Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force.
14. **Chill**: These are metallic objects which are placed in the mould to increase the cooling rate of castings to provide uniform or desired cooling rate.
15. **Riser**: A column of molten metal placed in the mold to feed the castings as it shrinks and solidifies. Also known as "feed head".
16. **Vent**: Small opening in the mold to facilitate escape of air and gases

Sand Molding Methods

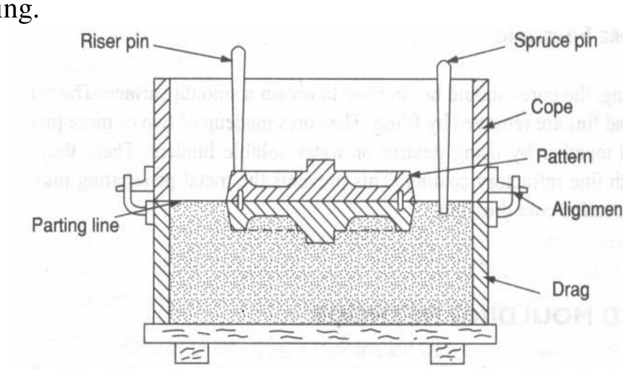
Green Sand Molding:

It involves ramming sand around a pattern inside a container called flask. The various steps are:

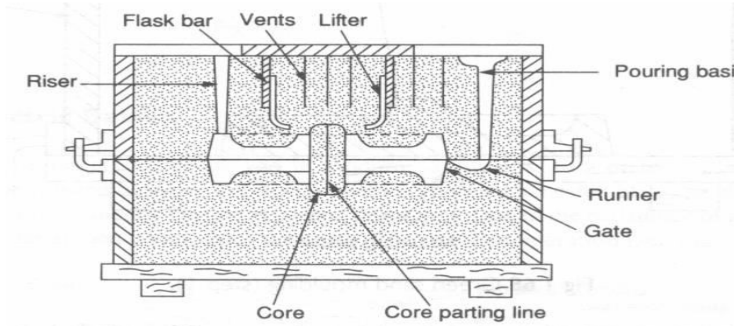
1. The bottom half of the flask (drag) is placed upside down on a molding board and then drag half of the pattern is placed inside the flask.
2. Parting Compound is dusted over the exposed surface. A layer of sand is riddled over the pattern and rammed. The drag is then filled, rammed and struck off.
3. Bottom board is placed on the drag and they are turned over. Molding board is removed and the top (cope) half of the flask is positioned using aligning pins. The cope half of the pattern is inserted.
4. Gating system is formed using sprue and riser pins. Risers and sprues are formed during ramming of the cope. Runners or gates are also formed during the molding process. The sprue is an opening through which the metal enters, the runner leads the metal into the mold cavity and the gate controls the floor of the metal into the cavity. Riser is a reservoir connected to the cavity, which provides metal during solidification and for offsetting shrinkage, Venting is often done at this point.
5. The flask is separated and the two pattern halves are removed. Cores needed for added details are placed in the mold cavities.
6. Mold is closed and metal is poured slowly into the mold and allowed to solidify.
7. The mold is destroyed to recover the casting.



Green sand moulding (step 1)



Green sand moulding (step 2).



Green sand moulding (step 3).

Dry Sand Molding

It is similar to green sand molding except that a different sand mixture is used and all parts of the mold are dried in an oven before being reassembled for casting. The green sand retains its shape depending upon moisture and the natural clay binder in the sand. But he sand used in dry sand molds depends upon added binding materials such as resin, clay, molasses and flour.

The materials are mixed thoroughly and tempered with thin clay water. The amount of binder is determined by the size of the casting. Metal flasks are used to withstand heat in the oven.

Before drying, the inside surfaces of a dry sand mold are coated with wet blacking, a mixture of carbon black and water, with a small addition of gum, to smoothen the surface of the casting.

Skin Dried Molding

This is similar to dry sand molding but instead of the whole mold, the skin of the mold, to a depth of 0.5 inch is dried using gas torches or heaters. Method is applicable for very large molds.

General Steps in Making Sand Castings process

There are six basic steps in making sand castings: 1. Patternmaking 2. Core making 3. Molding 4.Melting and pouring 5. Cleaning

PATTERN

Pattern is a replica of the product needed, with some allowances to compensate for the solidification and withdrawal of pattern after preparing the mold. The quality of the casting mainly depends on the material of the pattern, dimensional allowances given and technology used for pattern making.

Various factors affecting the selection of pattern materials are:

1. Accuracy and surface finish requirements in the casting (Metal and plastic patterns used)
2. Type of casting process and molding methods (machine molding- metal patterns, loam molding- plaster of Paris)
3. Possibility of frequent design changes (economical pattern-wood)
4. Number of casting to be produced (more quantity-repeated usage- metal pattern)
5. Intricacy of the casting (complicated shapes- metal pattern).

Requirements of a good pattern:

Easily available, Easy to machine, Light weight, Strong	Hard and durable, Dimensionally stable, Repairable and reusable, Facilitate good surface finish after machining

PATTERN MATERIALS

Sl.No	Pattern material and properties	Advantages	Limitations
1	**Wood-** Widely used when small numbers of castings are made. **Teak wood, mahogany and impregnated wood laminates are used**	Cheaper, easy to work, takes good surface finish and light in weight.	Cannot be used in machine molding as easily affected by moisture and abrasion of sand.
2	**Metal:** Used when large number of castings are needed. The metal pattern is itself cast from a wooden pattern called master pattern.	Dimensional stability, accuracy and strength. Not affected by moisture. Used for machine molding	Costly, heavier than wooden pattern and relatively difficult to work.
	Cast-Iron	Strong, takes smooth surface, resistance to abrasion	Heavy, easily broken rusted by moister
	Brass	Strong, does not rust, takes good surface finish and withstands wear and tear	Costlier, heavier
	Aluminium	Light, easy to work, resistant to corrosion, melts at low temperature, takes good surface finish, more accuracy	Soft and easily damaged
	White Metal -Used for making complicated and fine shapes in die-casting process	Low melting point, dimensionally stable, can cast intricate shapes	Soft and easily damaged
3	**Plastic:-** Cast from master wood pattern. Both thermosetting plastics and thermoplastic are used. Thermoplastics can be reused but not thermosetting plastics.	Does not absorb moisture, strong and dimensionally stable, ability to acquire glossy surface, light in weight and resistance to wear and tear. Can be withdrawn without affecting the mold.	
4	**Rubber:-** Dies for forming operations are normally done used for investment castings. Silicon rubber is commonly used.		
5	**Plaster- plaster of paris**	Has high compressive strength (300kg/sqm). Need a master pattern	Can be used for small patterns only.
6	**Wax:** Excellent material for investment casting**.** Additives are used for polymerizing and stabilizing.	Takes a high degree of surface finish. High tensile strength, hardness and weld strength.	

PATTERN ALLOWANCES

To compensate for any dimensional and structural changes which will happen during the casting or patterning process, allowances are usually made in the pattern. A pattern is different from the casting in dimensions and shape. The various allowances given in patterns to obtain the correct size and shape in the finished casting are:

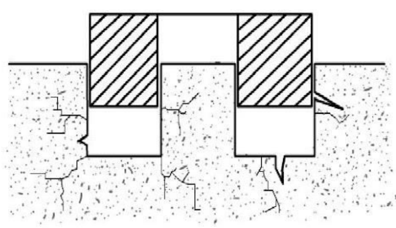
1. Shrinkage allowance
2. Distortion allowance
3. Finish allowance
4. Shake allowance
5. Draft allowance

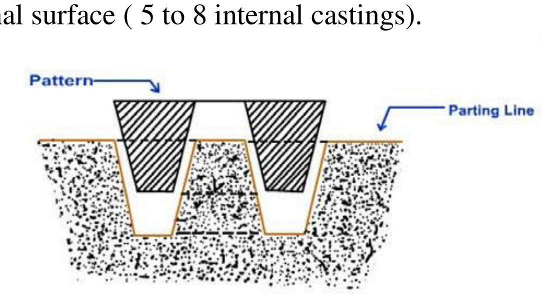
Shrinkage allowance

As the molten metal solidifies, it shrinks and contracts in size. To compensate for this, the pattern is made larger than the required casting by giving contraction / shrinkage allowances. This is done by using shrinkage/ contraction rule like 10 mm/m length of the casting. Different materials has different/varying shrinkages hence according to the metal, it will be applied on pattern making.

Draft allowance

When the pattern is to be removed from the sand mold, there is a possibility that any leading edges may break off, or get damaged in the process. To avoid this, a taper is provided on the pattern, so as to facilitate easy removal of the pattern from the mold, and hence reduce damage to edges. The taper angle provided is called the *Draft angle*. The value of the draft angle depends upon the complexity of the pattern, the type of molding (hand molding or machine molding), height of the surface, etc. Draft provided on the casting 1 to 3 degrees on external surface (5 to 8 internal castings).





Machining/ Finishing allowance

Rough surfaces of casting are to be machined to get exact dimension, surface finish etc. Extra metal provided on the surfaces is called machine finish allowance. Amount of machine finish allowance depends on

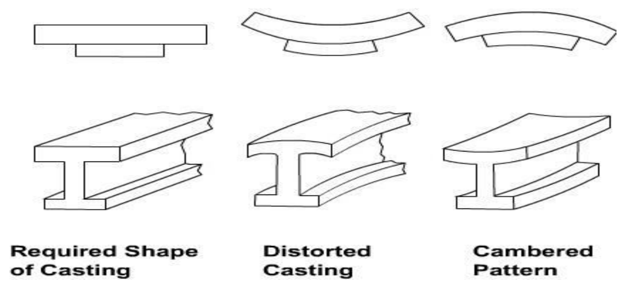
1. Type of metal used in casting
2. Size and shape of pattern
3. Method of moulding

Shake allowance

Usually during removal of the pattern from the mold cavity, the pattern is rapped all around the faces, in order to facilitate easy removal. In this process, the final cavity is enlarged. To compensate for this, the pattern dimensions need to be reduced. There are no standard values for this allowance, as it is heavily dependent on the personnel. This allowance is a negative allowance, and a common way of going around this allowance is to increase the draft allowance.

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.



TYPES OF PATTERNS

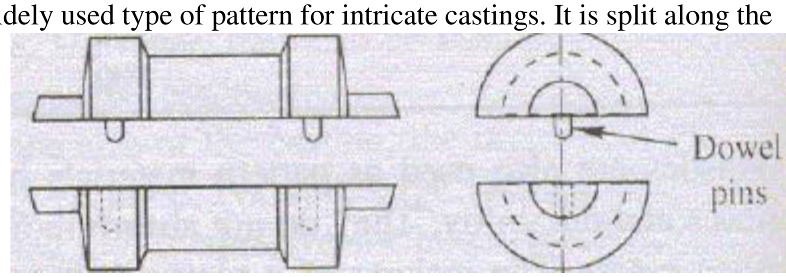
There are various types of patterns depending upon the complexity of the job, the number of castings required and the molding procedure adopted.

Single Piece Pattern

The one piece or single pattern is the most inexpensive of all types of patterns. This type of pattern is used only in cases where the job is very simple and does not create any withdrawal problems. It is also used for application in very small-scale production or in prototype development. This type of pattern is expected to be entirely in the drag and one of the surfaces is expected to be flat which is used as the parting plane. A gating system is made in the mold by cutting sand with the help of sand tools. If no such flat surface exists, the molding becomes complicated

Split Pattern or Two Piece Pattern

Split or two piece pattern is most widely used type of pattern for intricate castings. It is split along the parting surface, the position of which is determined by the shape of the casting. One half of the patternis molded in drag and the other half in cope. The two halves of the pattern must be aligned properly bymaking use of the dowel pins, which are fitted, to the cope half of the pattern. These dowel pins match with the precisely made holes in the drag half of the pattern.



Gated Pattern

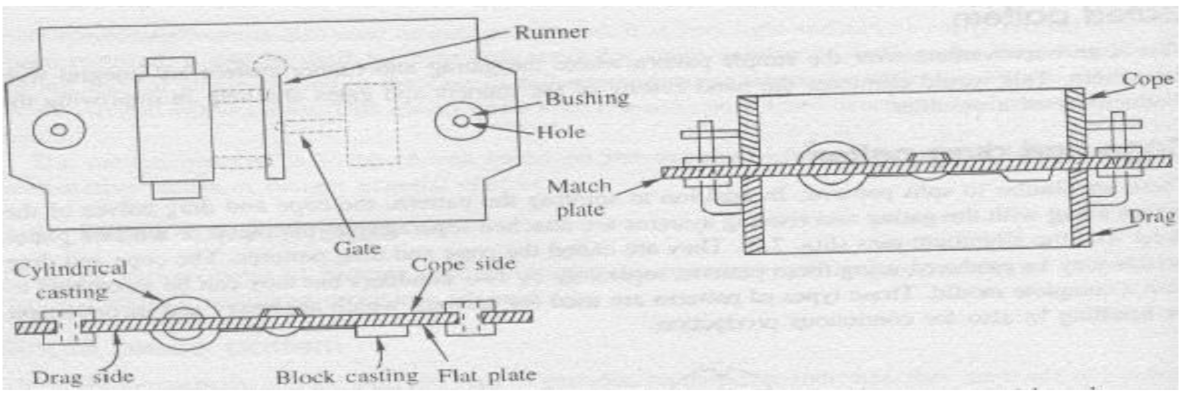
This is an improvement over the simple pattern where the gating and runner system are integral with the pattern. This would eliminate the hand cutting of the runners and gates and help in improving the productivity of a molder.

Cope and Drag Pattern

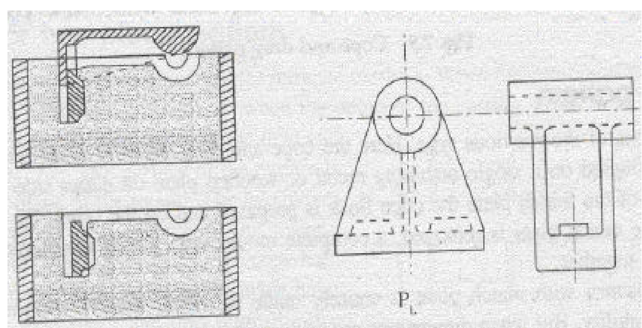
These are similar to split patterns. In addition to splitting the pattern, the cope and drag halves of the pattern along with the gating and risering systems are attached separately to the metal or wooden plates along with the alignment pins. The cope and drag moulds may be produced using these patterns separately by two molders but they can be assembled to form a complete mould. These types of patterns are used for castings which are heavy and inconvenient for handling as also for continuous production.

Match Plate Pattern

These are generally used for small castings with higher dimensional accuracy and large production. Several patterns can be fixed to a single match plate, if they are sufficiently small in size. These are used for machine molding.

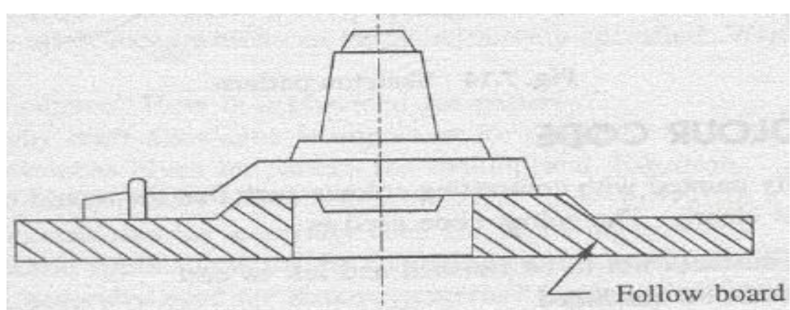


Loose Piece Pattern



This type of pattern is used when the contour of the part is such that withdrawing the pattern from the mould is not possible. Hence during moulding the obstructing part of the contour is held as a loose piece by a wire. After molding is over, first the main pattern is removed and then loose pieces are recovered through the gap generated by the main pattern. Molding with loose pieces is a highly skilled job and is generally expensive and therefore, should be avoided wherever possible.

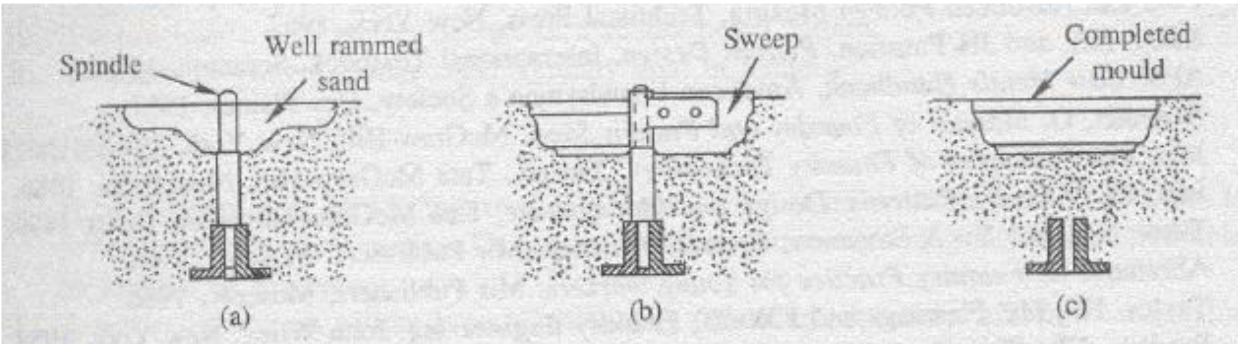
Follow Board Pattern



This type of pattern is adopted for those castings where there are some portions which are structurally weak and if not supported properly are likely to break under the force of ramming. Hence the bottom board is modified as a follow board to closely fit the contour of the weak pattern and thus support it during the ramming of the drag.

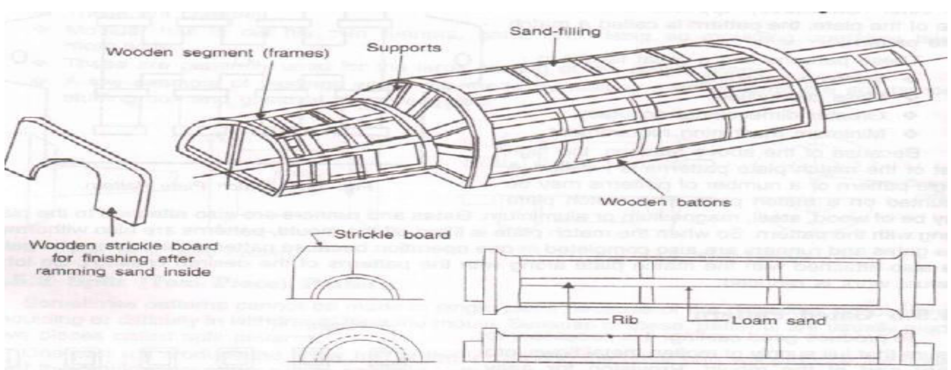
Sweep Pattern

It is used to sweep the complete casting by means of a plane sweep. These are used for generating largeshapes which are axi-symmetrical or prismatic in nature such as bell shaped or cylindrical. This greatlyreduces the cost of a three dimensional pattern. It is suitable for very large castings such as the bells forornamental purposes used which are generally cast in pit moulds..



Skeleton Pattern

It is made of strips of wood and is used for building the final pattern by packing sand around the skeleton. After packing the sand, the desired form is made with the help of a strickle. This type of pattern is useful for large castings, required in small quantities where large expense on complete wooden pattern is not justified.



MOLDING SAND

Molding sand is principle raw material used in sand molding because it possesses several major characteristics. Sand is formed by the breaking up of rocks due to the action of natural forces such as frost, wind rain, heat and water currents. The principle ingredients of molding sand are:

1. Silica sand grains
2. Clay
3. Moisture
4. Miscellaneous materials

Silica sand grains

Silica sand grains are the basic components of the molding sand. Molding sand contains 80-90% of silica, silica is obtained from quartz rocks or by decomposition of granite composed of quartz and feldspar. Silicon oxide imparts refractoriness, chemical receptivity and permeability.

Clay

Clay can be defined as those particles (below 20 µm in dia.) that fail to settle at a rate of 25 µm per minute, when suspended in water. It holds the sand together (bonds). The bonding depends on amount and quality of clay- normally 5 -20% of clay is used.

Moisture:

Clay imparts bonding action and strength to the molding sand in the presence of moisture, Generally 2-5% of water is added to sand. When water is added to the mixture, it penetrates and forms a microfilm coating on each particle.

Miscellaneous

Oxides of iron, limestone, magnesia, soda and potash, and other substances are found in the molding sand. Good molding sand contains less than 2 % impurities.

TYPES OF MOLDING SAND

General Classification

Natural molding sand Synthetic sand Special sand

According to use

1. Green sand
2. Dry sand
3. Loam sand
4. Facing sand
5. Backing sand
6. System sand
7. Parting sand
8. Core sand

Sl.No	Type of Sand	Details
1	**Natural Molding Sand**	It is obtained from natural resources like riverbeds. It has the required amount of clay to act as a bond between particles. It can also be obtained by crushing and milling yellow sand stone and carbiniferrous rocks. Advantages are – Ease of availability, Low cost and High Flexibility.
2	**Synthetic Sand**	Also called high silica sand, containing little or no binder in natural form and is also obtained by crushing quartzite sandstone. Binding is obtained by the addition of bentonite, water and other materials. Advantages of synthetic sand over natural sand are more flexibility, low maintenance cost and improved permeability. High cost and needs more control while use.
3	**Special Sand**	Used when special characteristics are needed. Zircon, Olivine, Chamotte, Chromate and chrome-magnatite.
4	**Green Sand**	Mixture of silica sand with 18-30% clay and 6-8% water. Contains water and is moist in natural state. Fine, soft, light and porous.Has sufficient plasticity and retains shape. Used for small and medium sized castings. Coal defects are mixed in green sand to prevent defects in castings. Molds prepared using green sand are called green sand molds.
5	**Dry Sand**	Does not contain water. Green sand is baked to remove all moisture. Suitable of large castings. Very strong and compact when compared to green sand molding. Blow holes will not occur. Dry sand molds are prepared thro this.
6	**Loam Sand**	Mixture of clay and sand, which is milled into plastic state. Loam sand contains up to 50% of clay. When it is applied to vertical surfaces it adheres to the surface. Loam sand moulds are prepared by sweeping the pattern over the sand. When dried, loam sand becomes hard.
7	**Facing Sand**	It contains silica sand and clay-not mixed with used sand. Has high strength and refractoriness. Different forms of carbon are added to prevent the metal from burning with sand. The thickness of the layer is 20-30mm and is usually 10-15% of the whole amount of molding sand.
8	**Backing Sand or Floor Sand**	Repeated used old sand. Used to fill behind the facing layer. Also called black sand due to presence of coal and burning when sand comes in contact with hot metal.
9	**System Sand**	Used in mechanized foundries. It is the used sand which is rejuvenated or reactivated by the addition of water, binder and special additives. No facing sand is used. Whole flask is filled with this sand.
10	**Parting Sand**	Dry and clean, clay- free silica sand. Used to prevent green sand from sticking to the pattern and also to prevent clinging of sand on cope and drag. When oil is used in molding sand, lycopodium is used as parting compound.
11	**Core Sand or Oil Sand**	Used of making core. It is the mixture of silica sand, linseed oil, light mineral oil, resin and other binding materials. Pitch or floor and water are used in making large cores.

SAND PROPERTIES

Molding sands, also known as foundry sands, are defined by eight characteristics: refractoriness, chemical inertness, permeability, surface finish, cohesiveness, flowability, collapsibility, and availability/cost.

Refractoriness — This refers to the sand's ability to withstand the temperature of the liquid metal being cast without breaking down. For example some sands only need to withstand 650 °C (1,202 °F) if casting aluminum alloys, whereas steel needs sand that will withstand 1,500 °C (2,730 °F). Sand with too low a refractoriness will melt and fuse to the casting.

Chemical inertness — The sand must not react with the metal being cast. This is especially important with highly reactive metals, such as magnesium and titanium.

Permeability — This refers to the sand's ability to exhaust gases. This is important because during the pouring process many gases are produced, such as hydrogen, nitrogen, carbon dioxide, and steam, which must leave the mold otherwise casting defects, such as blow holes and gas holes, occur in the casting. Note that for each cubic centimeter (cc) of water added to the mold 16,000 cc of steam is produced.

Surface finish — The size and shape of the sand particles defines the best surface finish achievable, with finer particles producing a better finish. However, as the particles become finer (and surface finish improves) the permeability becomes worse.

Cohesiveness (or **bond**) — This is the ability of the sand to retain a given shape after the pattern is removed.

Adhesiveness — The sand particles must be capable of adhering to another body. It is due to this property that the sand mass does not fall out of the molding box but is held firmly in it when the mold is removed or the molding box is lifted.

Flowability – The ability for the sand to flow into intricate details and tight corners without special processes or equipment.

Collapsibility — This is the ability of the sand to be easily stripped off the casting after it has solidified. Sands with poor collapsibility will adhere strongly to the casting. When casting metals that contract a lot during cooling or with long freezing temperature ranges, a sand with poor collapsibility will cause cracking and hot tears in the casting. Special additives can be used to improve collapsibility.

Availability/cost — The availability and cost of the sand is very important because for every ton of metal poured, three to six tons of sand is required. Although sand can be screened and reused, the particles eventually become too fine and require periodic replacement with fresh sand.

In large castings it is economical to use two different sands, because the majority of the sand will not be in contact with the casting, so it does not need any special properties. The sand that is in contact with the casting is called *facing sand*, and is designed for the casting on hand. This sand will be built up around the pattern to a thickness of 30 to 100 mm (1.2 to 3.9 in). The sand that fills in around the facing sand is called *backing sand*. This sand is simply silica sand with only a small amount of binder and no special additives.

CORES AND CORE MAKING

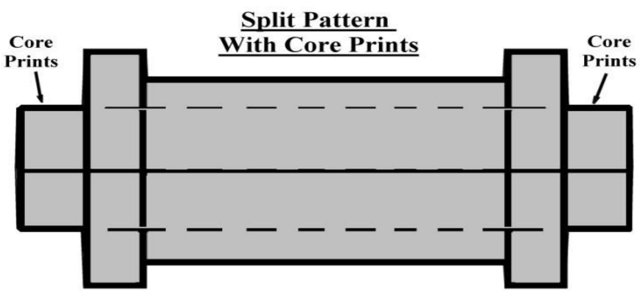
Many cast parts have interior holes (hallow parts), or other cavities in their shape that are not directly accessible from either piece of the mold. Such interior holes are generated by inserts called cores. A **core** is a device used in casting and molding processes to produce internal cavities and reentrant angles. The core is normally a disposable item that is destroyed to get it out of the piece. They are most commonly used in sand casting, but are also used in injection molding.

Cores are useful for features that cannot tolerate draft or to provide detail that cannot otherwise be integrated into a core-less casting or mold. The main disadvantage is the additional cost to incorporate cores.

Core are made by baking sand with other binder so that they retain their shape when handled. Binders added to the sand are linseed oil, phenol, bentonite, urea and water. To improve the properties of the sand, additives, such as pitch corn flour, straw, graphite, core dung and sea coal are also added.

Core Print

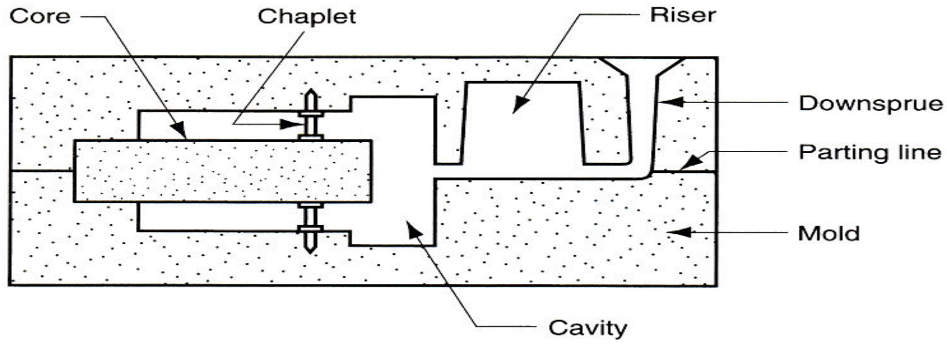
For supporting the molds in core cavity, an impression in the form of a recess is made in the mold with the help of a projection suitably placed in the mold. This projection on the pattern is called the core print.



The core print design should consider the following

- The print must balance the body, so that the core stays in place during mold assembly.
- The Print must withstand the buoyancy force of the metal and not get crushed.
- The print must not shift during mold filling
- The print should minimize the deflection of the core.
- The print should maximize heat transfer from the core to the mold.
- The print should allow the internal gases generated in the core to escape to the mold.
- Asymmetrical holes should have foolproof prints to prevent incorrect assembly.
- The prints of adjacent cores may be combined into one.

Chaplet: Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force. These are small metal supports that bridge the gap between the mold surface and the core, but because of this become part of the casting. As such, the chaplets must be of the same or similar material as the metal being cast. Moreover, their design must be optimized because if they are too small they will completely melt and allow the core to move, but if they are too big then their whole surface cannot melt and fuse with the poured metal. Their use should also be minimized because they can cause casting defects or create a weak spot in the casting.



CORE MAKING

Core making consists of the following operation:

1. Core sand preparation
2. Core molding
3. Baking
4. Core Finishing

Core Sand Preparation:

The core sand mixture must be homogenous so that the core has uniform strength throughout. Core sands are generally mixed in roller mills and core mixers.

Core Molding:

Normally a core box is required for the preparation of cores. Green sand cores are made by ramming the sand mixtures into boxes, the interior of which have desired shapes and dimensions. Ramming is done by machines. Core making machines can be broadly classified as (I) core blowing machines and (2) core ramming machines e.g., jolting, squeezing, slinging,. The degree of compactness needed for a core depends on the type of binder used and the on the size and shape of core.

Fragile and medium sized cores are normally reinforced with steel wires or rods. In large cores, perforated pipes or arbors are provided for reinforcement and for venting.

Core Baking:

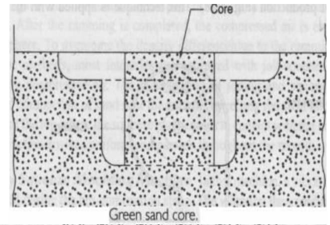
Cores are placed on metal plates or carriers and are baked in core ovens at a temperature of 150° C to 400°C depending on the type of binder to remove the moisture and to improve strength of the binder used in the core, size of the core and the length of the baking time. As a rule one or more vents are provided in the core to assist in discharge of gases.

Core Finishing:

After baking operation, cores are smoothened and rough places and unwanted fins are removed. A fine refractory coating or core wash is applied to the surface to prevent the metal from penetration into the core and to provide a smoother surface to the casting.

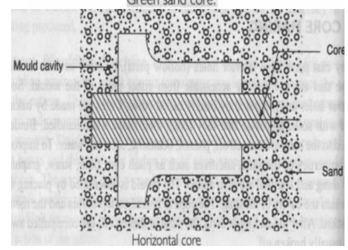
Types of Cores

Green Sand Core: This core is made by the pattern itself. When a pattern leaves a core as a part of the mold, that body of sand used to make the core is called the green sand core. It is made out of the same sand as that of the Mold.



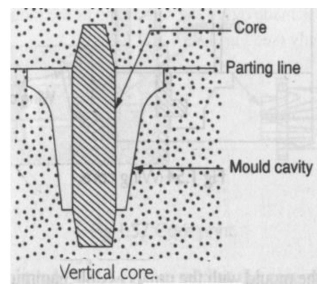
Green sand core.

Horizontal Core: This core is positioned horizontally in the mold and is commonly used in foundries. It is usually cylindrical shape. It may also have other shapes depending on the cavity needed. It is seated in the mold in the cavities made by the core prints.



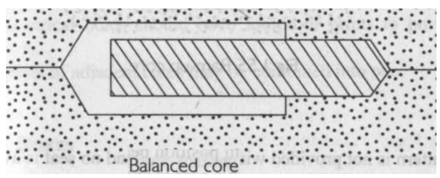
Horizontal core

Vertical Core: Core is placed vertically in the mold. The upper end of the core is forced into the cope and the lower end into the drag. On the cope the core needs more taper (15°) so that it does not damage the mold in the cope while the cope and drag are assembled

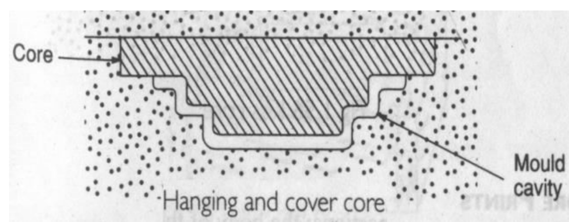


Vertical core.

Balanced Core: Core is supported and balanced at one end only. It extends horizontally in the mold. The core needs only one core print and produces an opening at only one side of the casting.

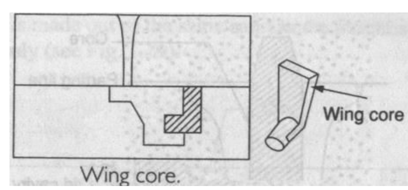

Balanced core

Hanging and Cover Core: This core hangs from the cope. It is supported from the top and hangs vertically in the mold. It has no support at the bottom. The cover is also known as cover core as it covers the mold.



Hanging and cover core

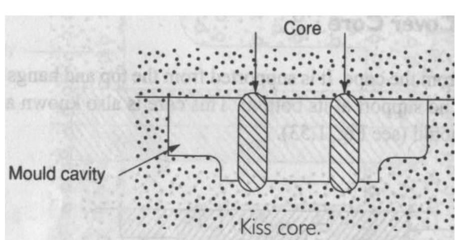
Wing Core: It is used to form a hole or recess in the casting, which is not in line with the parting line. Depending on the usage it is also called drop core.



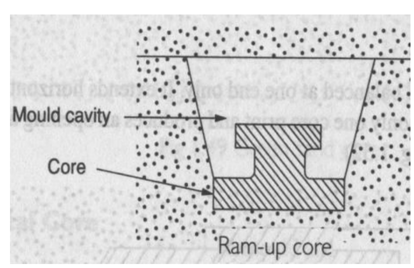
Wing core.

Ram-up Core: This core is set in the mold with the pattern before ramming. It is used when the cored detail is located in an inaccessible position.

Kiss Core: 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 pressure of the cope.



Kiss core.



Ram-up core

Preparation of Sand

Preparation of sand includes

1. Mixing of sand
2. Tempering of sand
3. Sand conditioning

Mixing of sand

4 to 5 m^3 of molding sand is expended to make one tonne of casting. As very few molding sands have all the properties required for molding, the deficiency is made up by mixing it with other materials such as clay, lime, magnesia, potash, soda, horse manure, saw dust, cow dung, coal dust etc., in small quantities. Silica has high temperature withstanding capability but for bonding, clay is used. Additives are added to make the casting soft.

Coal dust is most widely used as it helps to cool the mold after it has been poured. The coal dust, immediately after coming in contact with the molten metal, gives off CO_2 and water in mold gets converted into steam. The CO_2/CO separate the molten metal from the mold.

Mixing of molding materials should ensure uniform distribution of clay, moisture and other constituents between the sand grains ensure better qualities in the sand.

Tempering of sand

To prepare foundry sand it should be tempered and cut through. The process by which sufficient moisture is added to the molding sand is known as sand tempering. To temper the sand, water is thrown over the heap in a sheet by giving a backward swing to the pail as the water leaves it. Then the sand is cut through layer by layer letting the air through the clay in the sand.

Sand conditioning

New sand as well as used sand must be properly conditioned before being used. Proper sand conditioning accomplishes uniform distribution of the binder around the sand grains, controls the moisture content, eliminates foreign particles, and aerates the sand so that it flows readily around and takes up the detail of the pattern. It renders sand suitable for ramming.

SAND TESTING METHODS

Foundry sand testing is a foundry process used to determine if the foundry sand has the correct properties for a certain casting process. The sand is used to make moulds and cores via a pattern. In a sand casting foundry there are broadly two reasons for rejection of the casting — metal and sand — each of which has a large number of internal variables. The defects arising from the sand can be prevented by using sand testing equipment to measure the various properties of the sand.

A basic set of parameters to test are:

A. Moisture content in the mixture (ranges from 2-7% depending on the casting method)
B. Clay content (dust content)
C. Fineness number (grain size/AFS Number) of the base sand
D. Permeability (ability of compacted mould to pass air through it)
E. Strength

i. Green and Dry compression
ii. Green Tensile
iii. Green and Dry Sheer
iv. Bending

F. Hot Strength
G. Refractoriness
H. Mold Hardness

SAND TESTING METHODS

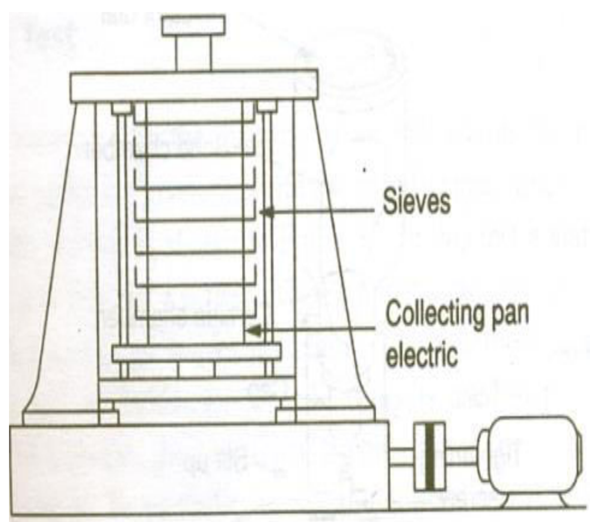
The moulding sand should be tested for its composition and properties.

The essential tests are:

1. Grain fineness test
2. Moisture content test
3. Clay-content test
4. Permeability test
5. Compression strength test
6. Mould and core hardness test

Grain Fineness test

Grain fineness is designated by a number called grain fineness number. Grain fineness number corresponds to the number of meshes in a standard diameter sieve. The test is conducted with the standard set of sieves, which are numbered according to their fineness of mesh. These sieves are fixed into a motor-driven shaker in the order of coarse sieve to fine (Figure).A sample of dry sand, free from clay is placed on the upper sieve and the sieve is vibrated for 15 min. The amount retained in the sieve is computed on a percentage basis. This percentage figure is multiplied with multiplier (which is given to each sieve). The product of this multiplication is added to obtain the total product. Then the grain fineness number is calculated as follows:

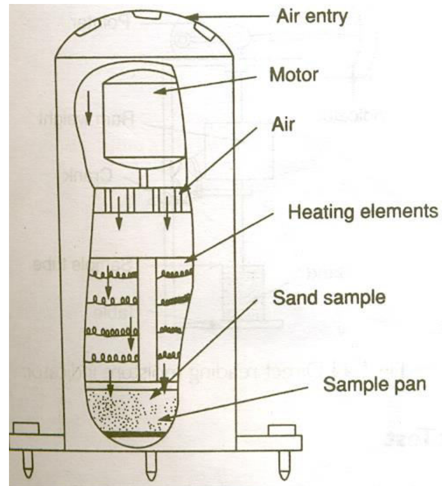


Sieve shaking machine.

$$\text{Grain fineness number} = \frac{\text{Total product}}{\text{Total percentage of sand retained on each sieve}}$$

Moisture Content test

The moisture content is calculated by measuring the difference in weight between moist and dry sand. The drying of moist sand is carried out at 105° C and 110° C in a heated oven and then cooled to room temperature. Figure shows the sand moisture drying device.

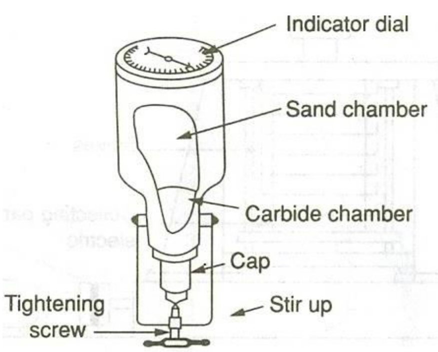


Sand moisture drying device.

As the conventional method is time consuming and cumbersome, direct reading instruments are often used to quickly assess the moisture content such as:

1. Moisture teller
2. Moisture meter

Moisture Teller

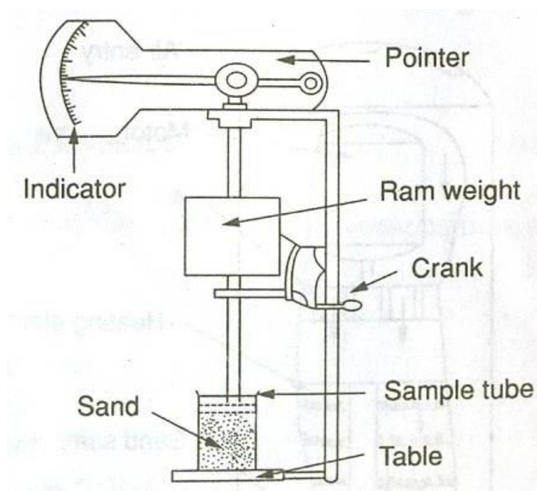


Moisture teller.

This instrument blows hot air for 3 min through the 5g moist sand, which is placed in a pan. The bottom of the pan is a 500-mesh metal screen. Moisture is effectively removed and a precision balance determines the loss of weight of the sample (Figure).

Moisture Meter

This instrument shows the moist content of the sand instantly. The instrument contains two arms. These arms are inserted into the moist sand and the electric current is passed through (via arms) the sand. The current flows easily when the moist content is more and gives the level of moist content. Another type of direct reading instrument is shown in figure, which uses a fixed weight for ramming the sand sample.



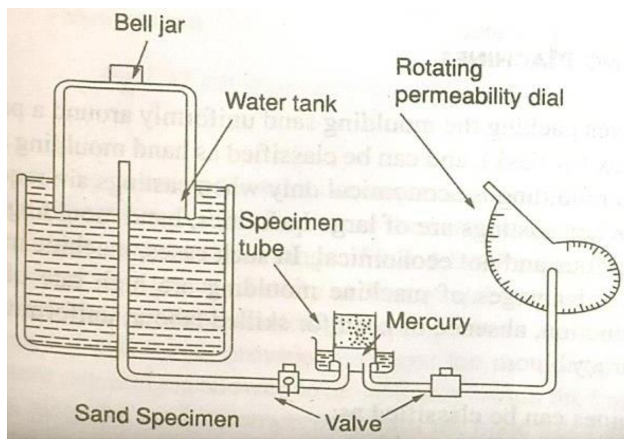
Direct reading moisture indicator.

Clay-content test

In this test, a sample of 50 g sand is agitated in water so as to separate clay from the sand particles, and then remove the clay which fails to settle down within the period of 5 min in distilled water at room temperature. The equipment consists of a drying oven, a balance and weights, and a sand washer. Fifty grams of dry sand is taken in a wash bottle. Then 47cc of distilled water and 25 cc of a 3% caustic soda solution are added to this sand. This mixture is stirred for 5 min in a rapid sand stirrer for 1 h in a sand washer (rotating type). Then it is allowed to rest .after 5 min, the material on top of the water is collected. This process is repeated until the water is clear after 5 min settling period. Then the bottle is placed in an oven. After the sand is dried, the difference in weight shows the amount of clay.

Permeability Test

Permeability is measured by the quantity of air that passes through a standard specimen of sand under the given pressure (p) at prescribed time (t).The arrangement for permeability test is shown in fig. In this test a standard rammed 5.08 x 5.08 cm^2 size test-piece is used. The equipment consists of a water tank on which an inverted bell or air holder is floating. The specimen tube is connected to a manometer and air holder by tube. Mercury is used at the bottom of the specimen to provide an airtight seal. When the pressure in the manometer reaches 10 gm/cm^2 it is closed. Permeability number is defined as the volume of air (v) in 2000 cc air that will pass under pressure (p) of 10 gm/cm^2 through 5.08 cm^2 area (a) specimen.



MOLDING MACHINES

The use of molding machines are advisable when large number of repetitive castings are to be produced since hand molding is more time consuming. Molding machines are classified according to

1. The method of compacting the molding sand
2. The method of removing the pattern

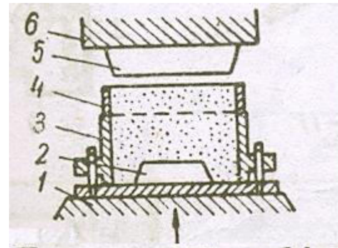
Methods for compacting the molding sand

1. Squeezer machine
   a. Top Squeezer
   b. Bottom Squeezer
2. Jolt machine

3. Jolt-Squeezer machine
4. Sand -Slinger

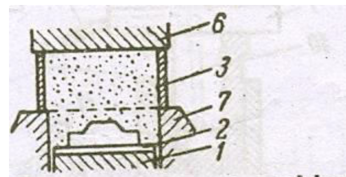
Squeezer machine: The molding sand in the flask is squeezed between the machine table and the overhead squeeze pneumatically or hydraulically until the mold attains the desired density.

Top Squeezer: The principle of operation of a top squeezer is illustrated in the figure. The pattern 2 is placed on a mold board which is clamped on the table 1. The flask 3 is then placed on the mold board and the sand frame 4 on the flask. The flask and frame are filled with molding sand and leveled off. Next the table is raised by the table lift mechanism against the platen 5 on the stationary squeezer head 6. The platen enters the sand frame upto the dotted line and compacts the molding sand. After the squeeze, the table returns to the initial position.



Top squeezer machine

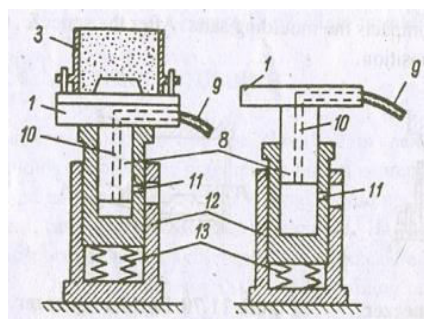
Bottom Squeezer: The pattern is placed on the mold board which is clamped to the table.The flask 3 is placed on the frame 7 and is filled with sand. Next the squeeze head is brought against the top of the flask and the table with the pattern is raised upon the dotted line. After squeezing, the table returns to the initial position.



Bottom squeezer machine

Limitation: Sand is packed more densely on the top of the mold from which the pressure is applied, and the density decreased uniformly with the depth. At the parting plane, density is the lowest.

Jolt Machine: The flask is first filled with the molding sand and then the table supporting the flask is mechanically raised and dropped in succession. Due to the sudden change in inertia at the end of each fall, the sands get packed and rammed. The action of raising and sudden dropping is called jolting.



Jolt machine

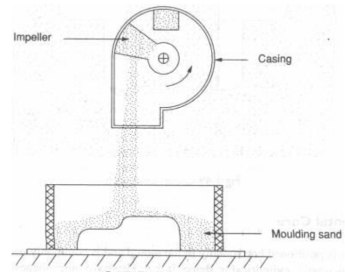
The principle of jolting machine is illustrated in the figure in which the table 1, with the platen and flask 3, filled with molding sand, is raised to 30 to 80mm at short intervals by the plunger 8 when compressed air is admitted through the hose 9 and the channel 10. The air is next released through the opening 11 and the table drops down suddenly and strikes the guiding cylinder 12 at the bottom. This sudden action causes the sand to pack evenly around the pattern. Springs 13 are used to cushion the table blows and thus reduce noise and prevent destruction of the mechanism and the foundation.

Limitation: The sand is rammed hardest at the parting plane and remains less dense at the top. Therefore after jolting hand ramming is done near the mold.

Jolt-Squeeze machine: In order to overcome the draw backs of both the squeeze and jolt principles of ramming the sand, a combination of squeeze and jolt action is often employed. A jolting action is used to consolidate the sand on the face of the pattern and it is followed by a squeezing action to impart the desired density throughout the mass of the sand.

Sand Slinger: In this operation, the consolidation and ramming are obtained by the impact of sand which falls at a very high velocity.

The principle of sand slinger is shown in the figure. The overhead impeller head consists of the housing in which the blade rotates at a very high speed. The sand is delivered to the impeller through the opening by means of conveyor buckets. The impeller head by the rotation of the blade throws the sand through the outlet down the flask over the pattern at a range of 500 to 2000kg per minute. The desnisty of the sand can be controlled by the speed of the blade.



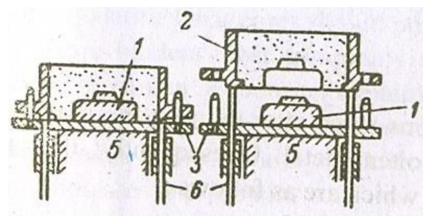
Sand slinger.

This is used for medium sized castings. Hardness can be controlled by sound velocity.

Methods of removing the pattern

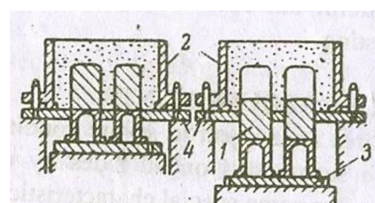
1. Straight Draw molding machine
2. Stripping plate molding machine
3. Turn-over molding machine

Straight Draw molding machine: In this machine, the pattern 1 is fixed on the pattern plate 3 on the table 5 and the flask or molding box 2 is placed over it and filled with sand. It is then roughly rammed round the edges of the box. The squeeze head is next swung over in a position and it squeezes the mold. The flask is then lifted from the pattern by stripping pins 6.



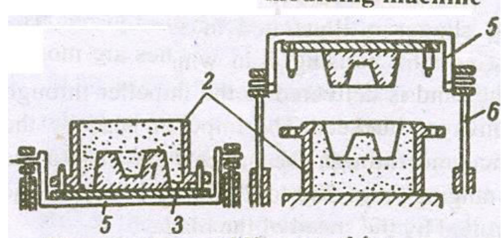
Straight draw moulding machine

Stripping plate molding machine: In this the stripping plate 4 arranged between the flask 2 and pattern plate 3. The stripping plate has a recess whose contours equal those of the pattern 1. When the mold is ready the pattern is withdrawn from the mold downwards through the stripping plate, which supports the mold when the pattern is removed.



Stripping plate moulding machine

Turn-over molding machine: This is used for large size, high molds, having parts which might easily break away. The flask 2 rests on the pattern plate 3 during the molding operation. Then the flask together with the work table 5 is rotated 180° and pins 6 lift the table 5 together with the pattern 1 out of the mold.



Turn-over moulding machine

MELTING FURNACES

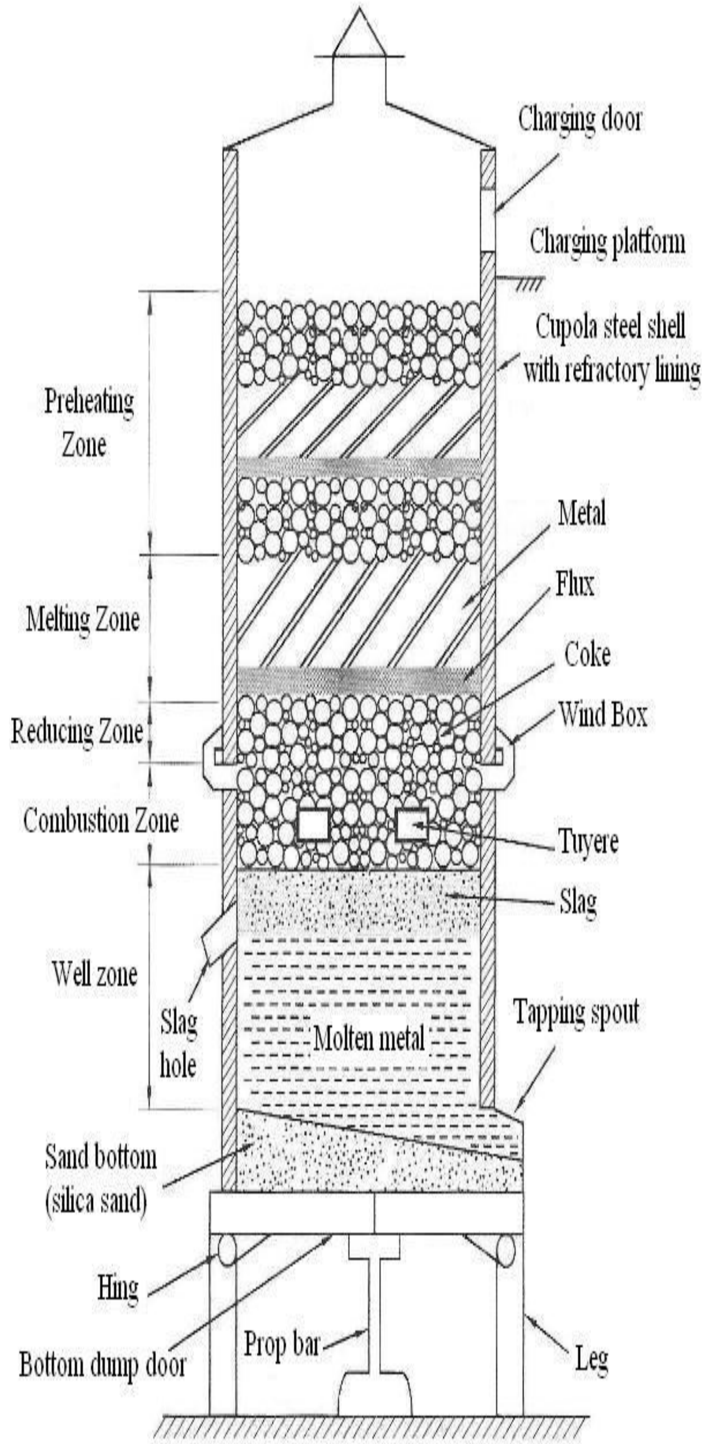
Cupola Furnace

A cupola furnace basically consists of a cylindrical steel shell with both its top and bottom being open. The inner walls of the shell are lined with heat resisting materials such as the fire brick. The bottom opening is closed by a cast iron drop bottom door supported by a metal prop. This door swings out after the melting when the metal prop support is removed.

After closing the bottom door, a sloping sand bed is prepared for giving the necessary heat resistant bottom for the molten metal and the fuel. Just above the sand bed is the metal tapping hole through which the molten metal is taken out and poured into the ladle. A spout called the tapping spout is provided for guiding the molten metal out. Above the tapping hole and opposite to it is a hole with a spout for removing the slag generated during the melting. It is called the slag hole.

Above the slag hole is the wind box which surrounds the cupola shell and supplies air at a given pressure and quantity. Air comes to the wind box through the air blast pipe from the air blower. Air enters into the cupola furnace through the tuyeres which extend through the steel shell and the refractory lining. The number of tuyeres and their spacing along the circumference of the shell varies with the size of the cupola furnace.

A cupola furnace is provided with a charging platform or floor and a charging door for feeding the charges. The charge consists of pig-iron, scrap iron, coke and fluxes. At its top, the cupola furnace has a metal shield or a spark arrester. It arrests the spark or burning particles from going outside while allowing the hot gases to escape out.



Cupola Furnace

Zones of the Cupola funace:-

A. **Well:** It extends up to the bottom of the tuyeres from the sand bed. It is a sort of well of molten iron. Molten iron collects in this zone before tapping.

B. **Combustion Zone 'or' Oxidizing zone:**- (Super heating zone) . This zone starts from the tuyeres and extends upto 15-30 cms above the top of the tuyeres. Combustion takes place in this zone with the aid of oxygen from the air blast. Some exhothermic reactions which occur in this zone are:

$$\mathbf{C + O_2 \longrightarrow CO_2 + Heat}$$

$$\mathbf{Mn + O_2 \longrightarrow MnO_2 + Heat}$$

$$\mathbf{Si + O_2 \longrightarrow SiO_2 + Heat}$$

The temperature of this zone varies from 1550 – 1850° C

C. **Reducing Zone:-** The reducing zone starts from the top of the combustion zone and extends upto the bottom of the first metal charge. In this zone, the endothermic reaction of reducing CO2 to CO takes place.

$$\mathbf{CO_2 + C\ (coke) \longrightarrow 2\ CO - Heat}$$

This reduces the heat in this zone and the temperature of the zone is around 1200°C.

D. **Melting Zone:-** Melting zone starts with the first layer of the metal charge and extends upto 90 cms or less. The metal charge melts in this zone and moves down the well. The temperature of this zone is around 1600 and the following reaction which adds to up the carbon content of metal takes place.

$$\mathbf{3Fe + 2CO \longrightarrow Fe_3C + CO_2}$$

E. **Pre-heating zone:-** Preheating zone starts from the top of the melting zone and extends upto the charging door. The charge in this zone is preheated by the hot gases such as CO_2, CO and N_2. Moving upwards from the combustion and the reducing zone.

F. **Stack Zone:-** Stack zone extends from the end of the preheating zone to the end of the cupola shell and includes the spark arrester. Hot gases from the cupola pass though the stack zone and escape to the atmosphere through the spark arrester.

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

Advantages of Cupola:-

- Simple design and easier construction
- Low initial cost as compared to other furnaces of same capacity
- Simple to operate and maintain in good condition

- Economy of operation and maintenance
- Less floor space requirements as compared to those of other furnaces of same capacity.
- Cupola can be continuously operated for many hours.

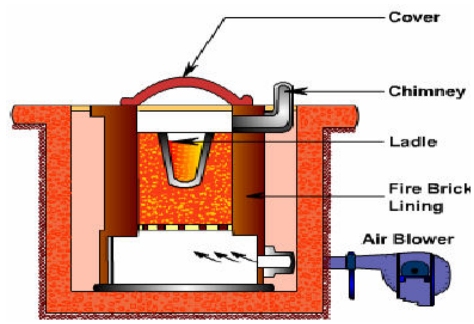
Limitations of Cupola:-

Since molten metal and coke come in contact with each other, certain elements like Si and Mn are lost while others like sulphur are picked up. This changes the final analysis of molten iron.

Direct fuel-fired furnaces

A direct fuel fired furnace contains a small open hearth in which the metal charge is heated by fuel burners located on the side of the furnace. The roof of the furnace assists the heating action by reflecting the flame down against the charge. The typical fuel is natural gas and the combustion products either the furnace through the stack.
At the bottom of the hearth is a tap hole to release the molten metal. Direct fuel-fired furnaces are generally used in casting for melting non-ferrous metals such as copper based alloys and aluminium.

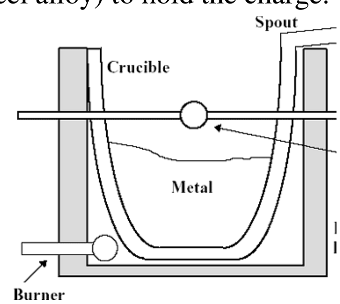
Crucible furnace



These furnaces melt the metal without direct contact with the burning fuel mixture. For this reason, they are sometimes called indirect fuel-fired furnaces.
Different types of crucible furnaces are:

- Lift-out
- Stationary
- Tilting

They all utilize a container (crucible) like pot made out of a suitable refractory material (ex: clay-graphite mixture or high temperature steel alloy) to hold the charge.

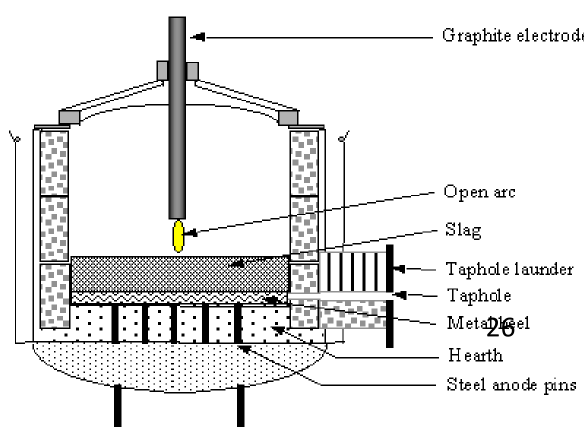


In lift out crucible furnace, the crucible is placed in a furnace and heated sufficiently to melt the charge. Oil, gas and powdered coal are typical fuels for these furnaces. When the metal is melted, the cruible is lifted out of the furnace and used as a pouring ladle.

The other two-types, sometimes referred to as pot furnaces have the heating furnace and containers as one integrated unit. In the stationary pot furnace, the furnace is stationary and the molten metal is ladled out of the container. In the tilting –pot furnace, the entire assembly can be tilted for pouring. Crucible furnaces are used for non-ferrous metals such as bronze, brass and alloys of zinc and aluminium. Furnace capacities are generally limited to several hundred pounds.

Electric Arc Furnace

An electric arc furnace is a system that heats charged material by means of an electric arc struck between carbon electrodes and the metal bar. Temperatures inside an electric arc furnace can rise to approximately 2000°C.

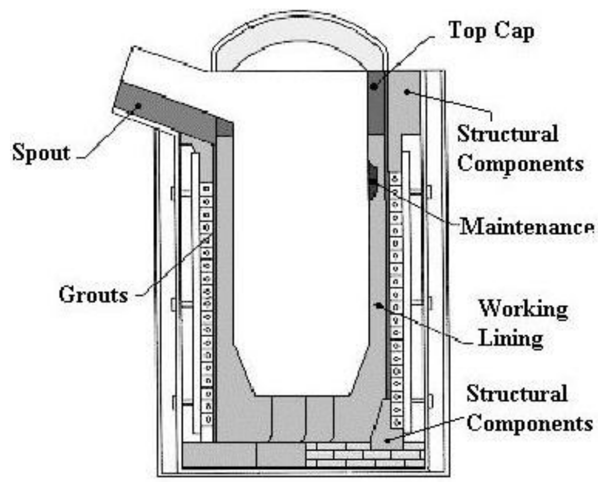


Arc furnaces range in size from small units of approximately one ton capacity used in foundries for producing cast iron products to about 400 tonnes units used for secondary steel making.

Electric arc furnaces may be categorized as direct arc or indirect arc. Both types of units are suited for melting of high melting point alloys such as steel. They may be lined with acid or basic refractory depending type of steel to be melted.

Induction Furnace

Induction heating is a heating method. The heating by the induction method occurs when an electrically conductive material is placed in a varying magnetic field. Induction heating is a rapid form of heating in which a current is induced directly into the part being heated. Induction heating is a non-contact form of heating.



The heating system in an induction furnace includes:

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

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

Advantages of Induction Furnace

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

Disadvantages of Induction Furnace

- High capital cost of the equipment
- High operating cost

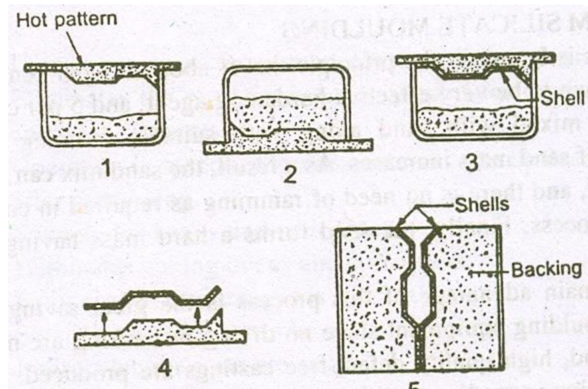
SPECIAL CASTING PROCESSES

SHELL-MOLDING

- The mould is formed from a mixture of fine sand (100-150 mesh) and a thermosetting resin binder that is placed against a heated metal pattern, preferably made of grey cast iron.

- When the mixture is heated in this manner, the resin cures, causing the sand grains to adhere to each other forming sturdy shell that conforms exactly to the dimensions and shape of the pattern and constitutes half of a mould.

- After the shell has been cured and stripped from the pattern, any cores required are set, the two halves of the mould are secured together, placed in a flask and backup material added; then the mould is ready for pouring.



Shell moulding process

- In actual practice, the metal pattern is heated to about 200 to 300° C, the melting point of resin. Then after a silicon parting agent is sprayed on the surface, the resin and sand mixture is deposited on the pattern by blowing or dumping.

- The resin starts melting and, in a few seconds, forms together with the sand a uniform and resin-soaked layer of about 4 to 12 mm in thickness, depending on the heating period.

- The pattern is then turned over to allow the unbounded sand to be removed, leaving the shell on the pattern. The shell is then stripped mechanically and once more heated for 3 to 5 minutes in a special oven to cure the plastic material. The curing takes place at temperatures of up to about 420° C, depending on the type of resin used.

- In this way, stable shell moulds are obtained which are made in two sections. Both sections are matched and joined by guides to obtain the casting mould. Finally, they are placed in a metal case, and surrounded by about 37 mm of steel shot, sand and other backup material to support them during pouring. The gates, sprues and risers are usually a part of the mould.

Advantages :

1. More productivity
2. Saving of material
3. Thin sections can be cast
4. Machining of castings is reduced
5. Tooling costs are reduced
6. Close dimensional tolerance and better surface finish can be obtained.
7. Floor space and sand quantity are reduced.
8. Shells can be stored and transported easily.
9. Unskilled labour can be employed.
10. Process can be used for all cast metals.

Limitations :

1. High pattern cost.
2. High resin cost.
3. High equipment cost.
4. Uneconomical for small runs.
5. Maximum casting size and weight are limited.

INVESTMENT MOULD CASTING

It consists mainly of two stages which are illustrated in fig. First, a master pattern is made of wood or metal around which a mould is formed. It does not consist of mould sand but of gelatine or an alloy of low melting point which is poured over the master pattern. This master mould consists of the usual two sections and thus can be opened. It is used for making the "lost pattern".

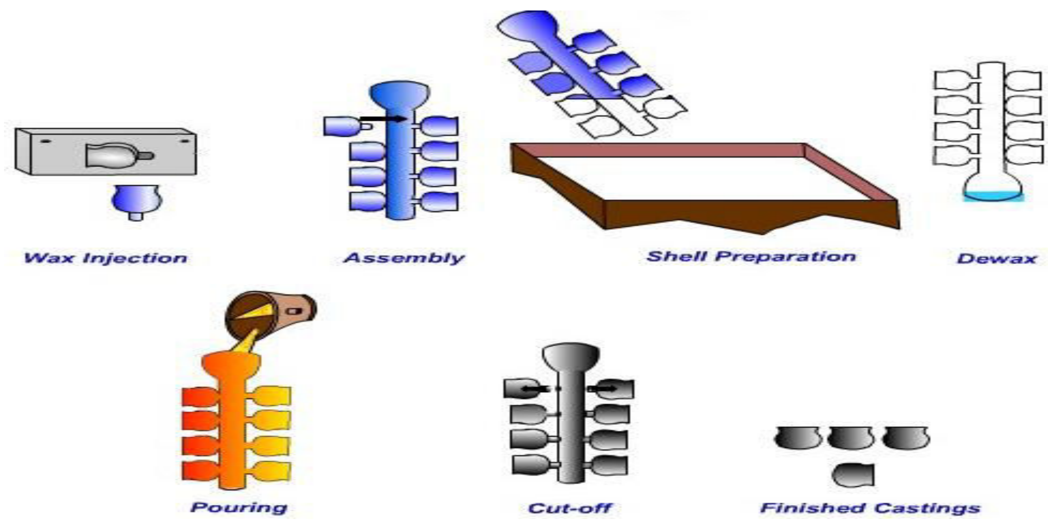


Figure Investment moulding in stages

The master mould is then filled with liquid wax, with a thermoplastic material liquefied by heating or with mercury. The heated materials become solid when they are cooled to normal room temperature. If mercury is used, the master mould must be cooled down to about-60° C (freezing up) to become solid.

The second pattern produced in this way is used for preparing the casting mould properly. The expandable wax pattern is coated with slurry consisting of silica flour and small amounts of kaolin and graphite mixed with water. This process is referred to as the "investment" of the pattern.

However, the pattern is then used to make up moulds similar to those used in the conventional moulding process, but the pattern within the mould is not taken out of the mould which is not opened after this moulding process. This is the reason why a high precision is achieved in casting.

The finished mould is dried in air for 2 to 3 hours and then baked in an oven for about 2 hours to melt out the wax. At a temperature of 100° to 120° C, the wax melts and runs through a hole in the bottom plate in to a tray, thus providing a cavity of high dimensional accuracy for the casting process. After this the mould is sintered at about 1000°C to improve its resistivity. Finally, it is cooled down to a temperature between 900° and 700°C for casting.

It is possible to combine several hundred lost patterns of small workpieces into what is called a “bunch of patterns” by one common gate, make one combined mould, and cast them in one common process.

Investment castings produced by this process have a good surface finish and are exact reproduction of the master pattern. This is used for casting turbine plates, parts of motor-cars, sewing machines, typewriters, and calculating machines, as well as for various instruments.

Advantages:

1. Smooth surface can be produced with close tolerances
2. High dimensional accuracy
3. Complicated shape can be produced
4. Machining operation can be eliminated.

Disadvantages

1. Process is relatively slow
2. Use of cores makes the process more difficult
3. The process is relatively expensive than other process
4. Pattern is expendable
5. Size limitation of the components part to be cast- majority of cast products is below 05kg.

Plaster Mould Casting

In **plaster mold casting**, a plaster, usually gypsum or calcium sulfate, is mixed with talc, sand, asbestos, and sodium silicate and water to form a slurry. This slurry is sprayed on the polished surfaces of the pattern halves (usually brass). The slurry sets in less than 15 minutes to form the mold. The mold halves are extracted carefully from the pattern, and then dried in an oven.

The mold halves are carefully assembled, along with the cores. The molten metal is poured in the molds. After the metals cools down, the plaster is broken and the cores washed out.

Parts cast are usually small to medium size, ranging in weight from 30 g (1 oz) to 7 kg (15 lb). The section thickness can be as small as 0.6 mm (0.025 in) and tolerances are 0.2 % linear. The draft allowance is 0.5-1.0 degree. The surface finish is 1.25 µm to 3 µm (50 µin to 125 µin) rms.

Low temperature melting materials such as aluminum, copper, magnesium and zinc can be cast using this process. This process is used to make quick prototype parts as well as limited production parts.

Advantages:

1. Warping and distortion of thin sections can be avoided since plaster has no chilling tendency due to low rate of heat conductivity.
2. A high degree of dimensional accuracy and surface finish is obtained and machining cost is therefore eliminated.
3. Highly suitable for reproduction of fine form and detail as are necessary for ornamental casting, statues, jewellery, etc.

Disadvantages:

1. Low permeability of plaster of paris.
2. Suitable only for nonferrous castings as plaster of paris destroys at 1200°C.

CERAMIC MOULDING

Similar to plaster mold casting, the pattern used in **ceramic mold casting** is made of plaster, plastic, wood, metal or rubber. A slurry of ceramic is poured over the pattern. It hardens rapidly to the consistency of rubber. This can be peeled of the pattern, reassembled as a mold. The volatiles are removed using a flame torch or in a low temperature oven. It is then baked in a furnace at about 1000 °C (1832 °F) yielding a ceramic mold, capable of high temperature pours. Additionally, the pour can take place while the mold is until hot.

Tolerances can be held to 0.4 %, surface finishes can be better than 2 - 4 µm (.075 - .15 µin). Add 0.3 mm (.012 in) for parting line tolerances. Wall thickness can be as small as 1.25 mm (.050 in), and the weights can range from 60 g (2oz) to a ton. Draft allowance of 1° is recommended.

This process is expensive, but can eliminate secondary machining operations. Typical parts made from this process include impellers made from stainless steel, bronze, complex cutting tools, plastic mold tooling.

Advantages:

1. Highest precision and accuracy obtained
2. Suitable of all types of cast metals including titanium and uranium.
3. Castings do not normally need risers, venting or chilling a cooling is very slow.

Disadvantages:

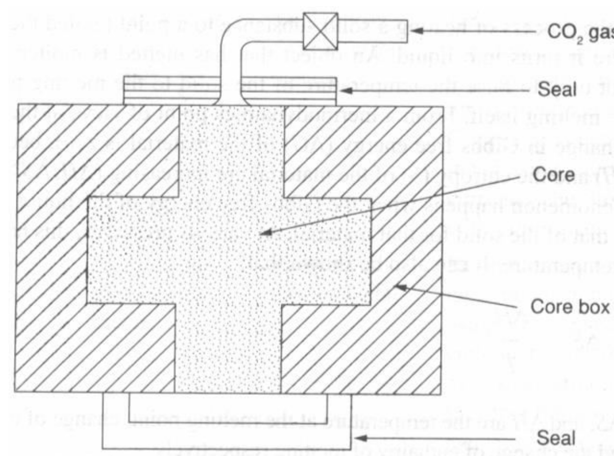
1. Impractical to control dimensional accuracy
2. Process is expensive.

CARBON-DI – OXIDE (CO_2) MOULDING

Basically, **CO_2**molding is the hardening process for molds and cores. If **CO_2** is passed through a sand mix containing sodium silicate, the sand becomes strongly bonded by silica gel immediately. The chemical reaction is as follows:

$$Na_2+(x)\,SiO_2+xH_2O+CO_2 \longrightarrow Na_2CO_3+SiO_2+(x)H_2O$$

Where x is 2,3,4,or 5.
Strength of the sand rises with the grain fineness measured upto 80mesh size. After that it decreases and reaches zero with 120 mesh size.



CO_2 core making.

However that strength of the fine sand can be increased by CO_2 method by hardening. The sand is thoroughly mixed with 3-5% of sodium silicate liquid base binder for 3-4 minutes. Other additives such as coal powder, wood flour, sea coal, and dextrin may be added to obtain certain specific properties. The suitable sand mixture can be packed around the pattern in the flask or in the core box.

After the packing is complete, CO_2 gas is forced into the mould at a pressure of 1.45kgf/cm^2 (142KN/m^2) for a specified time. The reaction takes place and the compressive strength of sand mixture reaches maximum value when a critical amount of gas is passed.

CO_2 requirement can be calculated by the amount of sodium silicate. For every 1 kg of sodium silicate, 0.5-0.75 kg of gas is required. Over-gassing is wasteful and may deteriorate the sand. It will be effective only when the gases present in the poured holes is completely evacuated by CO_2 The flow rate of CO_2 gas determines the depth of penetration.

After this the hardness is further increased by placing the mould in free atmosphere for a short while. Sometimes it is heated to around 200°C to creased hardness. The patterns commonly used are made of wood, metal or plastic.

Advantages

1. Eliminates baking ovens and core driers
2. Moulds and cores can be used immediately and therefore productivity is more.
3. Floor requirement is less.
4. Greater dimensional accuracy
5. Suitable for heavy and rush orders
6. Semi-skilled labour can be used.

Limitation

1. Sand cannot be resused
2. More expensive
3. Life is short
4. Poor collapsibility
5. Shake out properties are poor.

DIE CASTING

Die-casting is similar to permanent mold casting except that the metal is injected into the mold under high pressure of 10-210Mpa (1,450-30,500) psi . This results in a more uniform part, generally good surface finish and good dimensional accuracy, as good as 0.2 % of casting dimension. For many parts, *post-machining can be totally eliminated*, or very light machining may be required to bring dimensions to size.

Die-casting can be done using a cold chamber or hot chamber process.

In a *cold chamber process*, the molten metal is ladled into the cold chamber for each shot. There is less time exposure of the melt to the plunger walls or the plunger. This is particularly useful for metals such as Aluminum, and Copper (and its alloys) that alloy easily with Iron at the higher temperatures.

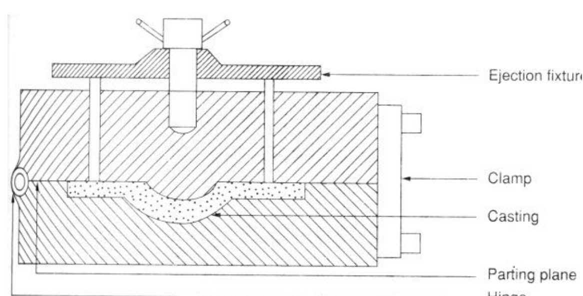
In a *hot chamber process* the pressure chamber is connected to the die cavity is immersed permanently in the molten metal. The inlet port of the pressurizing cylinder is uncovered as the plunger moves to the open (unpressurized) position. This allows a new charge of molten metal to fill the cavity and thus can fill the cavity faster than the cold chamber process. The hot chamber process is used for metals of low melting point and high fluidity such as tin, zinc, and lead that tend not to alloy easily with steel at their melt temperatures.

Die-casting processes may be divided into the following types:

1. Gravity die-casting
2. Low pressure die-casting
3. High pressure die-casting
    a. Hot chamber die casting
    b. Cold chamber die casting
4. Centrifugal casting
    a. True centrifugal casting
    b. Semi-centrifugal casting
    c. Centrifuge casting
5. Continuous casting

Gravity Die Casting

Metal is poured directly into the mold by hand. The casting is removed as soon as the metal has solidified. The hot, relatively soft castings that could easily distort are stacked on racks to cool. The mold is then blown clean.



Gravity die-casting.

In gravity die-casting, the two parts of the die are split along a joint line passing through the die cavity. The running, feeding and venting systems are provided in the same plane. Dies are provided with various arrangements such as pin locators, clamping devices and ejection systems for casting removal. To prevent the casting from sticking to the mold, graphite is coated to reduce the casting's tendency to stick to the mold. The mold is held at a temperature of 260° C.

Mechanical properties are improved by chilling effect of the metal mold. This ensures even flow of metal within the mold cavity. The gravity type is limited to basically non-ferrous alloys namely, aluminium, copper or magnesium. Iron and steel can also be cast using graphite molds.

Advantages:

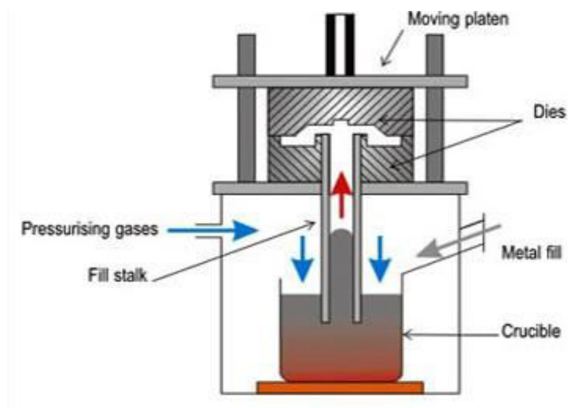
1. Higher production rate
2. Closer dimensional tolerances
3. Good surface finish
4. Tensile strength and ductility are considerably higher than sand castings
5. Less floor space required
6. Minimum total cost for high volume

Disadvantages

1. Non economical in small runs
2. Initial cost is high
3. Suitable only for fluid alloys owing to high freezing rates obtained in metal molds.

Low Pressure Die-Casting

In this process, first, a metal die is positioned above a sealed furnace containing molten metal. A refractory-lined riser extends from the bottom of the die into the molten metal. Low pressure air (15-100kPa, 2-15 psi) is then introduced into the furnace. This makes the molten metal rise up to the tube and enter the die cavity with low turbulence. After the metal has solidified, the air pressure is released so that the molten metal in the riser tube to fall back into the furnace. After subsequent cooling, the die is opened and the casting extracted.



High quality castings of aluminium alloys, along with magnesium and other low melting point alloys are usually produced through the process. Castings of aluminium in the weight range of 2-150 kg are commonly done.

High Pressure Die Casting

Here, the liquid metal is injected with high speed and high pressure into the metal mold. The basic equipment consists of two vertical platens. The bolsters are placed on these platens and this holds the die halves. Out of the two platens, one is fixed and the other movable.This helps the die to open and close. A specific amount of metal is poured into the shot sleeve and afterwards introduced into the mold cavity. This is done using a hydraulically-driven piston. After the metal has solidified, the die is opened and the casting eventually removed.

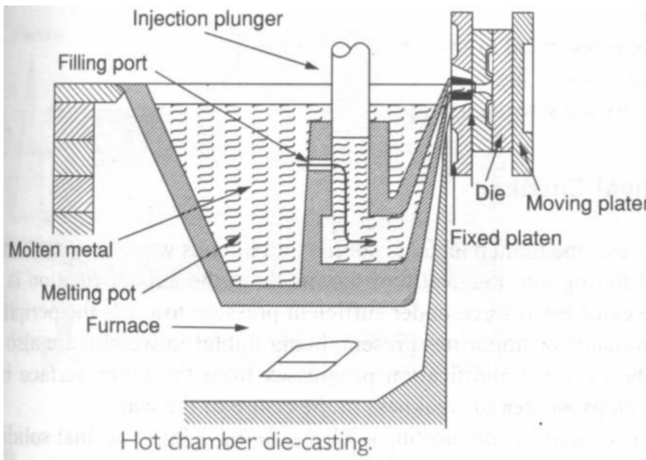
Types of High Pressure Die Casting:

- **Hot Chamber Process**
- **Cold Chamber Process**

Both the processes are described below. The only difference between the two processes is the method being used to inject molten metal into the die.

Hot Chamber Process

The hot-chamber process is applicable only for zinc and other low melting point alloys that does not affect and erode metal pots cylinders and plungers. The basic components of a hot-chamber die-casting machine and die are illustrated below:



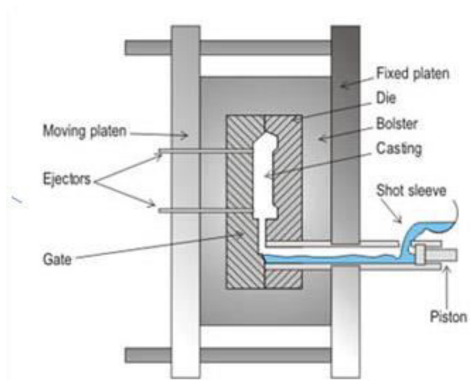
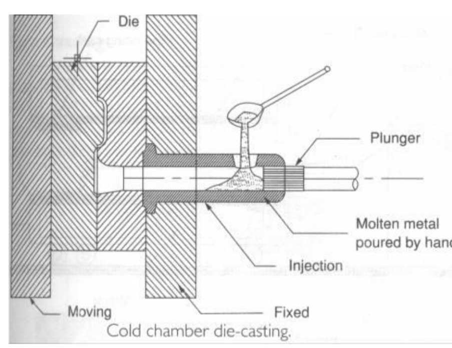


Figure Die casting machines
(a) Hot chamber die-casting (b) Cold chamber die-casting

The molten metal for casting is placed in the holding furnace at the required temperature adjacent to(sometimes as part of the machine itself) the machine. The injection mechanism is placed within the holding furnace and most of its part is in constant touch with the molten metal. When pressure is transmitted by the injection piston, the metal is forced through the gooseneck into the die. On the return stroke, the metal is drawn towards the gooseneck for the next shot.

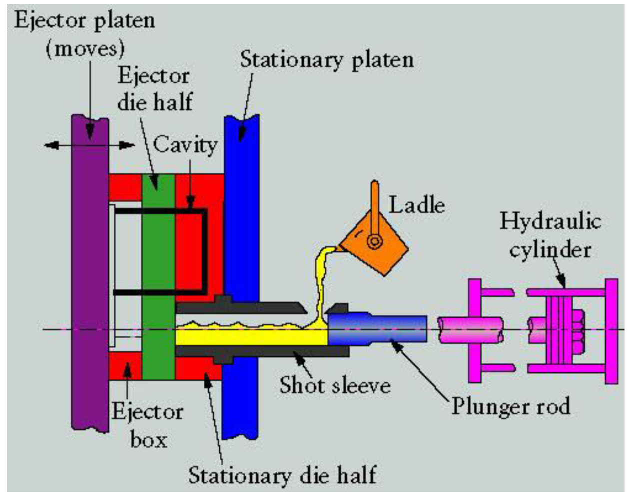
This process ensures minimum contact between air and the metal to be injected. The tendency for entrainment of air in the metal during injection is also minimized. This process is limited to metals, which melt below 800° F (427° C). The hot chamber machine is used for zinc die-casting, but may also cast tin and lead. The hot chamber machine operates at high speeds. It is possible for a machine to make 500 shots per hour on small castings.



Cold Chamber Die-Casting The difference of this process with the hot-chamber process is that the injection system is not submerged in molten metal. On the contrary, metal gets transferred by ladle, manually or automatically, to the shot sleeve. The metal is pushed into the die by a hydraulically operated plunger. This process minimises the contact time between the injector components and the molten metal, which extends the life of the components. However the entrainment of air into the metal generally associated with high-speed injection can cause gas porosity in the castings. In the cold chamber machine, injection pressures over 10,000 psi or 70,000 KPa is obtainable. Generally steel castings along with aluminium and copper based alloys are produced by this method

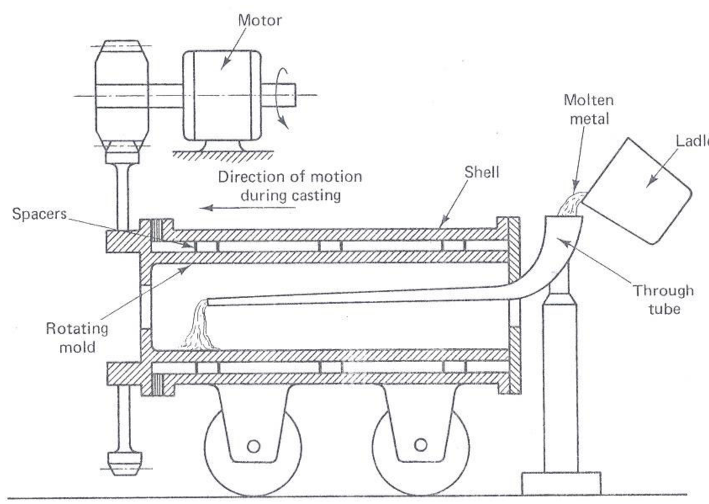
Advantages:
1. Higher production rate
2. Closer dimensional tolerance
3. Good surface finish
4. Less floor space required
5. Minimum unit cost

Limitations:
1. Not economical in small runs
2. High initial cost
3. Restricted size of casting.



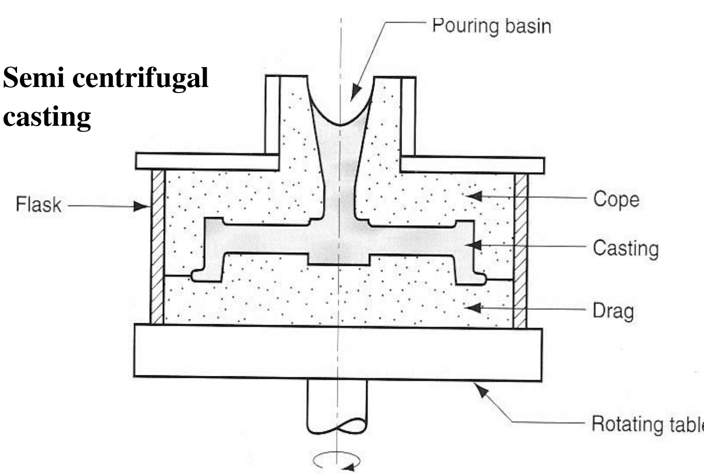
CENTRIFUGAL CASTING

Centrifugal casting as a category includes Centrifugal Casting, Semi-Centrifugal Casting and Centrifuging.



Centrifugal Casting: In centrifugal casting, a permanent mold is rotated about its axis at high speeds (300 to 3000 rpm) as the molten metal is poured. The molten metal is centrifugally thrown towards the inside mold wall, where it solidifies after cooling. The casting is usually a fine grain casting with a very fine-grained outer diameter, which is resistant to atmospheric corrosion, a typical situation with pipes. The inside diameter has more impurities and inclusions, which can be machined away. The mold can be rotated about a vertical, horizontal or an inclined axis or about its horizontal and vertical axes simultaneously. The length and outside diameter are fixed by the mold cavity dimensions while the inside diameter is determined by the amount of molten metal poured into the mold.

Semi centrifugal casting



Only cylindrical shapes can be produced with this process. Size limits are upto 3 m (10 feet) diameter and 15 m (50 feet) length. Wall thickness can be 2.5 mm to 125 mm (0.1 - 5.0 in). The tolerances that can be held on the OD can be as good as 2.5 mm (0.1 in) and on the ID can be 3.8 mm (0.15 in). The surface finish ranges from 2.5 mm to 12.5 mm (0.1 - 0.5 in) rms.Typical materials that can be cast with this process are iron, steel, stainless steels, and alloys of aluminum, copper and nickel. Two materials can be cast by introducing a second material during the process. Typical parts made by this process are pipes, boilers, pressure vessels, flywheels, cylinder liners and other parts that are axi-symmetric.

Semi-Centrifugal Casting: The molds used can be permanent or expendable, can be stacked as necessary. The rotational speeds are lower than those used in centrifugal casting. The center axis of the part has inclusion defects as well as porosity and thus is suitable only for parts where this can be machined away. This process is used for making wheels, nozzles and similar parts where the axis of the part is removed by subsequent machining.

Centrifuging: Centrifuging is used for forcing metal from a central axis of the equipment into individual mold cavities that are placed on the circumference. This provides a means of increasing the filling pressure within each mold and allows for reproduction of intricate details. This method is often used for the pouring of investment casting pattern.

Advantages:

1. Formation of hollow interiors in cylinders without cores.
2. Less material required for gate.
3. Fine grained structure at the outer surface of the casting free of gas and shrinkage cavities and porosity.

Disadvantages:

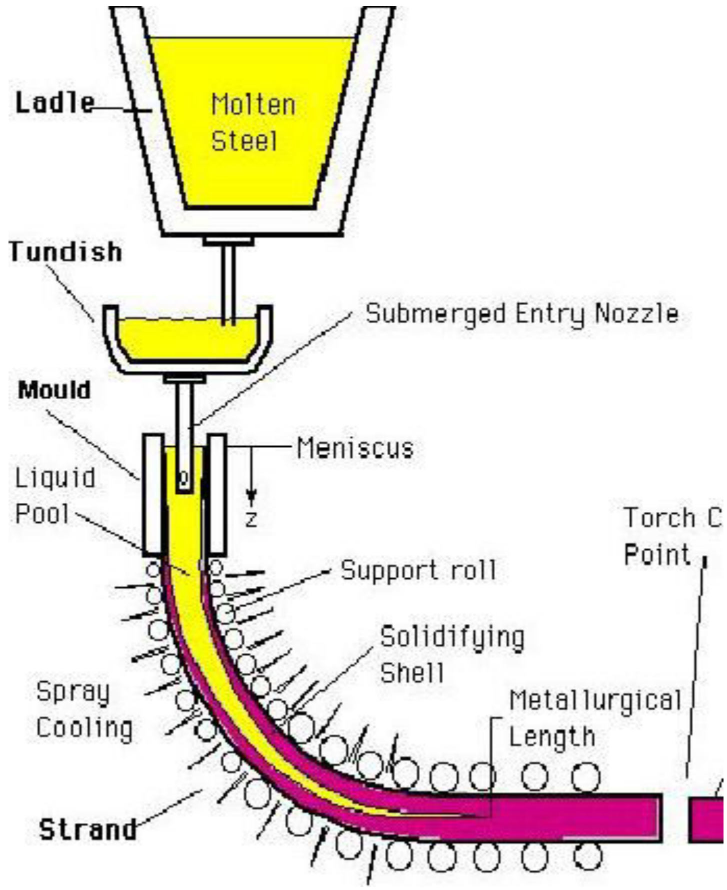
1. More segregation of alloy components during pouring under the forces of rotation
2. Contamination of internal surfaces with non-metallic inclusions.
3. Inaccurate internal diameter.

Comparison of various types of casting process

Process	Advantages	Disadvantages	Examples
Sand	Wide range of metals, sizes, shapes, low cost	poor finish, wide tolerance	engine blocks, cylinder heads
Shell mold	better accuracy, finish, higher production rate	limited part size	connecting rods, gear housings
Expendable pattern	Wide range of metals, sizes, shapes	patterns have low strength	cylinder heads, brake components
Plaster mold	complex shapes, good surface finish	non-ferrous metals, low production rate	prototypes of mechanical parts
Ceramic mold	complex shapes, high accuracy, good finish	small sizes	impellers, injection mold tooling
Investment	complex shapes, excellent finish	small parts, expensive	jewellery
Permanent mold	good finish, low porosity, high production rate	Costly mold, simpler shapes only	gears, gear housings
Die	Excellent dimensional accuracy, high production rate	costly dies, small parts, non-ferrous metals	precision gears, camera bodies, car wheels
Centrifugal	Large cylindrical parts, good quality	Expensive, limited shapes	pipes, boilers, flywheels

Continuous Casting

Continuous casting, also called **strand casting**, is the process whereby molten metal is solidified into a "semifinished" billet, bloom, or slab for subsequent rolling in the finishing mills. Prior to the introduction of continuous casting in the 1950s, steel was poured into stationary molds to form ingots. Since then, "continuous casting" has evolved to achieve improved yield, quality, productivity and cost efficiency. It allows lower-cost production of metal sections with better quality, due to the inherently lower costs of continuous, standardised production of a product, as well as providing increased control over the process through automation. This process is used most frequently to cast steel (in terms of tonnage cast). Aluminium and copper are also continuously cast.



Molten metal is poured steadily from the top of the tower into a long mold and cooled by water. The passage of steel through the mold is so controlled that the metal engages from the other end in the shape of products of a primary rolling mill. The main task is to devise a mold that will withstand the heat and fasten the solidifying steel into desired shape without obstructing its steady flow. Copper is normally used with efficient cooling system.

Advantages

1. High rate of production
2. Closer dimensional accuracy
3. Good surface finish
4. Less cost of production

Limitations

1. Not economical in small runs
2. High initial cost

SAND CASTING DEFECTS

A properly designed casting, a properly prepared mould and correctly melted metal should result in a defect free casting. However, if proper control is not exercised in the foundry, a variety of defects may result in the casting. Defective castings, even at advanced foundries, account for 2 to 5% and sometimes from 10 to 25% of the number of produced castings.

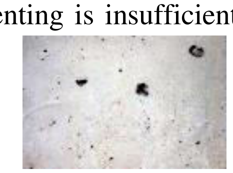
Classification of Defects:

Classification may be made by grouping the defects under certain broad types of origins, such as those caused due to improper

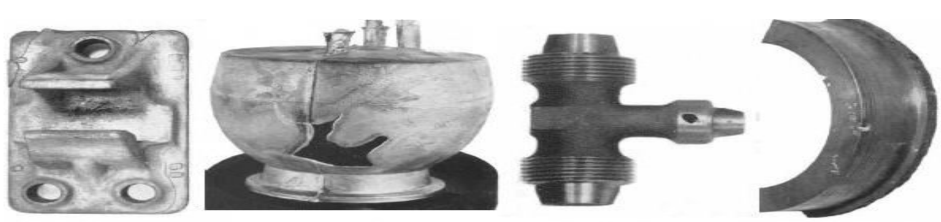
- Patterns and molding box equipment (mismatch or mold shift, improper wall thickness, etc)
- materials used for molding and core making
- I sand mixing and distribution
- Molding, core making and gating
- Drying and core baking
- Closing of molds
- Molten metal
- Heat treatment , And other reasons being Warpage, during fettling etc.

Some of the common defects discussed below are:

1. **Blow Holes:** Blow holes are smooth, round holes appearing in the form of a cluster of a large number of small holes below the surface of a casting. These are entrapped bubbles of gases with smooth walls. Blow holes are caused by excessive moisture in the sand, or when permeability of sand is low, sand grains are too fine, sand is reamed too hard, or when venting is insufficient. Blowhole is a kind of cavities defect, which is also divided into pinhole and subsurface blowhole. Pinhole is very tiny hole. Subsurface blowhole only can be seen after machining. To prevent blow holes, the moisture content in sand must be well adjusted, and of proper grain size should be used, ramming should not be too hard and venting should be adequate.



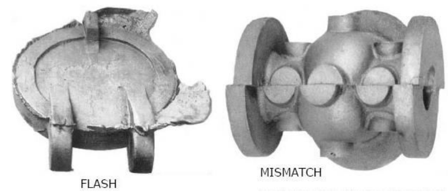
2. **Misrun or short run:** These defects occur due to incomplete cavity filling. The reasons could be inadequate metal supply, too low mold or melt temperature, improperly designed gates or length to thickness ration of the casting is too large.



COLD SHUT MISRUN BLOW HOLE GAS POROSITY

3. **Cold Shut:** It is an interface within the casting that is formed when two metal streams meet without complete fusion. The causes are same as for misrun.

4. **Mismatch:** Mismatch is a shift of the individual parts of a casting with respect to each other. This may occur due to mold shift or core shift. The causes can be an improper assembly of the two halves of the mold, wearing of pin bushes and pins and dimensional discrepancy between the core prints of the pattern and core prints of the core.



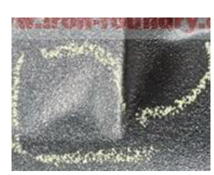
5. **Fin:** A thin projection of a metal, not intended as a part of the casting is called the fin. Fins usually occur at the parting of the mold or core sections. Molds and cores incorrectly assembled will cause fins. Insufficient weighting of the molds or improper clamping of flasks may also produce fins.

6. **Metal Penetration and Rough Surface:** This defect appears as an uneven and rough external surface of the casting. The metal penetration between the sand grains occurs due to low strength, large grain size, high permeability and soft ramming of the sand.

7. **Drop (Crush):** Drop or crush in a mold is an irregularly shaped projection on the cope surface of a casting. This defect is caused by the break away of a pair of mold sand as a result of weak packing of the mold. Low strength of the molding sand, malfunctioning of the mold equipment, strong jolts and strikes of flask when assembling the mold. The loose sand that falls into the cavity will also cause a dirty casting surface, either on the top or bottom surface of the casting, depending on the relative densities of sand.

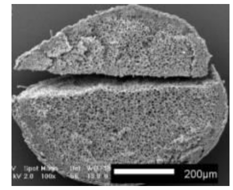
8. **Run Out:** Run out is the defect of metal leaking out of the mold during pouring. This defect occurs due to faulty molding and faulty flask equipment.

9. **Cut or wash:** These appear as rough spots and areas of excess metal, and are caused by erosion of molding sand by the flowing metal. This is caused by the molding sand not having enough strength and the molten metal flowing at high velocity. The former can be taken care of by the proper choice of molding sand and the latter can be overcome by the proper design of the gating system.



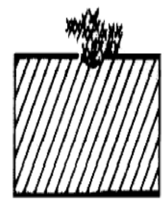
10. **Shrinkage Cavity:** It is a depression or an internal void in a casting that results from the volume contraction that occurs during solidification.

11. **Hard spots:** This defect occurs only with certain metals such as grey CI with insufficient silicon. Such metals may become hardened by the chilling effect of molding sand, which results in machining difficulties.
12. **Sponginess or Honeycombing:** It is an external defect, consisting of a number of small cavities in close proximity, which usually come through and are apparent in the surface. Caused by 'dirt' and 'inclusions' held mechanically in suspension in the molten metal and is due to imperfect skimming of slag in the ladle and incorrect gating design. The impurities being lighter than the metal, rise to the upper part of the casting, often accompanied by bubbles of gas if the venting in not proper.



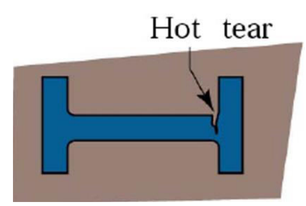
13. **Tat-Tail, Buckle and Scab:** A **rat tail**, **buckle**, and **scab** all originate in the same way and differ mainly in degree. They are caused by uncontrolled expansion of the sand. If the condition is not too bad, a rat tail is formed. The surface of the sand buckles up in an irregular line that makes the casting look as though a rat has dragged his tail over it. If sand expansion is even greater, the defect is called a buckle. If it is still worse so that molten metal can get behind the buckled sand, it is a scab.





14. **Swell:** • A swell is an enlargement or bulging of the casting surface resulting from liquid metal pressure. It occurs due to poor ramming of the mould or not properly reinforcing deep moulds. Swells can be avoided by proper ramming of the sand and providing adequate support to the mould.

15. **Hot Tear:** They are internal and external cracks having ragged edges occuring immediately after the metal has solidified. Hot rears may be produced if the casting is poorly designed and abrupt sectional changes takes place, no proper fillets and corner radii are provided, and chills ar wrongly placed, incorrect pouring temperatures and improper placing of gates and risers.



INSPECTION AND TESTING OF CASTINGS

The aims of inspection and testing of castings are to prevent defective castings being supplied from the foundry and to reduce the percentage of inevitable processing defects.
The various inspection and testing procedures are

1. **Visual Inspection:** By naked eye, identify defects such as misrun, cracks, warping, etc.
2. **Dimensional Inspection:** Dimensions are checked by measuring tools.
3. **Metallurgical Control:** Chemical composition, mechanical and other properties are determined in the laboratory
4. **Pressure Testing:** Water or air pressure test to identify leakage in vessels, cylinders or joints.
5. **Radio-Graphical Testing:** Internal defects in a casting such as cracks, voids, cavities and porosity, etc as well as surface cracks can be revealed by radio-graphic inspection using X-rays and γ-rays.

   In X-ray testing, short wave length rays from an X-ray tube are passed through the casting and recorded . It the casting has an internal defect, the density of the materials at that spot will be less as compared to the surroundings. This area will allow more penetration of the rays. This will result in the appearance of a dark shadow on the X-ray film reproducing the contour of the defect. The power source used for X-ray tube is a high voltage source: 200KV for casting thickness upto 50mm and one million volts for a thickness from 50 to 180mm.

   γ-ray testing is used for checking heavy-walled castings since these rays are more penetrating and less scattering as compared to X-rays. γ-rays radiate from radium or its salts contained in a capsule.

6. **Magnetic Testing:** In this method, the casting to be tested is magnetized and then placed between the poles of an electro-magnet or in the magnetic field of a solenoid coil. The energized coil is now moved along the casting. If the coil comes across a defect on its way, the magnetic flux changes its direction and induces an emf in the coil turns, the value of which shows up on the galvanometer. This method can detect cracks on the surface or slightly below the surface of a casting. Thus, it supplements the radio-graphical methods, which ordinarily cannot detect small cracks. However, the method can be applied to castings made from ferro-magnetic metals.

7. **Magnetic Particle Testing:** This method of inspection is a procedure used to determine the presence of defects at or near the surface of ferro-magentic castings.

8. **Eddy Current Inspection:** In this method, the material of the casting need not be ferro-magnetic. The test includes a probe which is supplied with high frequency current. It induces an electric field in the casting. The field changes in the presence of surface or near surface defects. These changes show up in the instrumentation.

9. **Liquid-Penetration Inspection:** This method can reveal surface defects only but can be used for any other material. The surface of the casting is thoroughly cleaned and dried. Then the liquid penetrant is applied as sprays or by immersion. The penetrant liquid contains either a material which will fluoresce under black light or a dye that can be visually detected. The liquid penetrant will be readilty drawn into extremely thin cracks. The surface is cleaned and dried. Then, a powder material called developer is sprayed on the surface. The penetrant trapped in defects bleeds out due to blotting action and delineate defects during development. The extent of the discontinuity in the casting surface will be proportional to the amount of penetrant bleeding out. If a florescent penetrant is used, defects show up as a glowing yellow green dots or lines against a dark background. In dye penetrant, defects are revealed as red dots or lines against a white background.

10. **Ultrasonic Testing:** This test is based on the fact that a beam of ultrasonic waves (frequency 20000Hz) passes through a solid (dense) material with little loss but is partially reflected from surfaces. Therefore this method can detect voids, cracks and porosity within a casting.
    The ultrasonic waves are produced by the application of reverse piezo-electric effect. That is, if an electric potential is applied across the flat ends of a crystal (quartz crystal), it will either contract or elongate in the normal direction.

    The crystal is held against a smooth surface of the casting with the help of a coupling fluid. A high frequency AC (I million Cycles per second) is impressed across the faces of the crystal with the help of an oscillator. The second waves produced travel through the casting. These will get reflected from the other end of the casting and the signals are measured with a CRO.
    If the casting has some flaws within it, some of the sound waves will be reflected back and will return to the instrument earlier. The location of the defects from the testing surface may be readily obtained by measuring the relative position of the flaw 'pip' between two 'pips' representing the metal thickness.

The tests for determining mechanical properties of the casting are called as "Destructive Testing" since the casting that undergo these tests become unserviceable. All other tests discussed above are called as "Non-Destructive Testing", since the casting after the test can be used in the usual way, if found suitable.

Manufacturing Technology-I
Unit-I

Two Marks Questions

1. State any four properties of molding sand.
2. List the different types of patterns used in modern foundries
3. What are chaplets?
4. What is meant by core prints?
5. Differentiate the terms mold and core.
6. Which type of furnaces are suitable for melting ferrous materials and why?
7. Write a note on chilled casting
8. Differentiate between semi centrifugal casting and centrifuge.
9. Define casting?
10. When do you make core (or) what is function of core in moulding sand?
11. Mention the specific advantages of carbon di oxide process?
12. Write the composition of good moulding sand?
13. What are the reasons for the casting defects of cold shuts and misrun?
14. Name four different casting defects.
15. How casting defects are identified?
16. Explain the core making process?

Sixteen Marks Questions

1. What are the pattern allowances? Explain briefly each.
2. Discuss the properties of moulding sand
3. Explain the **CO**2 process of core making state its advantages and applications.
4. State the different type of mould. Write a short note on „Green sand mould" and shell moulding
5. Write a neat sketch of a cupola, Explain its operate.
6. Explain with a simple sketch how metal is melted in a Electric arc furnace.
7. What are the different types of furnace used in foundry? Describe in detail with neat sketches any one of them.
8. Explain briefly the various moulding methods used in foundries.
9. Enumerate the continuous casting defects and suggest suitable remedies.
10. Explain the various non –destructive inspection methods of cast products.

UNIT II - JOINING PROCESSES

Fusion welding processes – Types of Gas welding – Equipments used – Flame characteristics – Filler and Flux materials - Arc welding equipments - Electrodes – Coating and specifications – Principles of Resistance welding – Spot/butt – Seam – Projection welding – Percusion welding – GS metal arc welding – Flux cored – Submerged arc welding – Electro slag welding – TIG welding – Principle and application of special welding processes – Plasma arc welding – Thermit welding – Electron beam welding – Friction welding – Diffusion welding – Weld defects – Brazing – Soldering process – Methods and process capabilities – Filler materials and fluxes – Types of Adhesive bonding

WELDING

Welding is a process of joining two similar metals by the application of heat with or without the application of Pressure and with or without the addition of filler metal. The process involves melting and subsequent solidification of the material forming a continuity of strong homogeneous material and composition of and characteristics of the two parts which are joined together. The assemblage of parts is called a weldment.

Weldability: It is the capacity of material being welded into inseparable joints having specified properties such as weld strength, proper structure, etc. Wedability depends on one or more of five major factors: 1. Melting point . 2. Thermal conductivity. 3. Thermal expansion. 4. surface condition and 5. Change in microstructure.

TYPES OF WELDING PROCESSES

There are two groups of welding processes according to the state of the base material during the welding process:

- Fusion welding or Non pressure welding (Liquid-state welding)
- Pressure welding or plastic welding (Solid-state welding)

In the Fusion welding, the material at the joint is heated to a molten state and allowed to solidify. Since no pressure is applied in this process, it is also known as Non pressure welding. Addition of filler material may be required for fusion welding. This includes Gas welding, Arc welding, Thermit welding, etc.

In the pressure welding, the pieces of metal to be joined are heated to a plastic state and then forced together by external pressure. In this welding, two parts are jointed together under pressure or a combination of pressure and heat. If heat is applied, the contact temperature is below the melting point of the base metal. No filler material is required in pressure welding.

Ex: Resistance welding – Butt welding, Spot welding, Seam welding, Projection welding and percussion welding falls under this category.

WELDING PROCESSES

Gas welding	Resistance welding
1. Oxy-acetylene **2.** Oxy- hydrogen 3. Air-acetylene	1. Butt 2. Spot 3. Seam 4. Projection 5. Percussion
Arc welding	**Solid State welding**
1. Carbon Arc 2. Metal Arc 3. Gas Metal Arc (MIG) 4. Gas Tungsten Arc (TIG) 5. Atomic-hydrogen Arc 6. Plasma Arc 7. Submerged Arc 8. Flux-Cored Arc 9. Electro-Slag	1. Friction 2. Ultrasonic 3. Diffusion 4. Explosive
Newer welding	**Related processes**
1. Electron beam 2. Laser beam	1. Oxy acetylene cutting 2. Arc Cutting 3. Brazing 4. Soldering
Thermit welding	

Weld Preparation

Cleaning of Metal

For proper fusing of metal at a joint interface, the interface should be cleaned thoroughly and be free from dirt, oil and grease. These can be removed by using

- Organic solvents like acetone and carbon tetrachloride-
- Wire brushing and emery
- Acid pickling.

While using acid and organic solvents, the surface should be cleaned before welding. Otherwise poisonous gases will be released.

GAS WELDING
Principle:

Gas welding is a type of fusion, non-pressure welding. In this, the require heat to melt the metal parts is supplied by a high temperature flame obtained by a mixture of two gases. The gases are mixed in proper proportions in a welding blow pipe called welding torch.

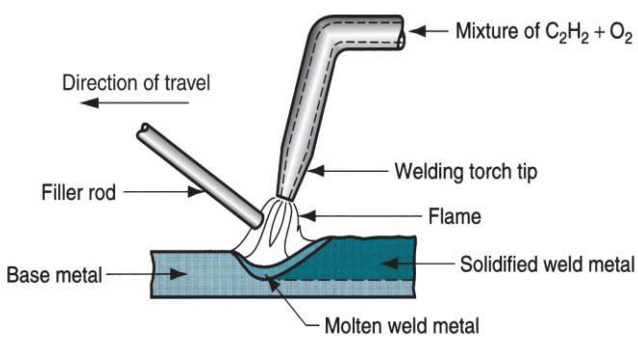
Gas welding is done by burning a combustible gas with air or oxygen in a concentrated flame of high temperature. The purpose of the flame is to heat and melt the parent metal and filler rod of a joint. The mixture of oxygen and acetylene gases is extensively used for welding purposes.

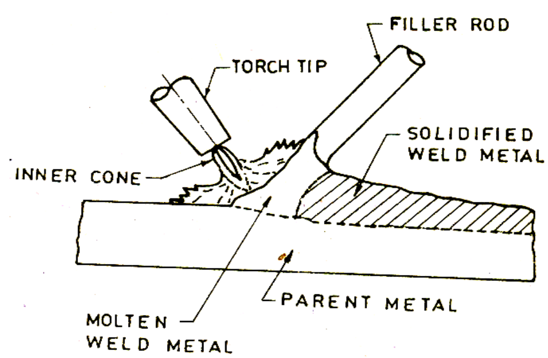
Most common processes use acetylene (C_2H_2) as a fuel. Other fuels such as hydrogen, propane, butane and natural gas are used for specific applications but not much useful because the heat is low and neutral flame is obtained. The flame is directed by a welding torch. A filler metal is sometimes added, which is available as rod or wire with or without flux.

Oxy-Acetylene Welding

Oxy-Acetylene gas welding is accomplished by melting the edges or surface to be joined by gas flame and allowing the molten metal to flow together, thus forming a solid continuous joint upon cooling. The temperature of the oxy-acetylene flame is 3200ºC.

The process is suitable for plates having thickness of 2 to 50 mm. For materials thicker than 15mm, additional filler metal is added to the weld in the form of welding rod. The composition of the filler rod is usually the same or nearly the same as that of the part being welded. To remove the impurities and oxides present on the surface of metal to be joined and to obtain a satisfactory bond, a flux is always employed during the welding except for mild steel which has more manganese and silicon that act as deoxidizing agents.





Filler rod or Welding rod:

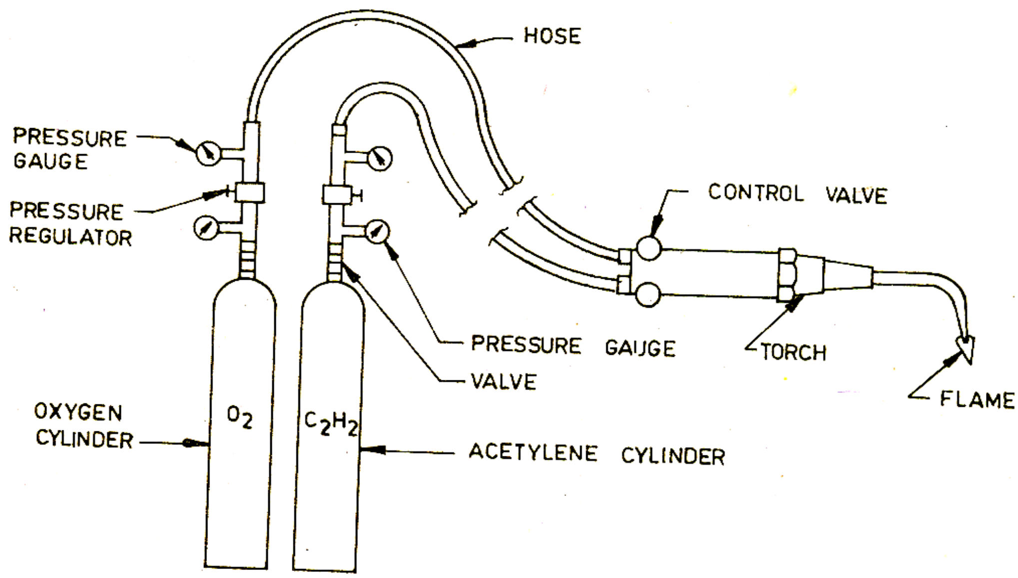
Filler rod is used in gas welding to supply additional metal to make the joint. It is melted by the heat of the gas flame and is deposited over the base metals. Filler metal is added to the weld for joining metal plates of thickness more than 15mm.

Filler rods are generally made of low carbon steels. Alloying elements such as nickel or chromium or manganese can be added to the filler rod to increase the strength of the joint. The diameter of the filler rod varies from 0.3 to 12 mm. the diameter of the rod to be used depends upon the thickness of the workpieces.

Flux:

A flux is used during welding to prevent oxidation and to remove impurities. The molten metal of the weld comes in contact with gases. Hence oxidation takes place and metallic oxides are formed. The flux should have a melting point lower than the parent metal and filler metal. It readily reacts with metallic oxides so that the oxides are completely dissolved by the time the molten pool solidifies. So formed slag forms a blanket to protect the metal from atmospheric oxidation.

GAS WELDING EQUIPMENT :



Gas Cylinders:

Oxygen and acetylene gasses are stored under high pressure in separate cylinder. The oxygen cylinder is generally painted black while acetylene cylinder is painted maroon for easy identification. Pressures of oxygen and acetylene are respectively15,000 kN/mm2 and 1600 kN/mm2.

Pressure Regulators:

Each cylinder is provided with a regulator to regulate the proportion of the two gases and to control the working pressures of the gases. The function of the pressure regulators are to reduce the cylinder pressure to the required working pressure and to regulate the flow of gas (gas volumetric rate) regardless of the pressure variations of the source. The required pressure for gas welding depends on the thickness of the plates to be welded.
For plates of thickness 1 to 25 mm- O2 and C2H2 varies from 0.15 to 0.70 kgf/cm2
For plates over 25 mm- O2 and C2H2 is around 0.98KN kgf/m2

Pressure Gauges:
There are two pressure gauges on each regulator. One pressure gauge shows the cylinder pressure and the other one shows the working pressure for welding.

Welding Torch:
This is a device in which oxygen and acetylene are mixed in the desired volume and the mixture is ignited at the end of its tip. The two control valves on the welding torch are used to control the quantity of oxygen and acetylene to adjust the flame.

Hoses:
The hoses used for the oxygen and acetylene cylinders are green and red in colour respectively.

Safety Devices:
Goggles and leather gloves are must in gas welding. The goggles protect the eyes of the operator from heat and ultra-violet rays while welding. Leather gloves protect the hands from burning and injuries.

FLAME CHARACTERISTICS:

The correct adjustment of the flame is important for doing work. The burning occurs in two stages, namely, Primary stage and Secondary stage.

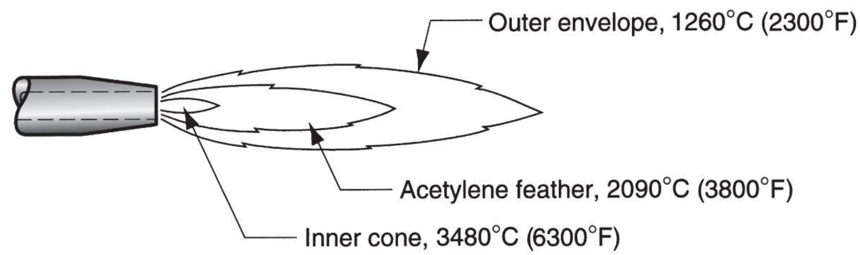
In the primary stage (primary combustion), equal volumes of O_2 and C_2H_2 are ejected from the torch to burn in the atmosphere ($2C_2H_2+2O_2$). When these equal volumes of gases go through the combustion, the inner zone is created, where the temperature reaches in between 3050ºC to 3450ºC. The reaction in this zone is

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

The secondary combustion process is in the outer envelop in which the flame attains a temperature of 2100ºC near the inner cone and around 1250ºC at the end point of the flame. The secondary combustion equation is

$$4CO+2H_2+3O_2 \longrightarrow 4CO_2 + 2H_2O + \text{Heat.}$$

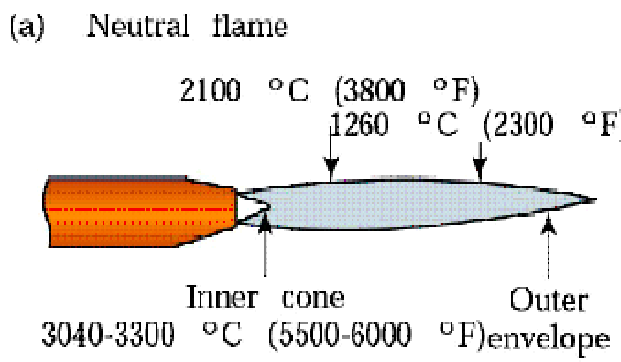
The temperature developed in the flame as a result of these reactions can reach 3200ºC to 3300ºC.



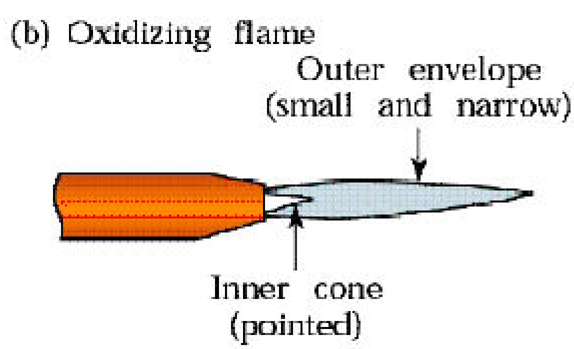
TYPES OF GAS FLAMES:

The heat liberated by the combustion depends upon the gas mixture. There are three possible types of mixtures.

1. Excess of acetylene- Carburizing flame
2. Equal mixture- Neutral flame
3. Excess of oxygen- Oxidizing flame

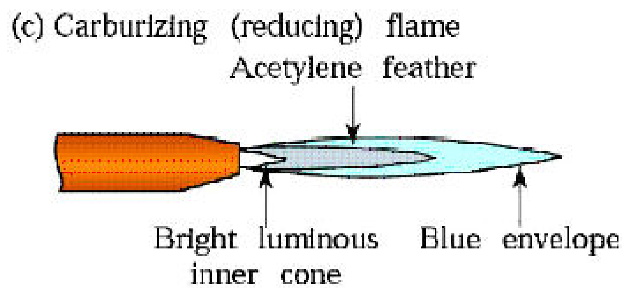


Neutral flame: Has two definite zones: 1. a sharp brilliant cone extending a short distance from the tip of the torch, and 2. an outer cone or envelop only faintly luminous and of a bluish color. The first one develops heat and the second one protects the molten metal from oxidation, because the oxygen in the surrounding atmosphere is consumed by the gases from the flame. The flame is widely used for welding steel, stainless steel, cast iron, copper, aluminum, etc.



Oxidizing Flame: In this flame there is excess of oxygen. This flame has two zones: 1. the smaller inner cone which has a purplish tinge and 2. the outer cone or envelop. In this case, the inner cone is not sharply defined as that of neutral or carburizing flame. This flame is necessary for welding brass. In steel this will result in large grain size, increased brittleness with lower strength and elongation.

Carburizing flame: It is obtained by supplying excess acetylene to the mixture. The flae has three zones- 1. the sharply define inner zone., 2. an intermediate zone of whitish color, and 3. the bluish outer zone. The length of the intermediate zone is and indication of the proportion of excess acetylene in the flame. When welding steel, this will tend to gives the steel in the weld a higher carbon content that the parent metal, resulting in a hard and brittle weld.



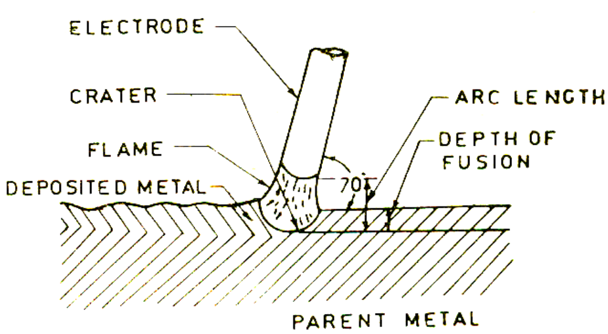
Oxy-hydrogen Welding

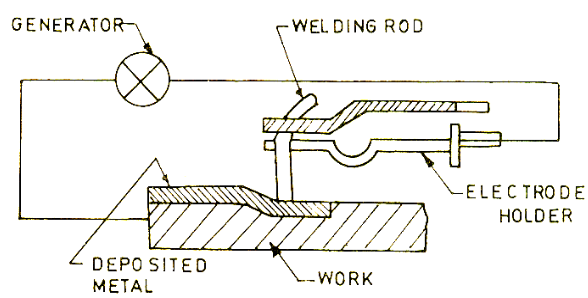
Oxy-hydrogen welding is a gas welding process using a using a combustion mixture of Hydrogen (H_2) and oxygen (O_2) for producing gas welding flame. Oxy-hydrogen flame has a temperature of about 4500°F (2500°C). Combustion reaction is as follows:

$$2H_2 + O_2 = 2H_2O$$

Oxy-hydrogen welding is used for joining metals with low melting points like aluminum, magnesium etc.

ARC WELDING

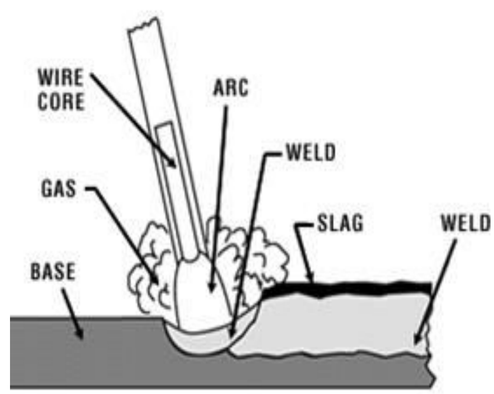




Arc Welding Equipment

Introduction

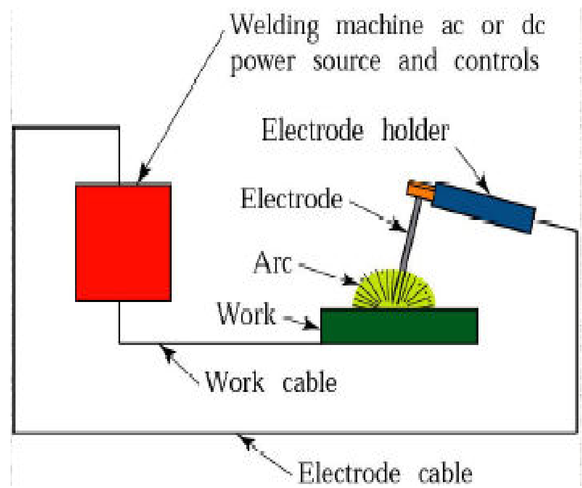
Arc welding is the fusion of two pieces of metal by an electric arc between the pieces being joined – the work pieces – and an electrode that is guided along the joint between the pieces. The electrode is either a rod that simply carries current between the tip and the work, or a rod or wire that melts and supplies filler metal to the joint.



The basic arc welding circuit is an alternating current (AC) or direct current (DC) power source connected by a "work" cable to the work piece and by a "hot" cable to an electrode. When the electrode is positioned close to the work piece, an arc is created across the gap between the metal and the hot cable electrode. An ionized column of gas develops to complete the circuit.

Basic Welding Circuit

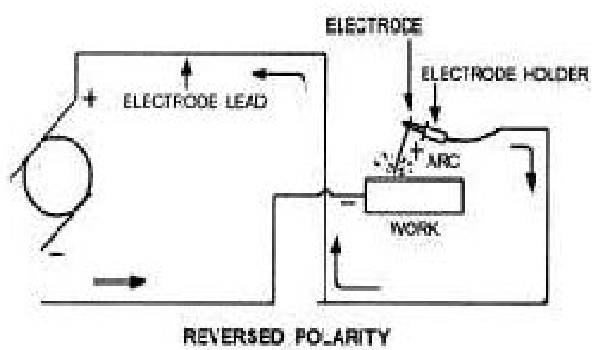
The arc produces a temperature of about 3600°C at the tip and melts part of the metal being welded and part of the electrode. This produces a pool of molten metal that cools and solidifies behind the electrode as it is moved along the joint.



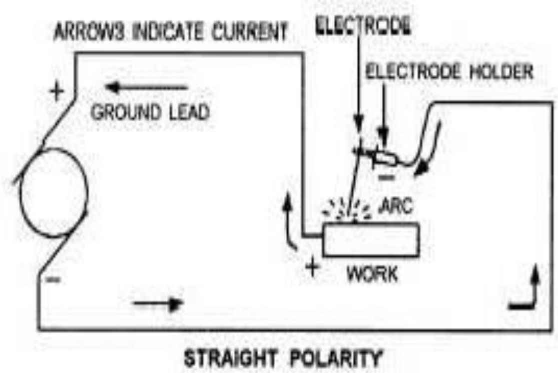
There are two types of electrodes. Consumable electrode tips melt, and molten metal droplets detach and mix into the weld pool. Non-consumable electrodes do not melt. Instead, filler metal is melted into the joint from a separate rod or wire. The strength of the weld is reduced when metals at high temperatures react with oxygen and nitrogen in the air to form oxides and nitrides. Most arc welding processes minimize contact between the molten metal and the air with a shield of gas, vapour or slag. Granular flux, for example, adds deoxidizers that create a shield to protect the molten pool, thus improving the weld.

Polarity

Polarity is the direction of the current flow in a circuit, as shown in figure. Polarity becomes an important factor in DC welding operation as current flows in one direction only. It is not a problem in AC welding. When using DC welding, we can weld either with straight polarity or reverse polarity. Polarity affects the amount of heat going into the base metal. By changing polarity, we can direct the amount of heat to where it is needed. In straight polarity,

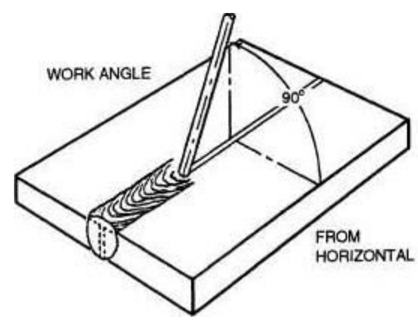


You can recognize the proper polarity for a given electrode by the sharp, crackling sound of the arc. The wrong polarity causes the arc to emit a hissing sound, and the welding bead is difficult to control.

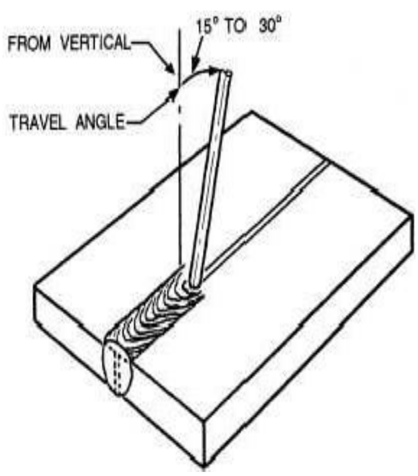


Straight	Reverse
The electrode is negative and the work piece positive; the electrons flow from the electrode to the work piece. Majority of the heat is directed toward the workpiece.	The electrode is positive and the work-piece negative; the electrons flow from the work piece to the electrode and the heat is concentrated on the electrode.
In some welding situations, it is desirable to have more heat on the workpiece because of its size of the workpiece and the need for more heat to melt the base metal than the electrode; therefore, when making large heavy deposits STRAIGHT POLARITY is used.	In overhead welding it is necessary to rapidly freeze the filler metal so the force of gravity will not cause it to fall. When you use REVERSE POLARITY, less heat is concentrated at the work piece. This allows the filler metal to cool faster, giving it greater holding power. Cast-iron arc welding is another good example of the need to keep the workpiece cool; reverse polarity permits the deposits from the electrode to be applied rapidly while preventing overheating in the base metal
In general, straight polarity is used for all mild steel, bare, or lightly coated electrodes.	Reverse polarity is used in the welding of nonferrous metals, such as aluminum, bronze, Monel, and nickel. Reverse polarity is also used with some types of electrodes for making vertical and overhead welds.

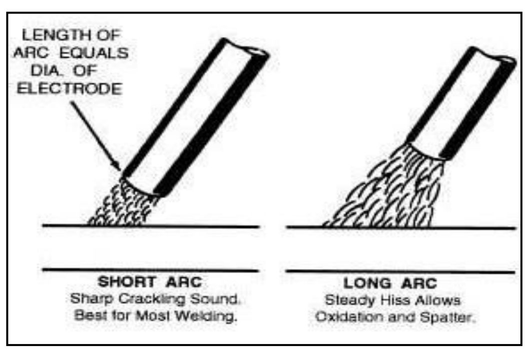
Electrode Angle:



The angle at which the electrode is held greatly affects the shape of the weld bead which is very important in fillet and deep groove welding. The electrode angle consists of two positions: **work angle and travel angle.** Work angle is the angle from the horizontal measured at right angles to the direction of welding. Travel angle is the angle in the direction of welding and may vary from 5 to 30 degrees, depending on the welder's choice and conditions .Work angle is especially important in multiple-pass fillet welding. Normally, a small variance of the work angle will not affect the appearance or quality of a weld; however, when undercuts occur in the vertical section of a fillet weld, the angle of the arc should be lowered and the electrode directed more toward the vertical section.



Length of the Arc:

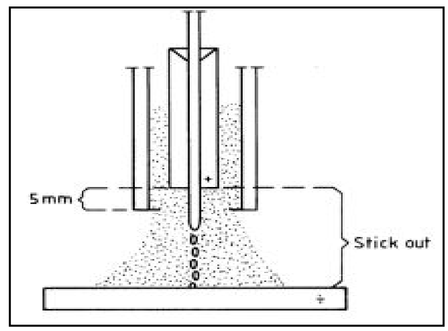


When an arc is too long, the metal melts off the electrode in large globules and the arc may break frequently. This produces a wide, spattered, and irregular deposit with insufficient fusion between the base metal and the weld. When an arc is too short, it fails to generate enough heat to melt the base metal properly, causes the electrode to stick frequently to the base metal, and produces uneven deposits with irregular ripples. The recommended length of the arc is equal to the diameter of the bare end of the electrode. The length of the arc depends upon the type of electrode and the type of welding being done; therefore, for smaller diameter electrodes, a shorter arc is necessary than for larger electrodes. In vertical or over-head position, a shorter arc is desirable because it gives better control of the molten puddle and prevents atmospheric impurities from entering the weld.

Metal Transfer:

Dip Transfer: (Short circuiting Transfer). Arc welding is carried out using currents below 200 A and 25V. Under this condition the arc is so short that the molten globules at the electrode (wire) tip short circuit to the work piece at rapid time intervals. The rise of the current melts the electrode tip and it reestablishes the arc. This cycle occurs approximately 100 times per second. This method is suitable for all positions of welding, thin material, open butt type joint, etc.

Spray Transfer: Using high currents and voltages, i.e., 250-500A an more than 25V, the metal is transferred across the arc in the form of fine droplets in a spray. It is used for high deposition rates and deeper penetration welds. Mainly used for thick materials in the flat position only.

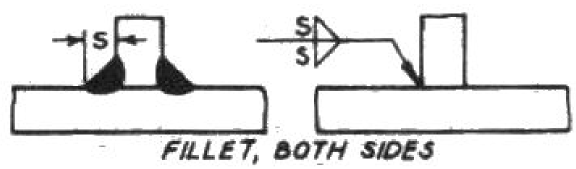


Types of Joints

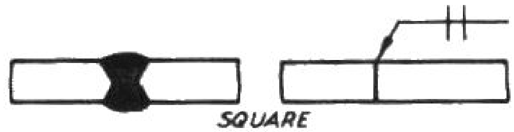
The relative position of the parts to be welded determines the types of joint. The major classification of weld joints are:

1. **Fillet 2. Butt 3. Lap 4. Corner 5. Edge**

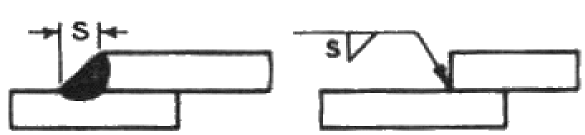
Fillet Joint: Normally used on T-Joints. This weld is roughly triangular in cross-section and between two surfaces not in the same plane, and the weld metal is substantially placed alongside the components being joined. T-joint is used to join two plates whose surface are at right angles to each other, such that the edge of one plate rests on the surface of other plate.



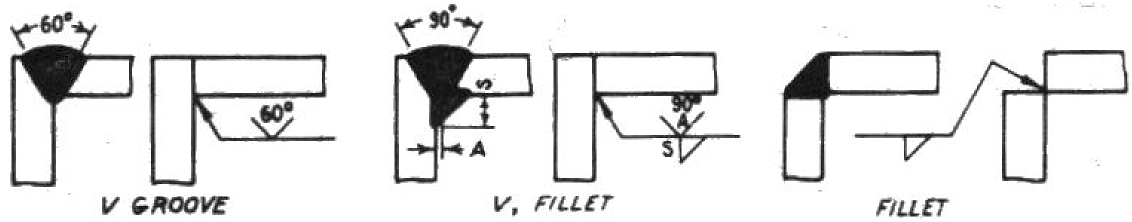
Butt Welds: Made between two pieces of metals usually in the same plane. It maintains continuity between sections.



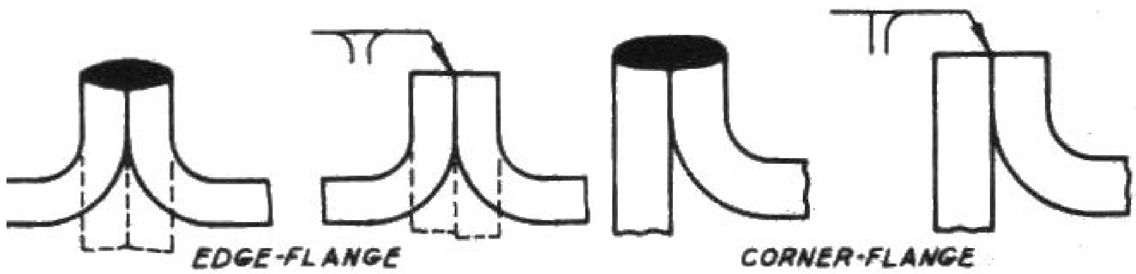
Lap Joint: It is used to joint two overlapping plates sop that the edge of one plate is welding to the surface of the other.



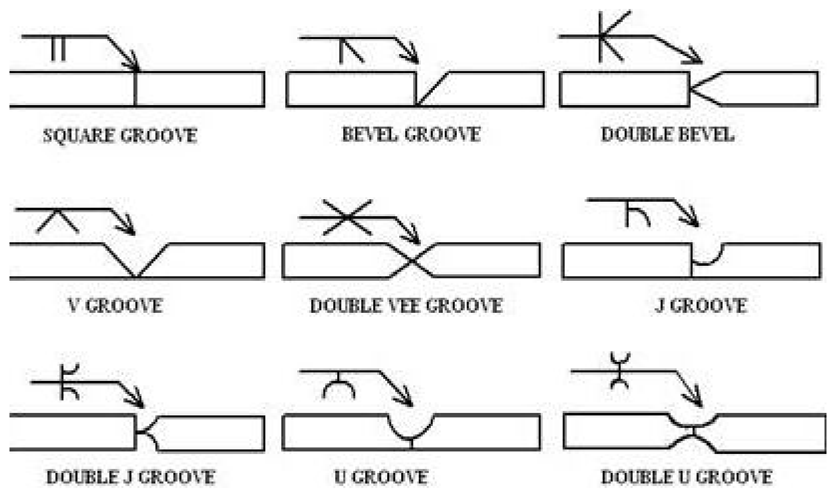
Corner Joint: It is used to join two plates whose included angle is 90°.



Edge Joint: It is used to joint two parallel plates and the weld is made on the edge of the plates

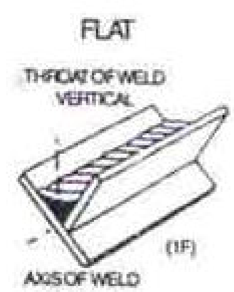


Edge Preparation: If joint preparation is done well, it results in reduced welding time, quality of workmanship and sound joint. For small thickness- no need to prepare the edge as the heat can penetrate to the entire depth of the joint easily. For metals with more thickness, it is necessary to penetrate the entire depth of metal. It is done by cutting, grinding and machining.

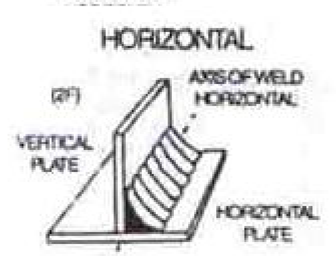


Position of Welding

It is an important criterion for making a quality weld joint.

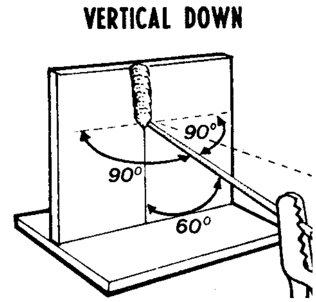


Flat position: The recommended electrode angle with work is 90°. The angle used in the direction of travel is 10-25° for bead weld and 10-20° for fillet weld.



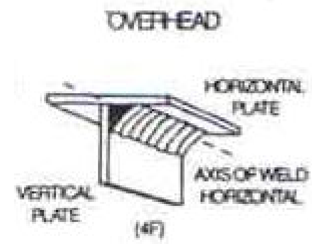
Horizontal Position: The electrode angle for horizontal bead weld is 5-25° with work and 10-25° in the direction of travel. The first run for a single fillet weld is made with 45°. In the second pass electrode angle is 60-70°. Third and final pass is 30° with work.

Vertical Position: Two basic techniques are available for welding vertically: uphill and downhill.



The uphill technique is favored in heavy sections and large fillets or where root penetration is very important. Current is reduced slightly below normal, the electrode tip in directed upwards into the jopint at an angle of 10-20°.

The down-hill technique is restricted to lighter sections and joints where penetration is not a problem (light sheet) or where excellent finish and minimum distortion is essential. The electrode tip points approximately 30° upwards.



Overhead Position: These welds should be done in flat position with due allowance for gravity. Obviously large pools of metal are not manageable in this position and wide weaves are rarely acceptable. Current slightly lower than normal are used. These travel faster and maintains short arc length. The electrode should be kept at right angles to the plate width, pointing back some 10-25° on to the molten metal.

Arc Welding Consumables and Equipment:

Equipment & Operation - One reason for the wide acceptance of the SMAW process is the simplicity of the necessary equipment. The equipment consists of the following items.

1. Welding power source
2. Electrode holder
3. Ground clamp
4. Welding cables and connectors
5. Accessory equipment (chipping hammer, wire brush)
6. Protective equipment (helmet, gloves, etc.)

Welding Power Sources - Shielded metal arc welding may utilize either alternating current (AC) or direct current (DC), but in either case, the power source selected must be of the constant current type. This type of power source will deliver a relatively constant amperage or welding current regardless of arc length variations by the operator. The amperage determines the amount of heat at the arc and since it will remain relatively constant, the weld beads produced will be uniform in size and shape. Whether to use an AC, DC, or AC/DC power source depends on the type of welding to be done and the electrodes used. The following factors should be considered:

Electrode Selection - Using a DC power source allows the use of a greater range of electrode types. While most of the electrodes are designed to be used on AC or DC, some will work properly only on DC.

Metal Thickness - DC power sources may be used for welding both heavy sections and light gauge work. Sheet metal is more easily welded with DC because it is easier to strike and maintain the DC arc at low currents.

Distance from Work - If the distance from the work to the power source is great, AC is the best choice since the voltage drop through the cables is lower than with DC. Even though welding cables are made of copper or aluminum (both good conductors), the resistance in the cables becomes greater as the cable length increases. In other words, a voltage reading taken between the electrode and the work will be somewhat lower than a reading taken at the output terminals of the power source. This is known as voltage drop.
Welding Position - Because DC may be operated at lower welding currents, it is more suitable for overhead and vertical welding than AC. AC can successfully be used for out-of-position work if proper electrodes are selected.

Arc Blow - When welding with DC, magnetic fields are set up throughout the weldment. In weldments that have varying thickness and protrusions, this magnetic field can affect the arc by making it stray or fluctuate in direction. This condition is especially troublesome when welding in corners. AC seldom causes this problem because of the rapidly reversing magnetic field produced. Combination power sources that produce both AC and DC are available and provide the versatility necessary to select the proper welding current for the application. When using a DC power source, the question of whether to use electrode negative or positive polarity arises. Some electrodes operate on both DC straight and reverse polarity, and others on DC negative or DC positive polarity only. Direct current flows in one direction in an electrical circuit and the direction of current flow and the composition of the electrode coating will have a definite effect on the welding arc and weld bead.

Electrode Holder - The electrode holder connects to the welding cable and conducts the welding current to the electrode. The insulated handle is used to guide the electrode over the weld joint and feed the electrode over the weld joint and feed the electrode into the weld puddle as it is consumed. Electrode holders are available in different sizes and are rated on their current carrying capacity.

Ground Clamp - The ground clamp is used to connect the ground cable to the work piece. It may be connected directly to the work or to the table or fixture upon which the work is positioned. Being a part of the welding circuit, the ground clamp must be capable of carrying the welding current without overheating due to electrical resistance.

Welding Cables - The electrode cable and the ground cable are important parts of the welding circuit. They must be very flexible and have a tough heat-resistant insulation. Connections at the electrode holder, the ground clamp, and at the power source lugs must be soldered or well crimped to assure low electrical resistance. The cross-sectional area of the cable must be sufficient size to carry the welding current with a minimum of voltage drop. Increasing the cable length necessitates increasing the cable diameter to lessen resistance and voltage drop.

Coated Electrodes - Various types of coated electrodes are used in shielded metal arc welding. Electrodes used for welding mild or carbon steels are quite different than those used for welding the low alloys and stainless steels. Details on the specific types will be covered in subsequent lessons.

Welding Electrodes, Coating and Specifications:

Welding electrodes are metal wires with baked on chemical coatings. The rod is used to sustain the welding arc and to provide the filler metal required for the joint to be welded. The coating protects the metal from damage, stabilizes the arc, and improves the weld.

The metal-arc welding electrodes may be grouped as bare electrodes, light coated electrodes, and shielded arc or heavy coated electrodes. The type used depends on the specific properties required that include: corrosion resistance, ductility, high tensile strength, the type of base metal to be welded; and the position of the weld that is flat, horizontal, vertical, or overhead. Welding electrodes must be kept dry. Moisture destroys the desirable characteristics of the coating and may cause excessive spattering and lead to the formation of cracks and weakness in the welded area.

The diameter of the wire, less the coating, determines the size of the welding rod. This is expressed in fractions of an inch such as 3/32", 1/8", or 5/32." The smaller the diameter means it requires less current and it deposits a smaller amount of filler metal.

The type of base metal being welded, the welding process and machine, and other conditions determines the type of welding electrode used. For example, low carbon or "mild steel" requires a mild steel welding rod. Welding cast iron, aluminum or brass requires different welding rods and equipment.

The flux coating on the electrodes determines how it will act during the actual welding process. Some of the coating burns and the burnt flux forms smoke and acts as a shield around the welding "pool," to protect it from that air around it. Part of the flux melts and mixes with the wire and then floats the impurities to the surface. These impurities are known as "slag." A finished weld would be brittle and weak if not for the flux. When the welded joint is cooled, the slag can be removed. A chipping hammer and wire brush are used to clean and examine the weld.

The American Welding Society's (AWS) classification number series has been adopted by the welding industry. The electrode identification example below is for a steel arc-welding rod labeled E6010:

- "E" indicates "electrode" for electric arc welding
- The first two (or three in some cases) digits (60) indicate tensile strength in thousands of pounds per square inch
- The third (or fourth in some cases) digit (1) indicates the position of the weld. An "O" indicates that this classification is not used; "1" is for all positions; "2" is for flat and horizontal positions only; 3 is for flat position only
- The last two digits together (10) indicate the type of coating and the type of power supply required, 10 organic coating and DC current with reverse polarity.

Therefore, a welding rod numbered E6010 indicates "E" an manual arc-welding electrode with (60) a minimum strength of 60,000 psi., that can be used (1) in all positions and (10) DC reverse polarity is required.

RESISTANCE WELDING

According to joule's law a poor conductor heats up to a higher degree than a good conductor when the same amount of amperes pass through it. When two pieces of metal are in contact, the area where they touch has a high resistance to electric current. In resistance welding the metal parts to be joined are heated to a plastic state over a limited area by their resistance to the flow of electric current and mechanical pressure is used to complete the weld. When electric current is passed across the surfaces in contact, heat (H) is generated which can be justified by the formula.

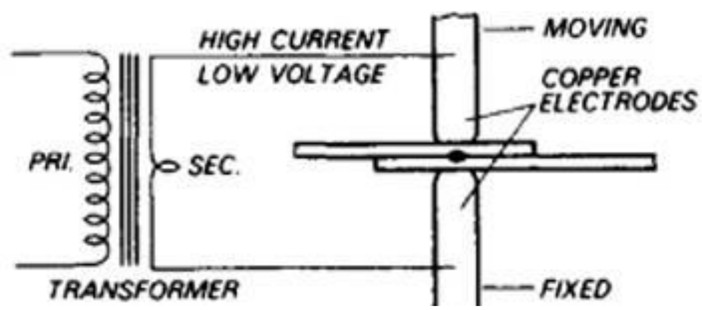
$H = I^2RT$. Where
H= Heat generated, I= Current in amperes,
R=Resistance in ohms and T= Time of the current flow in seconds.

Basically, this formula states that the amount of heat is directly proportional to the square of the amperes, times the resistance, times the current flow. If enough current is used for a long enough time, the metal surfaces heat until they become molten. If two pieces are pressed together while their surfaces are at a plastic state and allowed to cool, the pieces will fuse into one piece.

Resistance welding is based upon the above fundamental principle that when an electric current is passed through a metal, the resistance of the metal to this electric flow heats the metal. Two factors perform the welding operation: the resistance heating of the two pieces to be joined and the forging pressure exerted joining the two pieces of metal. Majority of the heat is generated where the two pieces of metal to be welded are in contact. When the temperature at this point reaches the fusion temperature, forging pressure is applied and welding occurs.

Total resistance= Resistance of electrodes + Electrode workpiece contact resistance + resistance of the parts to be welded and workpiece + workpiece contact resistance.

The schematic representation of the resistance welding is shown.



Advantages:
1. Very little or no skill needed
2. Higher production rate- suited for mass production
3. Economical
4. Less distortion due to heat affected area
5. Dissimilar metals can be welded
6. Fast joining of large castings and forgings
7. Excellent way to add fasteners to products

Limitations:
1. Relatively expensive equipment- requires high volume of production
2. High, short duration current loads
3. Plates of limited thickness can only be welded

Application:
- Commonly used for sheet metals made of carbon steel, stainless steel and alumunium.

Types of Electric Resistance Welding

1. Resistance Spot Welding
2. Resistance Seam Welding
3. Projection Welding
4. Percussion Welding
5. Flash Butt Welding

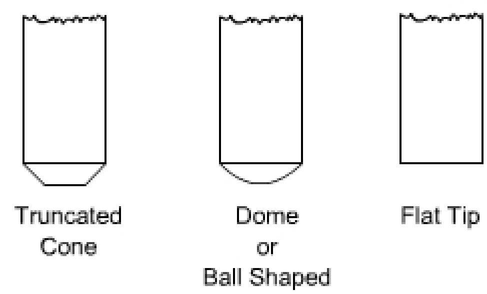
Resistance Spot Welding

Electrodes used in spot welding are made up of low resistance, hard copper alloy. The electrodes are capable of transmitting heat that is generated at the contact points. Electrodes are either water cooled or oil cooled. The electrodes should have high degree of hardness and the ability to maintain their shape even at high temperatures. Electrode points should be kept clear of scales, dust and other impurities at all times. The electrode diameter should be equal to the fusion zone of the weld spot.

Electrodes for Spot Welding

Three types of basic designs of electrodes tips are used, namely; Pointed, Domed and Flat.

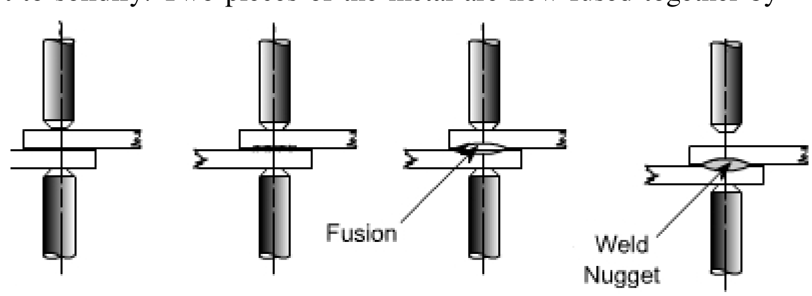
- Pointed electrodes (Truncated) are most widely used electrodes and used for ferrous metals. The angle of the point should be in the range of 120-140°.
- Domed electrodes are designed to withstand heavy currents and more mechanical force. They are mostly used for non-ferrous metals. Usually radius of cone is 50-100mm.



- Flat electrodes are used for spot welding deformation is not wanted. Usually one flat electrode is combined with one domed electrode.

Process of Spot Welding

The Process consists of lapping two pieces of metal and then clamping them between two electrodes. Current is passed between the electrodes and a small area is heated. The temperature of this weld zone is around 816-927°C. After the metal has been heated to plastic state, forging pressure is exerted on the pieces being joined. The current stops but the electrodes continue to hold the metal to allow the spot to solidify. Two pieces of the metal are now fused together by spot weld or weld nugget.



The stages of resistance spot welding cycle are:

Squeezing stage: The electrodes are clamped on to the pieces to be welded. The time required for this is called the squeezing time

Heating stage: The weld area is brought to the welding temperature by passing high ampere current through electrodes. The time required is called weld time. The machine controls the welding time but it can also be set.

Forging stage: After the metal has reached fusion point, the current is shutoff and the electrodes apply additional pressure to forge the weld area.

Holding stage: The pressure applied during the forging stage, is maintained until the weld is cooled and allowed to solidify. Then the next cycle begins to form.

Advantages:

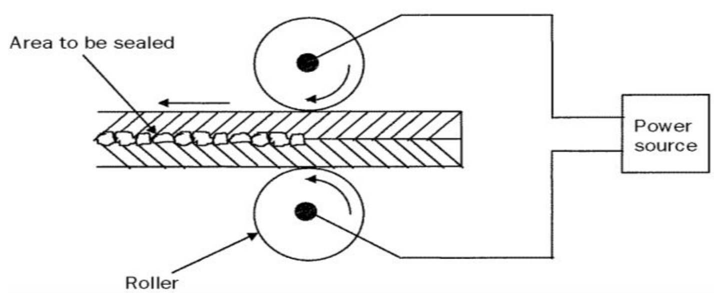
1. Fast welding rate
2. More versatility
3. Quick Setup time
4. Low unit cost per weld
5. Less energy waste
6. No skilled operators needed

Limitations:

1. High power consumption
2. High initial investment
3. Hard alloys cannot f\be spot welded
4. 1-5mm limiting thickness

Resistance Seam Welding

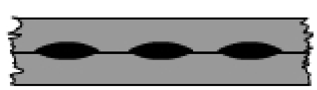
Resistance seam welding is similar to spot welding process. The only difference is the electrodes are in the shape of wheels and can be rotated.



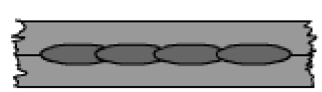
There are basically 4 types of seam welding machines, namely, Circular, Longitudinal, Universal and Portable. In the first three types, the face of the wheel is perpendicular, parallel, perpendicular and parallel to the column respectively. In the final one, the work is clamped to a fixture and the portable welding machine head is moved over the seam. Since the current continuously passes through the electrodes, flowing refrigerant fluids cool the electrodes.

Basically, three types of weld can be formed in seam welding by supplying current: Conventional (Overlap), intermittent (Tack) and continuous. Intermittent current produces spot welding, continuous produces gas and liquid leak proof lap joint.

Continuous Welding

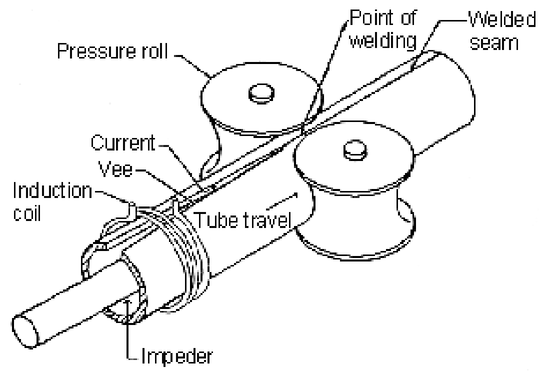


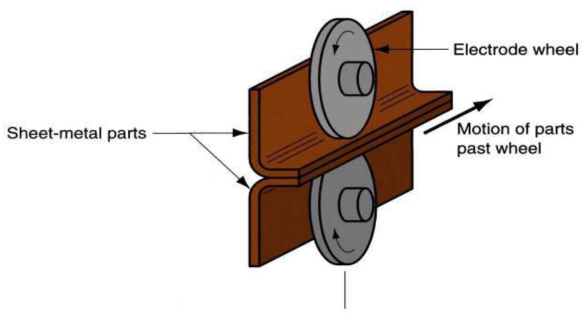
Tack Welding



Overlap Welding

Other variants of the resistance seam welding is the induction seam welding. In this high frequency alternating current in the range of 10,000-500,000 Hz and the rapid application of an upsetting force after heating is substantially completed. The electrodes are designed in such a way that they hold the pipe and apply the pressure effectively. Extremely thin sections (0.1mm) cab be welded since high frequency current flows over the surface of the work-piece by means of sliding contacts at the edge of the joint. This process is ideally suited for making pipes, tubing and structural shapes.





Advantages:

1. Used to produce highly efficient water and gas tight joints
2. Same machines can be used for intermittent spot welding called roll welding

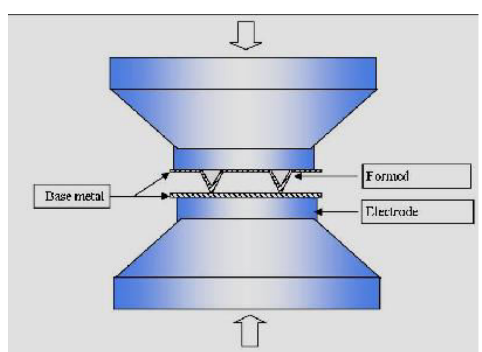
Limitations:

1. Restricted to metals that have low hardenability rating
2. Redistricted to welding thin materials
3. Possibility of shunting current
4. Excessive heat in welding requires cooling of electrodes.

Resistance Projection Welding

This is a variation of resistance spot welding. Basically, a projection is placed on one of the materials to be welded. This projection is then brought into contact with the second material.

Projections are the small deformations that will be made in the pieces of the metal to be welded. These projections are made to touch another piece to be welded. The purpose of the projection is to localize the heat at a specific location of the joint. The projection design determines the current density. Projections in sheet metal are made by embossing while projections in solid metal pieces are made either by forging or machining.

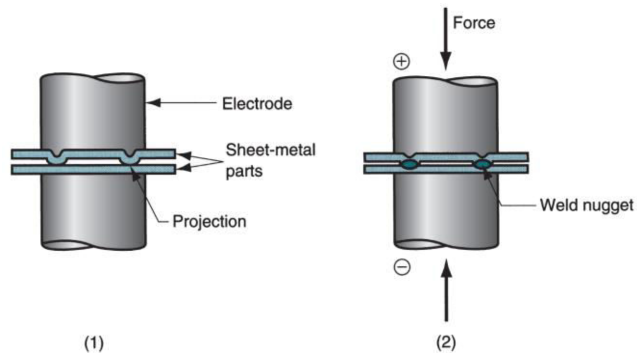


The electrodes used for projection welding are flat electrodes, which are slightly larger than the electrodes used for spot welding.

The requirements to be met in a sheet material are listed below:

- Rigid enough to bear the initial current force
- Should have sufficient mass to raise the spot or weld nugget in the plane surface to weld temperature.

- Collapses without extruding between parts
- Surface should be intimate contact after welding
- Easy to form, so that the punch and die require little maintenance
- Cause minimal distortion



The welding sequence is similar to resistance spot welding. The welding electrodes are used to apply both force and current across the configuration. The point of contact constricts current flow (point f high resistance) and heating occurs locally at that point. As the materials heats, it becomes soft, and the projection collapses under the force applied by the welding electrode. Due to the amount of plastic flow involved, melting is not always necessary to form a sound joint. The sequence of events during the formation of projection weld is shown.

Advantages:

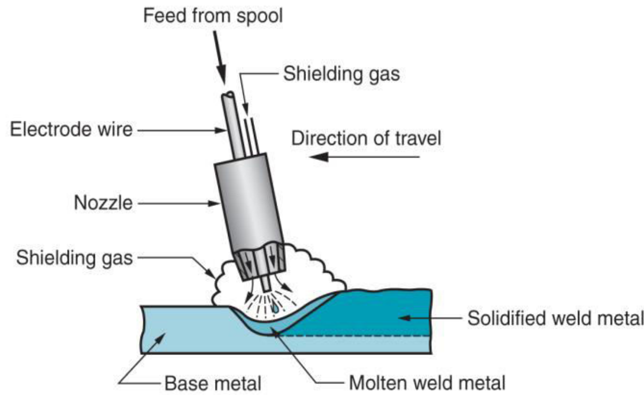
1. Projection welding is not limited to sheets. Any joint whose contact area is small compared to thickness can be welded (e.g., Wires).
2. Ease of obtaining satisfactory heat balance for welding difficult combinations.
3. Increased output per machine as many welds can be made simultaneously.
4. Longer electrode life.
5. Weld may be placed more closely together.

Limitations:

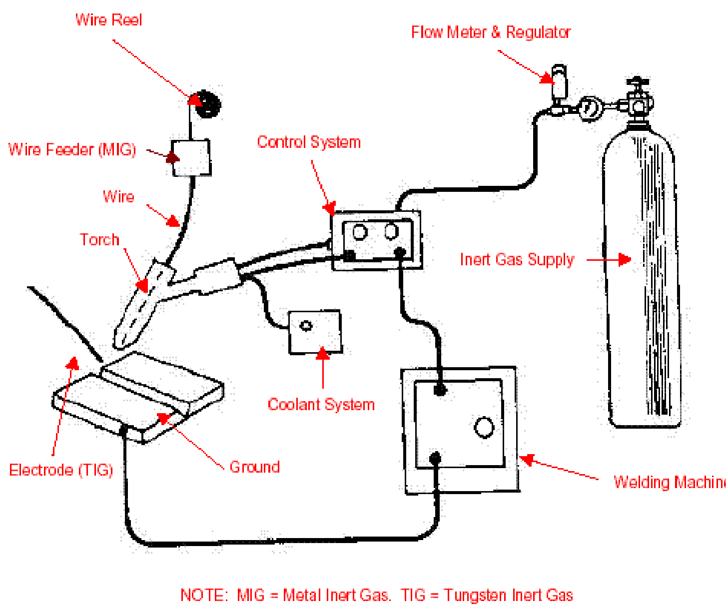
1. Surface preparation is difficult in large surfaces.
2. Restricted to thin materials

GAS METAL ARC WELDING (GMAW OR MIG)

GMAW or MIG welding uses source of heat as an arc formed between a consumable metal electrode and the work piece in the presence of a gaseous shield of inert gas such as argon, helium or an argon-helium mixture or active gases like CO_2 and O_2 for preventing contamination..



In this process, the wire is fed continuously from a reel through a gun to constant surface which imparts a current upon the wire. A fixed relationship exists between the rate of wire burn-off and the welding current so that the welding machine at a given feed rate will produce necessary current to maintain he arc. The welding machine is a DC constant voltage, with both straight and reverse polarities available.



When the gun is switched on, gas, wire feed and the power source are on simultaneously, the welding operation starts. The wire feeder pulls he wire electrode from a spool and pushes it through the gun at required speed. As the wire passes through the gun, it picks up electric current from the copper contact tube, which is electrically connected to the power source, and makes an arc with the work piece, The arc is protected from the oxidation and contamination by the gaseous shield formed by he shielding gas through the nozzle.

Advantages:

1. Welding can be done in all positions since only gases are used for shielding.
2. Higher welding speed due to continuous length of electrode.
3. Monitoring and controlling of arc is easier.
4. Use of smaller diameter wire for a given welding current, increases the current density leading to higher deposition rate.
5. Less distortion due to high welding speed.
6. Cleaning is easy due to absence of slag formation.

Limitations:

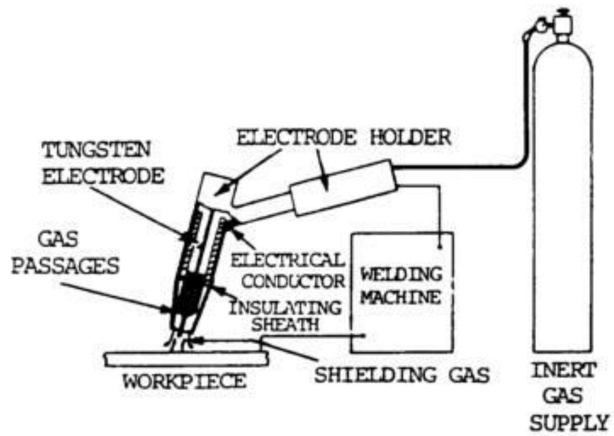
1. Costlier and more complex equipment
2. Less adaptable to weld in difficult to reach areas since welding gun should be close to weld area.
3. GMAW weld joints are more susceptible to weld cracking because of the uncontrolled rate of cooling.

Applications:

1. Used for welding of carbon steels, low and high alloy steels, nickel alloys, stainless steels, aluminium, titanium and zirconium alloys.
2. All welding positions applicable from about 1 mm thickness to thick-walled sections.

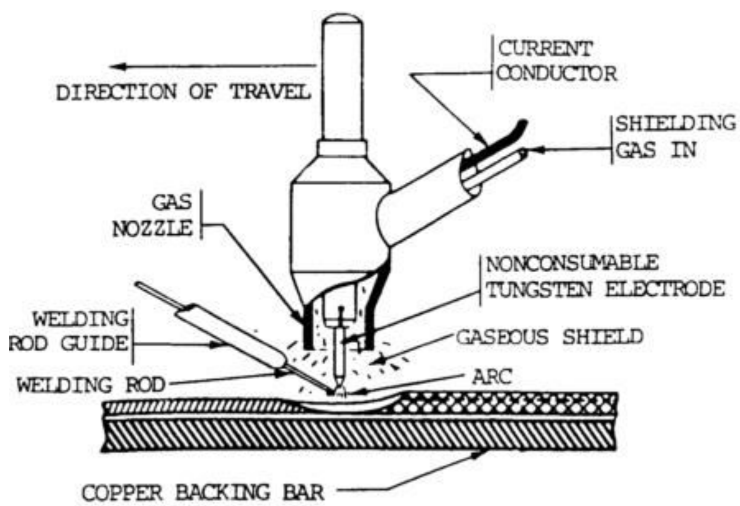
GAS TUNGSTEN ARC WELDING (GTAW or TIG)

It is an arc welding process that uses as arc between a tungsten non-consumable electrode and the work piece. The equipment consists of the power supply, the welding torch and connecting cables. The torch utilizes a non-consumable electrode usually alloyed with oxides such as thorium or cerium to improve the electrode performance. An adjustable collet is used to accommodate the electrodes with the torch. The torch also includes the shielding gas nozzle through which the shielding gas flows to cool the electrode and to shield the weld puddle or pool from oxygen.



Gas tungsten arc welding equipment arrangement

TIG welding process is included in the figure. This process uses a non-consumable tungsten electrode held in a torch. Shielding gas is fed through the torch to protect the electrode, molten weld pool and solidifying weld metal from contamination from the atmosphere. The electric arc is produced by the passage of current through the conductive, ionized shielding gas. The arc is established between the electrode tip and the work. Heat is generated by the arc, which melts the base metal. Once the arc and weld pool are established, the torch is moved along the joint and the arc progressively melts the facing surfaces. Filler wire, if needed is usually added to the leading edge of the weld pool to fill the joint.



Gas tungsten arc (TIG) welding (GTAW)

Advantages:

1. Weld can be done at all positions.
2. This process is well adapted for welding thin metal – 0.2mm.

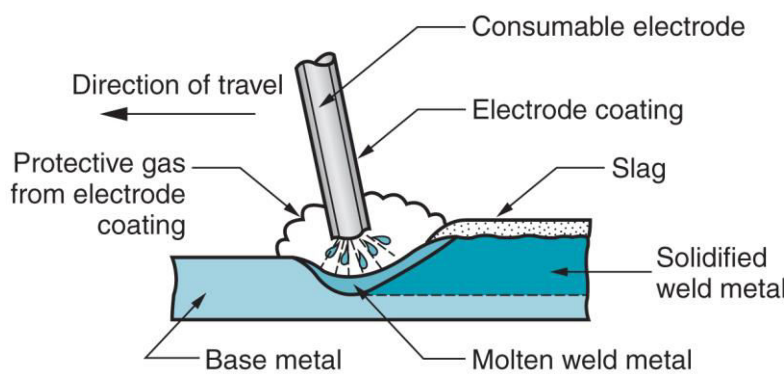
3. Increased welding speed.
4. Minimized distortion.
5. Quality of weld is improved.

Limitations:
1. to avoid overheating of the nozzle, cooling arrangement is needed.
2. High cost associated with gas and electrode.
3. Tungsten quality may impair the strength and corrosion resistance of the weld.

Applications:
1. Adaptable to both manual and automatic operation
2. Can be used to produce continuous welds, intermittent and spot welds.
3. Aluminium, Magnesium, Stainless steel, Copper, Alloy Steel etc., can be welded.
4. It is mainly used in aerospace and nuclear industries.

SHIELDED METAL ARC WELDING

Shielded Metal Arc Welding (SMAW) is an arc welding process that uses a consumable electrode consisting of a filler metal rod coated with chemicals that provide flux and shielding. The process is illustrated in the figure:



The coated welding stick (SMAW is sometimes called stick welding) is typically 200 to 450 mm long and 1.5 to 9.5 mm in diameter. The heat of the welding process melts the coating to provide a protective atmosphere and slag for the welding operation.

During operation the bare metal end of the welding stick is clamped in an electrode holder connected to the power source. The holder has an insulated handle so that it can be held and manipulated by a human welder. Currents typically used in SMAW range between 30 and 300 A at voltages from I5 to 45 V depending on the metals being welded, electrode type and length and depth of weld penetration required.

Shielded metal arc welding is usually performed manually. Common applications include construction, pipelines, machinery structures, shipbuilding, fabrication job shops, and repair work. It is preferred over oxyfuel welding for thicker sections above 5 mm because of its higher power density. The equipment is portable and low cost, making SMAW highly versatile and probably the most widely used of the AW welding processes. Base metals include steels, stainless steels, cast irons, and certain nonferrous alloys.

Advantages
1. Job of any configuration can be welded.
2. Quality and strength of the weld can be controlled equivalent to other manual methods using consumable electrodes
3. Can be done either in AC or DC.
4. Least expensive compared to other welding processes.
5. Highly versatile, can be done in any position, indoor or outdoors.

Limitations

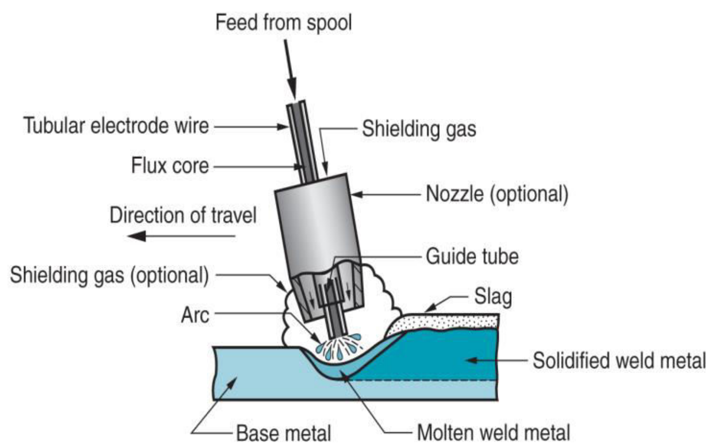
1. Low metal deposition rate and efficiency.
2. Fixed length of electrode leads to lot of wastage
3. Special precautions have to be taken to prevent moisture pickup.

Applications

1. Ship building and construction industry for Fabrication girders, beams and columns
2. Portable so useful for repair and maintenance of equipment, machinery and pipe welding.

FLUX CORED ARC WELDING

Flux-cored arc welding (FCAW), also known simply as flux-cored welding, is a form of arc welding that joins metals by heating them with an arc between a continuously-fed, consumable, tubular electrode wire and the work pieces. Flux present in the electrode's core acts as a shielding agent, eliminating the need for shielding gases (though they are used in some cases).



Flux-cored arc welding is generally considered an automatic or semiautomatic process because of the need for a continuously-fed electrode containing flux and a power supply (usually constant voltage).

The first type of flux-cored arc welding electrode is self-shielding or sometimes branded as Inner Shield wire and does not use shielding gases because the flux acts as a shielding agent, making them unnecessary. This makes it a portable welding technique just like SMAW.

The second type is dual-shield and makes use of externally-provided shielding gases. This method is more popular when the metals to be joined are either very thick or out of position, but it is not suitable for environments in which wind could interfere with the shielding gases and lead to greater build-up of slag.

Both these types of electrodes produce a slag over the weld the must be cleaned after the weld is finished.

Advantages

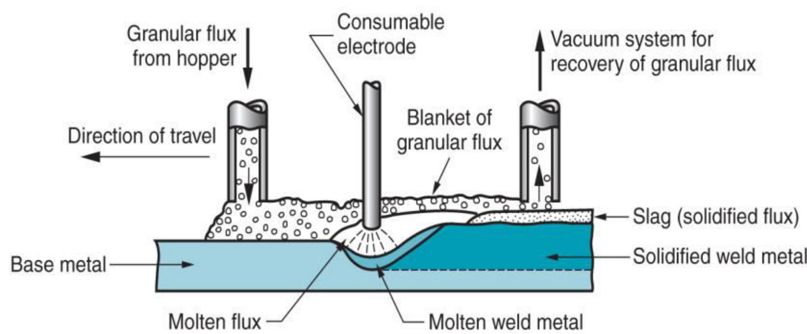
- Use of consumable electrodes makes flux-cored arc welding ideal for many positions.
- Welding may take place outside if shielding gases are not used.
- The highest deposition rate of all the manual welding processes.
- Less pre-cleaning of metals is required than with some other methods.
- Low operator skill is required.

Disadvantages

- Incomplete fusion of base metals may occur.
- Melted contact tips may result without a steady hand.
- Equipment failures may lead to irregular wire feeding or porosity (if gases are not released correctly).
- Method is not suitable for welding metals that need to be painted
- Some electrodes are only designed for flat and horizontal welding.
- Porosity in the weld or worm holes.

SUBMERGED ARC WELDING (SAW)

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. 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 results 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.

Advantages:

1. As a result of unique protection by the flux, the weld is exceptionally smooth.
2. Can be used in exposed areas with relatively high winds, where flux shield protects the weld.
3. High rate of weld deposition and with V-joint preparation, less material can be used to fill the gap.
4. Welding speed is more.
5. Less skill is required.
6. Shielding is not required to protect the operator, although protection is recommended.

Limitations:

1. Arc starting is very difficult.

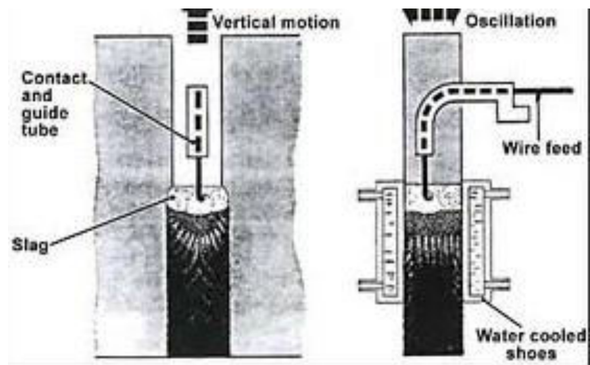
2. Flux is subjected to contamination that may cause weld porosity.
3. Only flat position welding is possible.
4. Slag removal is difficult after metal thicknesses less than 4.5mm.
5. Aluminium alloys, magnesium alloys and titanium cannot b welded because of non-availability of flux.

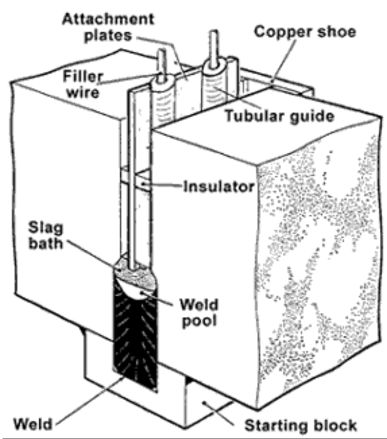
Applications:

1. Can be used in heavy steel plate fabrication such as pressure vessels, structures, machine building etc;
2. Used for deposit build up and abrasison resistant coating as steel structures that are subjected to wear.

Electroslag Welding

In electroslag process, the electric arc is used initially for a brief moment to heat and melt the flux and to convert it into slag. The molten slag then chokes and extinguishes the arc, but the current continues to pass between the electrode and the work via the molten conductive slag. The resistance offered by the molten slag to the electric current provides the heat necessary to keep the process going. Enough heat is generated to maintain the internal temperature of the bath at approximately 1900°C and the surface temperature at approximately1650°C. The weld is done vertically and it moves upwards





The consumable wire electrode used may be solid or flux coated but most of all the shielding is provided by an argon and CO_2 gas mixture injected into the gap. The welding wire is pulled from its source and fed down a steel tube to the molten puddle. The tube serves to guide the wire between the two plates, so that, neither the wire nor the tube touches the plates to be joined.

Water cooled copper shoes contain the molten weld puddle on either side of the gap between the two pieces of parent metal.

Advantages:

1. Welding energy density is much higher and more concentrated.
2. Solidification pattern is faster
3. The length and thickness of the joint that can be welded in limited by auxiliary equipment only
4. High deposition rate
5. Relatively low cost

Disadvantages:

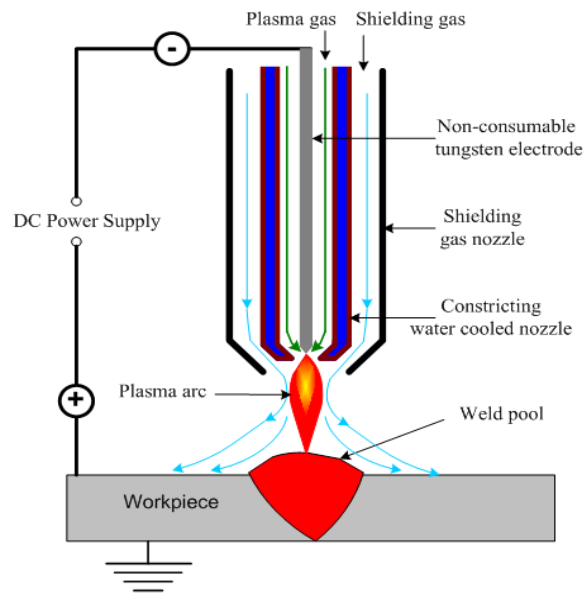
1. Under abnormal conditions, the weld may contain defects like slag inclusion, porosity and cracks
2. Improper fitting of copper shoes lead to undercut in the weld
3. Cooling arrangement is required
4. Not suitable for welding complex structures

Applications:

1. Welding of low carbon steels, medium carbon steels and to a lesser extent of high strength structural steel.
2. High strength alloy steels such as stainless steel and nickel alloys
3. Plates ranging from 19 to 460 mm in the vertical direction and large steel castings.

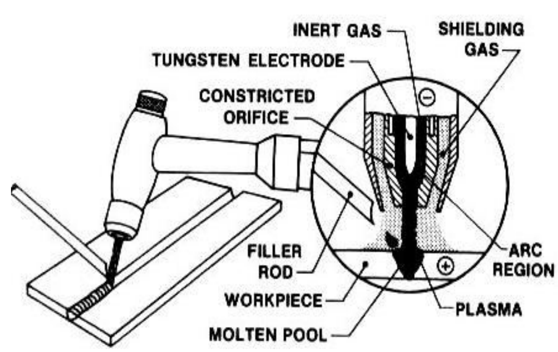
SPECIAL WELDING PROCESSES

PLASMA ARC WELDING



Plasma is high-temperature ionized (its atoms loose electrons) gas and occurs in any electric arc between two electrodes.

Plasma arc welding uses electrodes and ionized gases to generate an extremely hot plasma jet aimed at the weld area. The higher energy concentration is useful for deeper and narrower welds and for increased welding speed. If the arc is constrained by an orifice, the proportion of ionized gas increases and plasma-arc welding is created, which causes an intense source of heat primarily due to multiple collisions of the electrons within the particles, and provides greater arc stability. In normal arc welding, plasma jet has low velocity and diffuses over a wide area, which results in loss of power and lower zonal temperatures.



The non-consumable tungsten electrode within a water cooled nozzle is enveloped by gas. The gas is forced past an electric arc through a constricted opening at the end of the water cooled nozzle. As the gas passes through the arc, it is dispersed. This releases more energy and raised the temperature of the nozzle. Temperatures have been reported to be 10,000 to 30,000ºC.

The main function of the plasma gas is shielding the body of he torch from the extreme heat of the cathode. Any gas or mixture of gases that does not attack the tungsten or the copper cathode can be used; argon and argon mixtures are normally used. Usually the same gas is used of orifice as well as shielding.

Advantages:

1. Greater concentration of energy
2. Improved arc stability, especially at low currents.
3. Higher heat content
4. Low sensitivity to variation of arc length
5. No tungsten contamination

Disadvantages

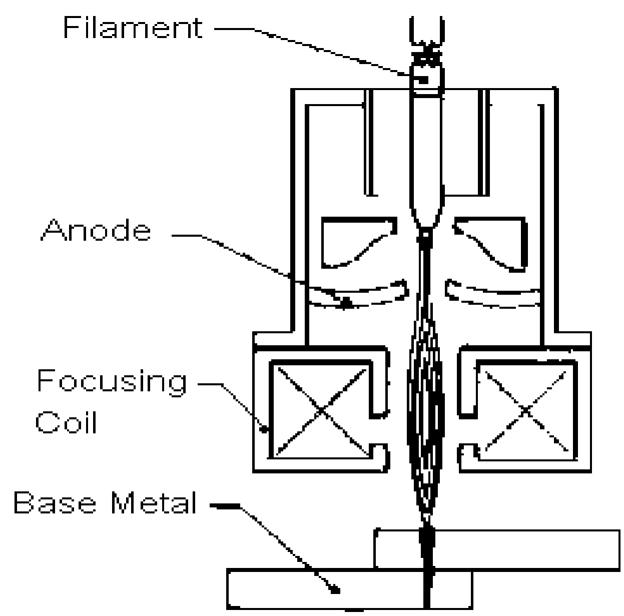
1. Higher cost of equipment
2. Short life of constricting nozzle and orifice bodey
3. Skilled welder required

Applications

1. Continuous and intermittent welds
2. Adaptable to joining carbon steel, alloy steels, heat resisting alloys, refractory metals etc.

ELECTRON BEAM WELDING

Electron beam machining is a fusion process for joining metals, which uses a highly focused beam of electrons in vacuum as a heat source. As an electron is a minute particle with a radius of 2.82×10^{-42} mm and amass of 9.109×10^{-28}g, it cannot travel any significant distance in air or other gases.



EBW gun typically comprises of a high-voltage power source, cathode, electron accelerating anode, beam focusing system, vacuum chamber or enclosure and a weld viewing system. The cathode for EBW gun is mostly made form the metals, which are reasonably workable and have fairly low thermionic or work function. Tungsten is normally used.

The electrons leave the cathode in all directions with a range of initial velocities. The randomly emitted electrons from the filament are given direction and speed, by a cup-shaped electrode called grid cup surrounding the emitter and accurately placed in the anode at a designed distance. They are magnetically focused into a spot with a power density of the order of 30,000W/mm^2. The electron beam is thus able to establish a ‘keyhole’ delivering heat, deep into the material being welded as shown. This produces a narrow near parallel fusion zone and the edges will be welded in a single pass for material thickness from 0.1mm to 200mm.

Advantages:

1. Low thermal input
2. High aspect ratio
3. Pure weld is possible
4. Deep penetration
5. Welds high conductivity metals

Limitations:

1. High joint preparation
2. Expensive
3. Non-productive pump down time
4. X-ray shielding required

Applications:

1. Involving high precision and high production rate such as aerospace, nuclear and electronics industries

THERMIT WELDING

Thermit welding is a casting cum welding process in which a mixture of aluminium powder and metal oxide, called thermit, is ignited to produce the required quantity of molten metal by an exothermic reaction. This molten metal is poured at the desired place which results in a weld joint on solidification. The thermo-chemical reaction tales place on the ignition of thermit is based on the following reaction

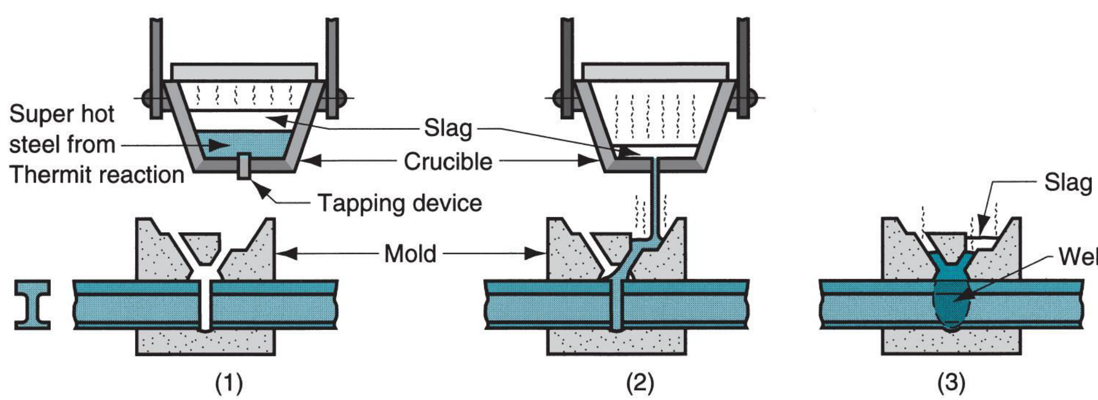
Metal oxide+ ALuminium (posder) --- Metal+ Aluminium oxide+heat

$$3Fe_3O_4 + 8Al \longrightarrow 9Fe + 4Al_2O_3 + \text{heat}$$

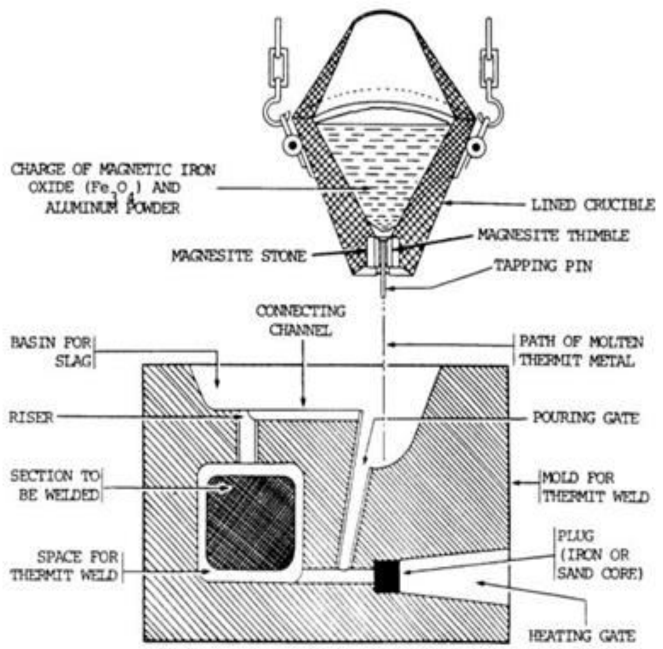
The temperature reached is of the order of 3000°C, the enormous heat liberated melts both the iron an aluminuim oxide to a fluid state. Non reacting constituents like steel scrap is added to control the temperatures and should not be lowered about 2100°C as Al_2O_3 solidified at about 2010°C.

There are two types of thermit welding

1. Plastic or pressure thermit welding
2. Non-pressure thermit welding



The plastic or pressure type thermit welding is used mainly for butt welding of thick vaults, pipes and rails. In this, weld pressure is used instead of fusion to join the metal pieces. The process uses thermit reaction as a heat source. The workpieces are clamped by cast iron molds and are forced together when the desired temperature is achieved.

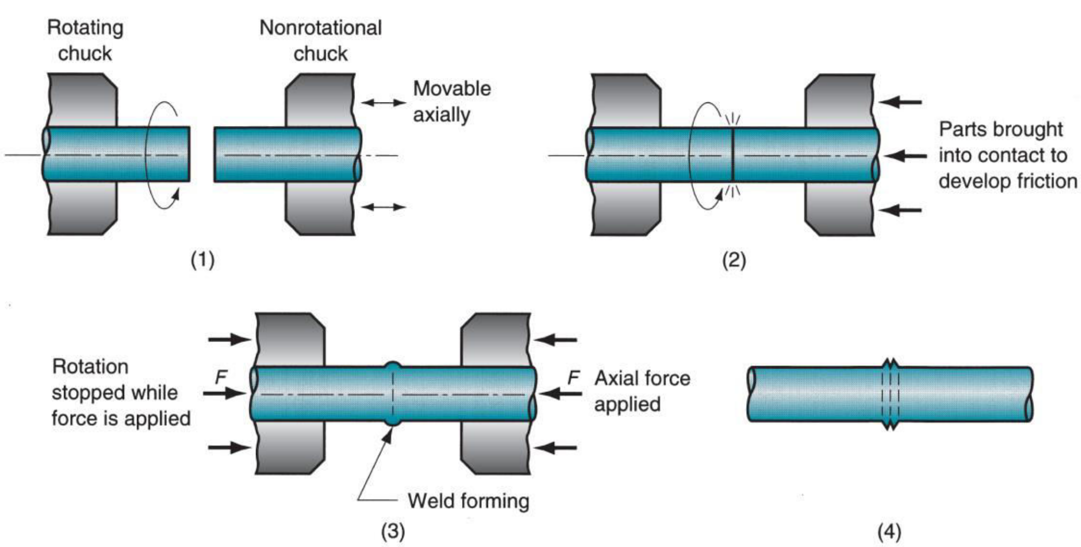


In non-pressure welding, the workpieces are lined up, leaving a space between the ends that are to be welded. Wax is placed between the joint. The whole frame is suspended in a mold and then the molten metal is poured. The first step in preparing the non-pressure thermit welding is the cleaning of the joint. All loose oxides and scales must be removed. When the metal has been ckeaned and spaced properly yellow wax must be prepared to make a pattern. The wax is placed in a container and heated to plastic state. The wax is hen shaped around the parts to be welded. A molding box is then placed around the portion toe be welded and molding material is rammed into the box. A pre-heating opening must be provided and is usually placed at the lowest portion of the wax mold to melt the wax. A gate for pouring molten metal into the mold and a riser to feed metal are provided when required. Vent holes are also provide for gases to escape.

Applications:

Used for welding very heavy thick plates, large sections such as locomotive rails, hsip hulls and large broken castings.

FRICTION WELDING



The heat required for this process is obtained by the friction between the ends of the two parts to be joined where one part rotated at a high-speed of around 12,000rpm and the other part is axially aligned with the second one and pressed tightly against it.

The machine for the friction welding is similar to centre lathe. The friction welding equipment consist of driven head, clamping arrangement, rotating and upsetting mechanisms, controls and braking mechanism.

Three major variables in friction welding are rotational speed, axial pressure and heating time. Rotational speed provides necessary relative velocity for the faying surfaces. High rotational speed is useful for welding but axial pressure and heating time are to be carefully considered to avoid overheating of the weld zone. The applied axial pressure controls the temperature gradient in the weld zone, power required for machine and axial shortening of the work piece. Heating time is controlled depending upon whether, a fixed reset time is allowed for heating or the extent of the axial upset is to be within the specified limits.

There are many types of friction welding

1. Rotary drive
2. Friction taper stitch
3. Radial friction
4. Friction stir welding etc

Advantages:

1. Simplicity in operation
2. Low power requirements
3. Easy to automate and used in mass production
4. Surface impurities and oxides are thrown off during welding
5. Dissimilar metals can be joined
6. No edge preparation required
7. No shielding gas or filler metal needed

Limitations

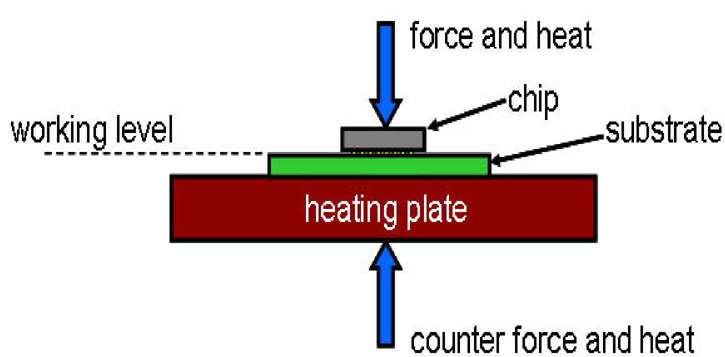
1. Applied to small pieces
2. Perfect alignment needed
3. Limited joint configuration
4. Flash removal
5. Difficult to inspect

Applications

1. Widely used in aerospace and automobile industries

Diffusion Welding

This process uses heat and pressure to join the metals by solid-state diffusion. The temperature is less than half the melting temperature of the metal to be welded. The process involves applying pressure for a period of few minutes to many hours depending on the diffusion bond welding required.



Heating is not essential for this process. However, if the temperature of the workpiece is increased , it will reduce the diffusion rate sufficiently, in turn the time element to make the bond can be cut to a matter of hours to minutes. The oxides on the surfaces dissipate over a period of time as in all solid state bonding. Because of the pressure, the dissipation rate greatly increases with the addition of heat.

There are three basic techniques in diffusion bonding:

1. **Gas pressure –** The workpieces to be joined are placed together intact in the inert gas atmosphere inside a heating system at a temperature of about 515°C. this technique is only used for non-ferrous metals and it cannot be used for steel and its alloys because o f the high temperature and pressure requirement.
2. **Vacuum fusion:** process carried out in vacuum. Mechanical or hydraulic force is used to make the intimate contact between the workpieces and so the process can be used on steel.
3. **Eutectic fusion:** Dissimilar metal foil of thickness 0.005-0.025mm is used between the components to be joined. Lowest temperature can be used to form the eutectic between the surfaces to be joined.

Applications

It can join metal to metal, metal to ceramics and metal to metal with intermediate bonding material, ripping of heavy cutting tools with carbide tips or hard alloys, joining of vacuum tube components. In aerospace, it is used for fabricating titanium components.

SOLDERING

Soldering is a method of uniting two or more pieces of metal by means of a fusible alloy or metal, called solder, applied in the molten state. Soldering is divided into two : Soft an Hard

Soft soldering is used extensively in sheet metal work for joining parts that are not exposed to the action of high temperatures and are not subjected to excessive loads and forces. It is employed for joining wires and small parts.The solder mostly composed of lead and tin, has a melting point of 150 to 350°C. A small amount of antimony may be added to improve quality and strength. A suitable flux is always used in soft soldering. Its function is to prevent oxidation of the surfaces to be soldered or to dissolve oxides that settle on the metal surfaces during the heating process. If the gap between the sheet metal pieces to be joined is controlled to about 0.08mm, the solder is drawn into the joint by capillary action, to give a uniform filling. Butt Joints are rarely made by soldering. A blow torch or soldering iron constitutes the equipment for heating the base metals and melting the solder and the flux.

Hot solder employs solders which melt at higher temperatures and are stronger than those used in soft soldering. Silver soldering is a hard soldering method, and silver alloyed with tin is used as solder. The temperatures of the various hard solders may vary from about 600 to 900 °C. The fluxes are mostly in paste form and are applied to the joint with a brush before heating.

The different compositions of solder for different purposes are as follows:

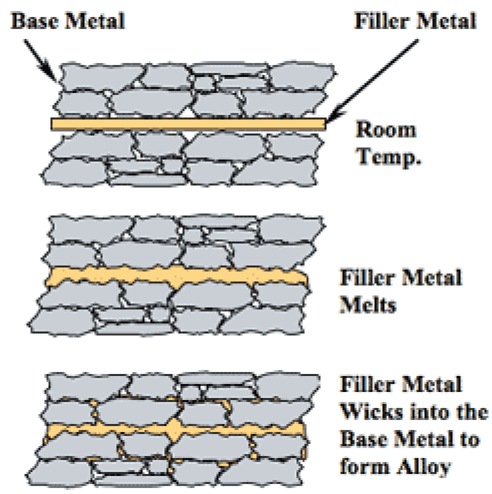
Soft solder	Lead 37%, tin 63%
Medium Solder	Lead 50%, tin 50%
Plumber's solder	Lead 70%, tin 30%
Electrician's solder	Lead 58%, tin 42%

Applications:

Soldering is used to make air tight joints. It is used extensively in the electronics industry.

BRAZING

Brazing is essentially similar to Soldering. The principal difference is he ue of a harder filler material, commercially known as spelter, which fuses at some temperature above red heat, but below the melting temperature of the parts to be joined.



A brazed joint is formed by the filler metal melting and flowing via a capillary effect into the pours of the closely fitted surfaces of the joint to form an alloy of the metals upon solidification.

The key to successfully achieving a good brazed connection is surface preparation. The presence of contaminants or oxides prevents the filler metal from coming into contact with one of the surfaces to be brazed. In the case of minor oxidation, the pours of the surfaces to be brazed will be sealed by the oxide. This prevents the capillary action and, ultimately, the brazing from occurring. Hence, the initial cleanliness of the surfaces to be brazed is extremely important, but it is equally important that the cleanliness of these surfaces be maintained during the brazing process.

Base Metal	Filler Meatal	Brazing temperature
Aluminium and its alloys	Aluminium-silicon	570-620
Magnesium alloys	Magnesium –aluminium	580-625
Copper and its alloys	Copper-Phosphorous	700-925
Ferrous and non-ferrous (except Al, Mg)	Ag and Cu alloys, Copper phosphorous	620-1150
Fe, Ni, Co base alloys	Gold	900-1100
Stainless steel, Ni, Co alloys	Nickel –Silver	925-1200

Brazing Methods

1. Torch brazing
2. Furnace brazing
3. Resistance brazing
4. Vacuum furnace brazing
5. Induction brazing
6. Dip brazing

Advantages:

1. Flexibility in use of least expensive protective atmosphere possible
2. Close temperature control and uniformity at all stages of brazing cycle
3. No flux is required because of the prepared protective atmosphere
4. High production rate
5. Efficient and economical

Limitations:

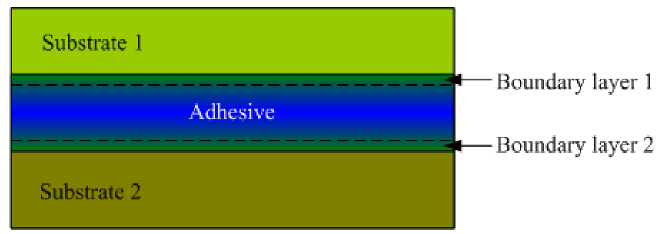
1. High temperature is required which exceeds average brazing temperatures that effect the life of the brazed components

2. Grain coarsening – required heat treatment
3. High initial cost
4. Possibility of explosion

Application:
1. Used in making common steel components such as mechanized parts, light stampings, deep drawn sheet metal parts, small forgings and some castings.

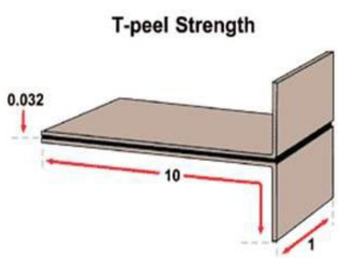
ADHESIVE BONDING

Structure of adhesive joint



Adhesive bonding is the process of joining materials by placing adhesive materials by placing adhesive materials called adherents between joining surfaces as shown in the figure. Like soldering and brazing, metallurgical bond does not take place though the surfaces may be heated but not melted.

The adhesive molecules are attracted by neighboring molecules as well as the metal atoms or foreign matters on the joining surfaces when the adhesive material is placed between the joining surfaces. If the surface energy of the joining surfaces is less than the adherent energy then the adhesive will not wet it.



The mechanical strength of the adhesive bonding depends on joint configuration, dimensions, nature of the adhesive and thickness between the surfaces to be joined. The joints of adhesive bonding are stronger in shear or tension and weaker in cleavage or peel, so the design of the joints should avoid cleavage or peel.

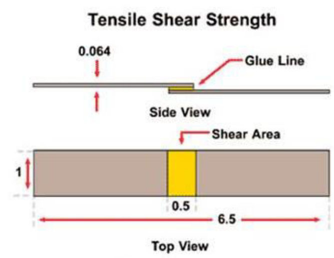
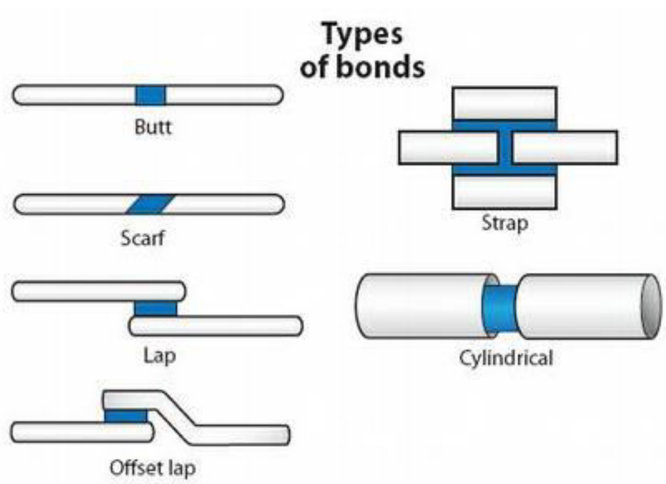


Figure alongside shows some of the acceptable adhesive bond joints.



Adhesives can be grouped into structural and non-structural adhesive. In metal bonding, only structural adhesives are used because of its high load carrying characteristics. Structural adhesives are classified into thermoplastics and thermosetting plastics.

The process of making adhesive bonding is:
1. Preparing the surface
2. Application of adhesives

3. Assembly
4. Curing the joint

Advantages:

1. Bonding of dissimilar materials at low processing temperatures of 65-175°C
2. Thin gauge material can be bonded effectively
3. It provides thermal and electrical insulations
4. Smooth surface appearance
5. Uniform stress distribution

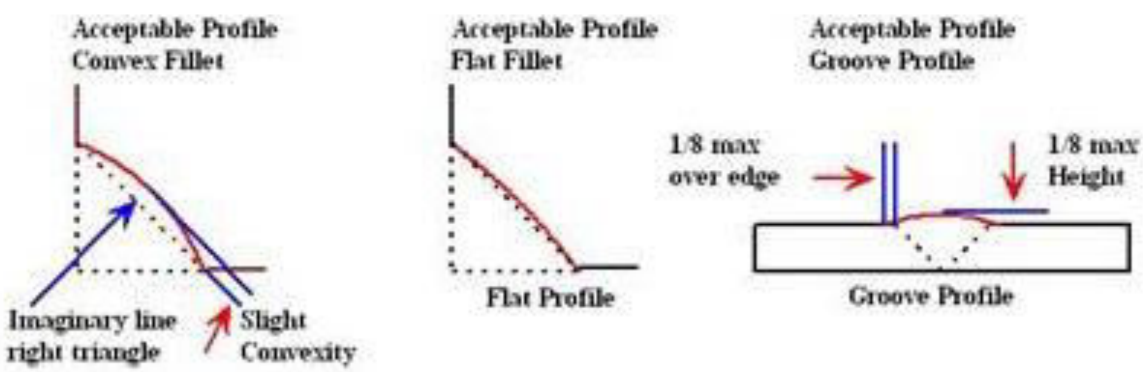
Limitations:

1. Do not support high peel loads
2. Need for elaborate jigs and fixtures resulting in high cost for equipment tooling
3. Adhesives deteriorate at faster rate under conditions of humidity and termperature
4. Joint are not as strong
5. Adhesives must be compatible with materials being joined
6. Service temperatures are limited
7. Cleanliness and surface preparation important
8. Curing times can impose a limit on production rates
9. Inspection of the bonded joint is limited

Applications:

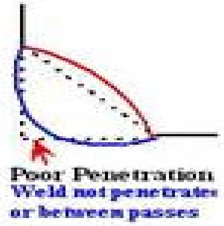
1. Adhesive bonding accounts for only 2% of metal-to-metal bonding
2. Comprises of over 50% of total assemblies of a modern aero plane
3. Fabrication of railway coaches, automobiles, boats, refrigerators ,storage tanks and microwave reflectors.

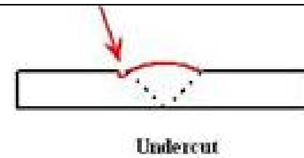
WELDING DEFECTS



The good profiles of welding is given below as reference.

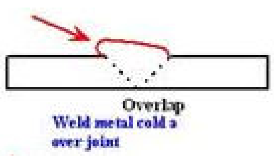
Incomplete Penetration: Weld metal fails to rach or fuse completely with the root aces or joint. This may occur between weld and weld metals or between successive weld beads in multi-pass welds. .A butt weld or fillet weld where the weld metal does not penetrate to the root results in insufficient throat thickness, which in turn causes reduced joint strength.

	Causes:	Remedies
	• Improper current • Incorrect size of electrode • Poor joint preparation • Excessive welding speed	• Temporary or permanent backing • Depositing first pass with high current • Usage of correct size electode • Improving joint preparation

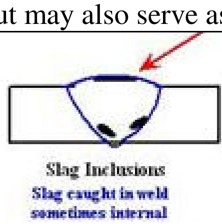
Undercut: It occurs in the toe of the weld in the base metal as shown. It is a sharp narrow groove along the toe of the weld and is due to the scouring action of the arc removing the metal and not replacing it with weld metal. It is usually considered as the worst defect. It reduces cross sectional area and strength, and provides a notch in the heat affected zone, which acts as a stress raiser.	

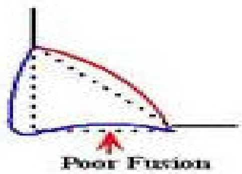
Causes:	Remedies:
• Excessive welding current • High speed of arc travel • Excessive arc length • Wrong electrode angle	• Proper welding current should be used according to size of the electrode, welding position and method. • Travel speed should be such that the deposited weld metal completely fills all melted out portion of the base metal. • Proper electrode angle should be used • The arc length should be as short as possible • Undercut area may be filled with metal

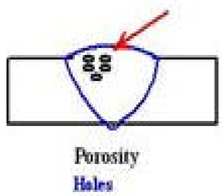
Overlap: It is the protrusion that occurs at the weld metal beyond the toe or root of the weld. It may act as stress raiser in dynamic loaded structures.

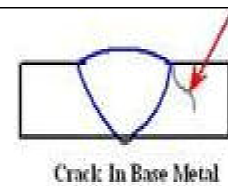
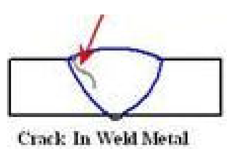
	Causes:	Remedies:
	• Incorrect electrode angle • Welding away from ground end • Incorrect size of electrode • High current coupled with low speed	• Correct size electrode should be used • Proper angle and handling of the electrode • Proper current with suitable speed should be used • Overlapping may be removed by grinding and chipping

Slag Inclusion: Non-metallic particles of comparatively large size entrapped in the weld metal are termed as slag inclusions. Linear slag inclusions along the axis if the weld are sometimes called "wagon tracks". Slag inclusions not only reduce cross-sectional area strength of the joint but may also serve as an initiation point for serious cracking, particularly in the hard steels.

	Causes:	Remedies:
	• Imperfect cleaning of the slag between the deposition of successive passes • Wide manipulation of electrode • Use of too large electrode • Erratic progression of electrode travel	• Proper cleaning of slag thoroughly between successive weld passes. • Use of proper welding consumables and keep joint surfaces an bare filter wires clean • Slag can be kept behind the arc by shortening the arc, increasing the travel speed and electrode angle.

<table>
<tr><td colspan="3">Lack of Fusion:Weld metal lies adjacent to unfused base material or previous runs without admixturei.e., the two sections are not welded together. This is opposite situation to undercut, where too much metal flows within the joint area..</td></tr>
<tr><td>
</td><td>Causes:
• Presence of dirt, oxide, scale, slag and other non-metallic particles
• Improper deslagging before overlapping pass is deposited.</td><td>Remedies:
• Keep joint surfaces clean before welding
• Deslag each weld pass throughly</td></tr>
</table>

<table>
<tr><td colspan="3">Porosity: The presenc of a group of gas pores scattered along the entire length of the weld bead caused by entrapment of gas during solidification is termed as porosity.</td></tr>
<tr><td>
</td><td>Causes:
• Chemically imperfect welding consumables
• Faulty composition of base metal or electrode (sulphur, phosphorous)
• Excessive current and improper arc length
• Quick freezing of weld deposit
Deoxiders not sufficient</td><td>Remedies:
• Pre-heating of electrodes
• Proper composition of base metal and electrodes
• Preheating and proper cleaning of work metal
• Using sufficient deoxidizers
• Striking the arc 20mm ahead of starting point
• Reduced travel speed</td></tr>
</table>

<table>
<tr><td colspan="3">Weld Crack: It is a discontinuity caused by the tearing of the metal while in plastic condition or by fracturing of the metal when it is cold. Two types of crack or hot and cold crack.
Hot crack most likely occurs at the root pass weld bead above 540ºC generally just after the weld starts to solidify because of the small cross section of the weld bead compared with the mass of the material welded.It is initiated in heavy fillet weld when it is subjected to localised stresses.
Cold crack occurs at the heat affected zone at near ambient temperature due to rapid cooling. Its occurance may be delayed for as long as several days as stresses within the weldment relieve themselves.

</td></tr>
<tr><td>
</td><td>Causes:
• Localized stress, contraction or shrinkage
• Inter-metallic compounds and complex carbides having lower melting point
• Rapid cooling</td><td>Remedies:
• Avoid use of inter-metallic compounds and carbides
• Allow uniform cooling
• Pre-heating the joint area
• Proper design of joint to avoid localized stresses
• Higher heat input during welding
• Surrounding surfaces should be thoroughly cleaned</td></tr>
</table>

ME 2201 : MANUFACTURING TECHNOLOGY - I
UNIT III - BULK DEFORMATION PROCESSES

Hot working and cold working of metals – Forging processes – Open, impression and closed die forging – Characteristics of the process – Types of Forging Machines - Typical forging operations - Rolling of metals – Types of Rolling mills - Flat strip rolling - Shape rolling operations – Defects in rolled parts - Principle of rod and wire drawing - Tube drawing - Principles of Extrusion - Types of Extrusion - Hot and cold extrusion - Equipments used

HOT WORKING AND COLD WORKING OF METALS

Bulk Deformation or Metal forming processes are broadly classified into two categories:

- **Hot Working**
- **Cold working**

The metal working processes that are carried out **above** recrystallisation temperature are **Hot working** processes whereas those **below** are **Cold working** processes.

When atoms reach a certain high energy level under the action of heat of and the force new crystals start forming. This is termed as **Recrystallisation**.

Hot working does not mean that the working of a metal is at elevated temperature. Lead and tin have a recrystallisation temperature below the room temperature, and hence working of these metals at room temperature is always hot working. But steel has recrystallisation temperature in the range of **600-700 ^{o} C**, hence working temperature **below** that temperature is still Cold working.

Hot Working
Advantages:

- No Strain hardening takes place since working is carried out above recrystallisation temperature.
- Material should have high ductility at high temperature. Brittle materials can also be hot worked easily.
- Shear stress will decrease when temperature increases and hence force required to achieve the necessary deformation is very less compared to cold working.
- Better mechanical properties will be achieved by controlling the temperature.

Limitations:

- At high working temperature scaling will be formed on the surface of the material which leads to loss of materials and poor surface finish.
- Due to thermal expansion of metals, dimensional accuracy is difficult to achieve.
- It is very difficult to handle and maintain hot metals.

Cold working

Advantages:

- High dimensional accuracy.
- Surface defects are removed.
- Thin gauge sheets are produced.
- Since cold working done at room temperature or low temperature no oxidation and scaling of the work piece occurs.

COMPARISON OF HOT WORKING WITH COLD WORKING

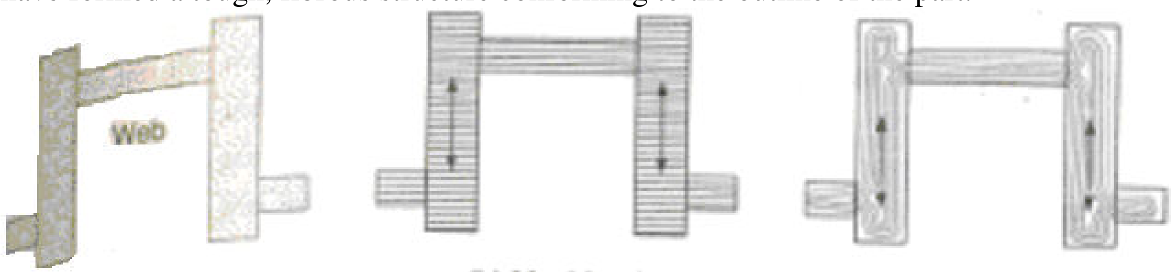
The comparison of hot working with cold working is given in Table

S. No.	Hot Working	Cold Working
1.	Hot working is carried out above the recrystallisation temperature and below the melting point. Hence the deformation of metal and recovery take place simultaneously.	Cold working is carried out below the recrystallisation temperature. As such, there is no appreciable recovery.
2.	No internal or residual stresses are set-up in the metal in hot working.	In this process internal or residual stresses are set-up in the metal.
3.	It helps in irradiating irregularities in metal composition breaking up the non metallic impurities in to tiny fragments and dispersing them through out the metal and thus facilitate uniformity of composition in the metal	It results in loss of uniformity of metal composition and thus affects the metal properties.
4.	Close tolerance can not be maintained	Better tolerance can be easily maintained.
5.	Surface finish of this process is comparatively not good	Surface finish of this process is better.
6.	It results in improvements of properties like impact strength and elongation	It results in improvements of properties like impact strength and elongation.
7.	Due to re-crystallisation and recovery no or very negligible hardening of metal takes place.	Since this is done below re-crystallisation temperature the metal gets work hardened.
8.	Due to higher deformation temperatures, the stress required for deformation is much less.	The stress required to cause deformation is much higher.
9.	Hot working refines metal grains resulting in improved mechanical properties.	Most of the cold working processes lead to distortion of grains.
10.	If cracks and blow boles are present in the metal, they are finished through hot working.	In cold working the existing cracks propagate and new cracks may develop
11.	If properly performed, it does not affect UTS, hardness, corrosion resistance, yield strength and fatigue strength of the metal.	It improves UTS, hardness, yield strength but reduces the corrosion resistance of strength of the metal.

FORGING

Forging is one of the bulk deformation processes in which compressive force is applied to manipulate the metal in such a way that the required final shape is obtained.Forging normally a hot working operation though cold forging is also used at times.The forging operation can create parts that are stronger than those manufactured by any other methods of production.

In forging, the grains remain unbroken (refer figures given below) and assume the contour of the part. Here it is easy to see that the grains, not only remain unbroken, but have formed a tough, fibrous structure conforming to the outline of the part.



(a) Casting **(b) Machined** **(c) Forged**

Grains flow in Crankshaft in three different manufacturing methods

Forgings are always used where reliability and human safety are critical.They are commonly used components like assembled items in air planes, automobiles, tractors, ships, oil rigs, engines, misssiles and all critical equipments.

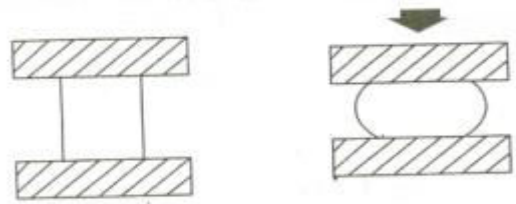
<table>
<tr>
<td>Cold-working Processes
❖ Squeezing
❖ Bending
❖ Shearing
❖ Drawing
❖ Special forming processes</td>
<td>Classifications of Squeezing Processes
❖ Rolling
❖ Swaging or Cold forging
❖ Staking
❖ Sizing
❖ Coining
❖ Burnishing
❖ Cold rolling
❖ Knurling
❖ Riveting
❖ Thread Rolling</td>
</tr>
<tr>
<td>Classifications of Drawing Processes
❖ Blank Drawing
❖ Tube Drawing
❖ Wire Drawing
❖ Embossing
❖ Metal Spinning
❖ Stretch forming</td>
<td rowspan="2">Classifications of Shearing Processes
❖ Punching
❖ Blanking
❖ Cutting off
❖ Trimming
❖ Perforating
❖ Notching
❖ Slitting
❖ Lancing
❖ Shaving</td>
</tr>
<tr>
<td>Classifications of Bending Processes
❖ Angle bending
❖ Roll forming
❖ Plate bending
❖ Seaming
❖ Curling</td>
</tr>
</table>

Classifications of Special forming Processes ❖ Explosive forming ❖ Electro hydraulic forming ❖ Magnetic forming ❖ Impact extrusion ❖ Shot peening	

FORGING OPERATIONS

Upsetting

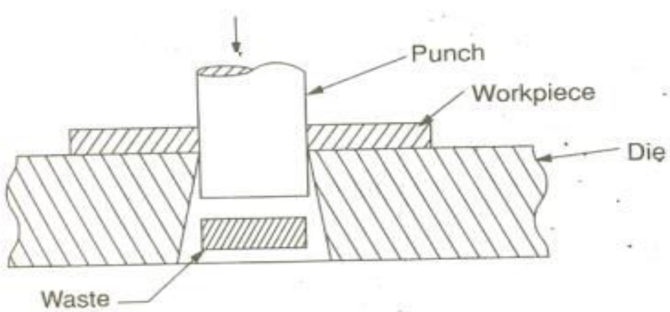
It is the process of increasing the cross-sectional area of the bar at the expense of its height. When a bar is compressed by the open dies the material is squeezed and upsetting takes place. Figure given shows the upsetting.



Upsetting.

Punching

Punching is the process of producing holes in workpiece as shown in figure below. Normally, the hole produced is cylindrical. Punching can be done by placing the workpiece over a hole in the anvil or over a cylindrical die of required size or over a correct size in a swage block. The hot punch is placed on the workpiece and hammered.



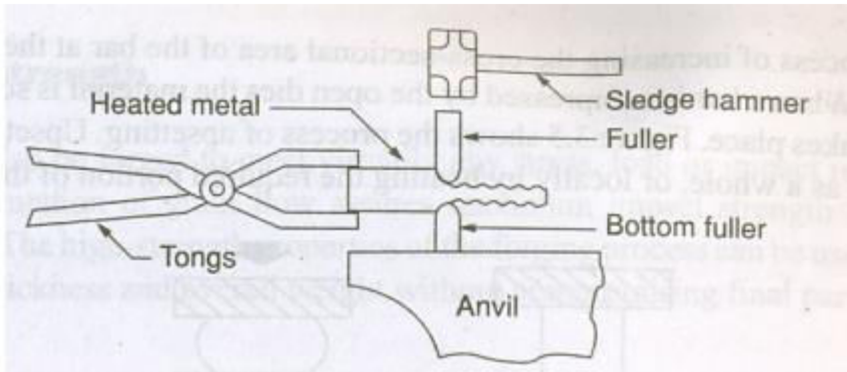
Punching.

Fullering

In this operation, the cross-section area of workpiece is reduced and lengthened for further operation like drawing like drawing down or setting down.

Drawing Down

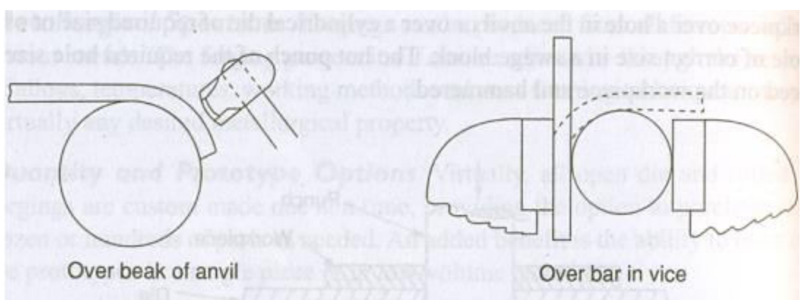
It is the processes of increasing the length of the bar. When the length increases, either the thickness or width decreases or both. The metal is heated to a required temperature, held with tongs and placed between two fillers over the anvil.The bottom fuller is positioned in a square hole (**Hardie hole**) in the anvil. The top fuller is placed over the job directly above the fuller using a sledge hammer.



Drawing Down

Bending

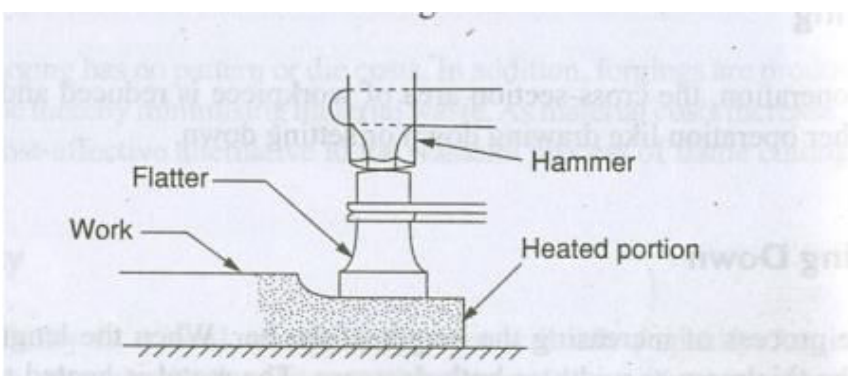
Bending is an important operation in forging. It is done frequently. The bend may be sharp cornered or circular. The sharp bend is made hammering the metal over the edge of the anvil. Circular bends may be made by using the beak of anvil.



Bending

Setting Down

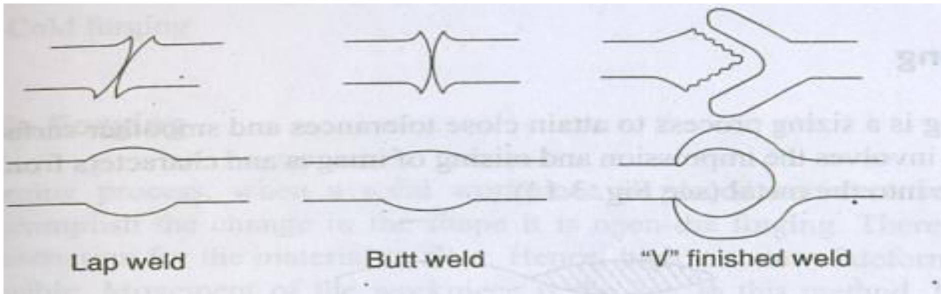
It is the operation of reducing the thickness of the work piece in a small area as shown in Figure.



Setting Down

Welding

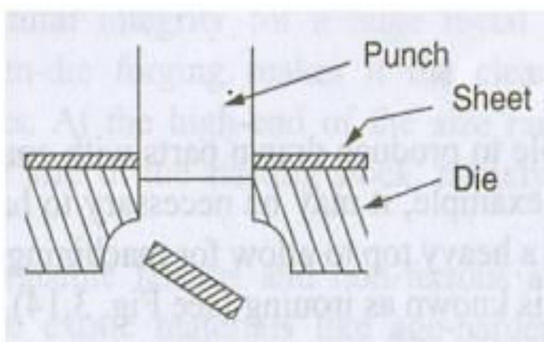
It is a process of joining two metal pieces by applying pressure after heating them to a higher temperature is known as forge welding .Wrought iron and mild steel are most suited for forge welding.



Welding

Cutting

This process is used to cut the large pieces into small pieces for further operations. Cutting can be done by using either cold or hot chisel.

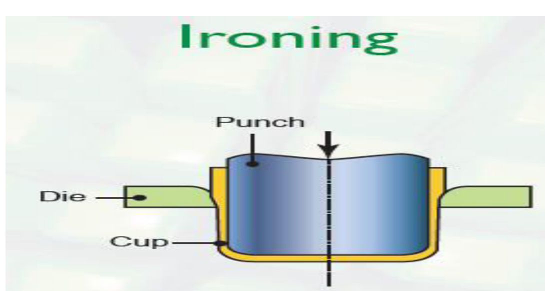


Cutting

Blocking
Blocking is an intermediate operation before finishing.

Trimming
It is the operation of removing flash material from the forged components.

Ironing
Sometimes, it is desirable to produce drawn parts with considerable variation in thickness of metal. The drawing process used to accomplish this is known as Ironing.



FORGING PROCESSES
Forging can be classified as:

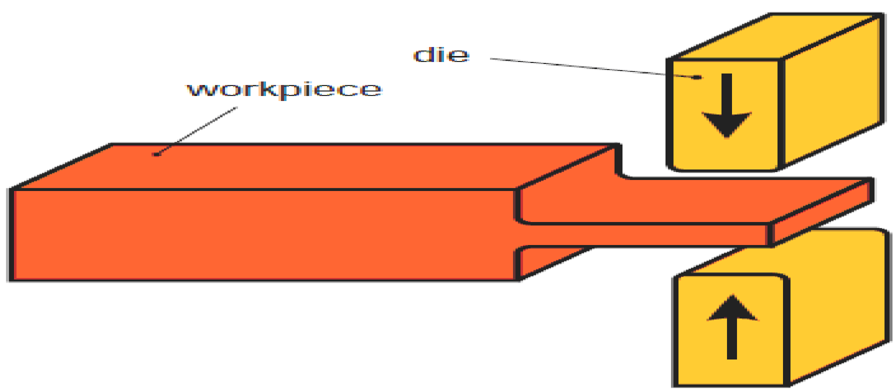
1. Smith forging or open-die forging or upset forging
* Hand Forging
* Power Forging
    - Hammer Forging
    - Press Forging

2. Impression Forging or Closed Die Forging
* Drop Forging
* Press Forging
* Machine Forging
* Seamless Rolled ring Forging
* Cold Forging

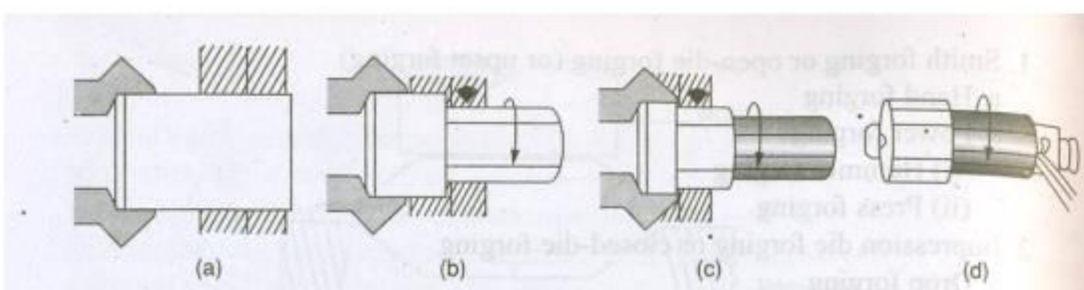
OPEN DIE FORGING

✸When a solid work piece is placed between two flat dies to accomplish the change in shape it is called Open –Die Forging.

✸There is no external restriction of for the material to flow. Hence high amount of deformation is not possible.



Open die forming

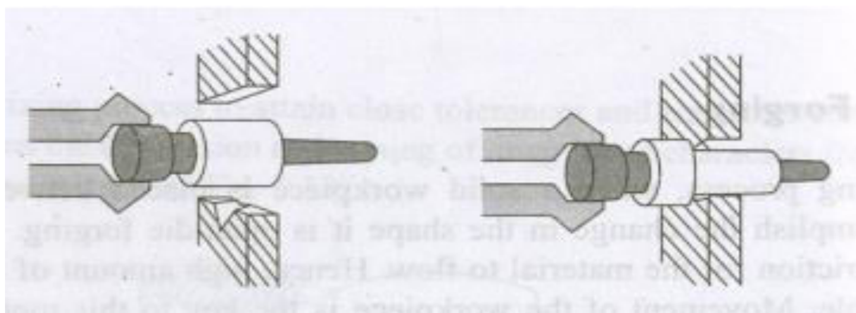


Shaft forging (a) Starting Stock held by manipulator
(b) Open-die forging (c) Progressive forging (d) Lathe turning to near net shape

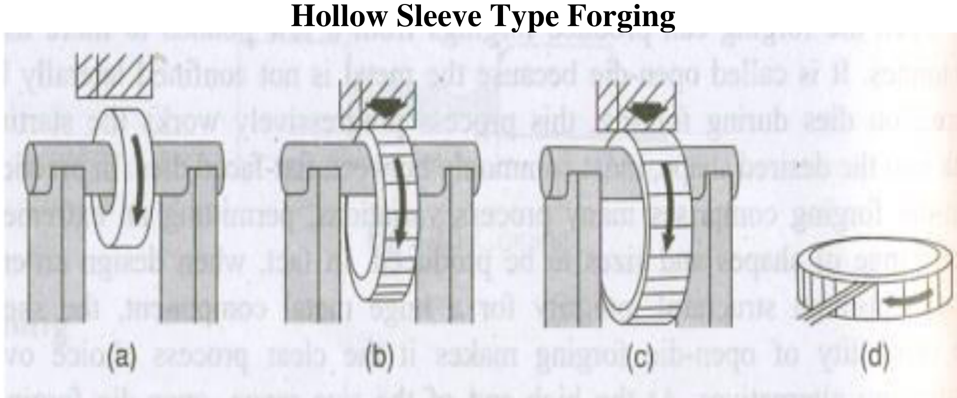
✷This process progressively works the starting stock into the desired shape, most commonly between flat –faced dies.

✷Open die forging comprises of many process variations, permitting an extremely broad range of shapes and sizes are to be produced.

✷Open-Die forging can produce Round, square, rectangular hexagonal bars and other basic shapes.



Hollow Sleeve Type Forging

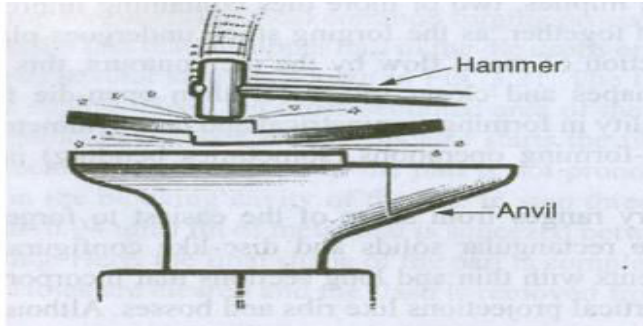


Ring Forging

(a) Preform mounted on Saddle/Mandrel
(b)Metal displacement reduces perform wall thickness to increase diameter
(c)Progressive reduction of wall thickness to producer ring dimensions
(d) Matching to near net shape

Hand Forging

Hand forging are made with repeated blows in an open die or an anvil when heated to the proper temperature, where the operator manipulates the work piece. This is an old manufacturing process and what a traditional blacksmith does.



Hand Forging

Various operations are drawing down, upsetting punching, bending setting down and welding. Hand forging is used for making simple shapes such as chains, hooks, shackles, and agriculture equipment and tools.

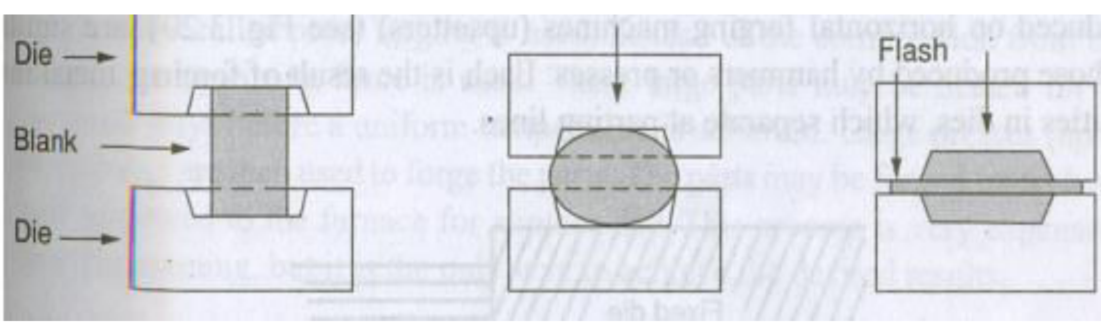
Applications
Open-die processes can produce:

1. Step shafts, solid shafts (spindles or rotors) whose diameter increases or decreases at multiple locations along the longitudinal axis.
2. Hollow cylindrical shapes, usually with length much greater than the diameter of the part Length, wall thickness, internal and outer diameter can be varied as needed.
3. Ring-like parts can resemble washers or approach hollow cylinders in shape, depending on the height/wall thickness ratio.
4. Contour-formed metal shells like pressure vessels, which may incorporate extruded nozzles and other design features.

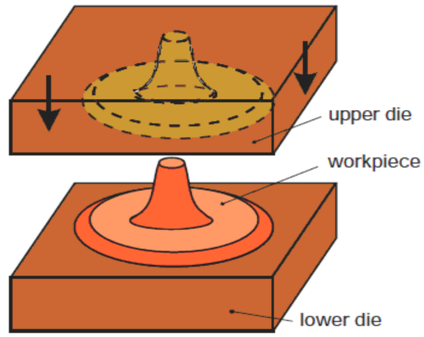
IMPRESSION DIE FORGING OR CLOSED DIE FORGING

☞ When a solid work piece is placed between two shaped dies, two dies are brought together and the work piece undergoes plastic deformation until it enlarges sides touches the side wall of die.

☞ Then a small amount of material begins to flow outside the die impression forming flash that is gradually thinned.



Closed Die Forging



Closed die forming

☞ The flash cools quickly and presents increased resistance to deformation and helps to build up pressure increased resistance to deformation.

☞ It also builds up pressure inside the bulk of the work piece that aids material flow into unfilled cavities in the die.

☞ Most Engineering metals and alloys can be forged like carbon and alloys, tool steel, stainless steel, alumminium and copper alloys.

Applications

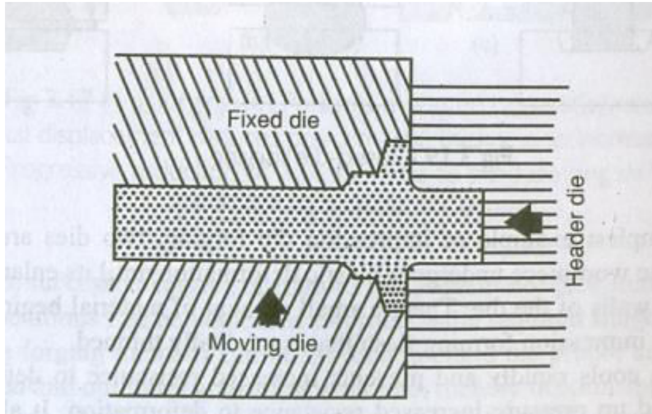
1. Part geometry's range from some of the easiest to forge simple spherical shapes, block-like rectangular solids, and disc-like configurations to the most intricate components with thin and long sections that incorporate thin webs and relatively high vertical projections like ribs and bosses.

2. Although many parts are generally symmetrical, others incorporate all sorts of design elements (flanges, protrusions, holes, cavities, pockets, etc.) that combine to make the forging very non-symmetrical.

3. In addition, parts can be bent or curved in one or several planes, whether they are basically longitudinal, equidimensional or flat.

Machine Forging

The chief difference between hand forging and machine forging is that in the latter technique various types of machine powered hammers or presses are used instead of hand sledges. The power hammer can be mechanical or pneumatic type. The stroke of the hammer varies from 350 mm to 1000 mm and corresponding speeds range form 200 to 800 blows per minute. These machines enable the operator to strike heavy blows with great rapidity and thus to produce forgings of large size and high quality as swiftly as required by modern production-line methods. Another advantage of machine forging is that the heavier the blows struck during forging, the greater the improvement in the quality of metallic structure.

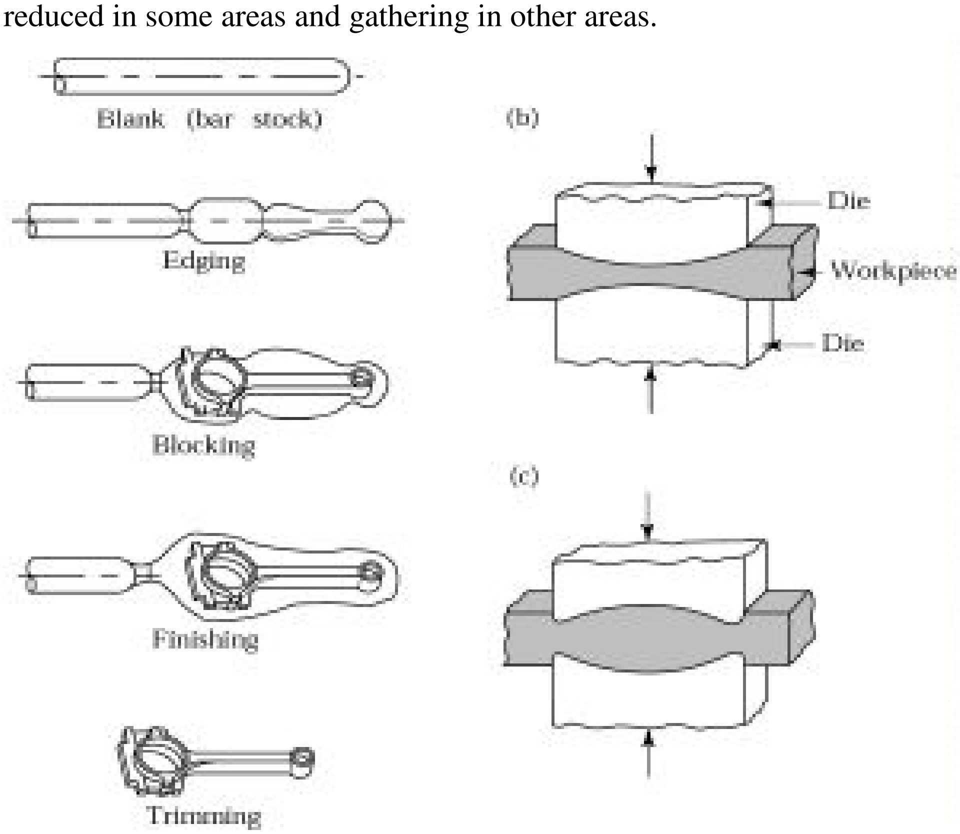


Machine Forging or Upsetting

Fine grain size in the forging, which is particularly desirable for maximum impact resistance, is obtained by working the entire piece. With large, hand-forged metal, only the surface is deformed, whereas the machine hammer or press will deform the metal throughout the entire piece.

Drop Forging

- Drop forging is the most common forging procedure that is in use.
- It gets its name from the fact that the upper half of the die drops onto the lower half.
- This process involves several steps.
- The first two steps are called fullerring and edging. Here cross-sectional area of the metal is reduced in some areas and gathering in other areas.



Steps in Drop Forging

✍ The third step is blocking and the shape of the part is not pronounced. This may take several drops in the blocking cavity of the die.

✍ In step three flash, begins to appear, this is a thin fin (0.04 mm) of metal that is squeezed between the dies.

✍ The fourth step is finishing operation which gives the final shape of the required part is completed.

✍ The final step is called trimming operation where holes are cleared and the flash is trimmed from the forging.

Press Forging

Press forging is a process similar to kneading, where a slow-continuous pressure is applied to the area to be forged. The pressure will extend deep into the material and can be completed either cold or hot. A cold press forging is used on a thin, annealed material, and a hot press forging is done on large work such as armor plating, locomotives and heavy machinery. In this type, only one blow is given as compared with number of blows in drop forging.

In press forging number of stages are used and only in last stage die cavity is used to get finished forging. Dies may have less draft, and the forging comes nearer to the desired sizes. Press forging are shaped at each impression with a single smooth stroke and they stick to the die impression more rigidly. Unless some provision is made, the escape of air and excess die lubricant may be difficult. Thus, press-forging dies require a mechanical means for ejecting the forging.

Press forging are generally more accurate dimensionally than drop forging. The cost of the process is three to four times than that in drop forging but with press forging, unskilled labour can be used and production rate is higher. The working conditions with the press are better as there is no noise and vibrations.

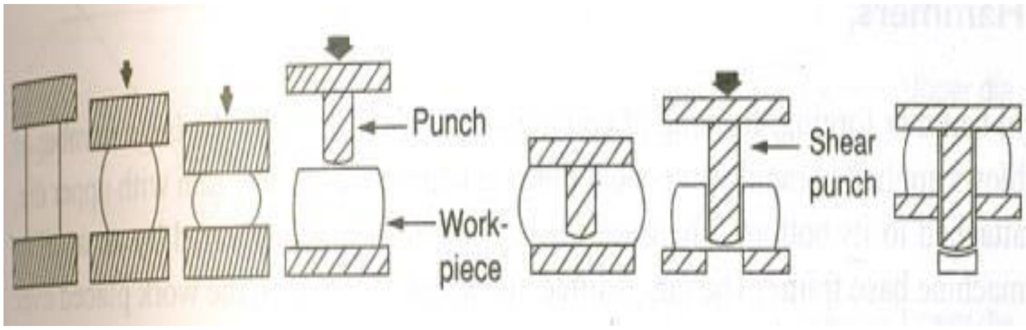
Cold Forging

Forging is mostly done by hot work, at temperature up to 1370° C.A variation of impression die forging is cold forging. Cold forging encompasses –Bending, cold working cold heading, coining, extrusions and more to yield a diverse range of part shapes. The temperature of metals being from room temperature to warm working temperature.

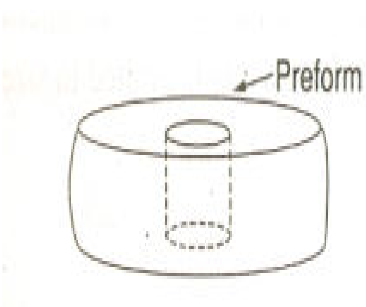
Seamless Rolled Ring Forging

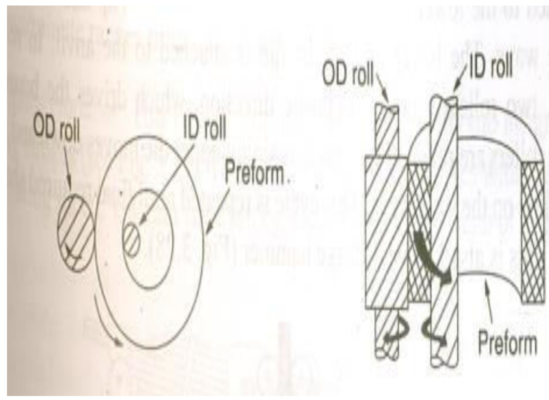
✍ The ring rolling process typically begins with upsetting of the starting stock on flat dies at its plastic deforming temperature.

✍ A punch forcing into the hot upset stock causing metal to be displaced radially.



Upsetting and Piercing





Preform **Ring Rolling Operation**

- A sequence of operation shearing serves to remove the small punch- out.
- After that it is kept in a rolling mill between Inner Diameter (ID) and Outer Diameter (OD) of the work piece.
- This squeezes it against the Outer Diameter roll imparts rotary action and achieved final part.

FORGING MACHINES

Hammers

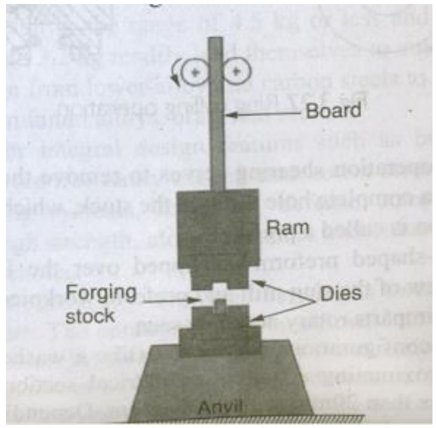
In hammer forging, forming of components is carried out by the large number of blows applied in rapid succession. Forging hammer is a heavy ram with upper die, attached to its bottom. The lower die is attached is stationary and supported by an anvil or machine base frame.

Types of Hammers

- **Gravity Drop Hammer**
- **Power Drop Hammers**
    - **Mechanical Hammers**
        - Helve Hammer
        - Lever Spring Hammer
        - Pneumatic Hammer
        - Air or Steam Hammer

Gravity Drop Hammer or Forge Hammer

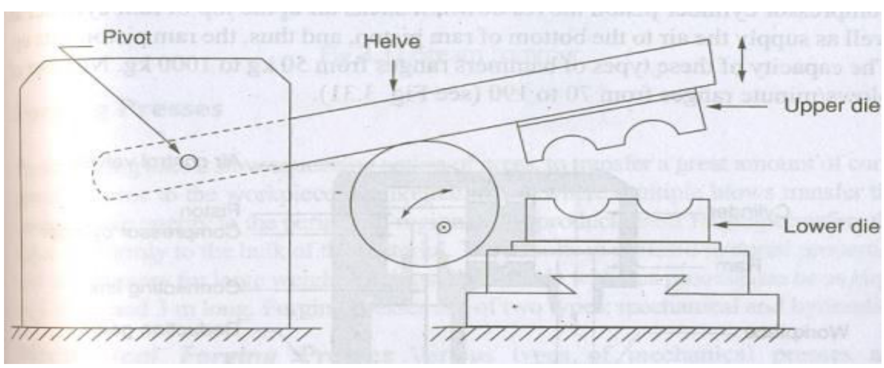
It consists of a heavy ram containing upper part of die attached to the lower part of the board. The ram moves up and down inside the guide ways. The lower part attached to the anvil. In roll lift hammers, two rollers rotate in opposite direction, which drives the board up. When the roller are released the ram containing the upper die moves die down and gives a heavy blow on the workpiece. This cycle is repeated until final required shape is obtained.



Gravity Drop Hammer

Helve Hammer

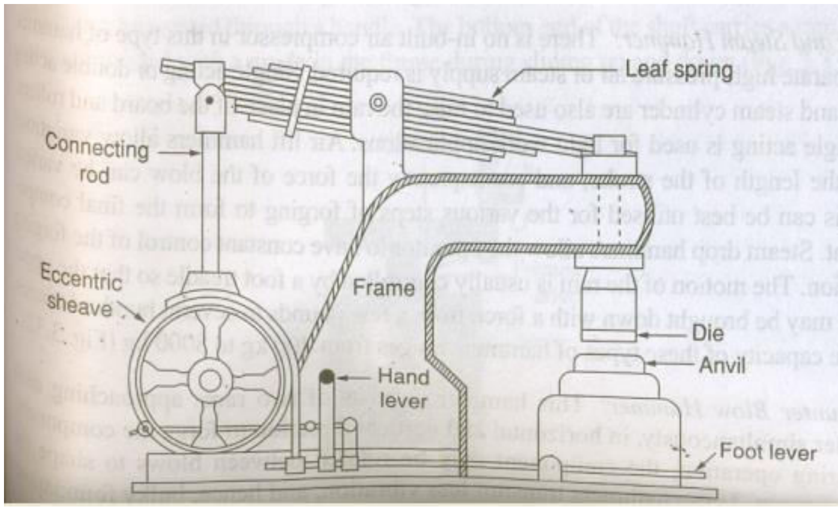
These are high speed hammers used for general engineering work, where there is a frequent change in size of the stock. It has **wooden helve** pivoted at one end with an eccentric. Range of hammers are 5-200 Kg.Number of blows /minute-175- 400.



Helve Hammer

Leaf Spring Hammer

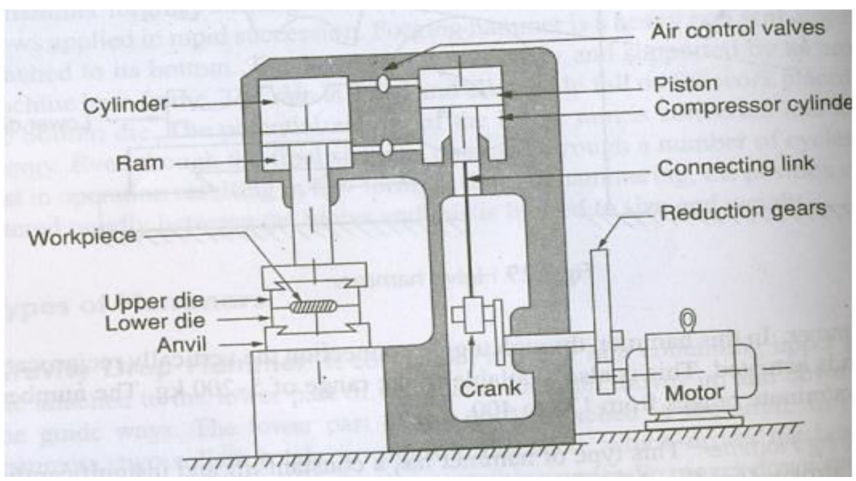
Hammer has a constant lift and with varying strokes. Number of strokes increases with increase in operation speed. Ram is driven by rocking lever and other end attached to vertical rod. Leaf spring is pivoted at middle with the machine frame. Capacity of hammer is 30 to 250 Kg.Number of strokes /minute -40 to 200.



Leaf Spring Hammer

Pneumatic Hammer

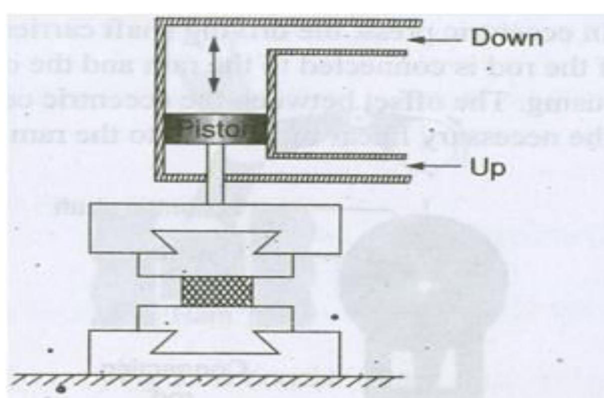
Hammer works by Air pressure. There are two cylinders one is ram cylinder and another is compressor cylinder. Capacity of the hammer is 50 to 1000 Kg. Number of blows/min ranges from 70 to 190.



Pneumatic Hammer

Air or Steam Hammer

There is no inbuilt air or steam compressor in this hammer. Seperate high pressure air or steam supply is required. Single or double acting is used to raise the ram in place of the board and rollers. Single acting is used for Light weight work.



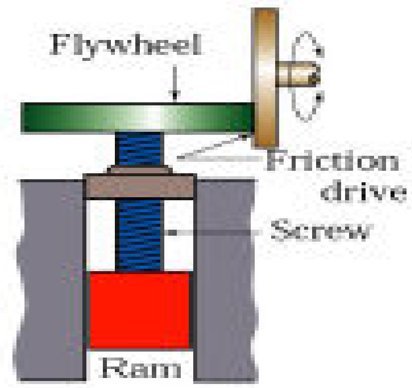
Forging Presses

Various types of mechanical presses are

✐ ***Fly screw press*** ✐ ***Eccentric press*** ✐ ***Toggle press*** ✐ ***Knuckle press*** ✐ ***Crank press***

Fly screw press

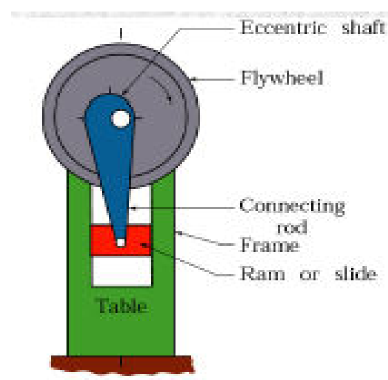
- ❖ A top of the frame a nut is provided and vertical screw can goes through the nut .
- ❖ A vertical shaft carries a wheel which can be rotated through the handle given.
- ❖ The ram carries by bottom side of shaft and the ram is provided with a guide in the frame during sliding up and down.



Fly Screw Press

Eccentric press

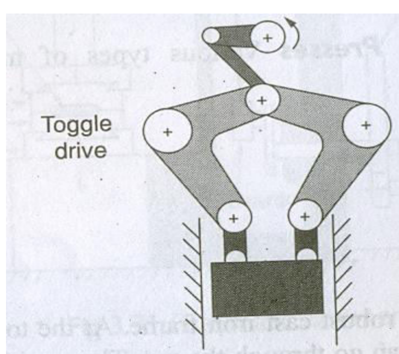
- ❖ The driving shaft carries an integral eccentric with it .One end of the rod is connected to the ram and other end is connected to eccentric housing.



Eccentric Press

Toggle press

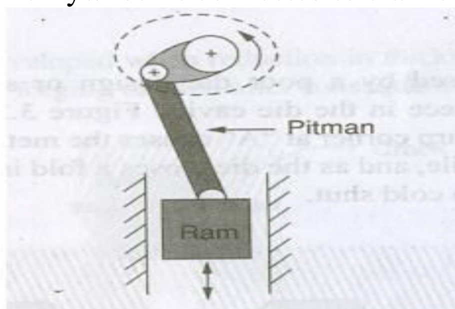
- ❖ A toggle drive is used to drive the outer sides of a double action press Knuckle press



Toggle press

Crank press

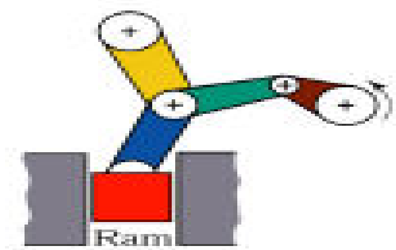
An electric motor is used to drive a pulley, which is connected to the flywheel through a V-belt**.** The flywheel is stopped by an auxiliary brake and pneumatic clutch is also used as an overloading safety device. The flywheel is connected to crankshaft through gears.



Crank press

Knuckle press

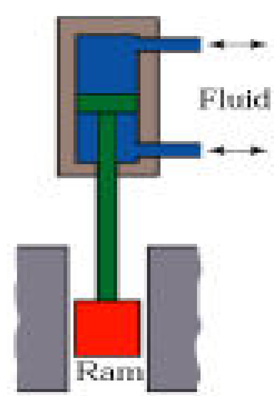
In this type of press, knuckle joint mechanism is used. One end of the upper link is attached to the frame and the end is attached to a horizontal link and lower link at the centre. The lower link is attached to the ram. The horizontal link is driven by a crank shaft which pulls the other links to a vertical position, in turn results in a short powerful movement of the ram.



Knuckle press

Hydraulic Forging Press

In the hydraulic drive, the ram is attached to a piston through a rod. The piston moves up and down in hydraulic cylinder. The oil at high pressure is pumped to press with the aid of an accumulator and distributor through the top side of the piston. The ram moves downwards. At the end of the stroke, the oil is pumped through bottom side of the piston. The ram then moves upwards. This type of press is used when heavy pressure is required on the ram. Hydraulic presses provide long strokes than mechanical presses and it is used for heavy duty jobs. The capacity of the hydraulic press is generally 100 tonnes.



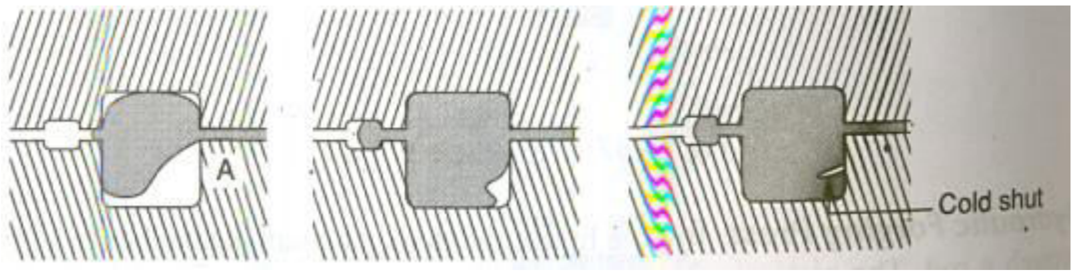
Hydraulic Forging Press

Forging Defects

Many forging defects from the starting material, including surface seams, out of tolerance cross-sections

Cold Shut

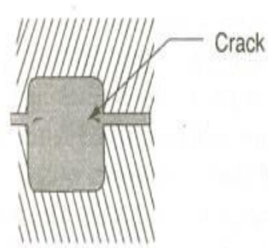
Cold shut is caused by a poor die design or some times by incorrect positioning of the work piece in the cavity. The sharp corner at “A” causes the metal to flow



Cold Shut because of Poor Design

Flash –Line cracks

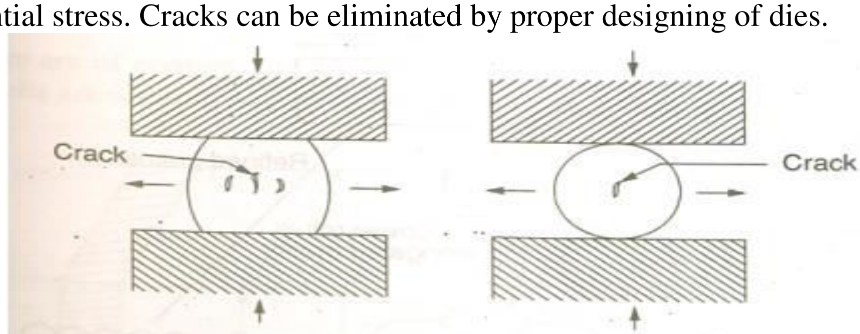
Flash –line crack is developed due to sudden reduction in thickness during forging is large Crack can develop after forging and also during heat treatment.



Flash –Line cracks

Internal Cracks

This type of crack can during upsetting of a round or a cylinder, as a result of circumferential stress. Cracks can be eliminated by proper designing of dies.

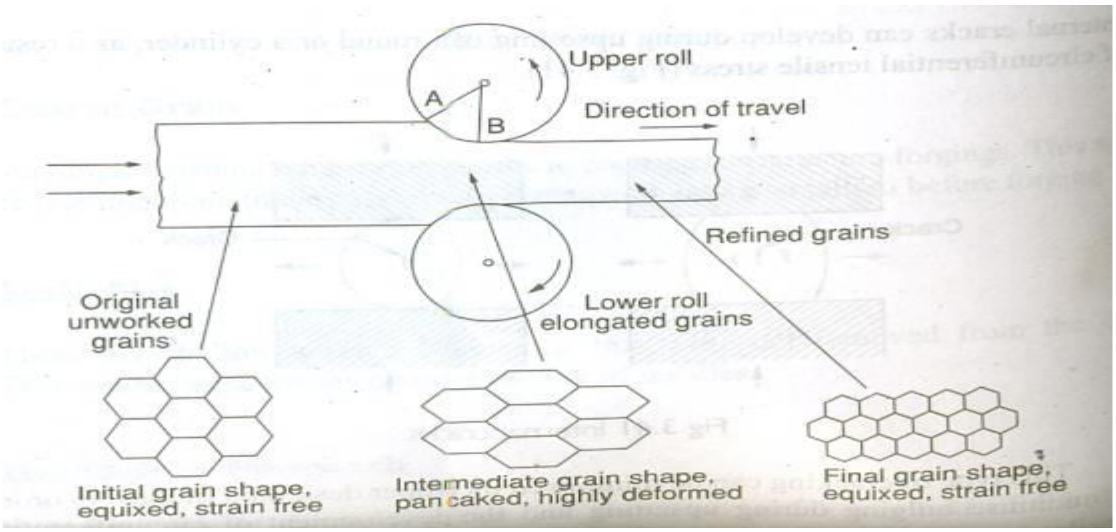


Internal Cracks

Concave are used to reduce bulging during upsetting and development circumferential tensile stress.

ROLLING

Rolling is a deformation process in which the thickness of the work piece is reduced by compressive forces exerted by two opposing rolls. Rolling is categorized into two types, Hot rolling and Cold rolling. In hot rolling, the metal is heated to just below its melting point before being fed into the rollers. It is very useful for brittle materials like Cast iron, the hot rolled steel cools down with finer grains in the crystalline micro-structure, and is stronger and less brittle, e,g. wrought iron. A structural change which occurs in the direction of rolling and the velocity of material at exit is higher than that at the entry. After crossing the stress zone, grains starts refining in the case of hot rolling. In cold rolling, grains retain the shape acquired by them during rolling.



Rolling process and Deformation of grains in Rolling

Rolling Operations

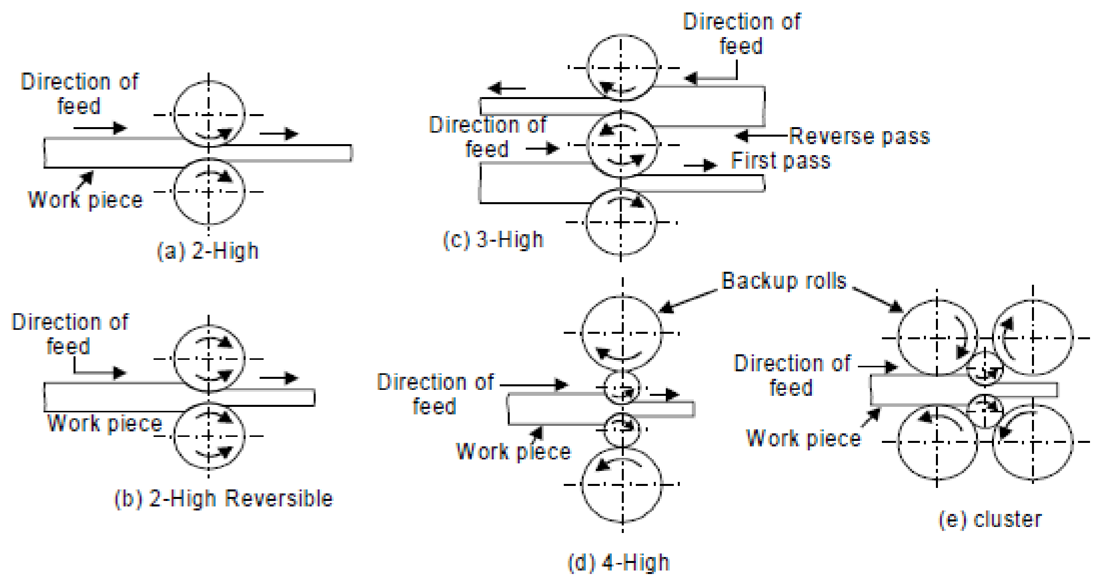
Main use rolling is in plants where the metal is made like steel- making plants, liquid iron is formed in a blast furnace by reducing the iron oxide. thus further processing of the liquid metal, including conversion from iron to steel, it is cast into raw stock shapes by a process called continuous casting. Large pieces of steel (several tonnes each) `with typical cross-sections including **Bloom** (square section 6x6 inches or larger) **Slab** (rectangular cross- section 10 x 1.5 inches), **Round bars** (circular cross-section), or **Beams** (I-sections).

TYPES OF ROLLING MILLS

A rolling mill consists of one or more roll stands, motor drive, reduction gears, and flywheel and coupling gears between units. The roll stand is the main part of the mill, where the rolling process is performed. It basically consists of housings in which bearings are fitted, which are used for mounting the rolls. Depending upon the profile of the rolled product, the body of the roll may be either flat for rolling sheets (plates or strips) or grooved for making structural members (channel, I-beam, rail).

Rolling mills are classified according to the number and arrangement of rolls in a stand. They are classified as:

(A) **Hot rolling of metals** (Two-high rolling mill, Three-high rolling mill)
(B) **Cold rolling of metals** (Four high rolling mill, Cluster rolling mill)



Hot rolling stand arrangements

(1) Two-high rolling mill: It is basically of two types i.e., non-reversing and reversing rolling mill. The two high non-reversing rolling stand arrangements is the most common arrangement. In this the rolls always move in only one direction, while in a two-high reversing rolling.

(2) Three-high rolling mill: It is used for rolling of two continuous passes in a rolling sequence without reversing the drives. After all the metal has passed through the bottom roll set, the end of the metal is entered into the other set of the rolls for the next pass. For this purpose, a table-tilting arrangement is required to bring the metal to the level with the rolls. Such type of arrangement is used for making plates or sections.

(3) Four-high rolling mill: It is generally a two-high rolling mill, but with small sized rolls. The other two rolls are the backup rolls for providing the necessary rigidity to the small rolls. It is used for both hot and cold rolling of wide plates and sheets.

(4) Cluster rolling mill: It uses backup rolls to support the smaller work rolls. In this type of mill, the roll in contact with the work can be as small as 1/4 in. in diameter. Foil is always rolled on cluster mills since the small thickness requires small-diameter rolls.

Roll Passes

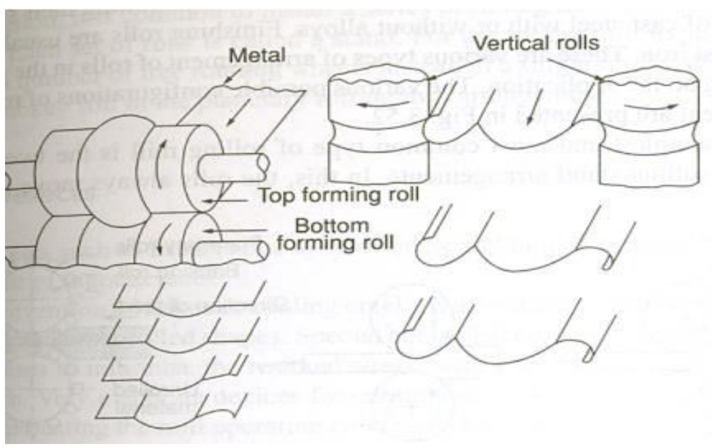
The final rolled products such as plates, flats, sheets, rounds and sections are obtained in a number of passes starting from billet or slabs. For rolling the flat product, plain cylindrical rolls are used but for sections, grooved rolls are used. The type of grooving done is decided by the final section desired.

The roll pass sequence can be broadly classified into three types:

1. Breakdown passes: These are used for reducing the cross-sectional area nearer to what is desired. These would be the first to be present in the sequence.
2. Roughing passes: In these passes also, the cross-section gets reduced, but along with it, the shape of the rolled material comes nearer to the final shape.
3. Finishing passes: These are the final passes which give the required shape of pass follows a leader pass.
The principal breakdown pass sequence is:
(i) Box pass series
(ii) Diamond square series
(iii) Oval square series

Flat Strip Rolling

Flat strip rolling uses a series of rolls to gradually change the shape of the metal. The fast moving continuous strip passes between the rolls, the cross-sectional shape changed to the desired form. The form is limitless in variations.



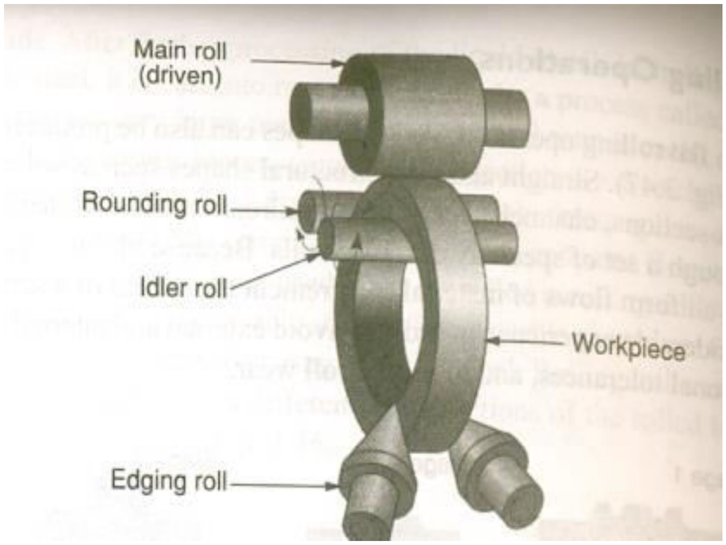
Cold forming of flat strips

Shape Rolling Operations

Apart from flat rolling operation, various shapes can also be produced by shape rolling. Straight and long structural shapes such as solid bars with various cross-sections, channels, I-beams and railroad rails are rolled by passing the stock through a set of specially designed rolls.

Ring Rolling

In this process, a thick ring is expanded into larger diameter with a reduced cross-section. Ring is placed between two rolls, one of which is driven and its thickness is reduced by bringing the rollers closer together as they rotate. The volume of the ring remains constant during deformation; the reduction in thickness is compensated by an increases in its diameter.



Ring Rolling

Advantages

- Favourable grain flow
- No wastage of materials
- Close dimensional tolerances
- High productivity rate

Applications

- Large rings for Rockets and Turbines.
- Gear wheel rims, and Ball bearing braces.
- Flanges and Reinforcing rings for pipes

Thread Rolling

One of the important use of rolling is to make screws and bolts. The threads of the screws are made by rolling a cylindrical stock between two dies that form the thread-shapes on the stock. A single rolling machine of this type can produce a minimum of ten screws per second. The thread rolling process is a cold forming process by which straight or taper threads are formed on the rod by either flat reciprocating dies or rotating cylindrical dies

Advantages

- Production rate is high. No wastages or burr formation. Surface finish is high.

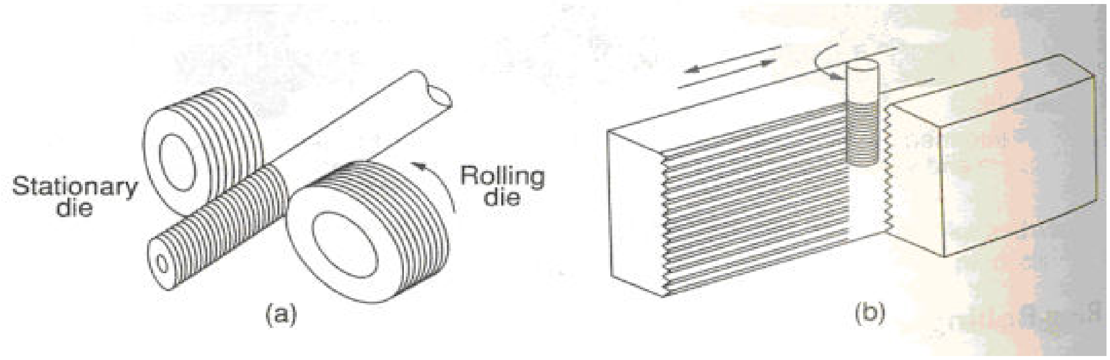
Applications of Rolling

Rolling is used to produce components having constant cross-section throughout its length. The whole range of rolled products can be divided into the following types:

(a) **Structural shapes or sections:** This includes sections like round, square, hexagonal bars, channels, H and I beams and special sections like rail section.

(b) **Plates and sheets:** These are produced of varying thickness

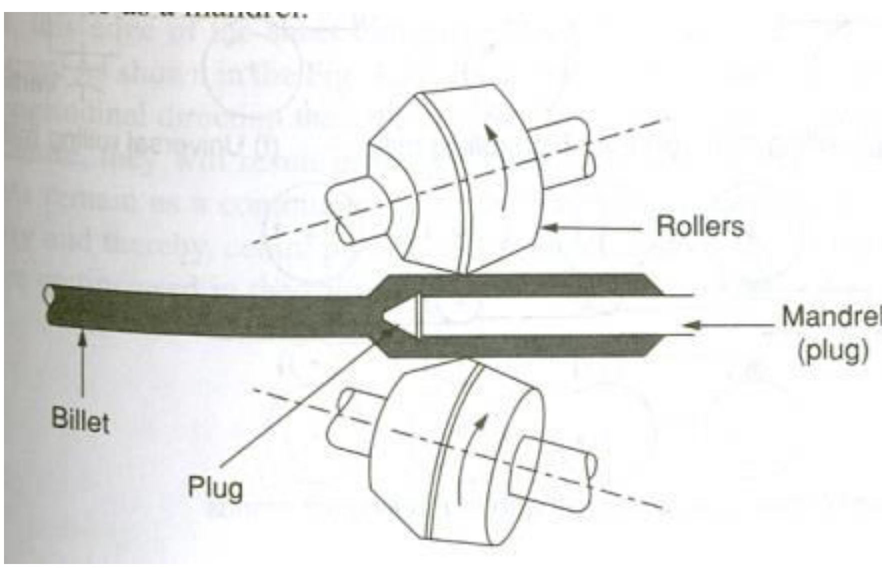
(c) **(c) Special purpose rolled products:** These include rings, balls, wheels and ribbed tubes.



Two types of thread –rolling processes
(a) Dual –roller dies (b) Reciprocating flat dies

Tube Piercing or Seamless Tubing

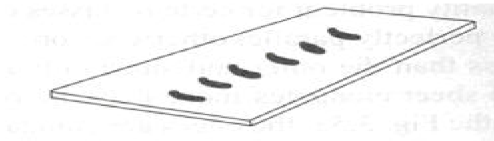
Process of making a hot pierced tube, consists of passing a hot rolled billet between two bi-conical rollers over a plug held on a support bar, often referred as mandrel. The bi-conical rolls serve to spin the round heated billet and force it forward. The piercing action is actually started before placing it between the rolls, by drilling, punching or piercing. their axes are inclined at a feed angle to permit forward and rotary motion of the billet. The squeezing and bulging of the billet open up a seam in its center pass makes a rather thick-walled tube which is again passed over plug and through grooved rolls in a two-high roll mill where the thickness is decreased and the length is increased. While it is still up to a temperature, it is passed on to a reeling machine which has two rolls similar to the piercing rolls, but with flat surfaces.



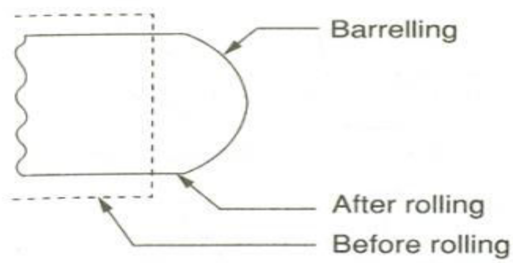
Tube Piercing or Seamless Tubing

Defects in Rolling

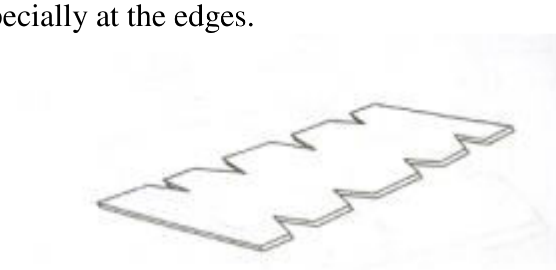
Zipper Cracks
Zipper cracks are usually caused by low ductility.



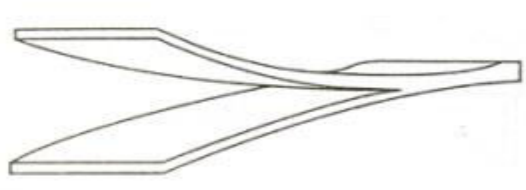
Barreling
Barreling is caused by interfaces, which records the free flow of the material.



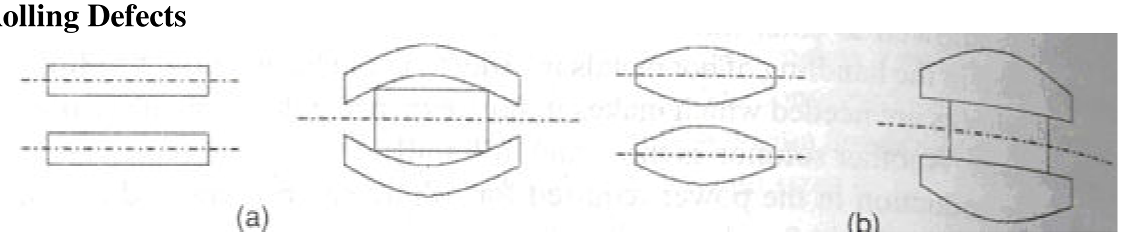
Edge cracks
Edge cracks are occurs in plates and slabs because of either limited ductility of metal or uneven deformation especially at the edges.



Alligatoring
Alligatoring is a complex phenomenon that results from inhomogeneous deformation of the material during rolling or from defects in the original cast ingot, such as piping. The work piece splits along a horizontal plane on exit from the rolls.



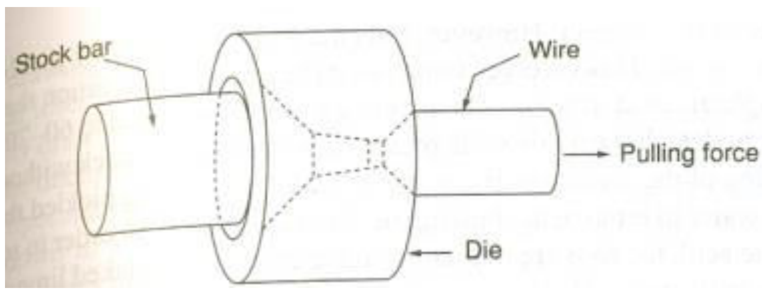
Rolling Defects



Roll Deflection **Roll Crowing**

ROD, WIRE AND TUBE DRAWING

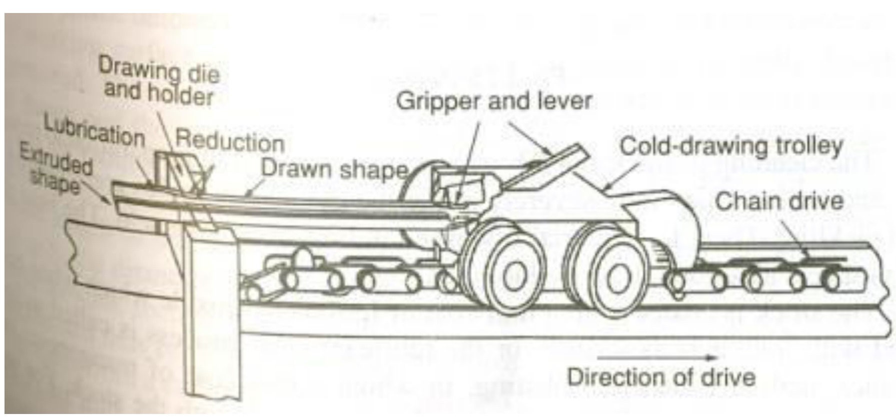
To manufacture long slender products (wire, tube), material is drawn through a die. The material is deformed by compression, but the deformation force is supplied by pulling on the deformed end of the wire or rod. This is termed 'indirect compression'. Most drawing is done cold. Wire drawing is an operation to produce wire of various sizes within certain specific tolerances. The process involves reducing the diameter of rods or wires by passing them through a series of wire drawing dies with each successive die having smaller bore diameter than the one preceding it. The drawing force must not exceed the strength of the drawn wire. Typically this means that the maximum reduction (as area, not diameter) attainable is less than 50%. In practice reduction is usually limited to 20-30% to avoid frequent breakage. The final wire size is reached as the wire passes through the last die in the series.



Schematic diagram of drawing process

Rod drawing

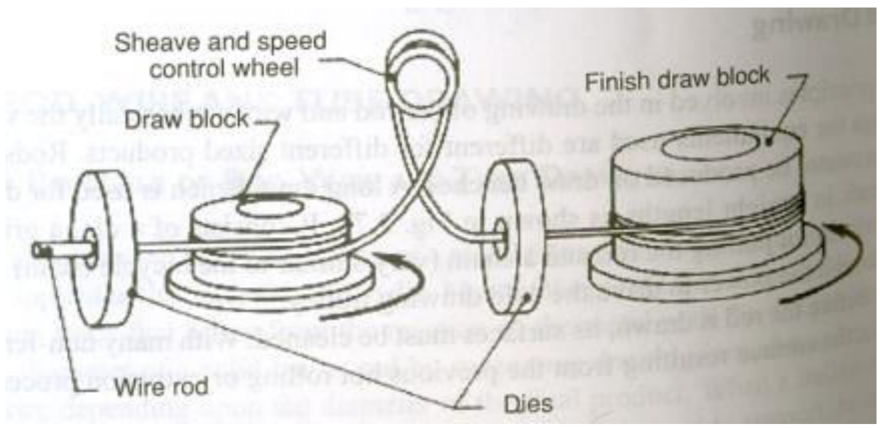
The principle behind in drawing of bar rod and wire are one and the same, though the equipments used are different for different sized products. Rods and tubes cannot be produced on drawing benches. A long draw bench is used drawing rod in straight lengths. It consists of a die, a gripper and lever for pulling the rod and a chain used to transmit the power to drive the cold drawing trolley. Before the rod is drawn, its surfaces must be cleaned. The Non-ferrous alloys, the surface resulting from the previous hot rolling or extrusion processes is adequate in this respect. Pointing rod is required for easy insertion and holding in the gripper jaws.



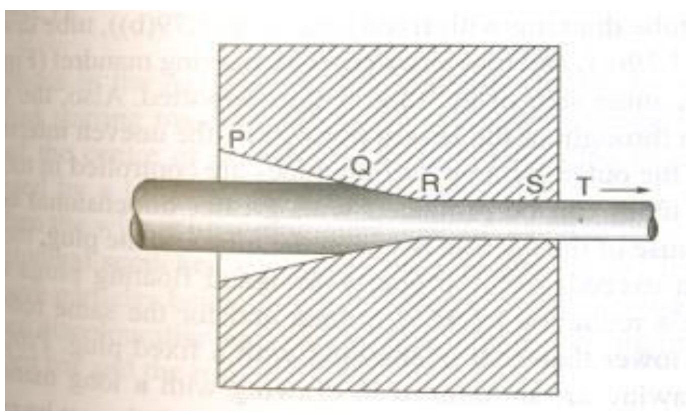
Draw Bench

Wire drawing

To manufacture long slender products (wire, tube), material is drawn through a die. The material is deformed by compression, but the deformation force is supplied by pulling on the deformed end of the wire or rod. This is termed ‘indirect compression’. Most drawing is done cold. Wire drawing is an operation to produce wire of various sizes within certain specific tolerances. The process involves reducing the diameter of rods or wires by passing them through a series of wire drawing dies with each successive die having smaller bore diameter than the one preceding it. The drawing force must not exceed the strength of the drawn wire. Typically this means that the maximum reduction (as area, not diameter) attainable is less than 50%. In practice reduction is usually limited to 20-30% to avoid frequent breakage. The final wire size is reached as the wire passes through the last die in the series.



Wire Drawing



Wire Drawing Die

Defects in Wire Drawing

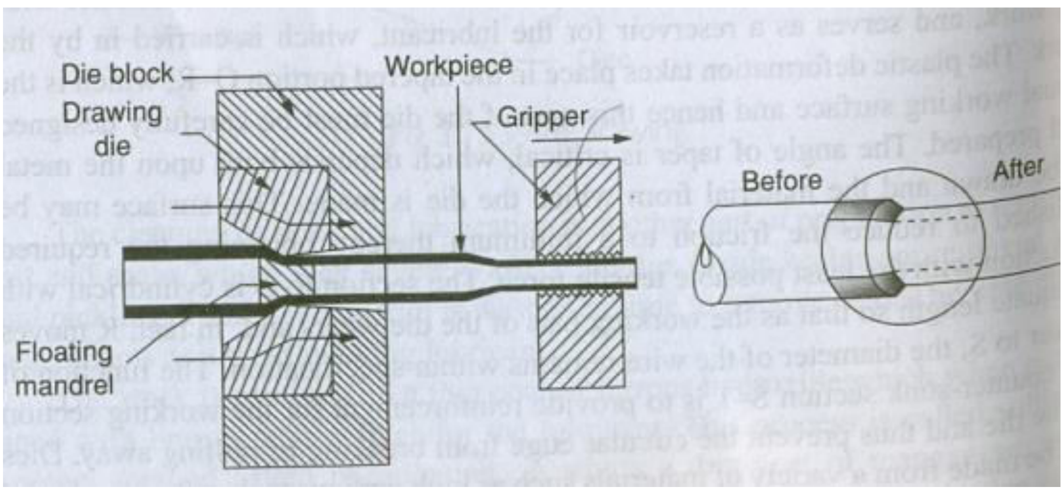
Defects occur in wire drawing because of ploughing by hard particles and local breakdown of the lubricating film. Some common defects are:

1. Bulge formation: This occurs in front of the die due to low reduction and high die angle.

2. Internal cracks (Centre burst or centre-cracking): The tendency of cracking increases with increasing die angle, with decreasing reduction per pass, with friction and with the presence of inclusions in the material.
3. Seams: These appear as longitudinal scratches or folds in the material. Such defects can open up during subsequent forming operations by upsetting, heading, thread rolling or bending of the rod or wire.
4. Surface defects: Various types of surface defects can also result due to improper selection of process parameters and lubrication.

Tube drawing

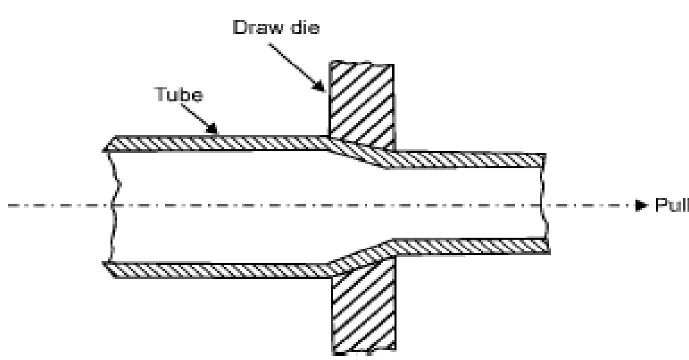
Tube drawing normally makes tubes to size from hollow 'tube shells' produced by extrusion. They are then cold drawn to size by a succession of passes, with inter stage anneals as required and supplied neither in straight lengths or coil. shows a typical tube drawing process with a floating mandrel.



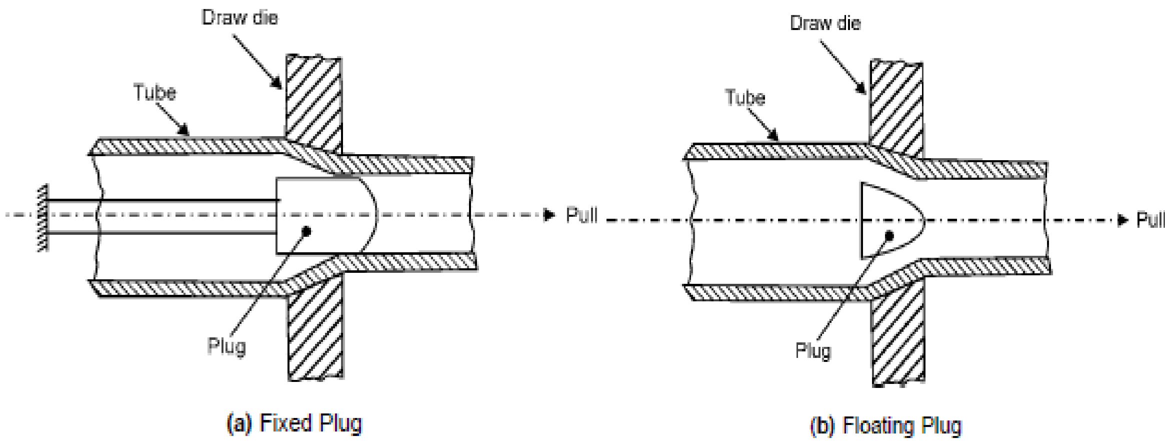
Tube Drawing

The common methods of tube drawing are: Tube sinking, Tube drawing with a plug or stationary mandrel and Tube drawing with a moving mandrel.

1. Tube sinking: This method is generally not preferred since no support is provided on the inner surface of the tube and as a result wall thickness may slightly increase.

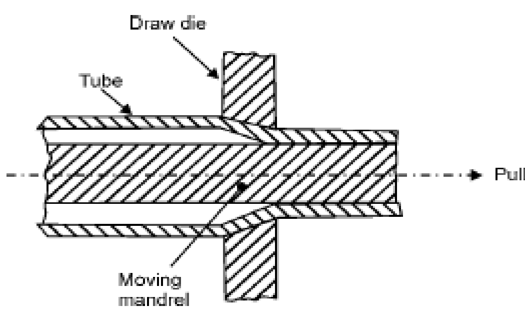


Tube drawing with a plug: In this method tubes of greater dimensional accuracy are obtained because of the proper support provided both at the inner and outer surfaces of the tube. The plug used may be of cylindrical or conical shape and is of either fixed or floating type. In a fixed plug, friction is more as compared to a floating plug. For the same reduction in area, the drawing load will be less with floating plug than with a fixed plug.



Tube Drawing with a Plug.

Tube drawing with a moving mandrel: This method is similar to that of a plug drawing except the difference that in this case a movable mandrel is used. Because of the movable mandrel, friction is minimized but the mandrel has to be removed by rolling, hence there is a slight increase in the diameter of tube. This results in reduction of dimensional tolerances.



Tube Drawing with a Moving Mandrel.

Defects

Internal defects in the rod and wire include cracks due to seam or pipe in the hot rolled starting material and a defect known as cupping. Cupping is the rupturing of the centre of the wire when it is subjected to tensile force is identified by necking during drawing or by cup and cone type fracture when wire is broken.
Surface discoloration and ground in oxide result from improper cleaning of hot rolled bar and the rod.

EXTRUSION

Extrusion differs from drawing in that the metal is pushed, rather than pulled under tension. Extrusion processes can be carried on hot or cold.

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. Cold extrusion can be used with any material that possesses adequate cold work ability–e.g., lead, tin, aluminum alloys, copper, titanium, molybdenum, vanadium, steel. Typical parts which are cold extruded are collapsible tubes, aluminum cans, cylinders, gear blanks.

The advantages of cold extrusion are:
1. No oxidation takes place.
2. Good mechanical properties due to severe cold working as long as the temperature created are below the recrystallization temperature.
3. Good surface finish with the use of proper lubricants.

Hot extrusion: Hot extrusion is basically a hot working process. It 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.

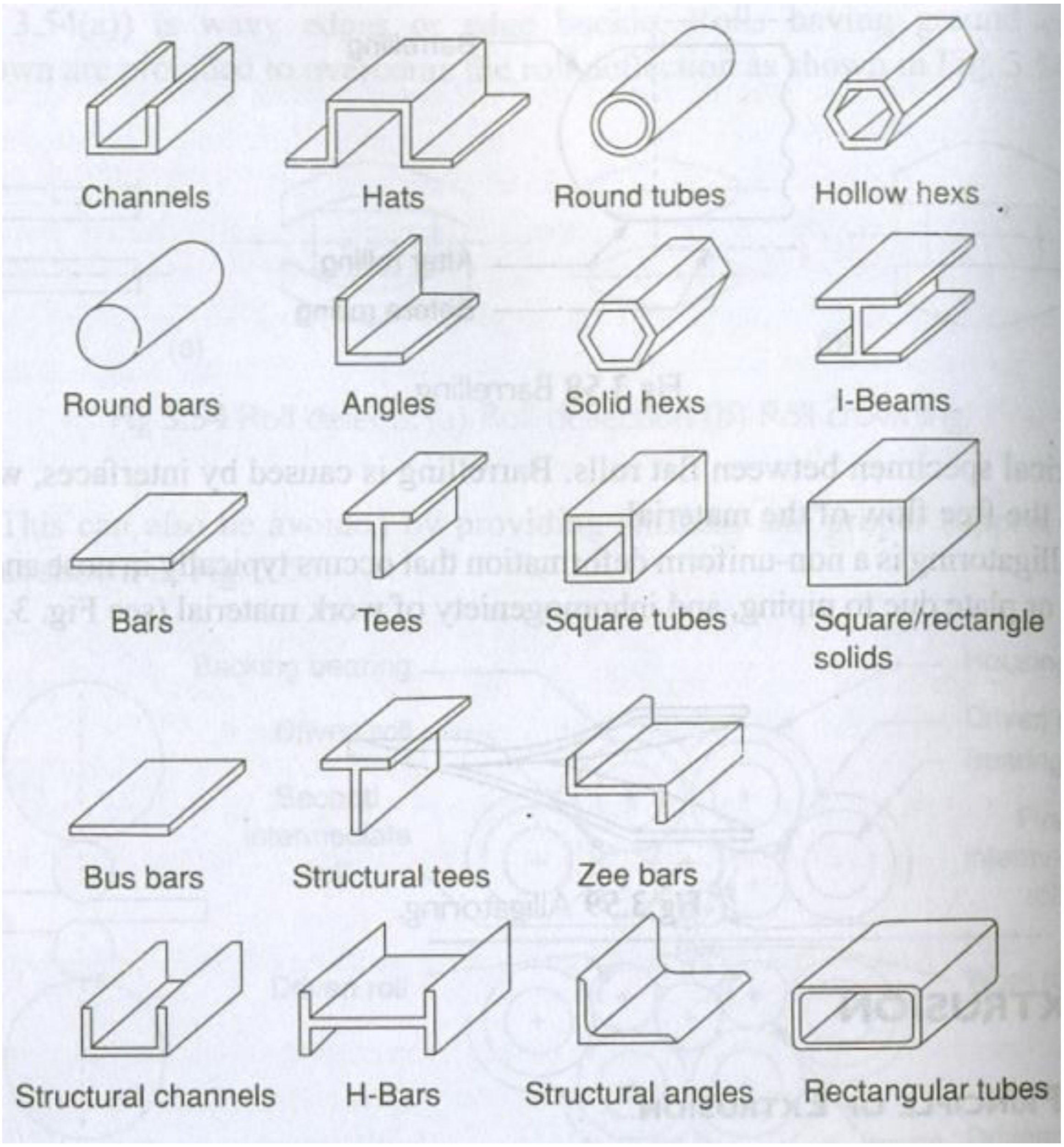
The principal variables, which influence the force required to cause extrusion, are:
(1) The type of extrusion
(2) The extrusion ratio
(3) The working temperature
(4) The speed of deformation, and
(5) The frictional conditions at the die and container wall.

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

Types of Extrusion

Extrusion process is classified as

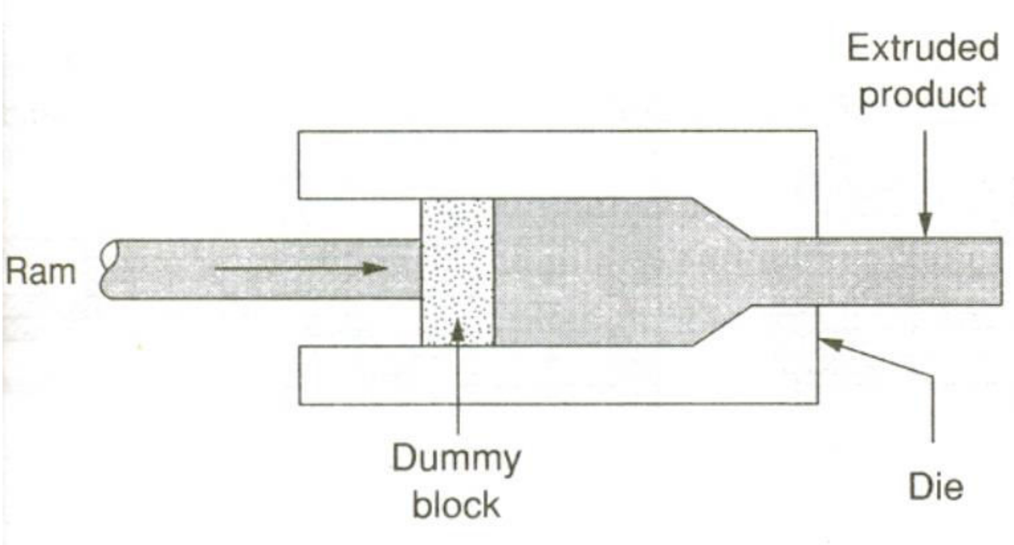
1. Direct or forward extrusion
2. Indirect or backward extrusion
3.Other extrusion processes
    - ☞ Tube extrusion
    - ☞ Hydrostatic extrusion
    - ☞ Impact extrusion
    - ☞ Cold extrusion forging
    - ☞ Side extrusion



Typical cross-section in extrusion

Direct or Forward Extrusion

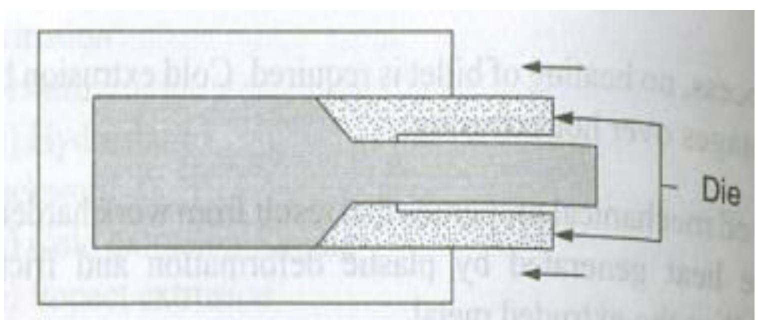
In this method, the heated metal billet is placed in to the die chamber and the pressure is applied through ram. The metal is extruded through die opening in the forward direction, i.e. the same as that of the ram. In forward extrusion, the problem of friction is prevalent because of the relative motion between the heated metal billet and the cylinder walls. To reduce such friction, lubricants are to be commonly used. At lower temperatures, a mixture of oil and graphite is generally used. The problem of lubrication gets compounded at the higher operating temperatures. Molten glass is generally used for extruding steels.



Direct or Forward Extrusion

Indirect or Backward Hot Extrusion

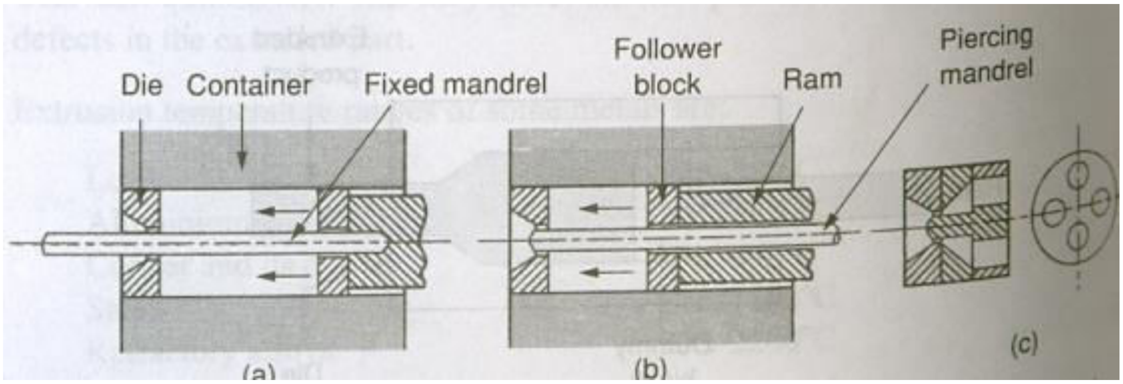
In indirect extrusion, the billet remains stationary while the die moves into the billet by the hollow ram (or punch), through which the backward extrusion takes place. Since, there is no friction force between the billet and the container wall, therefore, less force is required by this method. However this process is not widely used because of the difficulty occurred in providing support for the extruded part.



Backward Extrusion

Tube extrusion

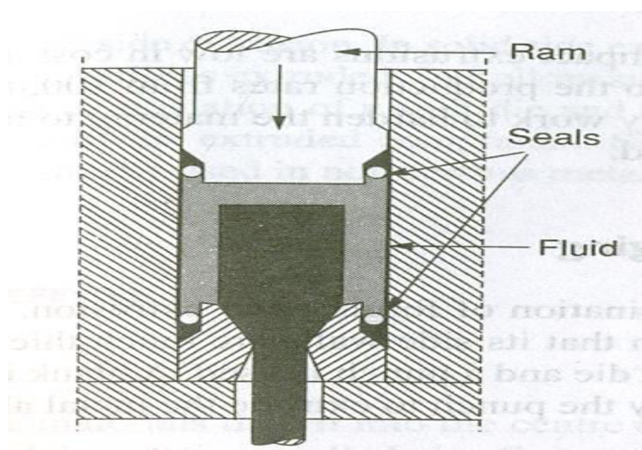
This process is an extension of direct extrusion process where additional mandrel is needed to restrict flow of metal for production of seamless tubes. Alumminium based toothpaste and medicated tubes are produced using this process.



Hollow products extruded with (a) Fixed (b) Piercing mandrels and (c) Bridge or spider type dies

Hydrostatic extrusion

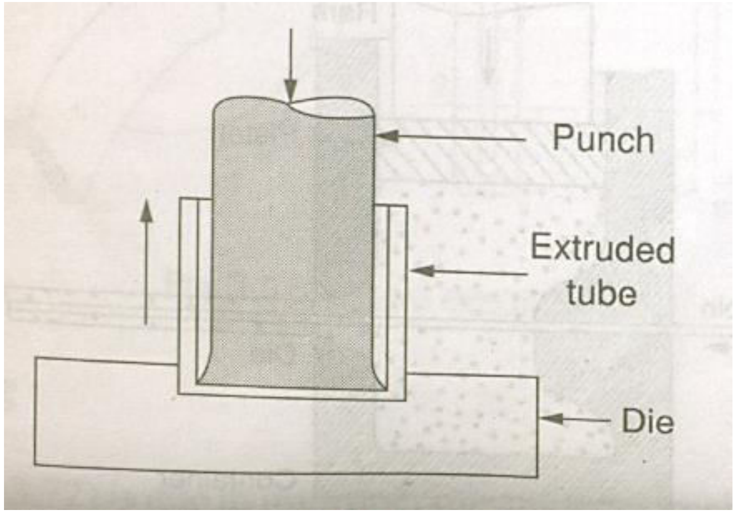
In this process, the chamber is filled with a fluid that transmits the pressure to the billet, which is then extruded through the die. There is no friction along the walls of the container. Because the billet is subjected to uniform hydrostatic pressure, it does not upset to fill the bore of the container as it would in conventional extrusion. This means that the billet may have a large length to diameter ratio (even coils of wires can be extruded) or it may have an irregular cross section. Because of the pressurized fluid, lubrication is very effective, and the extruded product has good surface finish and dimensional accuracy. Sin e friction is nearly absent, it is possible to use dies with very low semi-cone angle which greatly minimizes the redundant deformation. The only limitation with this process is the practical limit of fluid pressure that may be used because of the constraint involving the strength of the container and the requirement that the fluid does not solidify at high pressure.



Hydrostatic extrusion

Impact Extrusion

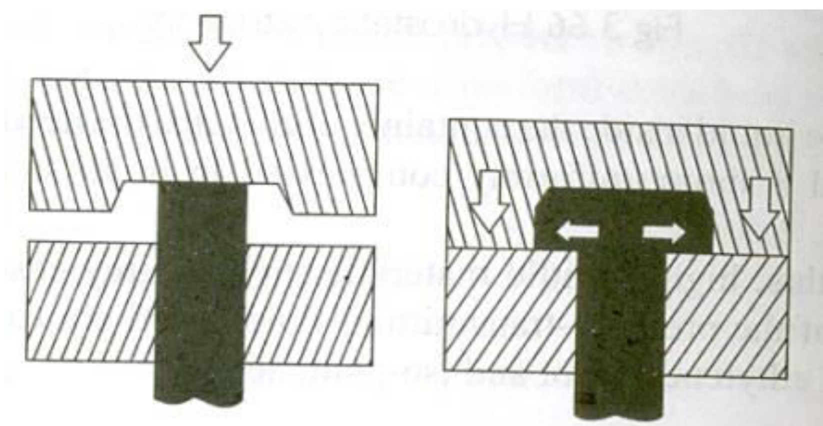
It is a form of indirect extrusion and is particularly suitable for hollow shapes. It is usually performed on a high-speed mechanical press. The punch descends at a high speed and strikes the blank, extruding it upwards.. The thickness of the extruded tubular section is a function of the clearance between the punch and the die cavity. Although the process is performed cold, considerable heating results from the high-speed deformation. Impact extrusion is restricted to softer metals such as lead, tin, aluminum and copper.



Impact Extrusion

Cold extrusion forging

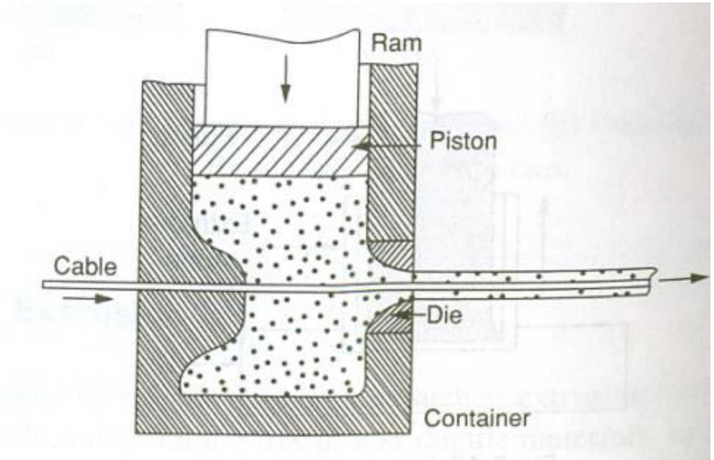
Cold extrusion forging is a combination of forging and extrusion. It is similar to impact extrusion, but different in that its side walls are much thicker and their height is smaller. In this method both die and punch is used. A blank is placed inside the die and pressure is applied by the punch to extrude the metal along the punch walls.



Cold extrusion forging

Side extrusion

In this side extrusion, the movement of the material is the direction perpendicular to that of ram motion. It can be a solid or a hollow side extrusion. In solid extrusion, a solid body of any protrusion of any profile is extruded. For hollow side extrusion, a tool opening is formed by the combination of a split die and a mandrel determines the hollow protrusion profile of the extruded component. The force used is high Non – ferrous metals and highly plastic metals like lead.

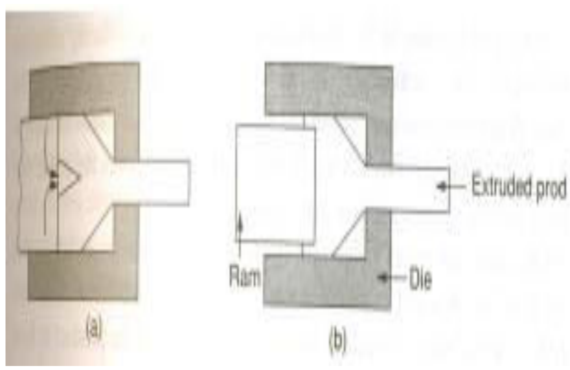


Side Extrusion

Extrusion defects

Piping

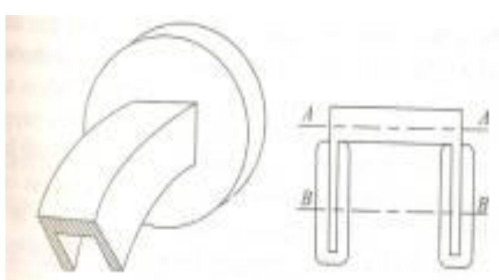
Piping is due to surface materials drawn into the centre as shown in figure. Severe surface material's serration, called the fir-tree defect, results from momentary sticking of extrusion in the die area.



Piping

Shape Error

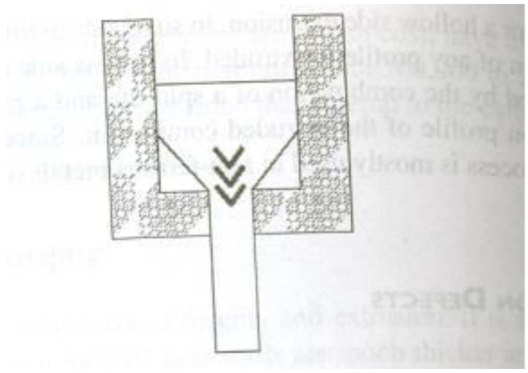
Shape error occurs because of the different extrusion speeds at different points of the vertical section of the componenet.It can be avoided by providing uniform speed throughout the vertical section.



Shape Error

Internal Cracking

It is due to improper die angle, extrusion ratio and friction.Chervon cracking occurs due to hydrostatic tension(outer layer in compression and inner layer in tension, if entire part is not plastic)It can be eliminated by reducing the friction



Internal Cracking

Advantages of Extrusion

- The tooling cost is low, as well as the cost due to material
- Intricate cross sectional shapes, hollow shapes and shapes with undercuts can be produced.
- The hardness and the yield strength of the material are increased.
- In most applications, no further machining.

Limitations of Extrusion

- High tolerances are difficult to achieve.
- The process is limited to ductile materials.
- Extruded products might suffer from surface cracking. It might occur when the surface
- Temperature rise significantly due to high extrusion temperature, friction, or extrusion speed.

MANUFACTURING TECHNOLOGY - I
UNIT-IV SHEET METAL PROCESSES

Sheet metal characteristics – Typical shearing operations – Bending – Drawing operations – Stretch forming operations –– Formability of sheet metal – Test methods – Working principle and application of special forming processes – Hydro forming – Rubber pad forming – Metal spinning – Introduction to Explosive forming – Magnetic pulse forming – Peen forming – Super plastic forming.

Introduction

Sheet metal work is generally regarded as the working of metal from 16 gauge to 30 gauge, with hand tools and simple machines into various forms of cutting, forming into shapes and joining. In most of the cases the manufacturing of sheet metal components is a cold working process because, the metal, when heated, has a lower resistance to deformation.

Common examples of sheet metal applications are canisters, guards, covers, hoppers, pipes, hoods, boxes, etc. Parts made of sheet metal have many attractive qualities such as good accuracy of dimensions, adequate strength, light weight and a broad range of possible dimensions. Knowledge of geometry, mensuration, and properties of metal is most essential since nearly all patterns come from the development of the surfaces of a number of geometrical models such as cylinder, prism, cones and pyramids.

Deformation in sheet metal occurs mainly due to tension. During a sheet metal operation, plastic flow of metal to finished size takes place. Thus a sheet metal should posses the following characteristics.

1. Plasticity
2. Malleability
3. Good bending properties
4. Stretchability
5. Good shearing characteristics
6. Formability

Materials used for sheet metal working :

Galvanised Iron	Aluminium
Statinless Steel	Tin Plate
Copper	Lead

Coated Materials and their applications :

1. Tin plate : Used on Steel food cans-tin is non-toxic and corrosion resistant
2. Galvanized sheet metal : Zinc gives excellent corrosion resistance
3. Terme Plate : Lead coating is used on steel to prevent corrosion of petrol tanks.
4. Aluminium : Used on steel exhaust pipes to reduce corrosion
5. Paint and Polymers : Used on many metals-part decorative and part corrosion resistance

Common Operations done on sheet metal

Sheet metal operations can be divided into five groups as follows :

Cutting				
Shearing	Piercing	Blanking	Shaving	Lancing
Perforating	Nibbling	Notching	Trimming	Slotting
Bending				
Supported and Unsupported bending		Press brake forming	Roll Bending & Roll Forming	Bending & Tube Bending
Flanging	Dimpling	Hemming or curling	Roll Forming	Twisting
Deep Drawing				
Pure bending		Ironing	Hydro forming	
High Velocity Forming				
Explosive Forming	Magnetic Pulse forming		Electro Hydraulic Forming	
Other Forming Operations				
Squeezing	Stretch Forming	Spinning	Peen forming	Super Plastic Forming

TYPICAL SHEARING OPERATIONS

Cutting Operations

Shearing is the mechanical cutting of materials without the formation of chips or the use of burning or melting. The process involves cutting of flat material forms such as sheets and plates using two cutting blades.

The group of sheet metal forming processes that involve cutting or shearing the sheet metal by subjecting it to shear stress between punch and die, or between the blades of a shear could be categorized into many processes such as punching, piercing, slitting, etc.

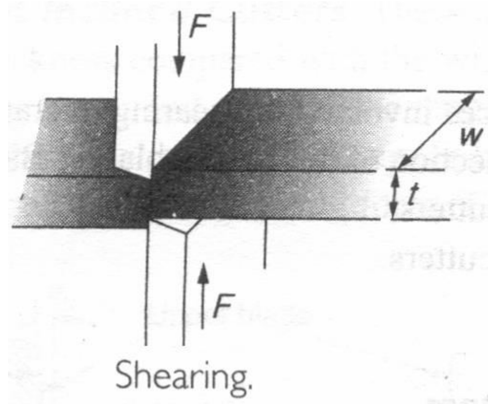
Operations that make up press work are varied, but ate broadly classified as shearing, bending and drawing. Press working tools are called punches and dies. The punch of the assembly is attached to the ram of the press and is forced into die cavity. The die has the opening to receive the punch.

Die I used in shearing typically have small clearances between the punch (moving part) and the die (non-moving backing). If the gap is too great, the parts will have rough edges and excess shear force will be required. Clearances that are too small lead to pre-mature wear.

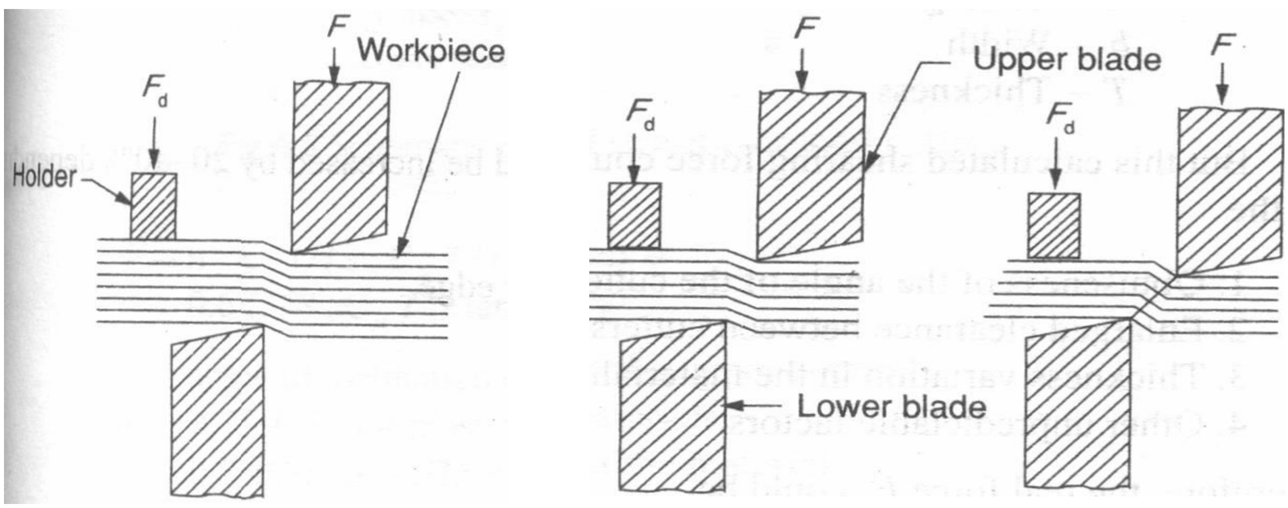
Shearing, Piercing and Blanking Operations

Shearing

Shearing is a general description for most sheet metal cutting, but in a specific case, it is cut along a straight line completely across a strip, sheet or bar. As a punch descends on the metal, the pressure first causes a plastic deformation to take place. The metal is highly stressed adjacent to punch and a die edges, and fractures start on both sides of the sheet as the deformation continues. When the ultimate tensile strength of the material is reached, the fracture progresses and if the clearance is correct and both edges of equal sharpness, the fractures meet at the centre of the sheet.



Mechanics of Shearing



During the shearing process, three phases could be distinguished as shown above.

Phase 1: Due to the action of the cutting force F, the stress on the material is lower than the yield stress. This phase is that of elastic deformation. In order to prevent the movement of material during the cutting operation, the material is held by the material holder at force $F_{d.}$

Phase 2: The stress on the material is higher than the yield stress but lower than the Ultimate Tensile Stress. The phase is that of plastic deformation.\

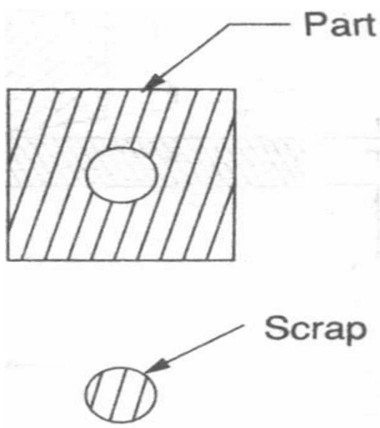
Phase 3: In this phase, the stress on the material is equal to the shearing stress. The material begins to part not at the beginning edge but at the appearance of the first crack or breakage in the material. Fracture of the material occurs in this phase. As the applied exceeds the shear strength, the material tears or ruptures through the remainder of the thickness.

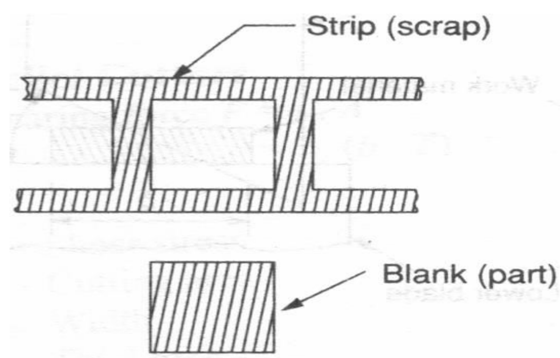
Because of the normal non-homogeneiti4es in a metal and the possibility of non-uniform clearance between the shear blades, the final shearing does not occur in a uniform manner. Fracture and tearing begins at the weakest point and proceeds progressively and intermittently to the next weakest location.l The results are usually rough and ragged edge.

Proper clearance between punch an die, or the shearing blades would result in sufficiently smooth edge condition which may be used without further finishing operation.

Blanking and Punching

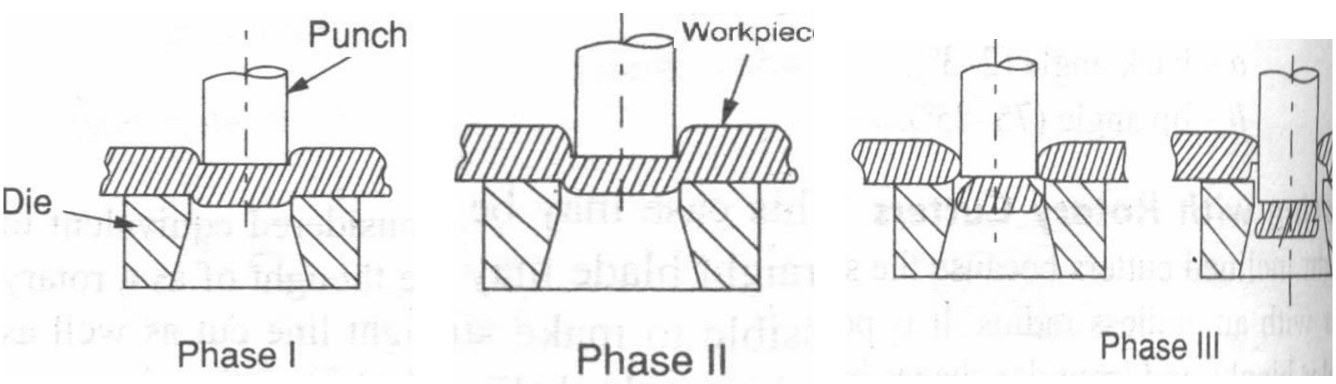
Cuts an entire piece from sheet metal, but there is stock entirely around the contour of the part in the work piece sheet metal. The usable part is called the blank. The remaining is part is often called the skeleton or the waste. If the operation is to cut a hole, and the material in the hole is a waste, then the operation is called piercing or punching.The basic tool of blanking and punching are die and punch.





There are three phases of this process.

1. Elastic 2. Plastic 3. Fracture



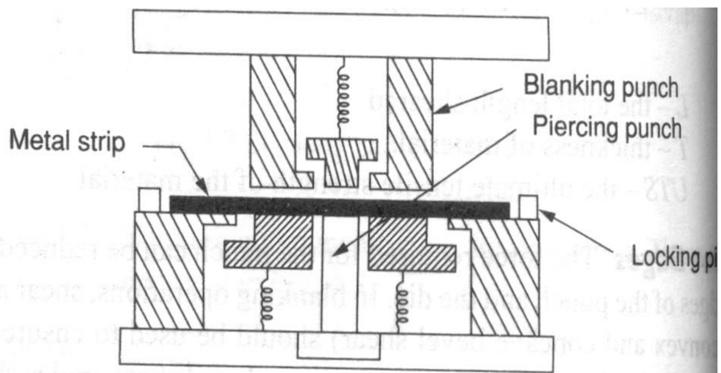
Elastic Phase: In this phase, the material gets compressed across and slightly deformed between the punch and die. The deformation in the metal does not exceed elastic limit.

Plastic Phase: Further progress of the punch causes plastic deformation at the rim, between the cutting edges of the punch and the die. At the end, the material shear strength will be reached but the material resists fracture.

Fracture Phase: The strain in the material reaches the fracture limit and micro cracks appear, propagate and becomes macro crack, followed by separation of the parts of the workpiece. The crack in the material starts at cutting edge of the punch on the upper side and cutting edge on the die at lower side of the material.

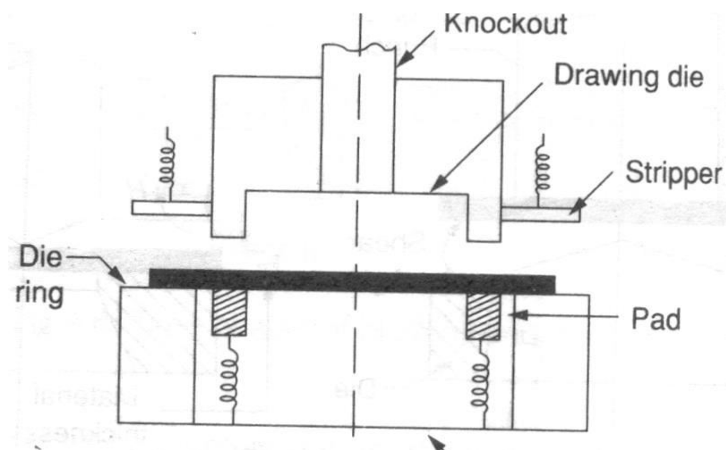
Shearing Dies:

Compound Dies: Several operations in the same strip may be performed in one stroke with a compound die in one station. These operations are usually limited to relatively simple shearing because they are somewhat slow, and dies are more expensive than those of individual shearing operations. Washers produced simultaneously by blanking and piercing operations. Economical in mass production.



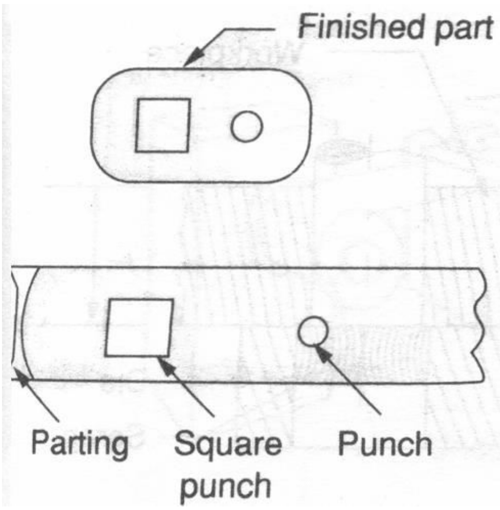
Compound dies.

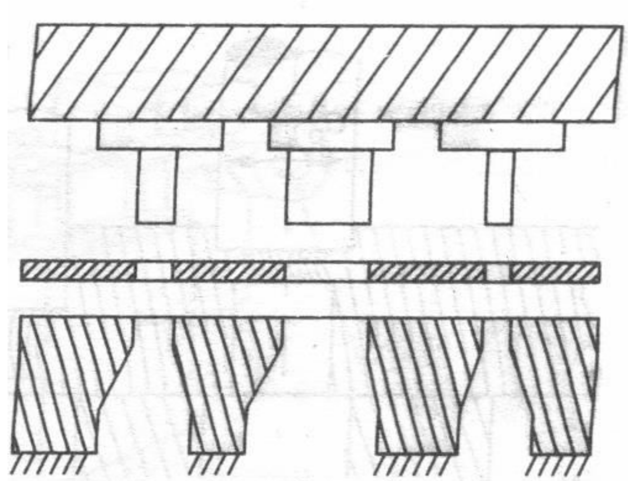
Combination Die: It differs from compound die in this, cutting operation is combined with bending or drawing (forming) operations. The die ring which is mounted on the die shoe, is counter-bored at the bottom to allow the flange of a pad to travel up and down. This pad is held flush with the face of the die by a spring. A drawing punch of required shape is fastened to the die shoe. The blanking punch is secured to the punch holder. A spring stripper strips eh skeleton from the blanking punch. A knockout extending through the centre opening. In operation, the blank holding ring descends as the part is blanked, then the drawing punch contacts and forces the blank into the drawing die which is made in the blanking punch.



Combination dies.

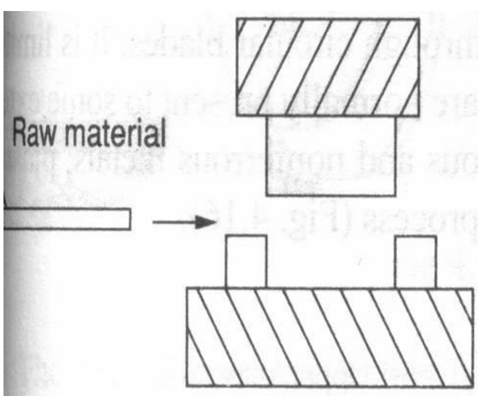
Progressive Dies: A progressive or a follow on die has a series of stations. At each station, an operation is performed on a workpiece during a stroke of the press. Between stroke, the piece of the metal strip is transferred to the next station. A finished work-piece is made at each stroke of the press. Parts requiring multiple operations, such as punching, blanking and notching are made at high production rates in progressive dies. The sheet metal is fed through a coil strip, and a different operation is performed in different stations.

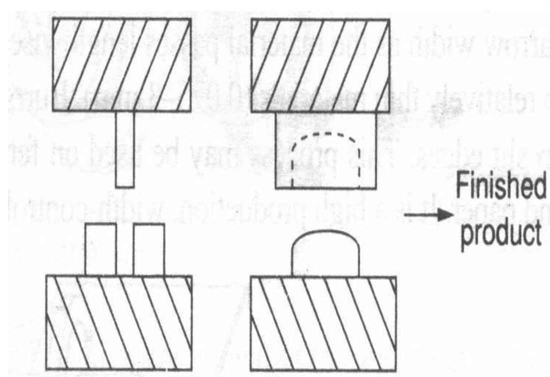




Progressive die.

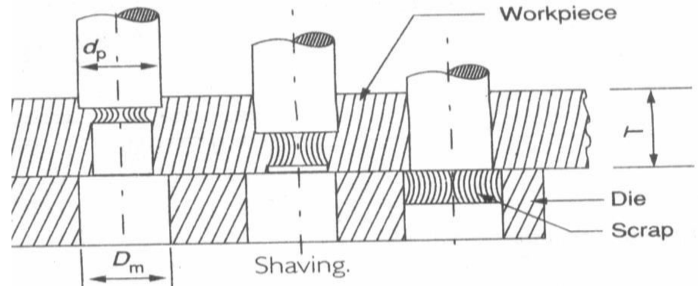
Transfer Dies: In this setup, sheet metal undergoes different operations in different stations, which are arranged along a straight line or a circular path. After each operation the sheet metal transferred to the next station for an additional operation.





Transfer die.

Other Sheet metal cutting operations:

<table>
<tr>
<td>Shaving: It is a finishing or sizing operation during which a slight amount of material (about 10%) of the material thickness is removed or shaved from the blanked or pierced edges in order to obtain edges which are smooth, square and within closer dimensional tolerances.</td>
<td>
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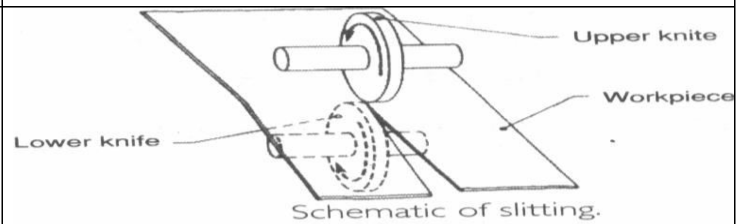
<tr>
<td>Slitting: Slitting is the length wise cutting of coil or sheet stock into narrower widths. Slitting is a shearing operation used to cut wide coils of materials into several coils of narrow width as the material passes lengthwise through circular blades.</td>
<td>
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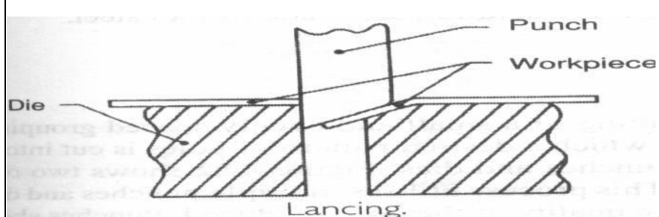
<tr>
<td>Lancing: Lancing makes a cut part way through a blank. Lancing is a combined shearing and bending operation where a portion of the periphery of a hole is cut into the workpiece and the remainder is bent to the desired shape. No material is removed from the workpiece.</td>
<td>
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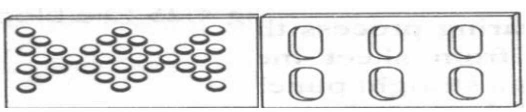
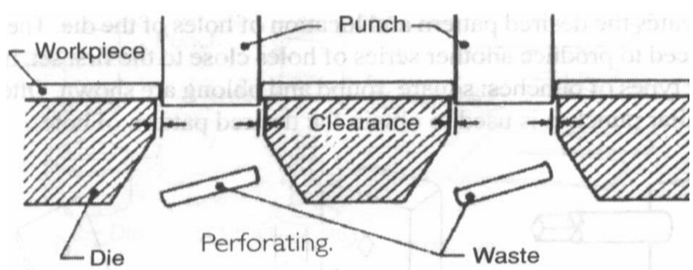
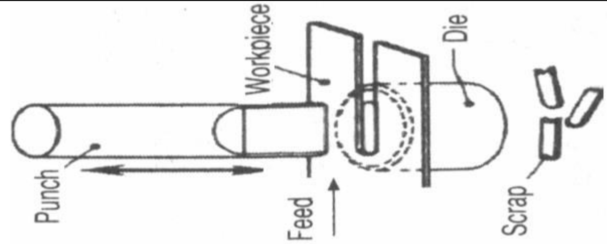
<tr>
<td>Perforating: Perforating is the cutting of a small and evenly spaced grouping of holes. It is a punching process in which a desired pattern of holes is cut into the workpiece by means of multiple punches and dies.
</td>
<td>
</td>
</tr>
<tr>
<td>Nibbling: Nibbling is a shearing process that utilizes a series of overlapping cuts to make complex shapes from sheet metal. In nibbling, a machine called a nibbler moves a straight punch up and down rapidly into a die.</td>
<td>
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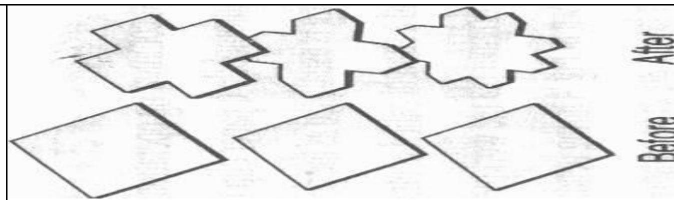
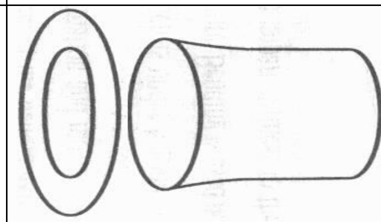
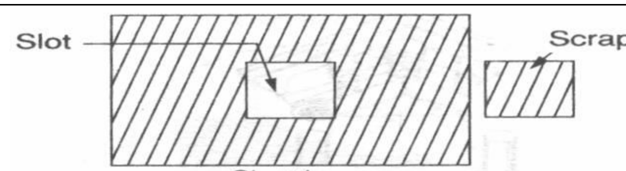
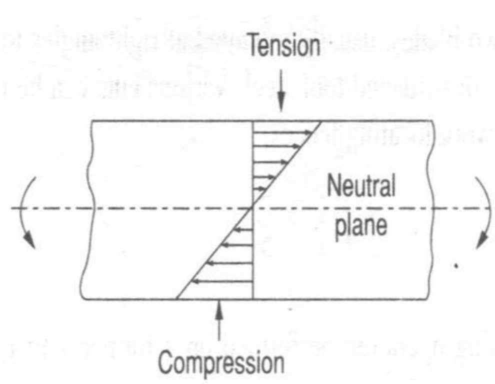
</table>

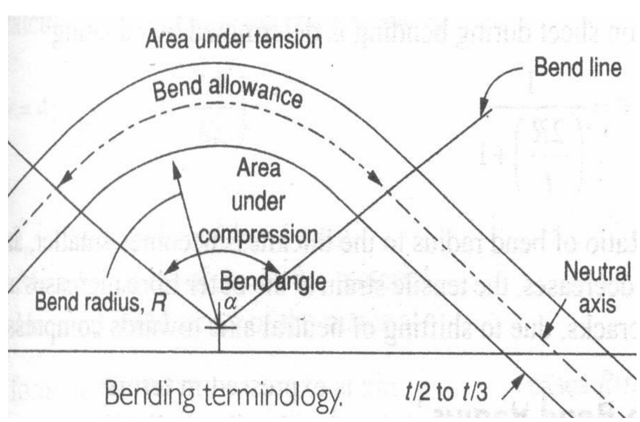
Notching: It is a cutting operation from the side of a strip or sheet or blank. It is a shearing operation by which metal scrap is removed from the outside edge of a workpiece by multiple shear blades set at right angles to each other.	
Trimming: It is a cutting operation performed on a formed part to remove excess metal and establish size. The term has the same basic meaning as in forging. Removing the top portion of a vessel.	 Trimming.
Slotting: Punching operation that cuts out an elongated or rectangular hole.	 Slotting.

BENDING

Bending is the metal working process by which a straight length is transformed into a curved length. It is a very common forming process for changing sheet and plate into channels, drums, tanks etc. During the bending operation, the outer surface of the material is in tension and the inside surface is in compression.. The strain in the bent materials increases with decreasing radius of curvature. The stretching of the bend causes the neutral axis of the section to move towards the inner surface. In most cases the distance of the neutral axis is 03 t to 0.5 t where 't' is the thickness of the part.



Stresses induced in the bending.



Bending terminology.

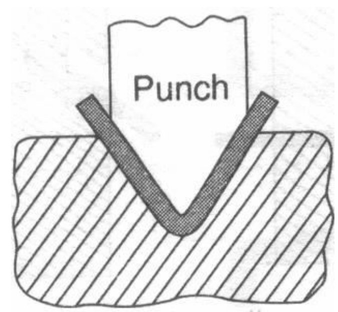
Types of Bending Operations:

i. Supported Bending: Any bending where a pad usually spring loaded, is included as support for the formed part. Ex: Finishing stage of U and V bending

ii. Unsupported Bending: Similar to the process of stretching, where a flat piece of metal, retained in die, stretches along with the application of tool pressure. Ex: Both U and V die bending are considered as unsupported bending processes at their beginning stages.

V-Die Bending:

During V-die bending, the punch slides down, coming first to a contact with the unsupported sheet metal. By progressing further down, it forces the material to follow along, until finally bottoming on the V-shape of the die.

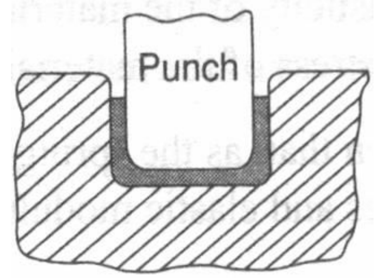


V-Die bending.

At the begin ing, the process is unsupported, but as the operational cycle nears its end, the bent up part becomes totally supported while retained within the space between the punch and die. Eventhough the most inaccurate of all bending processes, it is widely used because the tooling is simple and may be used for more than one flange and for more than one part.

U-Die Bending

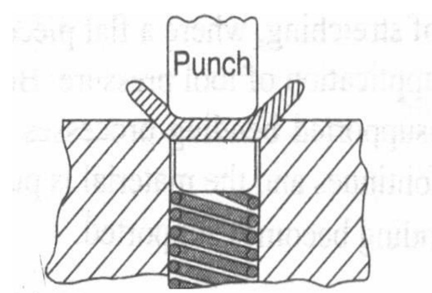
In this process, the process begins with a sheet metal positioned over a U-shaped opening or an insert of such a shape. As the punch progresses, it contact the sheet material first and pulls it along. On further progress, forcing it into a U-shaped opening.



U-Die bending.

U-Die Bending with a Spring Pad

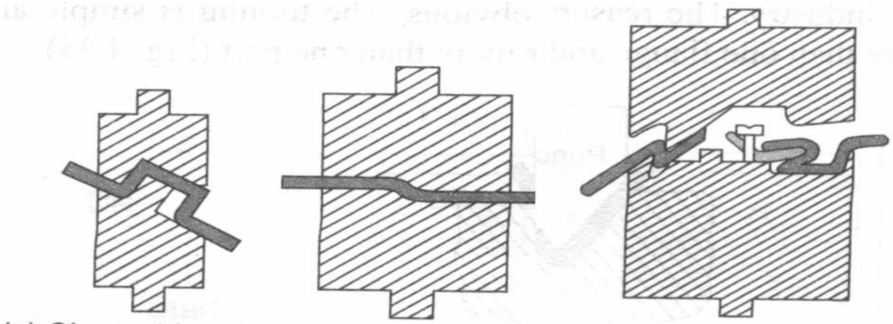
A spring loaded pressure pad is added to the U-Die bending. The blank, when pulled by the punch into the die opening, is firmly supported by the pressure pad already at the beginning of the forming operation. In this way, the punch cannot stretch the material , leaving the bottom of the part flat. When the punch metal pad sandwich finally bottoms, the formed part remains the same, with no bulging or distortion of any kind.



U-Die bending with spring pad.

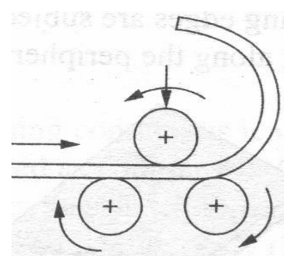
Press Brake Forming

Sheets that are 7m or longer, and their relatively narrow pieces, are usually bent in a press brake. This machine utilizes long dies in a mechanical or hydraulic press and is suitable for small production runs. The tooling is simple and is adaptable to a variety of shapes. Die materials for press brakes may range from hardwood to carbides.



(a) Channel forming (b) Joggle forming (c) Two stage lock seam

Roll Bending

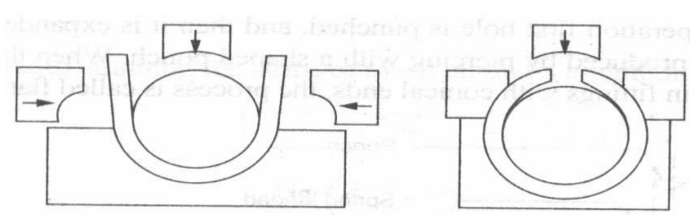


Roll bending.

A continuous form of three –point bending is roll bending, where plates, sheets and rolled shapes can be bent to a desired curvature on forming rolls. These machines usually have three rolls in the form of a pyramid with two lower rolls being driven and the position of the upper roll being adjustable by a frame on each end, one of the supports can often be swung clear to permit the removal of closed shapes from the rolls.

Bending in a Four Slide Machine

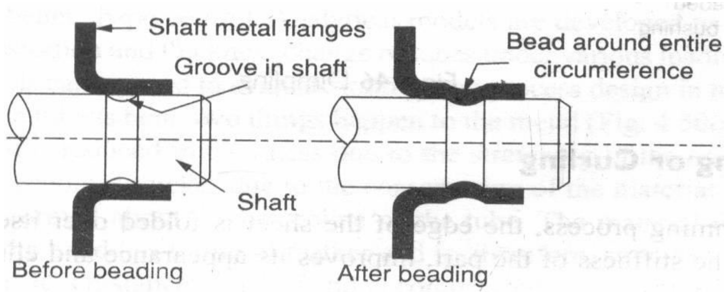
Bending of relatively short pieces can also be done on machines. These machines are available in a variety of designs an the lateral movements of the dies are controlled and synchronized with the vertical die movement to form the part to desired shapes.



Bending in a four-slide machine.

Beading

In beading, the periphery of the sheet metal is bent into the cavity of a die. The bead imparts stiffness to the part by increasing the movement of that section, It improves the appearance of the part and eliminates exposed sharp edges.

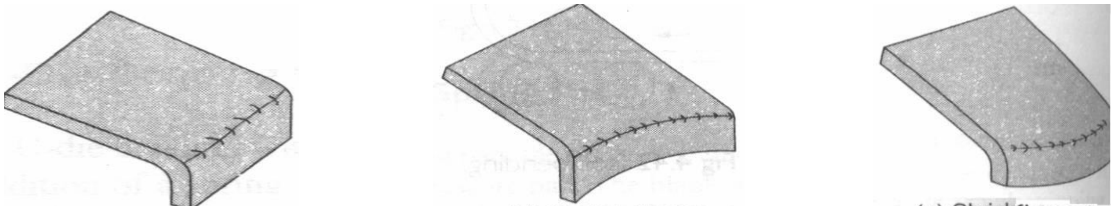


Flanging

It is the process of bending the edges of the sheet metal, usually to 90°. There are two types-

Shrink Flanging-Flange is subjected to compressive hoop stress which, if excessive, can cause the flange edges to wrinkle. The wrinkling tendency increases with the decrease in radius of curvature.

Stretch Flanging: The flanging edges are subjected to tensile stresses which, if excessive, can lead to cracking at the periphery.

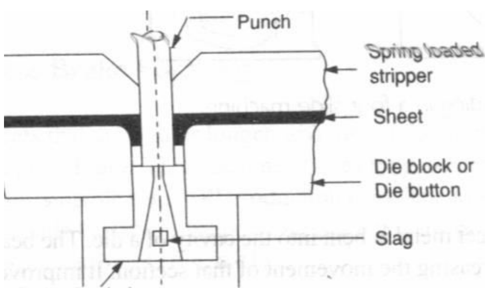


(a) Stright flange (b) Stretch flange (c) Shrinkflange

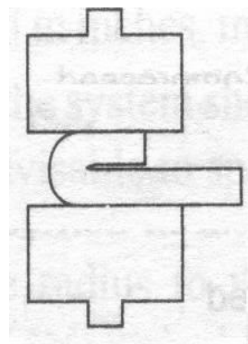
Flanging.

Dimpling

In this operation, first a hole is punched, and then it is expanded into a flange. Flanges may be produced by piercing with a shaped punch. When the bend angle is less than 90°, as in fittings with conical heads, the process is called flaring.



Dimpling.



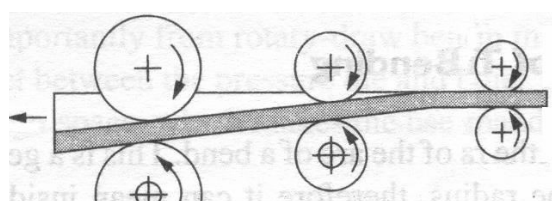
Hemming.

Hemming or Curling

In a hemming process the edge of the sheet is folded over itself. Hemming increases stiffness of the part, improves its appearance and eliminates sharp edges.

Roll Forming

This process is used for forming continuous lengths o sheet metal, and for larger production runs it is also called contour roll forming or cold roll forming. The metal strip is bent in stages by passing it through a series of rolls. The parts are then usually sheared and stacked continuously.



Roll forming.

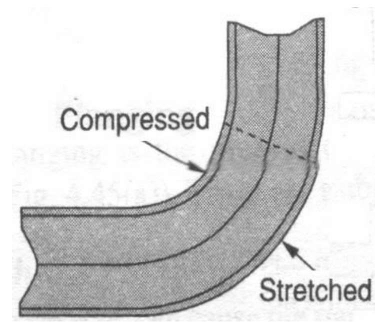
Twisting

It is the process of straining flat strips of metal around a longitudinal axis.

Twisiting.

Tube Bending

It is widely used process in aerospace, automotive and various other industries. Tube bending is generally a cold working process but depending on the material it may be performed as hot working. When tube is bent, two things happen to the metal. The outside wall is reduced in thickness due to stretching and the inside wall becomes thicker due to compressing. The material is actually formed about the centerline of the tube. The material that forms the outside of the bend has to travel further and is, therefore, stretched, the inside of the bend has less distance to travel and is compressed. An important aspect of making good bends is lubrication,. Lubrication comes in several different forms such as oil, grease, and paste. The kind of lubrication used depend on the material of the tune to be bent.



DRAWING

Drawing operation is the process of formation of flat pieces of material into hallow shape by means of a punch which causes the blank to flow into a die-cavity. The depth of the draw may be shallow, moderate or deep. If the depth of the formed cup is upto half of its diameter, the process is called 'shallow drawing'. If the depth of the formed cup exceeds the diameter, it is termed as 'Deep Drawing'. Parts of various geometries and sizes are made by drawing operation, two extreme examples being bottle caps and automobile panels.

As the drawing progresses, as the punch forces the blank into the die cavity, the blank diameter decreases and causes the blank to become thicker at its outer portions. This is due to the circumferential compressive stresses to which the material element in the outer portions is subjected. If the stress becomes excessive, the outer portions of the blank (flange) will have the tendency to buckle or wrinkle. To avoid this, pressure pads or blank holder is provided. The holding down pressure is obtained by means of springs, rubber pad, compressed air cylinder or the auxiliary ram on a double action press.

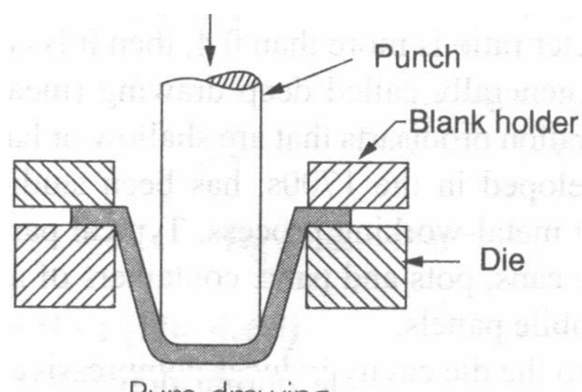
The portion of the blank between the die wall and the punch surface is subjected to nearly pure tension and tends to stretch and become thinner. The portion of the formed cup, which wraps around the punch radius is under tension in the presence of bending. This part becomes the thinnest portion of the cup. This action is termed as 'necking' and in the presence of unsatisfactory drawing operation, is usually the first place to fracture.

There are two types of deep drawing processes

i. Pure Drawing ii. Ironing

Pure Drawing

Pure drawing is the process done without reducing the thickness of the workpiece material. It is a cold forming process in which a flat blank of sheet metal is shaped by the action of a punch, forcing the metal into a die cavity.



Pure drawing.

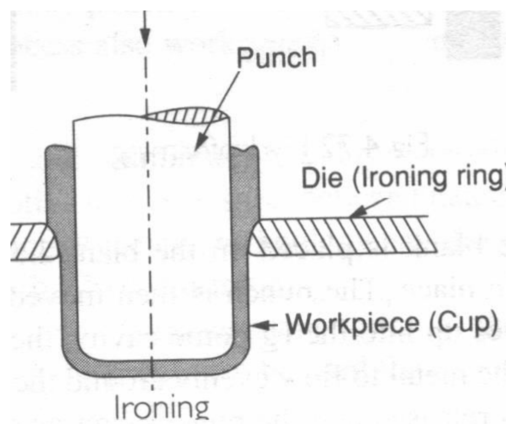
An important aspect of drawing is determining the extent of stretching and the extent of pure drawing is taking place. Either with a high blank holder force or with the use of draw beads, the blank can be prevented from flowing freely into the die cavity. The deformation of the sheet metal takes place mainly under the punch, and the sheet begins to stretch, eventually resulting in necking an tearing.

Significant independent variables in deep drawing are:

1. Properties of the sheet metal
2. The ratio of blank diameter to the punch diameter
3. The thickness of the sheet
4. The clearance between the punch and the die
5. The corner radii of the punch and the die
6. The blank holder force
7. Friction and lubrication at the punch, die and workpiece interfaces
8. The speed of the punch.

Ironing

Deep drawing with a reduction in thickness of the workpiece material is called ironing. If the thickness of the sheet as it enters of the die cavity is more than the clearance between the punch and die, the thickness will have to be reduced. This effect is known as ironing. Ironing produces a cup with constant wall thickness. The smaller the clearance, the greater the amount of ironing. The ironed cup will be longer than the cup produced with a larger clearance.



Edge Bending

In edge bending, a flat punch forces the stock against the vertical face of the die. The bend axis is parallel to the edge of the die and the stock is subjected to cantilever loading . To prevent the movement of the stock during bending, it is held down by a pressure pad before the punch contacts it.

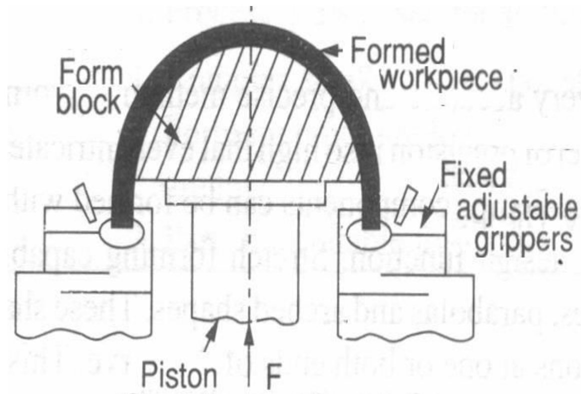
STRETCH FORMING

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 curtain wall components can be formed without loss of section properties or original design section.

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.

Like rubber-press forming, stretch forming uses only the male die or form block. Sheet metal is stretched to the yield point in tension, and then wrapped over and around the form block.

This process involves stretch forming a metal piece over a male stretch form block (STFB) using a pneumatic or 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.



Stretch draw forming with a form block.

The variety of shapes and cross-sections that can be stretch formed are almost unlimited. Window systems, skylights, store fronts, signs, flashings, curtain walls, walkway enclosures and hand railings can be accurately and precisely formed to the desired profiles.

Close and consistent tolerances, no surface marring, no distortion and no surface misalignment of complex profiles are important benefits in stretch forming.

Four methods of stretch forming are:

1. Stretch draw forming
2. Stretch wrapping
3. Compression forming
4. Radial draw forming

Features :

1. Large parts with shallow contours
2. Suitable for low-quantity production
3. High labour costs
4. High tooling and equipment costs

Advantages :

1. Compared to other forming methods spring-back is either greatly reduced or completely eliminated, since direct bending stresses are never introduced. All of the plastic deformation is tensile extension in the direction of pulling.
2. Low tooling cost as male dies or form blocks may be of wood, masonite, zinc alloys or cast iron.

SPECIAL FORMING PROCESSES

High Energy Rate Forming

These methods have been developed to form parts made of, new temperature-resistant, high strength metals, that require processing in short production runs and that, often, could not be formed by conventional methods. These methods can be grouped under two categories.

1. **High Energy Rate Forming Processes (HERF)**

These methods are so called because the energy (mainly chemical energy in explosive materials and electric/magnetic energy) needed for processing the material is released in a very short time, usually in milli-seconds or micro-seconds. The important processes in this category are: Explosive Forming (using chemical energy in explosive materials), Electric spark forming or Electro-hydraulic forming, and Electro-magnetic forming (using electric energy).

2. **High Velocity Forming Processes (HVF)**

In these processes, the metal is deformed by using high velocities (movement of ram/die). Since kinetic energy is proportional to velocity square, high energy (mechanical) can be delivered to the metal in these methods with relatively small weights (of ram and die). This reduces the cost and size of the machine. Also, due to very high accelerations, high velocities can be obtained by using short strokes of the ram, which makes it possible to increase production rate. In these methods, the energy stored in air/gas (at high pressure) or the stored chemical energy of a hydrocarbon (petrol or diesel) is used to move the ram/die.

The difference between HERF and HVF is that whereas in the former, the energy store in some medium is used directly to deform the metal, in HVF, it is converted into mechanical energy which imparts high velocities to ram/die.

A common feature of the above methods is a high rate of strain (conventional forming and forging takes place at relatively low velocities and strain rates). With increased rate of forming, the formability of most metals is improved. Also, spring-back is minimal in these methods. Although these methods are mostly applied to forming of sheet and plate products , often of very large size, these can be applied to certain-die forgings.

EXPLOSIVE FORMING

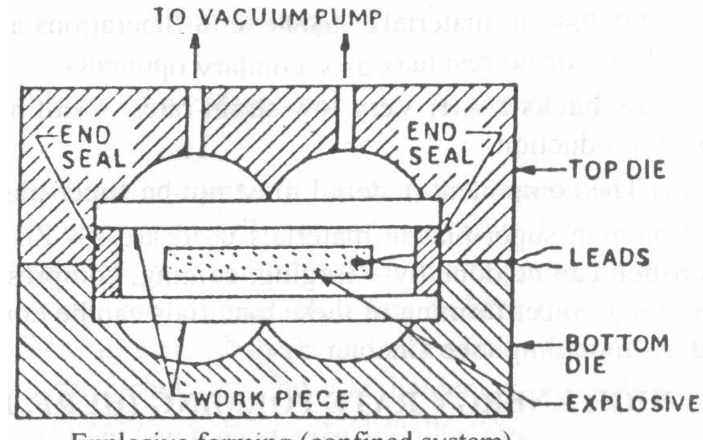
In explosive forming, the chemical energy stored in the explosives is used to process the material. A charge, detonated either above or within a pressure transmitting medium generates very high pressures, which can be used to form parts of large size. The pressure (shock waves) developed will depend upon the compressibility of the energy transmitting medium. Water, being less compressible than air is a better medium. There are two basic systems of explosive forming.

a) Confined System **b) Unconfined System**

Confined System:

This system is basically used for small and tubular parts for flaring and bulging operations. This system is not used much due to the following reasons

1. Being closed-die operation, there is a greater hazard of die failure due to high pressure generated
2. Die erosion is a big problem



Explosive forming (confined system).

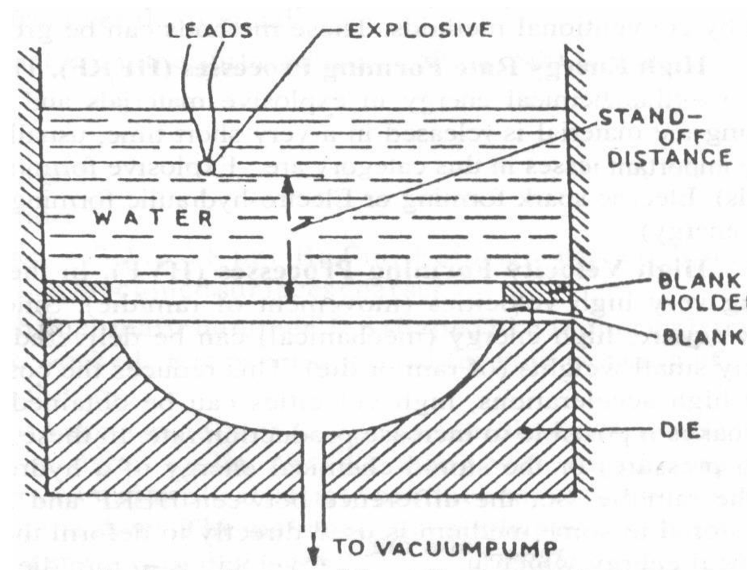
In this system the die, in two or more pieces, is used which completely encloses the work piece. When the explosive is detonated, a shock wave is produced in the energy transmitting medium, which forces the workpiece into the die. Vacuum should be created in between the die and the workpiece, otherwise, the trapped air will be subjected to virtually adiabatic compression, resulting in very high temperatures which can burn or melt the workpiece of the die. The trapped air will also prevent the complete forming of the part.

Unconfined System:

This system is used for forming large parts from very thin sheet metal upto large ship plates about 25mm thick. This method has been used for many years in ship building. The work piece or blank is clamped to the die and the entire die-work assembly is lowered into a swimming pool. An explosive is detonated above or within the water. The shock waves are produced in the body of water (energy transmitting medium) which in turn forces the workpiece into the die. Vacuum should be drawn in between the workpiece and the die.

The important process variables are:

- Type and amount of explosive
- Distance between explosive and workpiece
- Type of energy transmitting medium
- Work piece



Explosive Forming (Unconfined system)

Use of water as energy transmitting medium has the following advantages:

1. Since air is very much more compressible than water, the shock pressure produced are very much lower
2. With water, the noise level of explosion is reduced
3. Possibility of damage to the workpiece from particles of explosives and detonator is greatly reduced.

Basically two types of explosives are used:

i. Low pressure explosives or firing explosives, such as smokeless powder and black powder. With low pressure explosives, known as cartridge system, the expanding gas is confined and pressure may be build upto 700MPa.
ii. High pressure explosives or detonating explosives. The most widely used detonating materials are dynamite, amatol, TNT (Tri-nitrotoluene), RDX etc.

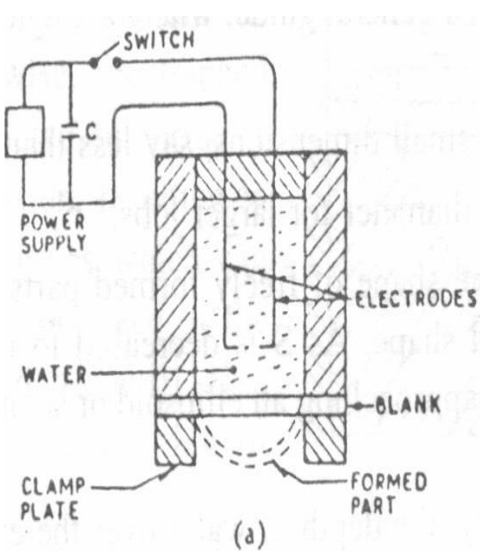
ELECTRO HYDRAULIC FORMING

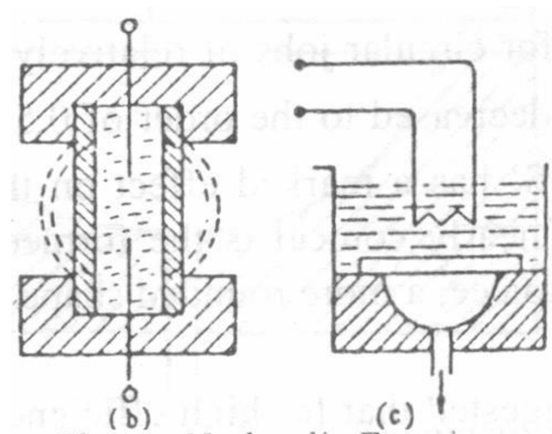
The effect produced by explosive forming can also be obtained by discharging stored electrical energy in a bank of condensers, across electrodes submerged in an electrolyte (usually water). This is the principle of operation of electro-hydraulic forming, also known as electro-spark forming.

The stored electrical energy can be discharged either through a wire or across a gap. A potential difference of about 50KV can jump a gap of about 25mm. When this discharge takes place under water, the arc (spark) produced converts water into steam. This generates high pressures which are utilized for forming the work piece. Again, if a potential difference of 30KV is discharged through a wire of 1 mm diameter, in water, the centre of the wire will instantaneously be raised to above 5100°C. The wire melts and vaporizes resulting in very high pressures and formation of water bubbles. The flow of current is temporarily disrupted by the formation of water vapour. As the water bubbles expand, vapour pressure drops and an arc is stuck between the electrodes. Due to this, high pressure shock waves are generated, which are used to form a workpiece. In types fig a and fig b, the parts are formed freely in air

Applications:

i. Very versatile process that can be used for the forming of tubular an dished shapes
ii. Since only female die is needed, tooling costs are substantially lower
iii. Production rate is higher compared to explosive forming
iv. Only relatively small components are made.

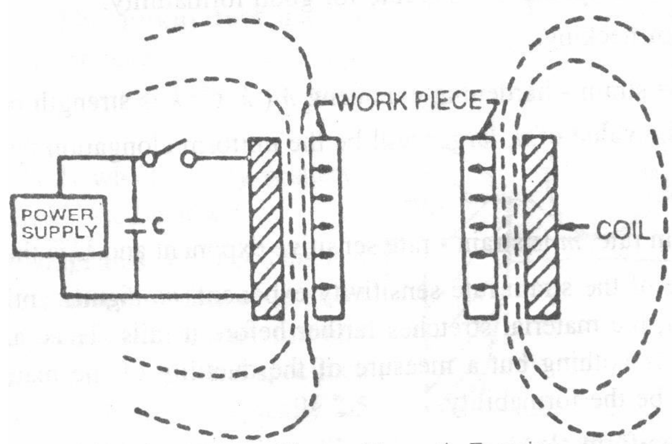




Electro-Hydraulic Forming.

ELECTRO MAGNETIC FORMING

Also called Magnetic pulse forming, is based on the fundamental principles of electrical technology Viz., when a current flows in a conductor, a magnetic field is set up around it. If the current and hence the magnetic field changes, a current is induced in any other conductor placed in the magnetic field. The direction of this induced current is such that the induced magnetic field opposes the magnetic field producing it. The two conductors get repelled due to the interaction of the two magnetic fields. In electo-magnetic forming, one conductor is a coil, through which current is suddenly discharged, giving rise to a rapidly changing magnetic field. The work piece is the second conductor, in which the eddy current is set up. The repelling forces between the coil and the work piece is high (to the order of $350 N/mm^2$ for several micro seconds), and since the coil is held rigidly in place, the work piece is repelled and forced against a die.



Electro-Magnetic Forming.

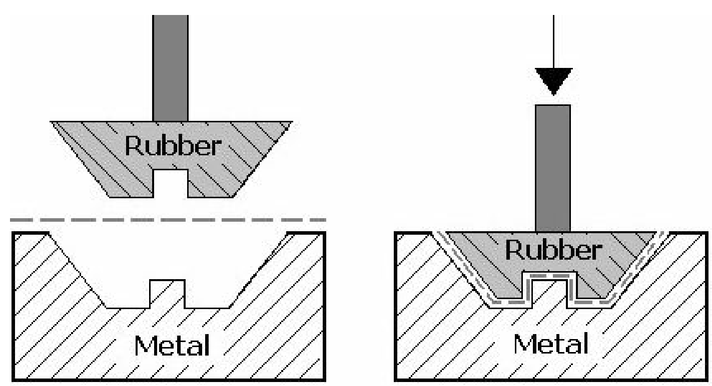
The energy charge is a bank of capacitors, charged to a predetermined voltage. The electric energy is discharged through a forming coil. By suitably designing the coil, the process is used for compression, expansion or for forming contours from sheet metal tubes.

Electromagnetic forming has the following characteristics

1. The process is simple, clean and safe to operate
2. Operating costs are low
3. A high cycle rate can be attained and the process is suitable for automation
4. Deep drawing is not possible, because of very short duration of pressure pulse
5. Asymmetrical parts are not suitable for this method
6. Irregularities such as slots, holes and slits present problems , because the magnetic field is disrupted.

RUBBER PAD FORMING

Rubber Pad forming or Rubber press forming is a sheet metal forming (bending and stretching or drawing) operation in which either the punch or the die is a piece of constrained elastomer (rubber or polyurethane).



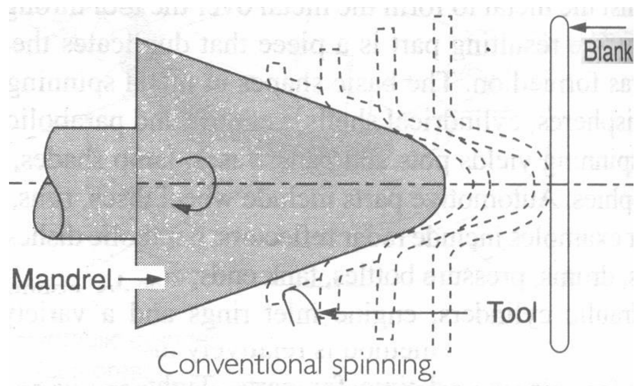
The basic principle of the process is that if a block or rubber or polyutherane is placed in a cylinder and pressure is brought to bear upon it by applying a force by a ram of a press, any such force must develop a resultant reaction on every surface with which the elastomer comes in contact. This resultant reaction force is uses for forming sheet metal to the required shape for forming sheet metal to the required shape using form blocks or punches or dies.

The process is becoming increasingly popular for short run production because of it economy since it eliminates the need for the more expensive mating steel dies. The process has the following advantages

1. Tools have fever components and are made of cheap an easy to machine materials
2. One rubber pad takes the place of many different die shapes
3. The forming radius decreases progressively during forming unlike fixed conventional dies.
4. There is almost no thinning of work piece material.

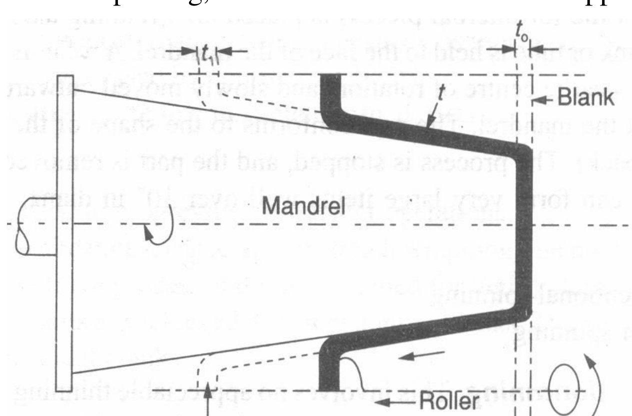
METAL SPINNING

Spinning is one of the oldest methods of sheet metal forming. Parts that have circular cross section can be made by spinning from sheet metal. The method involves the forming of a work piece over a rotating form block or chuck held in a special lathe. A smooth, hardened, rotating or stationary tool is held by the operator and is pressed against the blank to progressively bend the work-piece to conform to the chuck or mandrel. The mode of deformation of the metal during spinning is bending and stretching, making the process most suitable for shaping of hollow parts from ductile metals and alloys. The thickness of the spun part is nearly the same as the thickness of the undeformed blank. The thickness of the blank is around 6mm for soft non-ferrous metals and upto 5mm for low carbon steels.



Conventional spinning.

Spinning speeds vary from 1.5m/s for small parts to 25m/sec for large-diameter parts. Spinning has been used to produce parts more than 3.6m in diameter. Before spinning, a suitable lubricant should be applied to the surface of the metal. Soap, beeswax, white lead and linseed oil are commonly used.



Power spinning.

Applications: Funnels, Reflectors, Kitchenware, Bells, light fixtures, kettles, radar dishes, rocket motor cases and musical instruments.

Advantages

1. Low equipment cost
2. Low tool cost
3. Some complex parts like kettles, pitchers can be made economically

Drawbacks

1. Depends to large extent on skill of operator
2. Finished products not uniform and close tolerances cannot be obtained.

Comparison of Spinning and Drawing

1. Due to low tooling and equipment cost, spinning is normally used for low volume production
2. Drawing is used for mass production
3. Labor costs are higher for manual spinning and production rates are lower.
4. For complex shapes and big sizes of components, spinning becomes more competitive.

PEEN FORMING

Shot Peening

Shot peening is mainly employed to increase the fatigue strength of work pieces subjected to impact and/or fatigue loads. The other functions of shot peening are to prevent the cracking of work pieces in corrosive media and to improve the oil retaining properties of the processed surfaces. The process is based on plastic deformation o the surface layer and consist of subjecting the surface to impacts of high jet of shots. Many overlapping indentations are made, causing localized compressive deformation of the surface. Since bulk of the material is not affected, compressed residual stresses greatly offset any tendency to fatigue failure. The surface also gets slightly hardened and strengthened by shot peening.

Peen forming is a sheet metal working process utilizing the method of shot peening. It is a useful process of producing curvatures on thin metal sheets by striking shots on one side of the sheet. The main product application is the forming of smooth and complex curvatures on air craft wing skins. When the sheet metal is subjected to shot peening, the surface layer expands, while the bottom layer remains rigid.

SUPER PLASTIC FORMING

‘Superplasticity’ refers to large neck –free extensions before fracture, when deforming certain metals and alloys. Extreme examples of superplastic materials are Bubble gums and molten glass which can be drawn from melt into fibres without the fibres necking down. Common super plastic materials are: -Zn-22Al and Ti-6Al-4V.

Advantages

1. High ductility and low flow stress which leads to lower tooling cost and forging of difficult to work super alloys.
2. Forming of complex shapes with fine details and close tolerances
3. Savings in materials as secondary operations are eliminated
4. Little or no residual stresses in components

Draw Backs

1. Very low strain-rates, resulting in large forming times. So, best suited for batch production.
2. The component material must not be super plastic at service temperature.

ME 2201 MANUFACTURING TECHNOLOGY – I
UNIT V MANUFACTURING OF PLASTIC COMPONENTS

Types of plastics - Characteristics of the forming and shaping processes – Moulding of Thermoplastics – Working principles and typical applications of - Injection moulding – Plunger and screw machines – Compression moulding, Transfer moulding - Typical industrial applications – Introduction to Blow moulding – Rotational moulding – Film blowing – Extrusion - Thermoforming - Bonding of Thermoplastics.

PLASTICS

Plastic is term applied to compositions consisting of a mixture of high molecular compounds (synthetic polymers) and fillers, plasticizers, stains and pigments, lubricating and other substances. Some of the plastics can contain nothing but resin (for instance, polyethylene, polystyrene).

Types of Plastics:

Plastics are classified on the broad basis of whether heat causes them to set (Thermosetting) or heat causes them to soften and melt (Thermoplastics).

Thermosetting Plastics:

These plastics undergo a number of chemical changes on heating and cure to infusible and practically insoluble articles. The chemical change is not reversible. Thermosetting plastics do not soften on reheating and cannot be reworked. They rather become hard to completion of any left-over polymerization reaction. Eventually, at high temperatures, the useful properties of the plastics get destroyed. This is called degradation. The commonest thermosetting plastics are: alkyds, expoxides, melamines, polyesters, phenolics and ureas.

Thermoplastic Plastics:

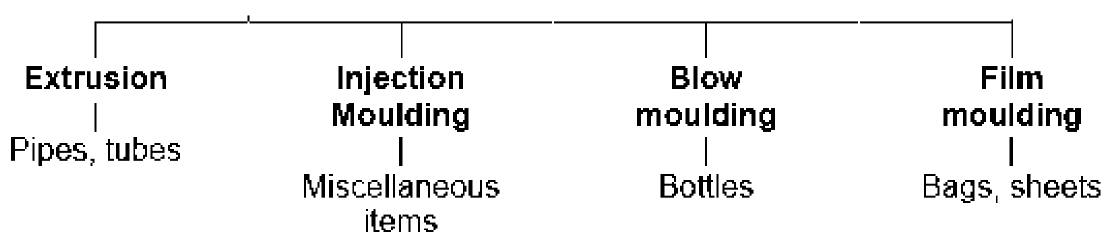
These plastics soften under heat, harden on cooling, and can be re-softened under heat. Thus, they retain their fusibility, solubility and capability of being repeatedly shaped. The mechanical properties of these plastics are rather sensitive to temperature and to sunlight and exposure to temperature may cause thermal degradation. Common thermoplastic plastics are : acrylics, ploy tetra fluoro ethylene (PTPE), polyvinyl chlorides (PVC), nylons, polyethylene, polypropylene etc.

Properties of Plastics:

1. Their comparatively low density (1 to 2 g/cm^2), substantial mechanical strength, higher strength- to –weight ratio, and high anti-friction properties have enabled plastics to be efficiently used as substitute for metals, for example, non-ferrous metals and alloys- bronze, lead, tin, babbit etc, for making bearing.
2. Because of corrosion resistance and silent operation, plastics can sometimes replace ferrous metals.
3. Easily manufacturable as they have low melting point.
4. Products have good surface finish and good damping capacity.
5. High heat and electric insulation capabilities permit the to be applied in electrical engineering industries.
6. Good chemical stability, water resistance, gas and steam –proof properties enable plastics to be used as engineering materials in automobile, tractor and ship building and other industries.

Disadvantages:

1. Comparatively higher cost of materials
2. Inability of most plastics to withstand even moderately high temperatures



PROCESSING OF THERMOPLASTIC PLASTICS

The common forms of raw materials for processing plastics into products are :- Pellets, Powders, Sheet, Plate, rod and tubing. Liquid plastics are used especially in the fabrication of reinforced-plastic parts.

Thermoplastics can be processed to their final shape by moulding and extrusion processes. However, extruding is often used as an intermediate process to be followed by other processes, for example vacuum forming or machining.

INJECTION MOLDING

An important industrial method of producing articles of the thermoplastics is injection moulding. The process is essentially as follows :

Ram type injection moulding machine

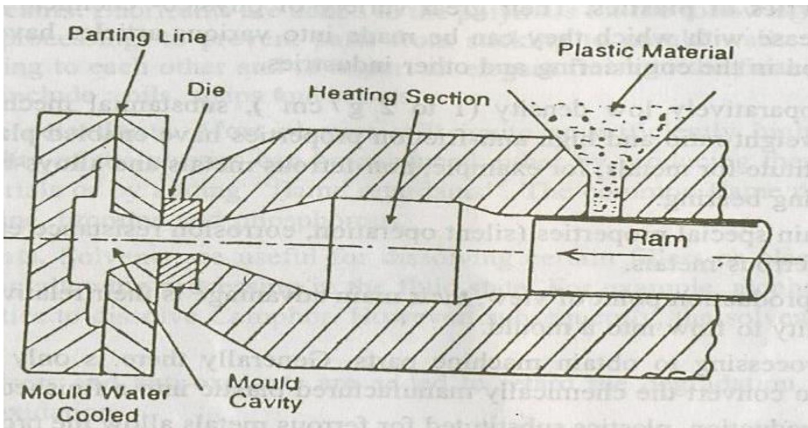


Fig. Injection Moulding Process

The molding material is loaded into a hopper from which it is transferred to a heating section by a feeding device, where the temperature is raised to 150 -370ºC and pressure is built up. The material melts and is forced by the injection ram at high pressure (35-140Mpa) through a nozzle and sprue into a closed mold which forms the part.

The mold is in atleast two parts to enable easy ejection. The pressure on the plunger is maintained during the period when the material in the mold cools and contracts. If no pressure is applied during this period, contraction during cooling would cause depression in the parts.

Reciprocating Screw injection moulding machine

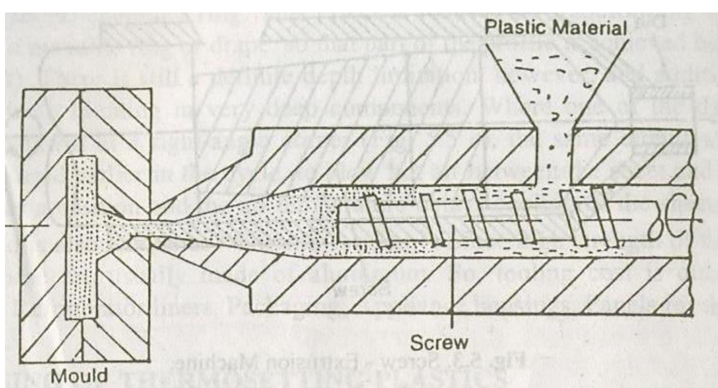


Fig. Screw injection moulding machine

The improvement to the ram type injection molding machine lies in the separation of the plasticizing and filling actions. The single-screw pre-plasticizer is the most common design of injection molding machines.

Plastic materials are fed from overhead hopper through the heated cylinder via the screw plunger as material becomes fluid. The injection nozzle is blocked by the previous stroke, and this causes the screw to pump itself backward through the cylinder. During this step, material is being plasticized and accumulated for the next shot. The rotation of the screw provides the plasticizing action by shearing and frictional effects and the axial motion of the screw provides the filling action. The advantage of the reciprocating screw over the straight plunger device and that the rotary shear effect of the screw melts and mixes the materials homogeneity.

Advantages:

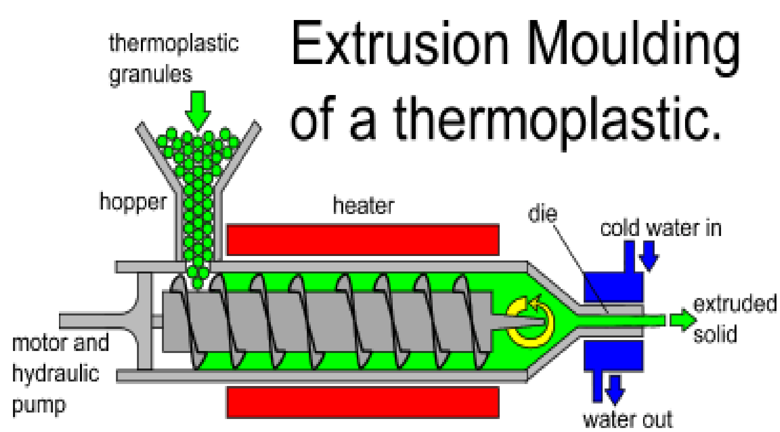
1. High production capacity
2. Lower unit cost
3. Suitable for making parts of intricate shapes, thin walled parts, and components with metal inserts, etc.
4. Complex parts can be produced with close tolerances
5. Practically no finishing requirements
6. Lower cleaning cost since very little excess material in the form of flash or gate aheres.

Limitations:

1. Equipment of cylinder and die must be non-corrosive
2. Expensive tooling
3. Reliable temperature controls are necessary

EXTRUSION PROCESS

The extrusion process produces material in an intermediate form for subsequent reprocessing to its final component form. The process is the same as for metals, that is, the expulsion of material through a die of the required cross-section. The cylinder of the machine (container) is filled with prepared plastic and extruded through a die under the pressure of the ram. The screw and ram type extruding machines are available.



There are two types of extruders; the melt extruder and the plasticizing extruder.

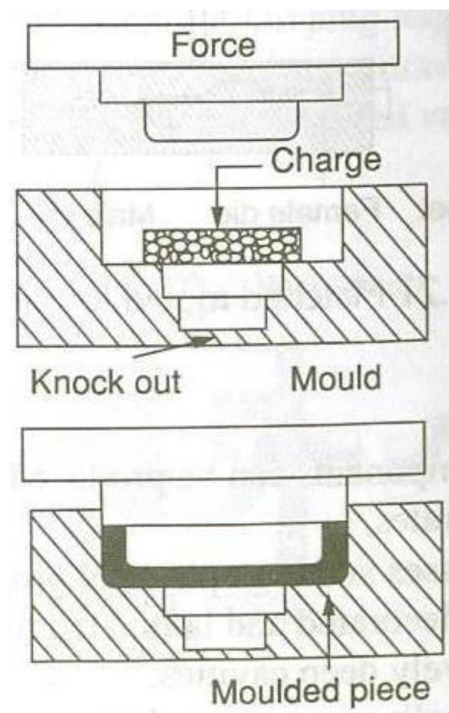
In the melt extruder, the materials is delivered to the extruder already melted and thus the function of the extruder is merely to push the material to the die and through the orifice.
In the plasticizing extruder, the material is in the form of granules or particles and so the extrude has to be compressed and worked until it melts before delivering it under pressure to the orifice.

The screw type extruding machine consists of a water cooled screw having a special thread from to suit the material being extruded; a barrel in which the screw rotates (including a form of heating in the case of plasticizing extruder); and an extrusion die. The material is fed through a hopper through a port in the cylinder where the rotation of the screw imparts both axial and rotary motion to the particles. The restricting effect of the die at the far end builds up a pressure in the particular mass which s then worked by shearing and heated by frictional effects until it is in a plastic state and can be extruded. Complex shapes wit constant cross-section can be extruded with relatively inexpensive tooling. The extruded product can be coiled or cut into desired lengths. Typical products are:- Rods, Pipes, Channels, Window Frames, Sheets, Architectural components etc.

PROCESSING OF THERMOSETTING PLASTICS

Compression molding and Transfer molding are the most common methods of processing thermosetting plastics. Although suitable for thermoplastics also, the main application of these methods is to thermosets.

COMPRESSION MOLDING



Compression molding is the equivalent of closed-die-forging. In this process, a premeasured quantity of plastics in the form of particles or briquettes, is placed in a heated mold and compressed at a suitable pressure and temperature. Hydraulic pressure is usually employed tp provide the pressure (which may range from 20 to 30 MPa or even higher upto 80MPa) for compressing plastic compound. Other equipment, such as friction and screw presses can also be used.

The material is brought to the molten state and is held in the mold until the curing stage is over when polymerization is complete. The process is slow with phenol and urea resins, but some of the newer resins have faster curing times.
When the plastic is completely trapped between the male and female die, it is called as ‘Positive Mold’. Closer tolerances can be held if a small flash is allowed to extrude, usually along the male die perimeter in “Semi positive Molds. Most plastic is lost in ‘Flash Molds” similar to used in compression die forging.

TRANSFER MOLDING

It is a modification of compression molding in which the material is first placed in a separate chamber (transfer pot), from which it is pushed through an orifice (sprue) into the mold cavity by the action of a punch as the mold closes. The material to be molded is often pre-heated by radio-frequency methods and, where it is desired to improve toughness and strength, reinforcing fillers may be used.

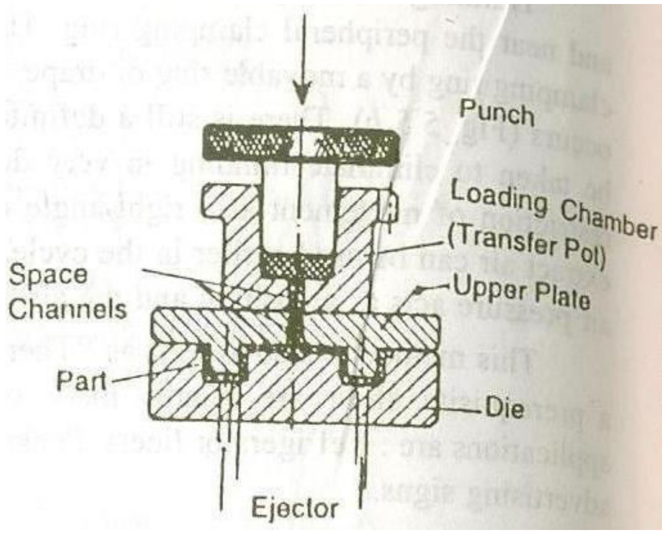


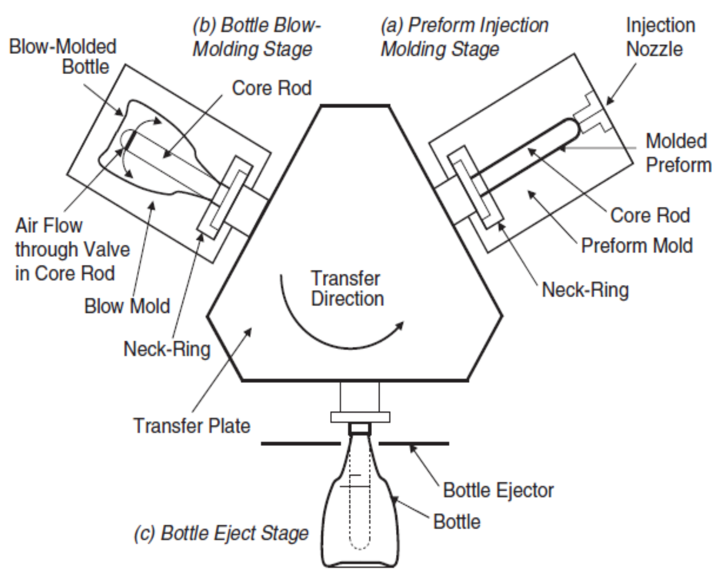
Fig. Injection Moulding

Advantages:

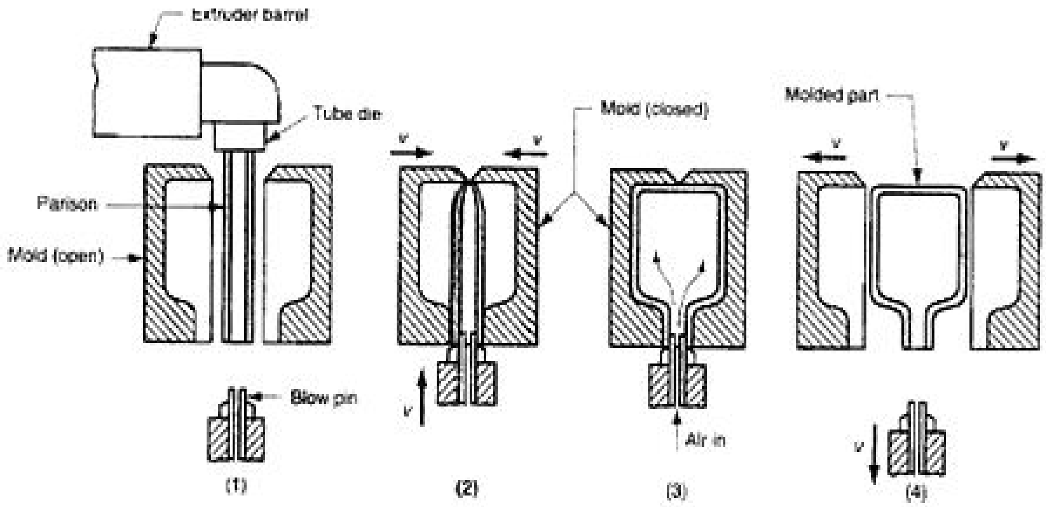
1. There is little pressure inside the mold cavity until it is completely filled, at which stage the full liquid pressure is transmitted.
2. The plastic acquires uniform temperature and properties in the transfer pot prior to transfer. The plastic is further heated by shearing through the orifice, viscosity is reduced, and the plastic fills the intricate mold cavities.
3. It scores over normal compression molding in that cold presses can be used, since, heating of the plastic is affected not by press itself, but by a simple heating jacket round the transfer chamber.

BLOW MOLDING

In this process, a hot extrude tube of plastic, called a parison, is placed between two part open mold. The two halves of the mold move towards each other so that the mold closes over the tube. The tube gets pinched off and welded at the bottom of the closing molds. The tube is then expended by internal pressure, usually by hot air, which forces the tube against the walls of the mold, the component is cooled and the old opens to release the component.

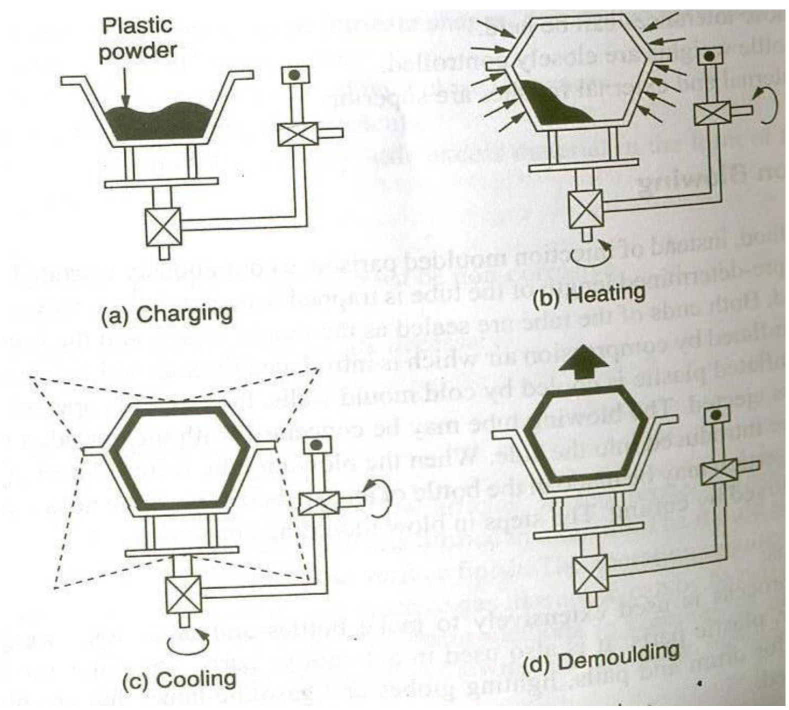


Application: Plastic beverage bottles and hollow containers



ROTATIONAL MOLDING

Also called roto-molding which is used to make relatively large thin-walled parts. In rotational molding, the product is formed inside a closed mold that is rotated about two mutually perpendicular axes, major and minor axis, as heat is applied. The difference between the other molding processes with rotational molding is that only heat is required for the mold where as in other processes, heat and pressure are required to plasticize the materials.



A powdered plastic is poured into the mold and its halves are then clamped shut. The loaded mold rotates the powder melts and is distributed on mold cavity walls by gravitational force and not by centrifugal force. The mold is then cooled and when the plastic has hardened sufficiently, the mold is opened and the article is removed. Thin cast aluminium molds are normally used. The mold halves should be tight enough to prevent any moisture entering into the mold and avoid warping. The rotational speed of the molds is 18 rpm and the temperature ranges from 260°C to 370°C.

Advantages:

1. Low initial investment
2. Varieties of shapes can be molded in the same equipment.
3. Low tooling cost
4. Excellent surface finish
5. Large hallow shapes with open end r enclosed shapes cane be produced

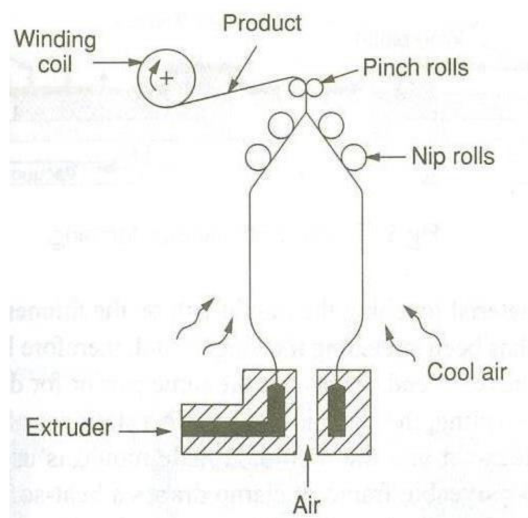
Limitations:

1. Low production rates
2. Relatively simple shapes can only be produced\

Applications:
Children's chairs, Toys, Drums for food storage, phonograph cases etc.

FILM BLOWING

Plastic film can be manufactured in a variety of ways including extrusion, calendering, blowing and casting. 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 into a larger diameter cylinder. The blown cylinder is air cooled as it rises vertically, then it is flattened by driven rolls before it reaches the winder. This process is used to produce trash bags and packaging materials.

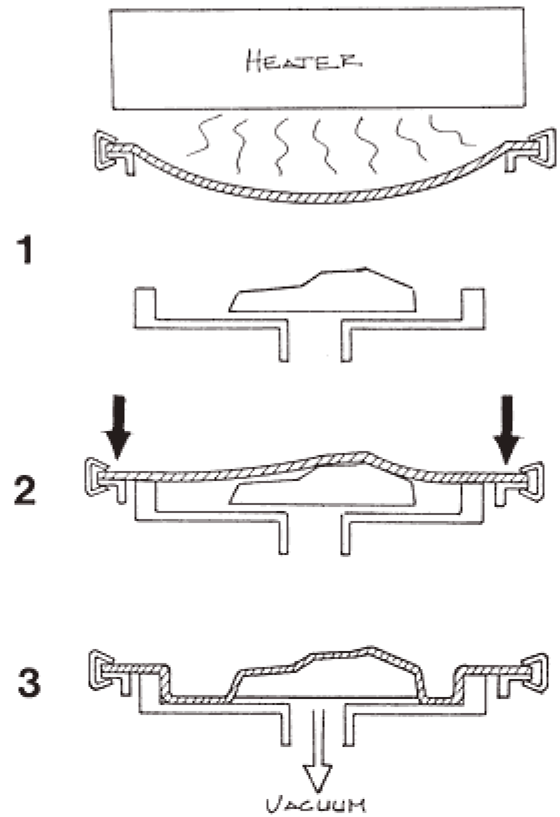


THERMOFORMING

Thermoforming is the shaping of hot sheets or strips of thermoplastic material into a 3D object either by mechanical or pneumatic methods. The sheets of plastic used in the thermoforming process are produced either by extrusion, calendering or pressing. Thickness of the sheets that are processed ranges from 0.125mm to 3.2mm or even greater. The sheet or film is heated between infra red natural gas and other heaters to its forming temperatures. Then, it is stretched over or into temperature-controlled, single surface mould. Cast or machined aluminium is the most common mold material, although epoxy and wood tooling are sometimes used for low volume production. The sheet is held against the mold surface until it is cooled. The formed part is then trimmed from the sheet. The sheet tri is usually re-ground, mixed with virgin plastic and re-processed into usable sheet.

Thermoforming Techniques: Vacuum Forming, Pressure Forming, Twin-Sheet Forming, Drape Forming, Free Blowing and Simple Sheet Bending.

The standard vacuum forming as shown is the simplest thermoforming method. A piece of plastic sheet is clamped into a frame. The plastic is heated, usually with electric heaters, until it begins to sag. Vacuum, air or mechanical pressure is then applied through small holes in the mold and the plastic is rapidly pulled tightly against the mold 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 he mould will be thinnest.



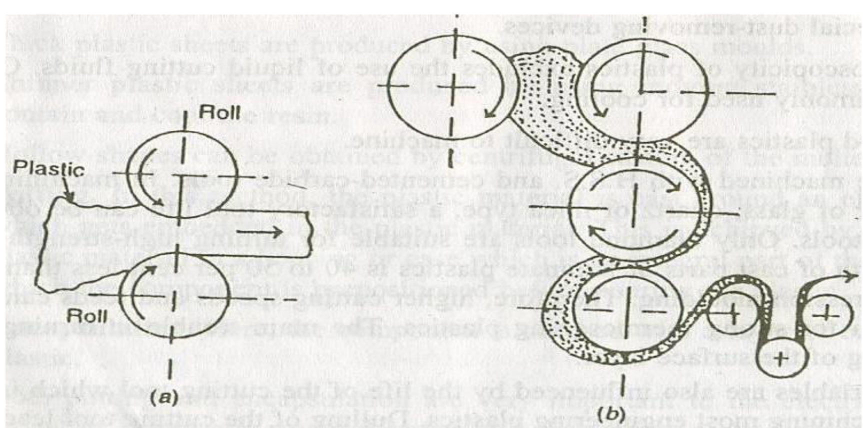
Advantages:

1. Varied size of components can be produced
2. High production rates
3. Low internal stresses and high physical properties
4. Parts can be pre-decorated and laminated to get different finishes
5. Machinery and tooling are relatively inexpensive
6. Material thicknesses and color changes are easy to make.

Application: Drinking Cup to Ship Hull, Refrigerator inner panels, lighting fixture, helmets etc.

Calendering

Calendering or rolling is used for thin film production or for coating plastic over a material. The calendar consists of several highly polished and very rapidly rotating rolls. The rolls may be chilled or heated as required. Calendering is used, in particular, when film



thickness specifications are tight. Films with embossed patterns may be obtained using special calendars. A widely used application for calendering is to coat fabrics and paper with plastic material. Plastic materials are evenly spread in the roller, then transferred to the fabric or paper stock. Pressure is exerted between the fabrics or paper feed roll and the plastic feed rolls.

The resulting material is widely used in upholstery, tablecloths, draperies, printing press blankets, flooring and numerous other products.

BONDING OF THERMOPLASTICS

Methods of Bonding

There are many methods available for bonding of thermoplastic, ranging from the simple application of heat to the edges being joined to the more exotic methods of induction and ultrasonic welding. The bonding methods can be grouped into two broad categories.

Chemical Bonding

Chemical bonding for assembly of plastic parts is an effective method of making permanent connections. This method produces aesthetically clean looking joints with low weight and sufficiently strong connections. This is a very effective joining method for heat sensitive plastics which would normally deform if welded. Chemical bonding involves fixtures, substances and safety equipments. It does not create stresses and is suited to leak-tight applications. Its main limitation is that adhesives and solvents are flammable and preparation and cure times are long. Testing should also make sure that the chemicals used in bonding do not deteriorate the plastics. This effect is generally slow, often requiring long clamp times and sometimes special ovens or curing conditions. In addition, the chemicals used may be toxic, so worker protection, ventilation and solvent recovery can be issues for concern.

Thermal welding

Thermal welding involves melting the bond line between two parts to form a weld. This method is a fast, economical and safe way to weld compatible plastics having similar melt temperatures. Methods include ultrasonic welding, hot plate, spin, induction and radio frequency energy. Special equipments are required and materials must be compatible and have similar melting temperatures.

Chemical Bonding
Solvent Bonding

Solvent bonding or solvent welding is a process in which the surfaces of parts to be joined are treated with a solvent. When this swells and softens the surfaces, bonding between these surfaces are obtained by applying pressure to the joint with the evaporation of the solvent. Adhesives are not used in this process for bonding. The process is commonly used with amorphous thermoplastics. This method is limited to compatible materials that dissolve in the same solvent or solvents. The chemical resistance of many plastics, especially crystalline resins, limits this method.

A slurry made of solvent up to 25 % of the base resin can be used to produce a smooth filled joint when the mating parts do not fit perfectly. Adding base resin makes the solvent easier to use. Safety equipment and proper handling of solvent is required. The procedure for making a solvent bond is given below:

1. The mating surfaces must be clean and grease free before bonding.
2. Parts having a single surface are simply pressed against a sponge or felt pad that has been impregnated with solvent.
3. It may be necessary to allow a few seconds to ensure sufficient swelling.
4. The parts are then clamped together with a moderate pressure.
5. The parts are removed from the clamping equipment and must not be used for a period of 24-48 hour to ensure that full strength has been achieved.
6. Heat can be used to accelerate the overall rate of evaporation and to reduce the cycle time.

Advantages :

1. Homogeneous distribution of mechanical loads.
2. Good aesthetics.
3. Economic assembly.
4. Low weight, no heavy screws, bolts and nuts.
5. Heat-sensitive constructions or materials.
6. Good sealing and insulating properties.

Limitations :

1. Entrapment of solvent in the joint.
2. Stress-cracking or crazing.
3. Reproducibility/process control.
4. High solvent evaporation time due to its entrapment in the polymer matrix.
5. No disassembly possible.
6. Assembly hazards such as fire or toxicity.

Adhesive Bonding

In adhesive bonding, a third substance bonds a plastic to another or to metal, rubber, ceramic, glass, wood, etc. Adhesives frequently used with thermoplastics include epoxy, acrylic, polyurethane, phenolic, rubber, polyester and vinyl. Cyano-acrylate adhesives are popular because they work rapidly. The main criteria for achieving good adhesive bonding are surface wetting and curing of the adhesive.

Advantages:

1. Application on various substrates like thermoplastics, thermosets, elastomers and metals.
2. Homogeneous distribution of mechanical loads.
3. Differences in thermal expansion of components can be compensated by using a thick adhesive layer.
4. Good aesthetics/no special requirements to hide the bond.
5. Economic assembly.
6. Low-weight, no heavy screws, bolts and nuts.
7. Heat sensitive constructions or materials, which welding would distort, can be joined.
8. No thermal stresses introduced.
9. Good sealing and insulating properties.

Limitations:

1. Joint may not last in the long term.
2. Stress cracking or crazing of the plastic may take place.
3. Dissimilar materials can only be joined if both are compatible with the adhesive.
4. Reproducibility/process control.
5. Curing time can be highly dependent on the adhesive.
6. No disassembly possible.
7. Assembly hazards such as fire or toxicity.

THERMAL WELDING

Welding is an effective method of permanently joining plastic components. Welding works on the principle of a phase change from solid to liquid (melt or in solution) at the interfaces to be joined and is followed by a solidification phase. In several welding processes, some material will be squeezed out of the weld by the pressure on the mating surfaces. The velocity of the out flowing material has a parabolic profile over the width and increases towards the edges of the part as a consequence of accumulating melt flowing from the centre to the edges.

In thermal welding, the flow direction of the polymer melt is perpendicular to the direction of injection moulding. After the polymer solidifies, this unfavorable orientation remains in the weld zone, which is the reason for the reduced strength of the weld compared to the bulk strength of the material.