II Year B.Tech. ME – II Semester

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(23HPC0307) MANUFACTURING PROCESSES

Course Objective: The objectives of the course are to

- Know the working principle of different metal casting processes and gating system.
- Classify the welding processes, working of different types of welding processes and welding defects.
- Know the nature of plastic deformation, cold and hot working process, working of a rolling mill and types, extrusion processes.
- Understand the principles of forging, tools and dies, working of forging processes.
- Know about the Additive manufacturing.

Course Outcomes:

COs	Statements	Blooms Level
CO1	Design the patterns and core boxes for metal casting processes	L6
CO2	Understand the different welding processes	L2
CO3	Demonstrate the different types of bulk forming processes	L3
CO4	Understand sheet metal forming processes	L2
CO5	Learn about the different types of additive manufacturing processes	L2

UNIT– I

Casting: Steps involved in making a casting – Advantage of casting and its applications. Patterns and Pattern making – Types of patterns – Materials used for patterns, pattern allowances and their construction, Molding, different types of cores, Principles of Gating, Risers, casting design considerations. Methods of melting and types of furnaces, Solidification of castings and casting defects- causes and remedies. Basic principles and applications of special casting processes - Centrifugal casting, Die casting, Investment casting and shell molding.

UNIT–II

Welding: Classification of welding processes, types of welded joints and their characteristics, Gas welding, Different types of flames and uses, Oxy – Acetylene Gas cutting. Basic principles of Arc welding, power characteristics, Manual metal arc welding, submerged arc welding, TIG & MIG welding. Electro–slag welding.

Resistance welding, Friction welding, Friction stir welding, Forge welding, Explosive welding; Thermit welding, Plasma Arc welding, Laser welding, electron beam welding, Soldering &Brazing.

Heat affected zones in welding; pre & post heating, welding defects –causes and remedies.

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UNIT–III

Bulk Forming: Plastic deformation in metals and alloys-recovery, recrystallization and grain growth.

Hot working and Cold working -Strain hardening and Annealing. Bulk forming processes: Forging-Types of Forging, forging defects and remedies; Rolling – fundamentals, types of rolling mills and products, Forces in rolling and power requirements. Extrusion and its characteristics. Types of extrusion, Impact extrusion, Hydrostatic extrusion; Wire drawing and Tube drawing.

UNIT– IV

Sheet metal forming-Blanking and piercing, Forces and power requirement in these operations, Deep drawing, stretch forming, Bending, Spring back and its remedies, Coining, Spinning, Types of presses and press tools.

High energy rate forming processes: Principles of explosive forming, electromagnetic forming, Electro hydraulic forming, rubber pad forming, advantages and limitations.

UNIT -V

Additive manufacturing - Steps in Additive Manufacturing (AM), Classification of AM processes, Advantages of AM, and types of materials for AM, VAT photopolymerization AM Processes, Extrusion - Based AM Processes, Powder Bed Fusion AM Processes, Direct Energy Deposition AM Processes, Post Processing of AM Parts, Applications

Textbooks:

1. Kalpak jain S and Steven R Schmid, Manufacturing Processes for Engineering Materials, 5/e, Pearson Publications, 2007.
2. P.N. Rao, Manufacturing Technology -Vol I, 5/e, McGraw Hill Education, 2018.

Reference Books:

1. A.Ghosh & A.K.Malik, Manufacturing Science, East West Press Pvt. Ltd, 2010.
2. Lindberg and Roy, Processes and materials of manufacture, 4/e, Prentice Hall India Learning Private Limited, 1990.
3. R.K. Jain, Production Technology, Khanna Publishers, 2022.
4. Sharma P.C., A Text book of Production Technology, 8/e, S Chand Publishing, 2014.
5. H.S. Shaun, Manufacturing Processes, 1/e, Pearson Publishers, 2012.
6. WAJ Chapman, Workshop Technology,5/e,CBS Publishers & Distributors Pvt. Ltd.
7. Hindustan Machine Tools, Production Technology, Tata McGraw Hill Publishers.
8. Ian Gibson, David W Rosen, Brent Stucker., Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing, 2/e, Springer, 2015.

Online Learning Resources:

- https://www.edx.org/learn/manufacturing/massachusetts-institute-of-technology-fundamentals-of-manufacturing-processes
- https://onlinecourses.nptel.ac.in/noc21_me81/preview
- www.coursera.org/learn/introduction-to-additive-manufacturing-processessera

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Metal Casting

2:1 Introdution:

Casting is one of the oldest manufacturing processes, and even today is the first step in manufacturing most products. In this process, the material is first liquefied by properly heating it in a suitable furnace. Then, the liquid is poured into a previously prepared mould cavity where it is allowed to solidify subsequently, the product is taken out of the mould cavity, trimmed and cleaned to shape.

2.2 :Steps Involved In Making Castings.

i) Preparation of moulds and patterns [used to make the mould]

ii) Melting and pouring of the liquefied metal.

iii) Solidification and further cooling to room temperature.

iv) Defects and inspection.

2.3: Advantages of Metal Casting:

Metal castings have the following advantages.

1) It is one of the most versatile manufacturing processes.

2) Casting provide uniform directional properties and better damping capacity to cast parts.

3) Intricate shaped components that are difficult to produce by other methods can be produced by casting.

4) Very complicated components can be cast in one piece. It eliminates many joining processes.

5) Metals like cast iron that are difficult to shape by other processes can be cast.

6) The casting process can be modernized by suitable mechanism for mass production of components.

7) Very heavy and bulky parts that are difficult to form by other process can be cast.

8) Casting provide greatest freedom of producting components in terms of design, shape, size and quality.

9) The overall cost of the components is low.

2.4: Applications of Metal Castings:

Great advances have taken place in foundry engineering due to lower cost and the above-mentioned advantages. There is hardly any product in engineering. Which doesn't have one or more cast components casting find the following applications in engineering.

i) Road transportation and vehicles – more than 90% automobile engine components more than 35% of car truck, bus components and more than 50% tractor components by weight are made by casting.

ii) Aeroplanes – more than 30% components used by weight in aeoplanes are cast components.

iii) Machine tool structures – beds of machines like planer, shaper, milling, lathes etc. are cast in cast iron.

iv) Paper mill stock breaker parts are castings of steel.

v) Defence – more than 50% components used in defence are cast.

vi) Cast components are used in communication, construction and atomic energy.

vii) Aircraft jet engine blades.

viii) Agricultural parts.

ix) Turbine vanes.

x) Sanitery fittings.

xi) Fish plates used in railways.

xii) Super charger castings.

xiii) Mill housings.

2.5: Disadvantages of Castings:

1) Casting is a very high energy consuming process. For example, about 2000Kwh of power is required to produce a ton of finished steel casting.

2) Casting process is a highly labour-intensive compared to the other processes.

Patterns and Pattern Making

3.1 Introduction

Pattern is the principal tool during the casting process. It may be defined as a model of anything, so constructed that is may be used for forming an impression called mould in damp sand or other suitable material. When this mould is filled with molten metal, and the metal is allowed to solidify, it forms a reproduction of the pattern and is known as casting. The process of making a pattern is known as pattern making.

Foundry engineering deals with the process of making casting in moulds prepared by patterns. The whole process of producing casting may be classified into five stages.

1. Pattern making
2. Moulding and core making
3. Melting and casting
4. Fettling
5. Testing and inspection

Except pattern making, all other stages to produce castings are done in foundry shops.

3.2 Pattern making:

A pattern is the replica or facsimile model of the desired casting, which when packed or embedded in a suitable moulding material produces a cavity called mould. This cavity when filled with molten produces the desired casting after solidification of the metal. The process of making a pattern is known as pattern making.

3.3 Pattern Materials:

The selection of pattern materials depends primarily on the following factors.

1. Service requirements, e.g. quantity, quality and intricacy of casting i.e., minimum thickness desired, degree of accuracy and finish required
2. Type of production of castings and the type of moulding process.
3. Possibility of design changes.
4. Number of castings to be produced, i.e. possibility of repeat orders.

To be good of its kind, pattern material should be :

1. Easily worked, shaped and joined.
2. Light in weight.
3. Strong, hard and durable, so that it may be resistant to wear and abrasion, to corrosion, and to chemical action,
4. Dimensionally stable in all situation.
5. Easily available at low cost.
6. Repairable and reused.
7. Able to take good surface finish.

The wide variety of pattern materials which meet these characteristics are wood and wood products, metals and alloys, plasters, plastics and rubbers, and waxes.

3.3.1 Wood:

Wood is the most common material for pattern as is satisfies many of the above requirements. It is easy to work and readily available. Wood can be cut and fabricated into numerous forms by gluing, bending, and curving, it is easily sanded to a smooth surface, and may be preserved with shellac, which is the most commonly used finishing material for wooden pattern. Wood has its disadvantage as a pattern material it is readily affected by moisture. It changes its shape when the moisture dries out of it, and when it picks up moisture from the damp moulding sand. It wears out quickly as result of sand abrasion, and, if not stored properly, it may warp badly. Owing to these reasons wooden patterns do not last long, and they are generally used when a small number of casting are to be produced.

Wood used for pattern making should be properly dried before it is used. Should be straight-grained, free from knots, and free from excessive sapwood. The most common wood used for pattern is teak wood-both Burma and c.p.teak. This wood is straight grained light, easy to work has tittle tendency to break and warp and has reasonable cost. When a more durable wood is necessary for fragile patterns, which are to be used, as so called "inasters", mahogany is preferred. It is more costly than c.p. Teak, has a uniform grain, and is also easy to curve and shape. Other woods, which may also easy be used in making patterns, are Sal, shishampine, deodar, and few other indigenous varieties.

3.3.2 Metal

Metal is used when a large number of castings are desired from a pattern or when conditions are too sever for wooden patter. Metal patters do not change their shape when subjected to moist conditions Another advantage of a metal pattern is freedom from warping in storage. Metal patterns are very useful in machine moulding because of their accuracy, durability and strength. Commonly a meal pattern is itself caste from a wooden pattern called master pattern when metal patterns are to be cast from master patterns, double shrinkage must be allowed.

Metals used for patterns include cast iron, steel, brass, aluminum, and white metal.

3.3.2.1 Cast iron:

cast iron is used for some highly specialized types of patterns. It is strong gives a good smooth mould surface with sharp edges and is resistant to the abrasive action of the sand. But cast iron patterns rust too much and require a dry storage area.

3.3.2.2 Brass:

Brass is used in patterns, particularly when metal patterns are small.

It is strong, does not rust, takes a better surface finish than cast iron, and is able to withstand the wear of the moulding sand. But brass patterns are heavier than cast iron. This is why they are restricted to small size patterns.

3.3.2.3 Aluminium:

Aluminium is probably the best all round metal because it melts at a relatively low temperature, is soft and easy to work, light in weight and resistant to corrosion. Aluminium, being rather soft, is liable to be damaged by rough usage.

i) Quantity of casting to be produced.

ii) The size and the complexity of the shape of the casting to be produced.

iii) Type of moulding method to be used (i.e. hand or machine moulding).

iv) Problems associated with the moulding operation such as with drawing the pattern from the mold etc.

v) Other difficulties resulting from poor casting design or pattern design

The different types of patterns commonly used are:

a) One piece pattern

b) Split pattern - two piece pattern

c) Loose piece pattern

d) Match plate pattern

e) Cope and drag pattern

f) Sweep pattern

g) Gated pattern

h) Skeleton pattern

i) Segmental pattern

j) Follow boa5rd pattern

3.4.1 One Piece (Solid) Pattern:

i) It is the simplest type of pattern.

ii) As the name suggests the pattern is made from one piece and does not contain loose piece or joints.

iii) It is in expensive.

iv) It is used for making new large size simple castings.

v) One piece pattern is usually made up of wood or metal depending upon the quantity of castings to be produced.

vi) For making the mold, One piece pattern is accommodated either in cope or in the drag

vii) One piece pattern molding operations (like cutting runners, gates and providing riser/risers), being largely manual consume a lot of time and for this reason one piece pattern is used for producing small number of castings only.

viii) Stuffing box of steam engine may be cast with the help of one piece pattern

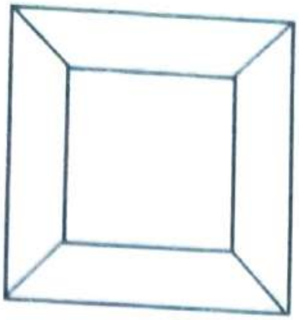

FIG. 3.1: One piece pattern.

3.4.2: Split Pattern:

i) Patterns of intricate shaped castings cannot be made in one piece because of the inherent difficulties associated with the molding operations (e.g. withdrawing the pattern from the mold etc.) Such patterns are, then, made as split or two-piece patterns.

ii) The upper and the lower parts of the split pattern are accommodated in the cope and drag portions of the mold respectively.

iii) Dowel pins are used for keeping the alignment between the two parts of the pattern.

iv) The parting (surface or) line of the pattern forms the parting (surface or) line of the mold.

v) Patterns for still more intricate castings are made in more than two pieces for facilitating their molding and with drawing.

vi) A pattern having three piece flask for the molding purposes(Fig 3.3)

vii) Castings like those of taps and water stop-cocks are produced with the help of split pattern shown in Fig 3.2

FIG. 3.2: Split pattern

vii) Cope and drag pattern are used for producing big castings which as a whole cannot be conveniently handled by moulder alone.

3.4.6: Sweep Pattern: -

i) Sweep pattern can be used for both green and sand molding.

ii) A sweep pattern is just a form made on a wooden board, which sweeps the shape of the casting into the sand all around the circumference. The sweep pattern rotates about the post.

iii) Once the mold is ready, sweep pattern and the post can be removed.

iv) Sweep pattern avoids the necessity of making a full large circular and costly three – dimensional pattern.

v) Making a sweep pattern saves a lot of time and labour as compared to making a full pattern .

vi) A sweep pattern is preferred for producing large castings of circular sections and symmetrical shapes.

vii) The manufacture of large kettles of cast iron requires a sweep pattern as shown in fig. 3.6

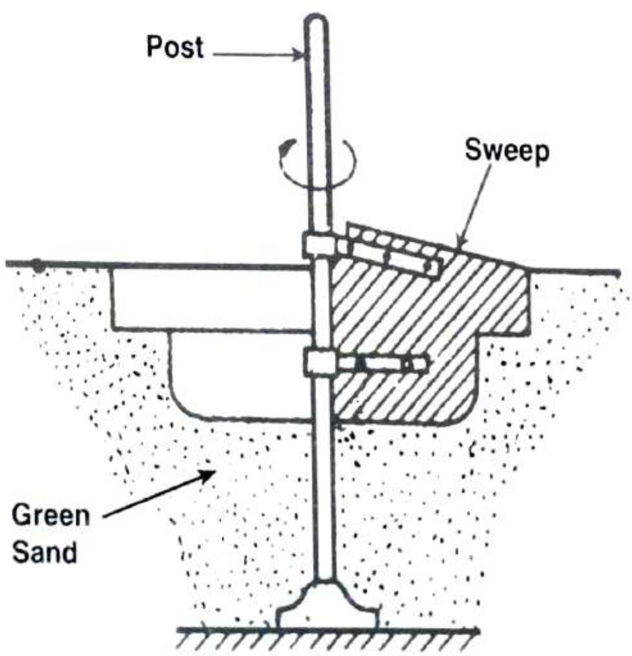

FIG: 3.6: - Sweep pattern

3.4.7: - Gated Pattern: -

(i) Gated pattern are usually made of metal which increases their strength and reduces the tendency to warp.

(ii) The sections connecting different patterns serve as runner and gates. This facilitates filling of the mould with molten metal in a better manner and at the same time eliminates the time and labour otherwise consumed in cutting runners and gates.

(iii) A match when used with a gated pattern saves still more time.

(iv) A gated pattern can manufacture many casting at one time and thus it is used in mass production systems.

(v) Gated pattern are employed for producing small castings which are shown in fig. 3.7

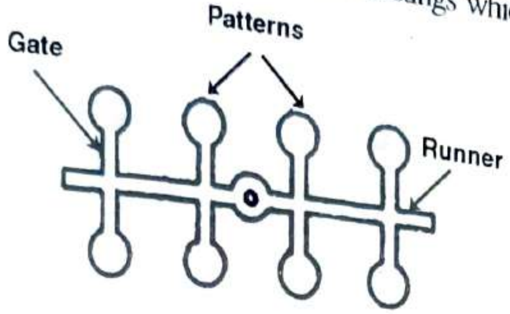

Fig 3.7 Gated Pattern

3.4.8: Skeleton Pattern: -

(i) A skeleton pattern is the skeleton of a desired shape which may be a S – bend pipe or a chute or something else. The skeleton frame is mounted on a metal base.

(ii) The skeleton is made from wooden strips(fig 3.8)and is thus a wooden frame work.

(iii) The skeleton pattern is filled with sand and is rammed.

(iv) A stickle (board) assists in giving the desired shape to the sand and removes extra sand.

(v) If the object is symmetrical like a pipe, two halves (of the pipe) can be molded by using the same pattern and then the two molds can be assembled before pouring the molten metal.

(vi) Cores if necessary can be produced separately.

(vii) Skeleton patterns are employed for producing a few large castings.

(viii) A skeleton pattern is very economical as compared to a solid pattern, because it involves less material costs.

(ix) Casting for turbine castings, water pipes, chutes, I-bends etc. are made with the help of skeleton patterns, shown in fig. 3.8

FIG: 3.10: -Follow board pattern

3.5: -Pattern Allowances:

As discussed earlier, a pattern is always made larger than the required size of the casting in order to allow for various factors, such as shrinkage, machining, distortion and rapping etc. The fowling allowances are provided in a pattern:

3.5.1 Shrinkage Allowance or Contraction Allowance:

Most of the metals used in casting work contract during coding from pouring temperature to room temperature. This contraction takes place in three forms, vif.liquid contraction, solidifying contraction and solid contraction, The first two are compensated by gates and risers and the last one by providing adequate allowances also differ. The prominent factors, which influence the metal contraction, are the following:

3.5.2: Machining or Finishing Allowance:

A casting may require machining all over or on certain specified portions, depending upon the assembly conditions and the operation it has to perform such portions or surfaces are marked duly in the working drawings.

The corresponding portions or surfaces on the pattern are given adequate allowance, in addition to the shrinkage allowance, by increasing the metal thickness there to compensate for the loss of metal due to machining on these surfaces. The amount of this allowance depends upon the metal of casting, method of machining to be employed, method of casting used, size and shape of casting and the degree of finish required on the machined portion. Ferrous metals need more allowance than the non- ferrous metals. Similarly, large and slander castings need more allowance than the shorter ones. This allowance varies from 1.5 mm to 16 mm but 3 mm allowance is quite common for small and medium size castings.

3.5.3 Draft Allowance or Taper Allowance:

All patterns are given a slight taper on all vertical surfaces, i.e. the surfaces parallel to the direction of their with drawal from the mould. This taper is known draft or draft allowance, It can be expressed either in degrees or in terms of linear measures. It is provided on both internal and external surfaces. The amount of draft on internal surfaces is more than on external surfaces. The purpose of providing this taper or draft is to facilitate easy withdrawal of pattern from the mould. The amount of draft varies from 10 mm to 25 mm per meter on external surfaces and from 40 mm to 70 mm per meter on internal surfaces. The factors influencing this amount are design of pattern, its vertical height and method of moulding.

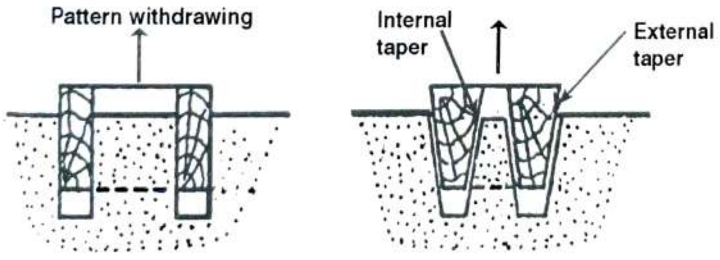

Fig: 3.11: -Taper Allowance

Fig. 3.11 shows two patterns one with taper allowance and the other without it. It come be visuals that it is easy to draw the pattern having taper allowance out of the mould without damaging mould walls or edges.

3.5.4: Rapping or Shake Allowance:

When a pattern is to be withdrawn from the mould, it is first rapped or shaken, by striking over it from side to side, so that its surface may be free of the adjoining sand wall of the mould. As a result of this the size of the mould cavity increases a little and a negative allowance is to be provided in the pattern to compensate the same and the pattern is made small size than the casting. However, it may be considered negligible for all practical purposes in small and medium sized castings.

3.5.5: Distortion or Camber Allowance:

The tendency of distortion is not common in all the castings. Only castings which have an irregular shape and some such design that the contraction is not uniform throughout will distort during cooling on account of the setting up of thermal stresses in them. such an effect can be easily seen in some dome shaped or 'U' shaped castings. To eliminate this defect an opposite distortion is provided in the pattern, so that the effect is neutralized and the correct casting is obtained.

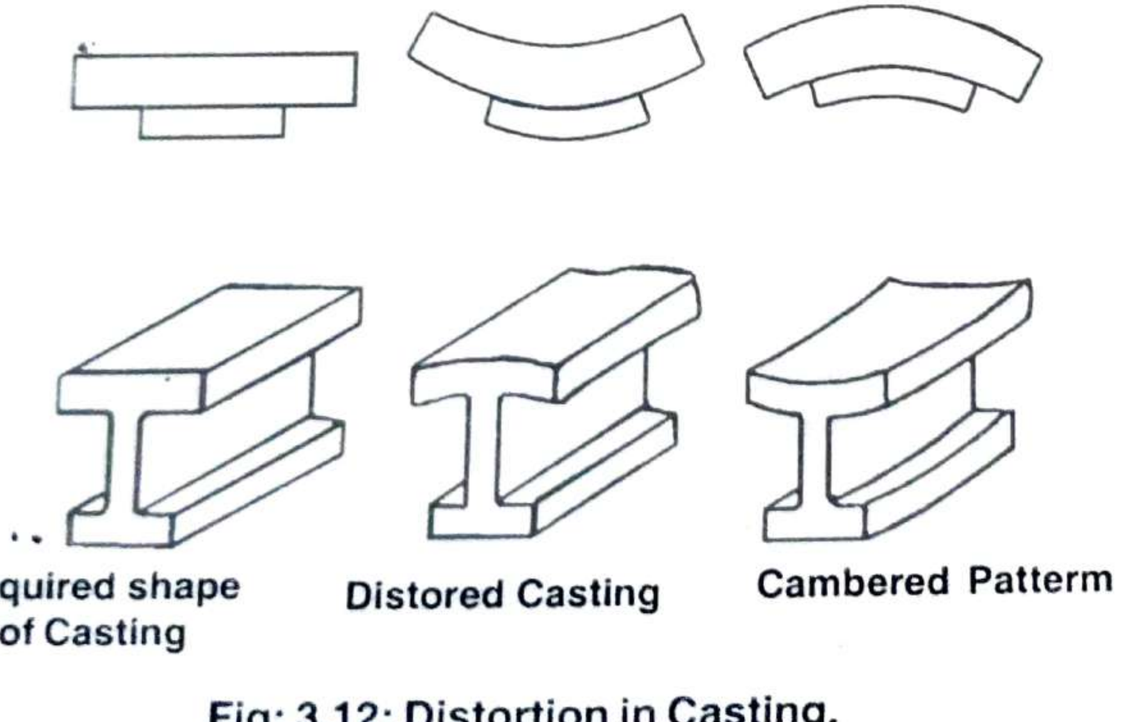

Fig: 3.12: Distortion in Casting.

Principles of Gating

4.1 Gating System:

The term gating system refers to all the passageways through which the molten metal passes enter the mould cavity. Since the way in which the liquid metal enters the mould has a decided influence upon the quality and soundness of the casting, the different components of a gating system should be carefully designed and produce. Different components of a gating system of shown in Fig: 4.1.

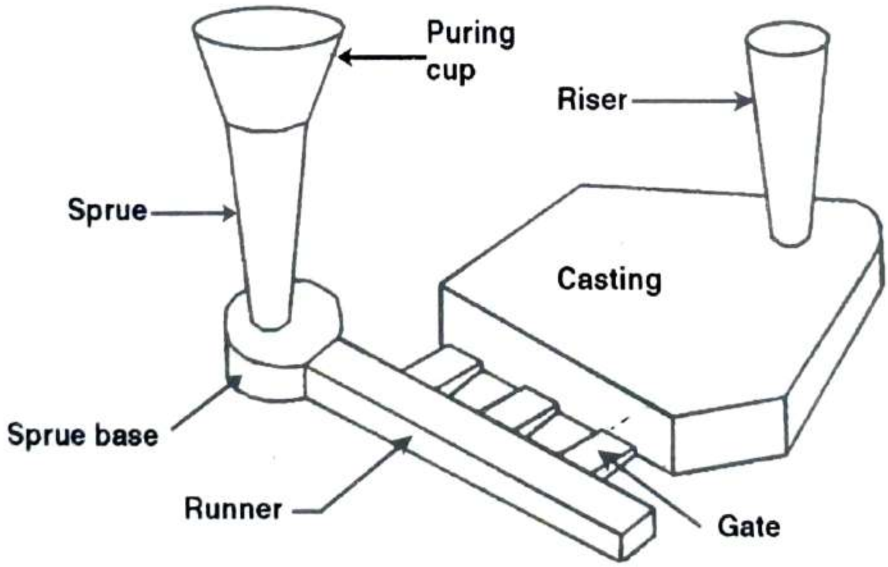

Fig. 4.1: Components Of Gating System

4.1.1 Pouring Cup

The molten metal is not directly poured into the mould cavity because it may cause mould erosion. Molten metal is poured into a pouring cup or basin, which acts as a reservoir from which it flows smoothly into the sprue.

4.1.2 Sprue

Sprue helps in feeding metal to the runner, which in turn reaches the cavity through the gates. The sprue may have either straight or taper shape.

4.1.3 Spruebase

This is a reservoir for the metal at the bottom of the momentum of the falling molten metal. The molten metal, as it moves down the sprue, gains in velocity, some of which is lost in the sprue base well, and the mould erosion is reduced. This molten metal changes direction in the spruce base and flows into the runner in a more uniform way.

4.1.4 Runner

Runner is used to take the molten metal from the sprue base and distribute it to several single gate, the runner may not be required.

4.1.5: Gate

The gate is a channel, which connects runner with the mould cavity and through which molten metal flows to fill the mould cavity.

4.1.6: Riser

A riser is a hole cut or moulded in the cope to permit the molten metal to rise above the highest point in the casting. The riser serves as a feeder to feed the molten metal into the main casting to compensate for its shrinkage during solidification. If the metal does not appear in the riser, it indicates that either the metal is insufficient to fill the mould cavity or there is some obstruction to the metal flow between the sprue and the riser.

4.2: Requirements or Functions of the Gating System:

A Gating system should,

1. Fill the mould cavity – completely before freezing;
2. Introduce the liquid metal into the mold cavity with low velocity and little turbulence, so that mold erosion, metal oxidation and gas pickup is prevented.
3. Help to promote temperature gradients favourable for proper directional solidification.

7.2 Centrifugal Casting Methods :-

Several Centrifugal casting techniques are in common use and are usually classified as,

1. True centrifugal casting
2. Semi – centrifugal casting
3. Centrifuge casting

7.2.1 True Centrifugal Casting :

1. True centrifugal castings are of straight uniform inner diameter and are produced by spinning the mold about its own axis, either vertically or horizontally.
2. They have more or less a symmetrical configuration (round, square, hexagonal etc.) on their outer contour and do not need any center core.

3. A cylindrical mold is mode to rotate on its own axis at a speed such that the metal being poured is thrown to the outer surface of the mold cavity. Thy metal Solidifies in the form of a hollow cylinder (Fig 7.7). The Cylinder wall thickness is controlled by the amount of liquid metal poured.

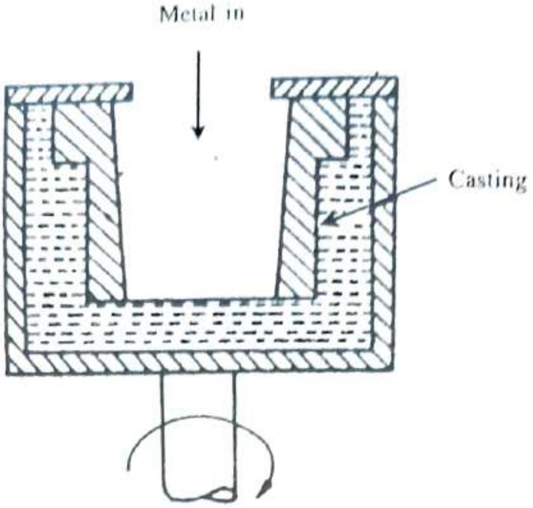

Fig 7.7 True centrifugal casting

4. Casting cools and solidifies from outside toward the axis of rotation, thereby providing conditions which setup directional solidification to produce castings free from Shrinkage.

5. True centrifugal castings may be produced in metal or sandlined molds, depending largely upon the quantity desired.

7.2.1.1 The Delavaud Process

a. Metal molds prove to be economical when larger quantities of castings are required to be produced

b. De lavaud process makes use of metal molds.

c. Figure 7.8 shows the essentials of de Lavaud casting process.

d. The de lavaud casting machine contains an accurately machined metal mold (die), entirely surrounded by cooling water

e. The machine is mounted on wheels and it can be moved length wise on a slightly inclined track.

f. At one and of the track there is a ladle containing proper quantity of liquid metal which flows though a long pouring spout initially inserted to the for extremity of the mold.

g. As pouring proceeds the rotating mold i.e., the casting machine is moved slowly down the track so that the metal is laid progressively along the length of the mold wall following a helical path; control being achieved by synchronising the rate of pouring, mold travel and speed of mold rotation.

h. After completion of the pouring, the machine will be at the lower end of its track with the mold rotating continuously till the pipe has solidified

i. The pipe, after it has solidified, is extracted from the metal mold by inserting a pipe puller which expands as it is pulled.

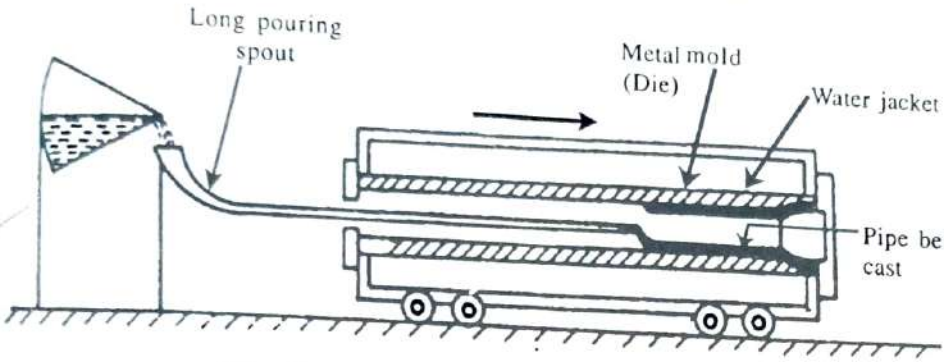

Fig : 7.8 De Lavaud casting machine.

7.2.1.2 Advantages of true centrifugal Casting :

1. Relatively lighter impurities within the liquid metal such as sand, slag, oxides and gas float more quickly towards the centre of rotation from where they can be easily machined out thereby giving clean metal casting.
2. Dense and fine grained metal castings are produced by true centrifugal casting technique (for the reasons explained under introduction).
3. Except with castings having greater wall thickness, there is proper directional solidification from outside (surface) towards inwards of the casting.
4. There is no need of a central core to make a pipe or tube.
5. Gating system is not required; this raises casting yield as high as 100% in certain cases
6. True centrifugal casting may be adopted for mass production.

7.2.1.3 Disadvantages

1. True centrifugal casting is limited to certain shapes
2. Equipment costs are high.
3. Skilled workers are required for operation and maintenance

and concentric with the asis of rotation

5. Spinning speeds need not be as high as those used for true centrifugal castings. A linear speed of the order of 180-200mpm at the outside edge of the casting is generally recommended.
6. Directional Solidification can be obtained by proper gating of the casting padding and selective chilling.
7. Casting shapes, more complicated than those suitable for true centrifugal casting can be made on semi-centrifugal casting machines.
8. A number of molds stacked together, one over the other can be fed by a common central sprue in order to produce more than one casting at a time.

7.2.2.1 Advantages :-

1. Semi - centrifugal casting ensures purity and density at the extremities of a casting such as a cast wheel or pulley.
2. Since the poorer structure forms at the center of the casting, it can be readily machined out if it is objectionable

7.2.2.2 Applications :

Disk shaped parts : wheels rings, rollers, pulleys, flywheels, gear blanks, Turbosupercharger diaphragm disks and steel railroad wheels etc.

7.2.3 Centrifuge Casting :

1. Parts not symmetrical about any axis of rotation may be cast in a group of molds arranged in a circle (Fig 7.10) to balance each other. The axis of mold and that of rotation do not coincide with each other. The setup is revolved around the center of the circle to induce pressure on the metal in the molds.
2. Casting shape imposes no special limitations in this process and an almost unlimited variety of smaller shape can be cast.
3. Mold cavities are fed by a central sprue under the action of centrifugal forces.
4. When castings in multiple layers one above the other are produced in one mold, the method is called stack molding. It is used for producing valve bodies, valve bonnets, plugs, yokes, pillow blocks and a wide variety of other industrial castings in large quantities.

7.2.3.1 Product applications :

Products may be irregular or non-symmetrical : Valve bodies, plugs, valve bonnets, pillow blocks and jokes etc. Jewelery is centrifugally cast by spinning the investment moulding during pouring centrifugal force transfers the metal and ansures good mould filling.

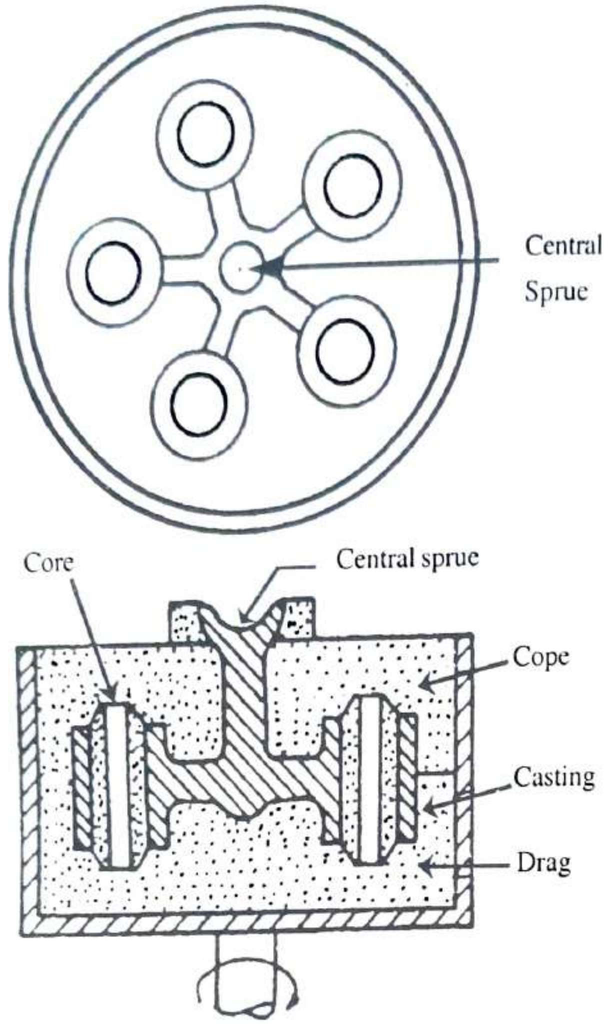

Fig 7.10 Centrifuge casting

7.2.4 Advantages of centrifugal casting methods :-

Different centrifugal casting methods are used in order to

1. Obtain castings of better quality
2. Produce castings more economically
3. Cast parts, which cannot be satisfactorily produced by other methods.
4. Achieve high casting yield as centrifugal casting seldom requires feed heads. Other advantages associated with centrifugal casting methods are
5. Fettling and cleaning costs are considerably reduced
6. Centrifugal casting produces denser castings which possess physical properties comparable with those of forgings.
7. Centrifugal casting, in some metals, improves tensile strength because of the resultant increased homogeneity and density.

8. Instead of having flow lines parallel to the lines of force as in conventional gear casting, there are no flow lines in centrifugal castings and grain structure runs perpendicular to the gear tooth line of force.
9. Castings with thin sections or fine outside surface details can be readily produced
10. The percentage of rejects is very low
11. Directional solidification can be achieved
12. It is similar to inspect the castings because defects if any will occur on the surface and not inside the castings other advantages and applications have been listed under individual centrifugal casting methods.

7.3 Die casting

Die casting machines perform the following functions:

1. Holding two die halves firmly together
2. Closing the die
3. In jecting molten metal into die
4. Opening the die
5. Ejecting the casting out of the die

Die casting machines are of two types

a. Hot chamber die casting machines

b. Cold chamber die casting machines.

7.3.1. Hot Chamber Die Casting :

1. In hot chamber die casting machines, the melting unit is in the machine itself that is why it is called hot chamber die casting machine.
2. The molten metal possesses normal amount of superheat and therefore less pressure is needed to force the liquid metal into die.

In this machine the goose neck type container always remains immersed in the metal pot. The molten metal from the container is forced inside the die with the help of a plunger submerged in the molten metal and operates hydraulically when the plunger moves up, the molten metal comes up and fills the cylinder and when the plunger moves down, the metal is forced into the die. The movable die platen is synchronized such that when plunger is moving up, the movable die platen moves away and the casting is removed.

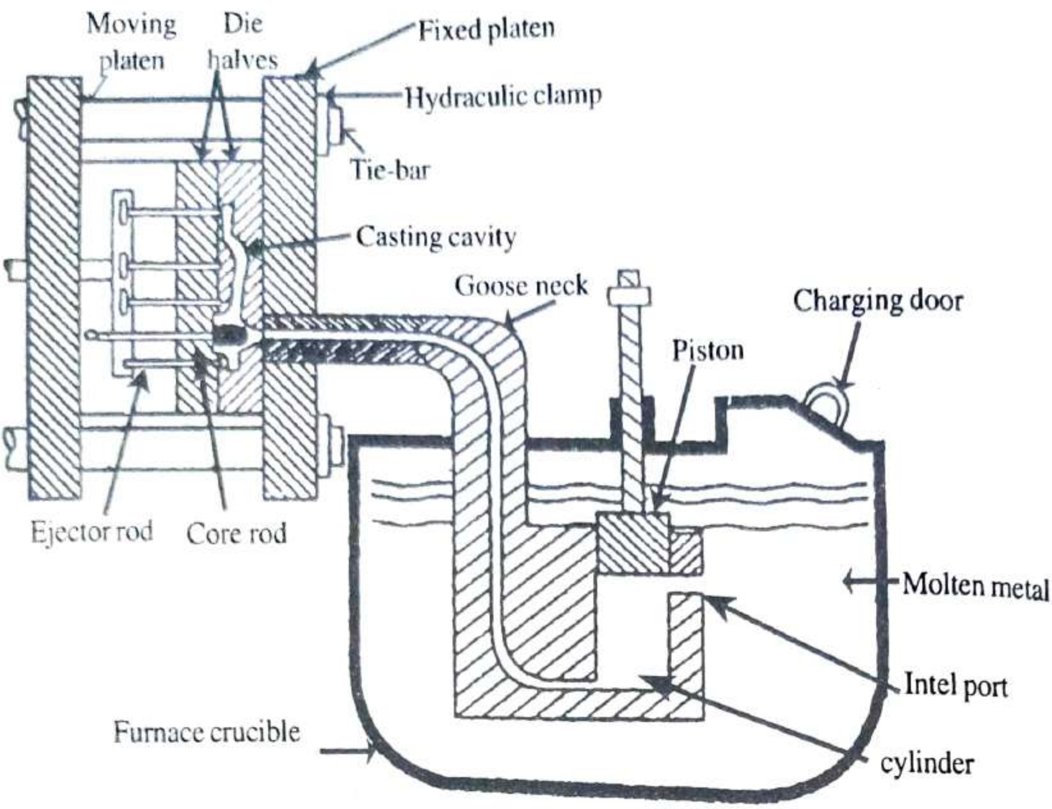

Fig 7.11 Goose neck Submerged plunger Type Hot Chamber Die Casting Machine.

7.3.2. Cold Chamber Die Casting :-

In these machines, the metal is melted separately in a furnace and transferred to these by means of small hand ladle. After closing the die, the molten metal is forced into the die cavity by a hydraulically operated plunger and pressure is mainted till solidification. These machines can either have vertical plunger or horizontal plunger for forcing molten metal into die. These machines are widely used for casting a good number of aluminium alloys and brasses

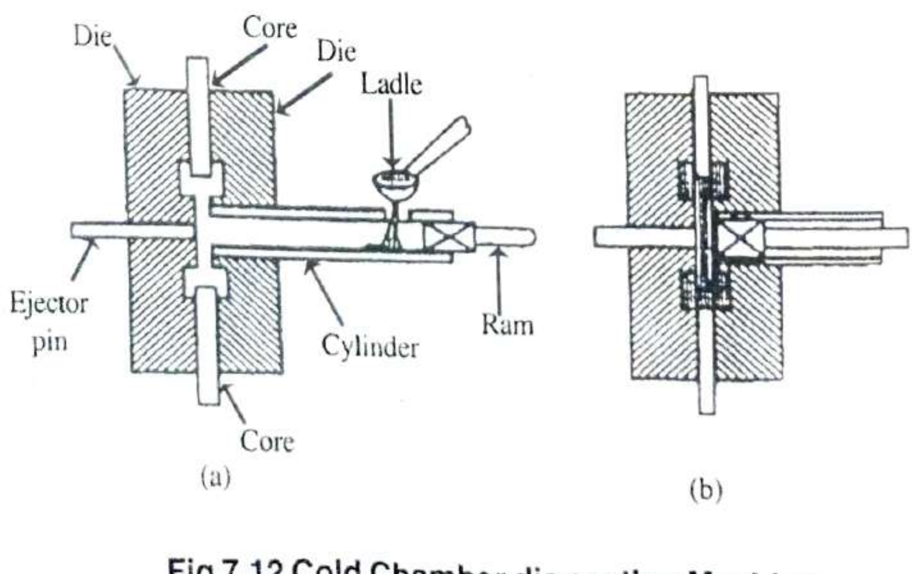

Fig 7.12 Cold Chamber die casting Machine

7.3.3. Advantages of Die Casting :

1. It requires less floor space
2. Die casting provides for precision manufacture with a subsequent reduction in machining cost.
3. Thin sections of the complex shape are possible
4. High production rate
5. Greater surface finish
6. Inserts can be easily cast in place
7. Die castings are less defective than sand casting
8. The increased soundness and reduction of defects provides increased yield.
9. The labour cast involved is less
10. Threads and other fine surface details can be easily obtained
11. A number of nonferrous alloys can be die cast
12. The die has a long life. It is possible to produce 1,00.000 castings in case of zinc base alloys and 75,000 castings in case of copper base alloys.

7.3.4. Limitations of Die Casting :-

1. The cost of die and equipment is high
2. The life of die decreases rapidly it metal temperature is high
3. Ferrous alloys are not cast and moreover a limited number of nonferrous alloys can be economically die-cast.
4. The size of the casting is limited.
5. The air in the die cavity gets trapped inside the casting and creates porosity.
6. Special skill is required for maintenance and supervision of die
7. The minimum economic quantity for die casting is around 20,000
8. Die casting technique requires comparatively a longer period of time for going into production (Set up time, preparation time)
9. In certain cases, dies may produce an undesirable chilling effect on the die casting.

7.3.5 Applications of Die Casting :

1. Die casting process has been used for many non-ferrous metals and alloys such as zinc, Aluminium, copper, magnesium, lead and tin.
2. Automobile parts
3. Marine uses
4. Domestic appliances
5. Instruments
6. Parts of the refrigerators, washing machines, television, typewriters, Projectors, Radio, Binocular, Camera
7. Lead base alloys are used in radiation shielding, battery parts, light duty bearings etc.

7.4 Investment Mould Casting :

7.4.1 Procedural steps in the Investment casting process :-

7.4.1.1 Producing a die for marking wax patterns :-

1. Dies may be made either by machining cavities in two or more matching blocks of steel or by casting a low melting point alloy around a (metal) master pattern.
2. For long production runs, steel dies are most satisfactory. They are machined from the solid blocks by die in sinking and are assembled in the tool room. The dies thus formed achieve the highest standard of accuracy and have considerable longer life.

7.4.12 Making of expendable patterns and gating System :-

1. Wax patterns are produced using wax-injection machines wax at 150-170°F is injected into the die (halves camped in position) at a pressure raging from 7 to 70kg/cm^2 [Shown in Fig 7.13(a)]
2. Small shallow vents cut in the parting surface of the die provide adequate venting.
3. Gates and sprues are formed in the same manner as the wax patterns and are attached to the pattern assembly. Shown in Fig 7.13(b).

7.4.1.3 Precoating the pattern assembly :-

1. The wax pattern assembly is dipped into a slurry of a refractory coating material

Methods of Melting

8.1. Introduction :-

Before pouring into the mould the metal to be cast should be in the molten or liquid state. This is done by melting the metal in a furnace. Quality of the final casting is greatly influenced by the molten metal state varieties of furnaces are available for melting the material. Few of then are : cupola furnace and open-hearth furnace. The selection of a particular type of furnace depends upon the amount and type of material to be melted. For example cupola furnace is used for melting cast iron and open-hearth furnace is used for melting steel. The cupola furnace is the oldest and most basic furnace for melting iron

8.2. Crucible Furnace :

A crucible furnace is very convenient for small foundries where the operation is intermittent and a variety of alloys are handled in small quantities. The metal to be melted is put in a heated crucible, which acts as a melting pot. The crucible is made of clay and graphite by moulding these materials into a standard shape and it is produced in sizes from number 1 to 400. The crucible number represents its approximate melting capacity in kg of copper. The capacity of a crucible for other metals may be determined by multiplying with the ratio of densities. The fuel used for heating the metal may be coke, oil, or gas.

8.2.1 Coke - Fired Furnace :

The coke - fired furnaced is commonly used for melting non-ferrous metals, such as brass, bronze and aluminium, owing to its low cost of installation, low fuel cost, and case in operation, Generally this furnace is installed in a in pit and so is reffered to as the pit type. (Fig 8.1). The furnace has a cylindrical steel shell lined on the inner side with refractory bricks closed at the bottom with a grate and covered at the top with a removable lid. The metal to be melted is contained in the crucible, which is embedded in burning coke.

Preparation of the furnace involves kindling a deep bed of coke from the top is removed and the crucible is lowered into the furnace. The coke is again added on all sides of the crucible. The metal is then charged in the crucible and the lid is replaced to facilitate the chimney draft. It forced draft is available from a blower, it is used to help in rapid combustion of the coke. When the metal reaches the desired temperature, the crucible is drawn out with special long-handled tongs and carried away for pouring

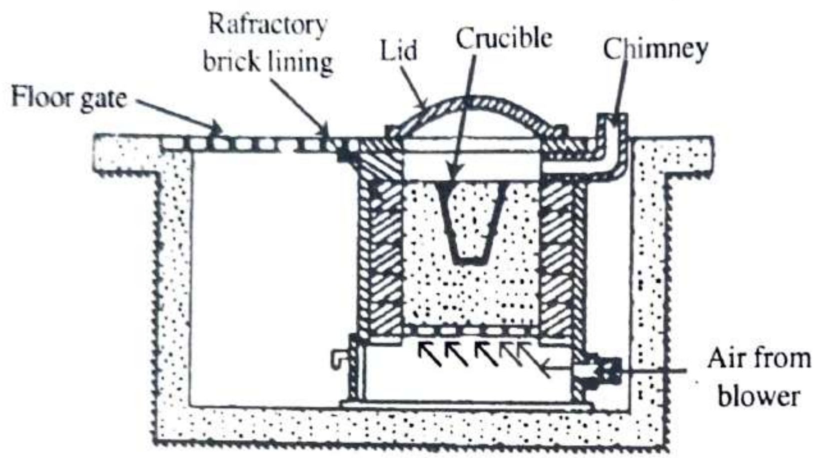

Fig 8.1: Pit type coke - fired crucible furnace

8.2.2 Oil – And gas – Fired Furnace :-

Some furnaces (Fig 8.2) make use of oil or gas as fuel for heating the crucible. The furnace is cylindrical in shape and the flame produced by the combustion of oil or gas with air is allowed to sweep around the crucible and uniformly heat it.

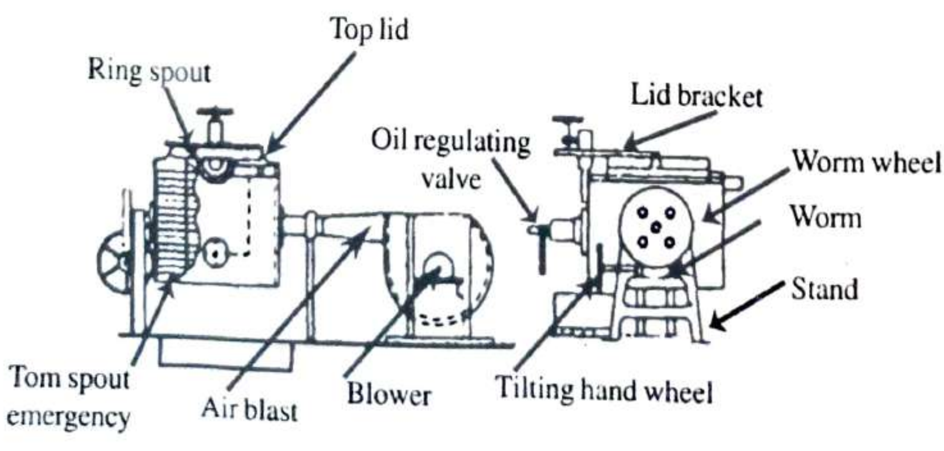

Fig : 8.2 Oil – Fired Tilting type crucible furnace

Gas or atomised fuel oil is fed through a manifold. It enters the furnace tangentially where it ignites and swirls upwards between the crucible and the refractory lining. The metal is charged through the opening in the centre of the head. Modern oil – and gas – fired furnaces are equipped for automatic propotioning, they produce a neutral flame by regulating the fuel and air ratio. The temperature is also controlled thermostatically.

The oil – and gas – fired furnaces are generally the tilting or the bale – out type. The tilting type of furnace is raised above floor level, mounted on two pendestals and rotated by means of a geared hand wheel. The lilting gear is customarily so designed that the furnace tilts on a central axis. The bale – out or life – out furnace is fixed, but, unlike the pit type, is installed on the floor. For extracting the molten metal the crucible has to be lifted out of the furnace with the help of tongs.

8.2.2.1 Advantages of Oil – And gas – Fired Furnace :-

i. There is no wastage of fuel : no sooner is the metal ready than the supply of oil or gas can be stopped. The fuel supply can also be regulated while working to suit the requirements.

ii. The output in a given times is greater due to higher efficiency

iii. Better temperature control can be maintained

iv. Less contamination of metal takes place.

v. Saving in floor space is achieved

vi. As stoking is not required labour cost is reduced.

8.2.3 Open – Hearth Furnace :-

Open – hearth furnace, in small sizes in the heigh bourhood of 25 tons, have been used in the casting industry for melting steel or producing steel from pig iron direct for casting. Lately however, these have been superseded by electric arc furnaces. The furnace may have basic or acid lining, depending on the type of pig iron used. The charge consists of pig iron in varying amounts along with steel scrap and limestone.

The open – hearth process is based on the regene rative principle of heating and involves obtaining very high temperatures, as required for steel, by preheating the gaseous fuel and air by the outgoing products of combustion. The hearth of the furnace. (Fig 8.3) 8.4. shallow – about 13m long, 5m wide and 0.5m deep and made of suitable refactory material. It has gas and airports at each end, and two pairs of regenerators one for gas and the other for air, with the necessary flues and the chimney.

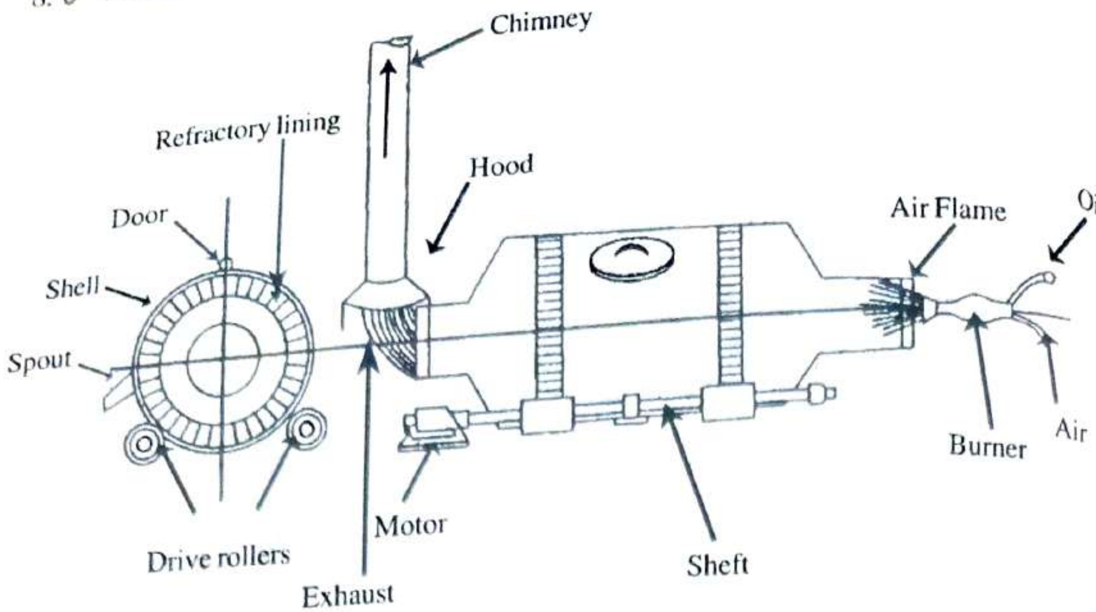

Fig : 8.5 : Oil/Gas Fired Rotary Furnace

8.3. Cupola

Cast iron produced in a cupola possesses the following advantages :

- ★ The cost of melting is low
- ★ The control chemical composition is better.
- ★ Temperature control is easier
- ★ Melter metals can be tapped from the cupola at regular interved
- ★ It consumes the easily available and less expensive fuels.

The main advantages of cupola is that it is not possible to produce iron below 2.81 carbon in this furnace. So for producing white cast iron (containing below 2.71 carbon) the duplex process is employed.

8.3.1 Description of a cupola

1. **Shell** Shell is a vertical and cylindrical in shape. It is made with sheet 6 to 12 mm thick and lined inside with acid revocatory bricks and clay. Refectory bricks and clay used for cupola lining consists of silicon ac (Sio$_2$) and Alumina (A/$_2$O$_3$). Cupola diameter varies from 1 to 2 mete and height is 3 to 5 times the diameter.
2. **Foundation :** The shell is mounted either on a brick works foundation on steel columns. The bottom of the shell consists of a drop bot works door, through which consisting of coke slag etc. can be discha at the end of a melting.
3. **Tuyers :** Air for combustion of fuel is delivered through the tuyers v are provided at the height of between 0.6 to 1.2 meters above the wc bottom.

4. **Wind Belt :** The air is delivered to the tuyers from a wind belt which is a steel plate duct mounted on the outer shell of the cupola.

5. **Blower :** A high pressure fan or blower supplies the air to the wind belt through a blast pipe.

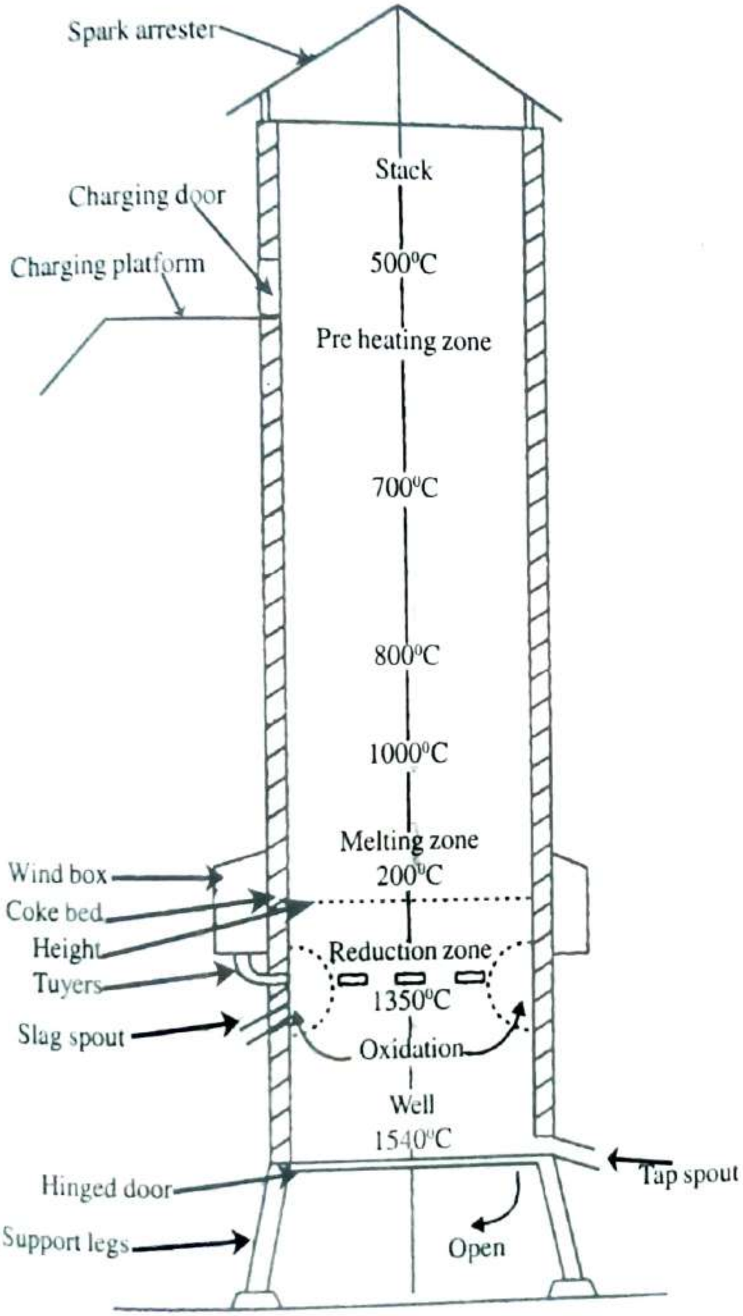

Fig : 8.6 : Cupola

6. **Slag Hole :** It is located at a level about 250mm below the centres of the tuyers. It is used to remove the slag.

7. **Charging Hole :** It is situated 3 to 6 metros above the tuyers through this hole, metal, coke and flux are fed in to the furnace.

8. Chimney or stack : The shell is usually continued for 4.5 meters to 6 meters above the charging hole to form a chimney.

8.3.2 Zones in a cupola.

The entire section of the cupola is decided into the following zones :

Crucible Zone : It is between top of the sand bed and bottom of the tuyers. The molten metal accumulates here. It is also called the 'well'.

Combustion or Oxidizing Zone : It is situated normally 150 to 300mm above the top of the tuyers. Heat is evolved in this zone because of the following oxidation reactions.

$$C + O_2 \rightarrow CO_2 + \text{Heat}$$

$$Si + O_2 \rightarrow SiO_2 + \text{Heat}$$

$$2Mn + O_2 \rightarrow 2Mno + \text{Heat}$$

$$Fe + O \rightarrow FeO + \text{Heat}$$

Reducing Zone :

This zone starts from the top of the combustion zone and extends up to the top of the coke bed. In this zone, the reduction of Co_2 + CO Occurs and temperature drops to about 1200°C.

$$CO_2 + C\ (\text{Coke}) \rightarrow 2CO - \text{Heat.}$$

Melting Zone :

The zone starts from the top of the coke bed and extends up to a height of 900mm. The temperature in this zone is highest approx. equal to 1600°C.

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

Preheating zone or charging zone :

It starts from the top of the melting zone and extends up to the Charging door. Charging materials are fed in this zone and get preheated.

Stack zone :

It starts from the charging zone and extends up to the top of the cupola. The gases generated within the futurnace are carried to the atmosphere by this zone.

8.3.3 Cupola Operation

1. Preparation of Cupola : Clean out the slag and repair the damaged lining with the mixture of fire clay and silica sand. After this bottom doors are raised and bottom sand is introduced. The surface of the sand bottom is sloped from all directions toward the tap hole. Slag hole is also formed to remove the slag.

2. Firing the cupola : A fire of kindling wood is ignited on the sand bottom. After proper burning of wood. Coke is added to a level slightly above the toyers. Air blast at a slower rate is turened on. After having red spots over the fuel bed, extra coke is added to the predetermined length.

3. Charging the Cupola : After proper burning alternate layers of pig iron, coke and flux (limestone) are charged from the charging door until the cupola is full. Steel scrap is also added to control the chemical composition. Flux will be added to prevent the oxidation as well as to remove the impurities (Flux is 2 to 3% of metel charge by weight).

4. Soaking of Iron : After the furnace is charged fully the charge gets slowly heated up since the air blast is kept. Shut for about 45 minutes, this causes the iron to get soaked.

5. Opening of Air Blast : At the end of Soaking period, the air blast is opened. Tape hole is closed to accumulate the Sufficient amount of metel. The rate of charging should be equal to the rate of melting so that the furnace remains full.

8.4. Steel Melting in foundry

Carbon and alloy steels are used extensively for casting components subjected to severe working conditions involving high tensile loads corrosion abrasion, heat as well as impact creep and fatigue stresses. Cast steels differ from wrought steels used in rolling forging etc. in their wider ranges of composition, less impurities and higher casting temperature. In addition, due to the variety of specification handled in foundries, careful segregation and control of charge materials (comprising foundry - returns) is needed. Generally, the size of melting units used for making cast steels range from 100kg to 20 tons, the most common range being 500kg to 5000kg. The preferred melting units in steel foundress are three-phases direct are furnaces and medium high frequency core-less induction furnace. Smaller sizes furnaces are more suitable fer jobbing foundry whereas larger furnace (above 10 tons) are preferred by mini-steel plants.

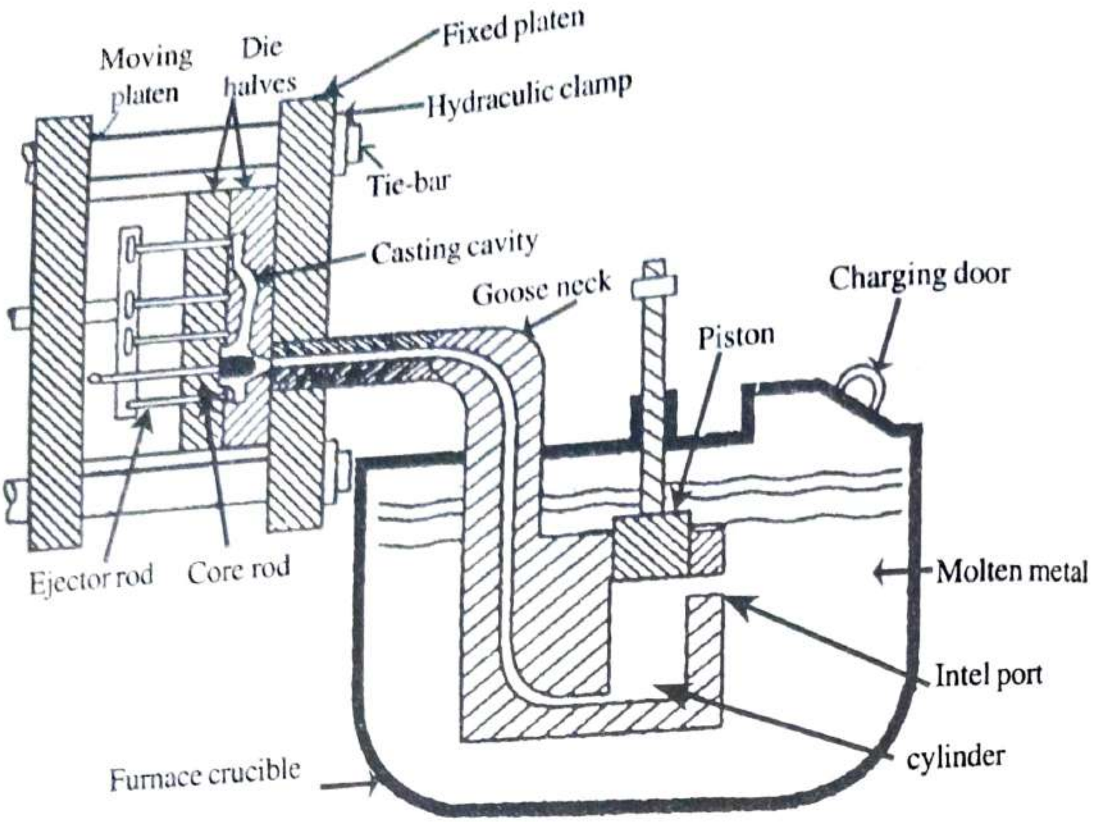

Fig 7.11 Goose neck Submerged plunger Type Hot Chamber Die Casting Machine.

7.3.2. Cold Chamber Die Casting :-

In these machines, the metal is melted separately in a furnace and transferred to these by means of small hand ladle. After closing the die, the molten metal is forced into the die cavity by a hydraulically operated plunger and pressure is mainted till solidification. These machines can either have vertical plunger or horizontal plunger for forcing molten metal into die. These machines are widely used for casting a good number of aluminium alloys and brasses

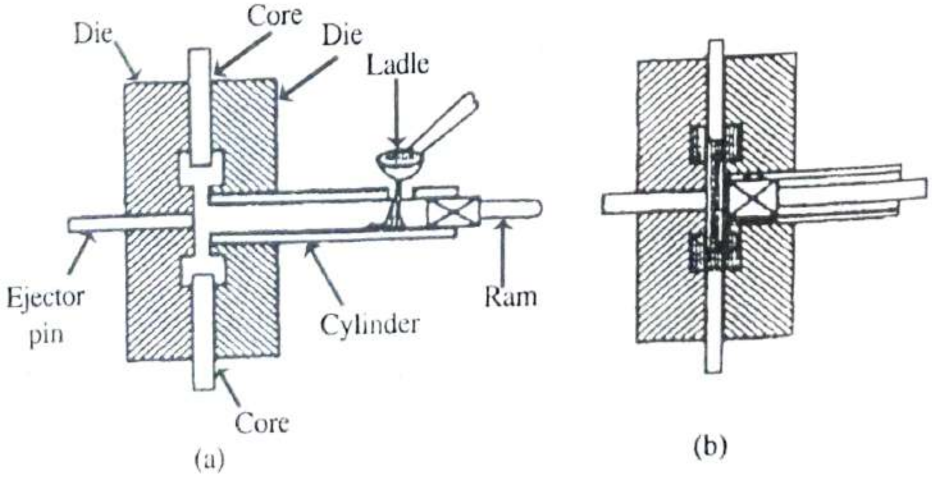

Fig 7.12 Cold Chamber die casting Machine

7.3.3. Advantages of Die Casting :

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3. Thin sections of the complex shape are possible
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7.3.5 Applications of Die Casting :

1. Die casting process has been used for many non-ferrous metals and alloys such as zinc, Aluminium, copper, magnesium, lead and tin.
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3. Marine uses
4. Domestic appliances
5. Instruments
6. Parts of the refrigerators, washing machines, television, typewriters, Projectors, Radio, Binocular, Camera
7. Lead base alloys are used in radiation shielding, battery parts, light duty bearings etc.

7.4 Investment Mould Casting :

7.4.1 Procedural steps in the Investment casting process :-

7.4.1.1 Producing a die for marking wax patterns :-

1. Dies may be made either by machining cavities in two or more matching blocks of steel or by casting a low melting point alloy around a (metal) master pattern.
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7.4.12 Making of expendable patterns and gating System :-

1. Wax patterns are produced using wax-injection machines wax at 150-170^{0}F is injected into the die (halves camped in position) at a pressure raging from 7 to 70kg/cm^2 [Shown in Fig 7.13(a)]
2. Small shallow vents cut in the parting surface of the die provide adequate venting.
3. Gates and sprues are formed in the same manner as the wax patterns and are attached to the pattern assembly. Shown in Fig 7.13(b).

7.4.1.3 Precoating the pattern assembly :-

1. The wax pattern assembly is dipped into a slurry of a refractory coating material

7.4.14 Investing the wax pattern assembly for the production of molds [Shown in Fig. 7.13 (d)]

1. The percoated wax pattern assembly is then invested in the mold.
2. Investment molds may be formed by either solid molding or shell molding.

7.4.1.5 Removing wax pattern from the investment mold [Shown in Fig. 7.13 (e)]

Solid molds are placed upside down in the progressive furnaces

First of all the wax pattern is melted and the wax is drained from the mold.

As the mold progresses through the furnace, it experiences high temperatures and gets cured in about 16 hours.

The oven which melts wax is kept at a temperature of 200 to 400°F whereas the curing or burn out oven works at a temperature of the order of 1300 to 1900°F.

The forces created by heating may damage some molds. For this reason instead by heating wax pattern may be removed by dissolving wax in a solvent such as trichloroethylene. It is more effective in removing wax from the investment shell molds.

7.4.1.6 Pouring metals into the molds [Shown in Fig. 7.13 (f)]

The metal should be poured may be melted in a careless induction or some other furnace and brought in small ladles to the preheated molds for pouring.

Molds are preheated (before getting poured) to about 1900°F depending upon the metal to be poured.

7.4.1.7 Removal of casting :-

After they are solidified, the castings are removed from the mold.

7.4.1.8 Cleaning, Finishing and Inspection

Each casting is separated from the assembly and the gates etc. are removed.

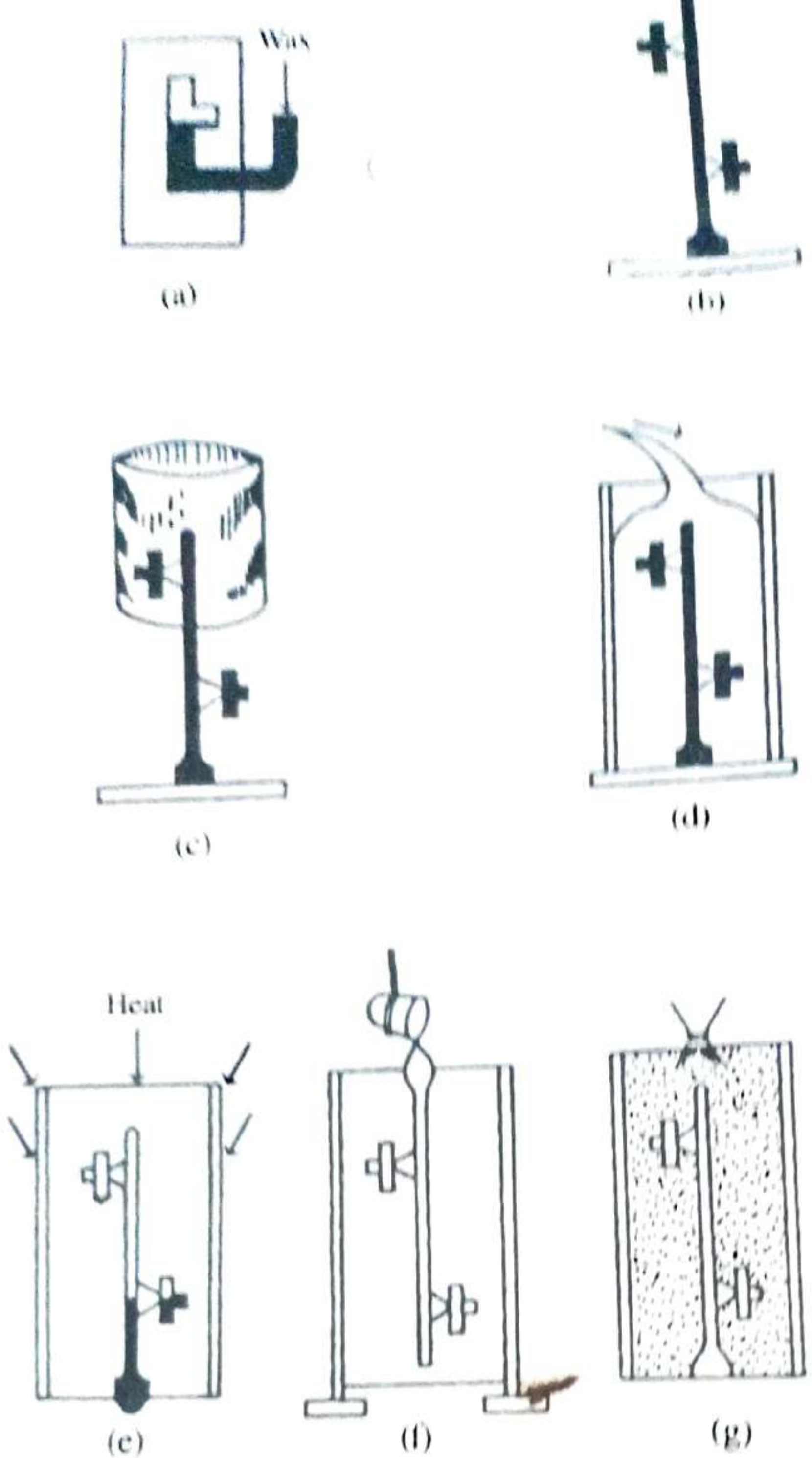


Fig : 7.13 Steps involved in Making an Investment casting

a. Wax injected into die to make pattern
b. Patterns have been gated to central sprue.
c. Placing metal flask around the pattern assembly.
d. Investing the wax pattern assembly.
e. Removing wax pattern from investment mold.
f. Pouring molten metal into the mold.
g. Removing casting from the mold by breaking mold material

7.4.2. Advantages of Investment Casting :-

1. Castings made by investment casting process, posses
   a) excellent details
   b) smoother surfaces (ranging from 1500 to 2250 miro mm root-mean square), and
   c) close tolerance (of ±0.03mm per mm)
2. Castings do not contain any disfiguring parting line
3. As a result, some machining operations can be eliminated thereby attaining considerable saving in cost.
4. Intricate shapes can be cast
5. Irregular parts which cannot be machined or difficult to machine alloys may be cast be investment casting process.
6. Sections as thin as 0.75mm may be cast.
7. Since molten metal is poured in preheated molds. The resultant cooling rate thus being slow, produces large grain size as well as sounder and denser castings.
8. With suitable heat treatment, the investment castings attain physical properties comparable to those of forged or rolled sections of same metal.

7.4.3. Disadvantages :-

1. Production of wax patterns and then investment molds etc., make the process relatively expensive as compared with other casting processes.
2. Size limitation of the component part to be cast. Majority of castings produced weigh less than 0.5kg.
3. Pattern is expendable; one wax pattern is required to make on investment casting
4. Process is relatively slow.
5. The use of cores makes the process more difficult.

The economic value of this process lies in its ability to produce intricate shapes in various alloys that could probably not be produced at all by any othercasting process.

7.4.4. Applications :-

1. To fabricate difficult - to machine and difficult - to - work alloys into highly complex shapes such as hollow turbine blades.

2. Parts for sewing machines, locks, rifles, beer barrels and burner nozzles.
3. Impellers and other pump and valve components in stainless steel and nonferrous alloys, wave guides die-inserts and parts for gun mechanisms.
4. Milling cutters and other types of tools.
5. In dentistry and surgical implants.
6. For making jewellery and art castings.
7. Parts of gas turbine used in locomotive propulsion.
8. Corrosion resistant and wear resistant alloy parts used in diesel engines, textile cutting machines, motion picture projectors, pulverizing equipments and chemical industry equipments.
9. Jet aircraft engine (Jet) outlet nozzles
10. Buckets for supercharges
11. Parts produced from stellite, Vitallium etc. for use in automotive and aircraft industries and for plastic molding dies, extrusion and drawing dies, refrigerators and power plants.

7.5 Shell Moulding :-

Shell moulding process is also known as corning process or C-process. Shell moulding replaces conventionals sand moulds by shell moulds made up of relatively thin (only 0.3mm to 0.6mm thick) rigid shells of approximately uniform wall thickness. Shell moulds are made up of mixture of dry silica sand and phenolic resins that are formed into thin half mould shells, which are held with clamps or adhesives for pouring.

The different steps involved in shell moulding are shown in

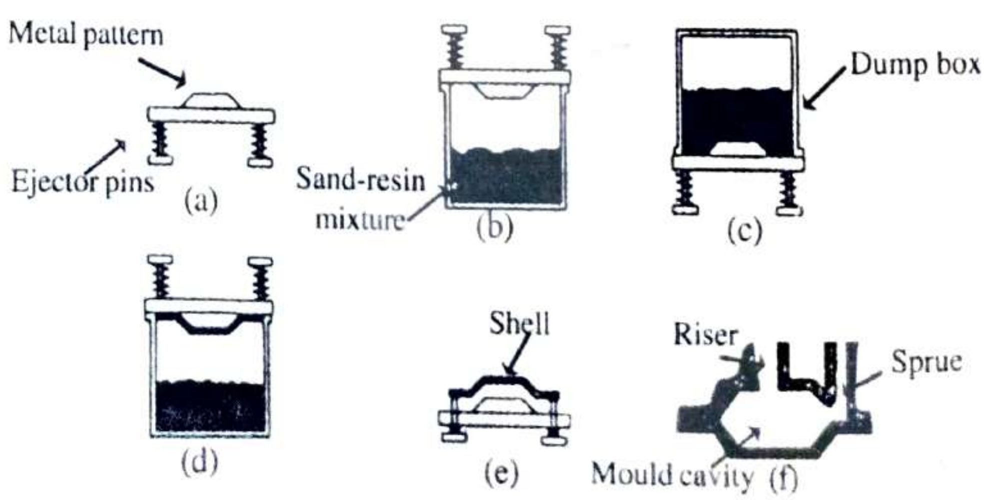


Fig. 7.14 : Shell moulding process :

The process consists of heating a metal pattern to 200-250°C [Fig 7.14(a)] and then the metal pattern is turned down and clamped over the open end of the dump box [Fig 7.14(b)] filled with sand-resin mixture. Then the dump box is inverted as in [Fig 7.14(c)], so that the dry sand-resin mixture falls on the metal pattern. The sand - resin mixture when comes in contact with the heated pattern, softens and fuses to form a soft and uniform shell on the surface of the pattern. Heat, first causes resin to become sticky; then additional heat hardens it. This process is finished within 30 seconds. Now, the dump box is turned over again as in Fig 7.14(d) and the excess sand -resin mixture falls back leaving a shell adhering closely to the pattern. Pattern and shell are then heated in an oven at 300°C for one minute and then shell is removed from the pattern with the help of ejector pins as shown in Fig 7.14 (e). A complete mould is made in two or more pieces that are assembled together as illustrated in Fig 7.14(f) Now the molten metal is poured into the cavity.

Using the shell mould casting process, castings having good surface finish and dimensional accuracy can be produced. However, this requires high initial investment and is limited to the small-sized castings only. This process can be used for the production of gears, bearing caps, and bushings.

7.5.1 Advantages :-

1. Castings as thin as 1.5mm and of high definition can be cast satisfactorily.
2. Since shell is an excellent heat insulator, there is no surface chilling or skin hardening of casting
3. Cooling rate of cast metal being flow castings possess grain sizes larger than those obtained in green sand moulds.
4. Shell mold made castings possess excellent surface finish.
5. Shell molding faithfully reproduces with sharp clean edges thereby machining unnecessary.
6. Tolerances of the order of 0.002 to 0.003mm per mm are possible to obtain in shell mold castings.
7. Less foundry space is required for shell molding.
8. Semiskilled operators can handle the process
9. Shells can be stored for a long time before use
10. Shell molding can be mechanised
11. Shells possess permeabilities higher than other types of molds.

7.5.2 Disadvantages :-

1. Shell molding is uneconomical on small scale production.
2. Resin costs are comparatively high.
3. The maximum size of the casting is limited by the maximum size of the shell which can be feasiloly produced and poured. Castings weighing upto 10kg may be cast by shell molding.
4. The comparatively small amount of break down sand from shell molds is not normally economically recoverable.
5. Low carbon steels castings made by shell molding may show depressions on their upper surface.

7.5.3 Applications

1. Shell molding is ideal for mass production of small castings where the degree of intricacy causes high rejection rates in green sand molding.
2. For casting automotive rocker arms and values.
3. Shell molding is suited to ferrous and nonferrous alloy castings in the range 0.1 to 10kg.
4. A number of small hydraulic castings in stainless steel and copper alloys are produced by shell molding.
5. Other components cast by shell molding are small pipes, camshafts, bushings, valve bodies, spacers, brackets, manifolds, bearing caps, shafts and gears.
6. Various alloys which can be satisfactorily cast by shell molding are aluminium alloys, copper alloys [including brasses, phosphor bronze and gum metal], cast irons [gray and especially malleable] stainless steels etc.

UNIT - II

Welding

Gas or atomised fuel oil is fed through a manifold. It enters the furnace tangentially where it ignites and swirls upwards between the crucible and the refractory lining. The metal is charged through the opening in the centre of the head. Modern oil – and gas – fired furnaces are equipped for automatic propotioning, they produce a neutral flame by regulating the fuel and air ratio. The temperature is also controlled thermostatically.

The oil – and gas – fired furnaces are generally the tilting or the bale – out type. The tilting type of furnace is raised above floor level, mounted on two pendestals and rotated by means of a geared hand wheel. The lilting gear is customarily so designed that the furnace tilts on a central axis. The bale – out or life – out furnace is fixed, but, unlike the pit type, is installed on the floor. For extracting the molten metal the crucible has to be lifted out of the furnace with the help of tongs.

8.2.2.1 Advantages of Oil – And gas – Fired Furnace :-

i. There is no wastage of fuel : no sooner is the metal ready than the supply of oil or gas can be stopped. The fuel supply can also be regulated while working to suit the requirements.

ii. The output in a given times is greater due to higher efficiency

iii. Better temperature control can be maintained

iv. Less contamination of metal takes place.

v. Saving in floor space is achieved

vi. As stoking is not required labour cost is reduced.

8.2.3 Open – Hearth Furnace :-

Open – hearth furnace, in small sizes in the heigh bourhood of 25 tons, have been used in the casting industry for melting steel or producing steel from pig iron direct for casting. Lately however, these have been superseded by electric arc furnaces. The furnace may have basic or acid lining, depending on the type of pig iron used. The charge consists of pig iron in varying amounts along with steel scrap and limestone.

The open – hearth process is based on the regene rative principle of heating and involves obtaining very high temperatures, as required for steel, by preheating the gaseous fuel and air by the outgoing products of combustion. The hearth of the furnace. (Fig 8.3) 8.4. shallow – about 13m long, 5m wide and 0.5m deep and made of suitable refactory material. It has gas and airports at each end, and two pairs of regenerators one for gas and the other for air, with the necessary flues and the chimney.

UNIT - II

Welding

Welded Joints

10.1. Types of Welding Joints :-

The type of joint defines the relative positions of joining and welding of two pieces. The basic types of joints are : butt joint, lap joint, corner joint, and T - joint that are shown in Fig 10.1. The position of welding is marked with a cross (×) in each case.

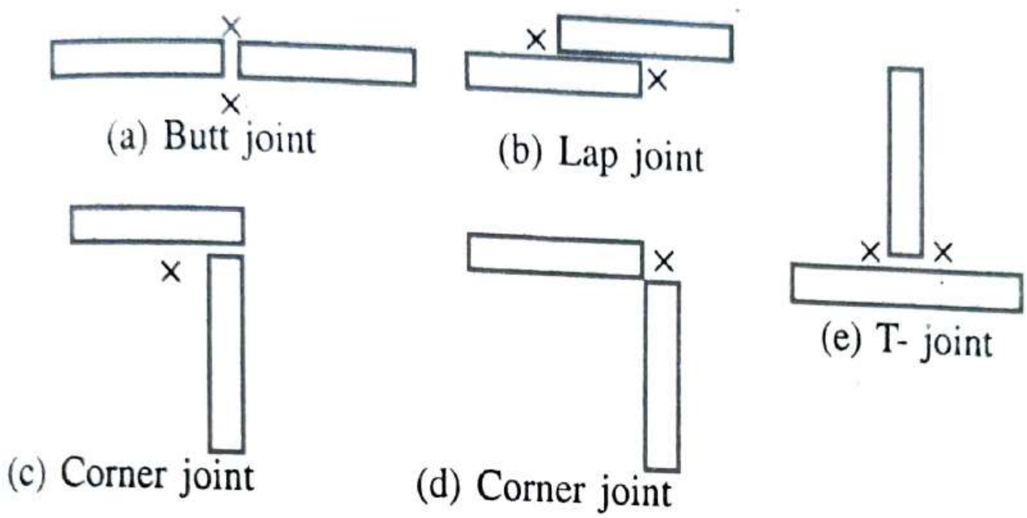


Fig : 10.1 Different types of joints :

10.2. Types of Welds :-

Fig 10.2 shows the various types of welds used in making a joint. A 'bead' weld is one in which the filler metal is deposited at a joint where the two surfaces adjoining the joint are in the same plane. A 'bead' is defined as a single run of weld metal. A "fillet" weld is one in which the filled metal is deposited at the corner of two intersecting surfaces, such as a T or Lap joint. A "groove" weld is one in which the filler material is deposited in a groove formed by edge preparation of one member or of the both the members. A "plug" or "slot" weld is one in which a hole is formed through one of the pieces to be welded and the filler material is then deposited into this hole and fused with the mating part.

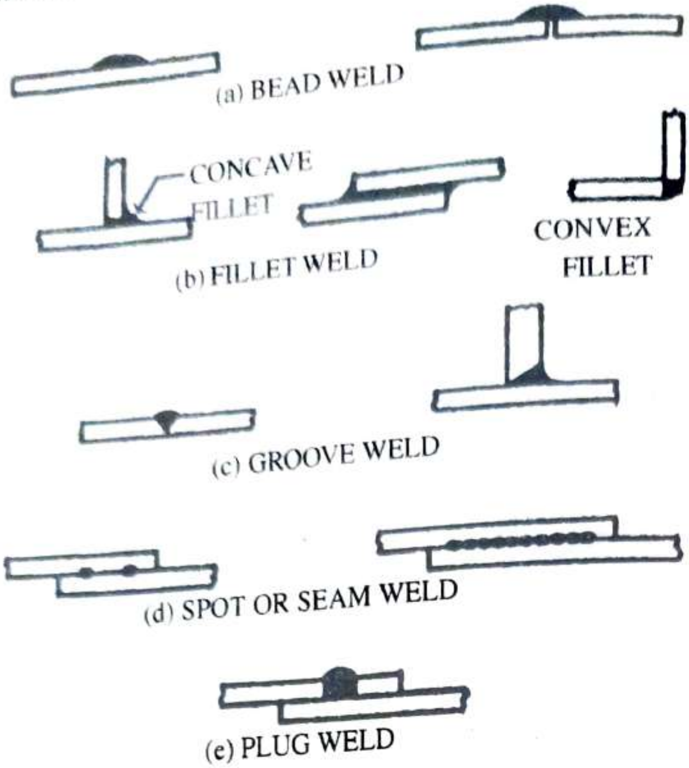


Fig : 10.2 : Types of Welds

10.3. Welding Positions :-

Welding may be done under various positions as depicted in Fig. 10.3

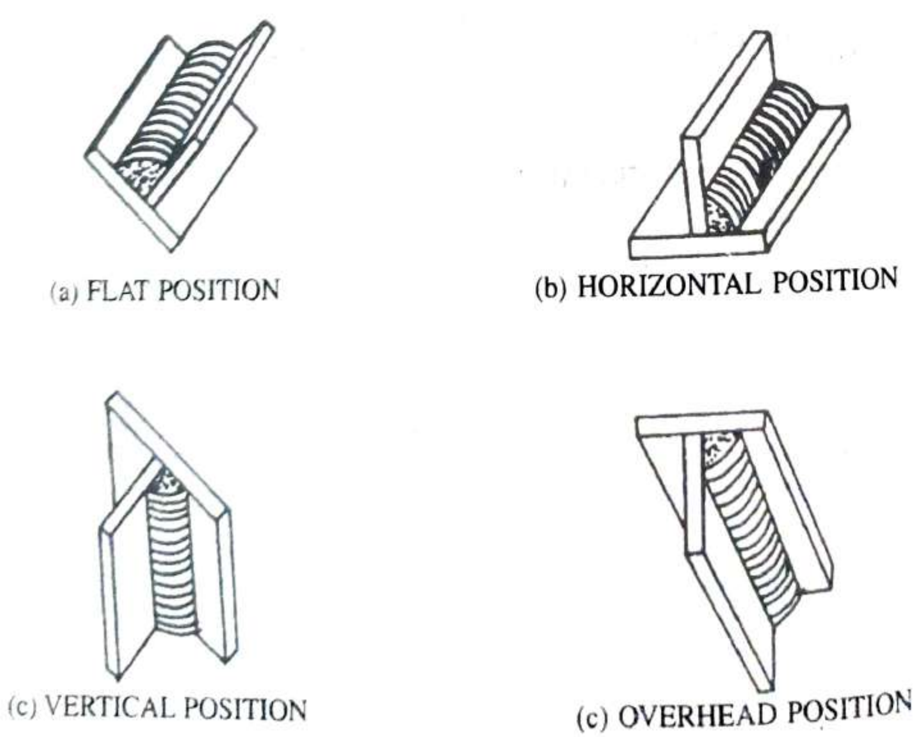


Fig 10.3 Different welding positions

11.1.2 Oxy-Acetylene Welding(Gas Welding)Equipment and Accessories :

The equipment of an oxy-acelylene welding set is shown in Fig 11.2. It consists of oxygen cylinder, acetylene cylinder, cylinder valves, pressure regulators, hoses and welding torch. The accessories for oxy-acetylene welding consists of goggles gloves and welding sleeves, spark lighters and tip cleaners etc.

11.1.2.1 Oxygen Cylinder :-

Oxygen (O_2) is produced by separating the various constituents of air by liquefaction process. It is a supporter of combustion.

Oxygen cylinder is made of steel and is painted black for identification. It contains oxygen at a pressure of 17.5 N/mm^2 (175 bar). Oxygen cylinder can store 7m^3 of gas and its mass is about 80kg when it is full.

11.1.2.2 Acetylene Cylinder :-

Acetylene (C_2H_2) is a fuel gas composed of 92.3% carbon and 7.7% hydrogen. It is the product of chemical reaction between calcium carbide and water.

Acytelene is produced by two methods

1. Water - to - carbide method [high - pressure system] - water falls on carbide to produce acetylene at high pressure.
2. Carbide - to - water method [low - pressure system] - calcium carbide grains fall on water to produce acytelene at low and medium pressures.

Acetylene cylinder is made of steel and is painted maroon. High pressure acetylene cylinders contain acytelene at a pressure of 1.5N/mm^2 (15 bar). The lower storage pressure of acetylenes is due to the instability of the gas at a pressure above 0.2N/mm^2 (2bar). Therefore the acytelene is safely stored at lower pressure in a dissolved from inside the cylinder. The normal capacity of acytelene in dissolved state is 6m^3.

Low pressure acetylene gas is stored in acetylene cylinder at a pressure of 0.07 bar.

These cylinders are called low - pressure acetylene cylinders. It the gas is produced and stored is cylinders at pressure from 0.07 bar to about 1 bar, then they are referred as medium pressure acetylene cylinders.

11.1.2.3 Cylinder Valves :-

The function of cylinder valves is to lock compressed gas in the cylinder. Valves for oxygen cylinder are made of brass and connected to the regulator by means of right - handed coupling nut. Acytelene cylinder valves is made of steel and connected to regulator by a clip, and the valve is opened and closed with a special socket wrench.

The shanks of cylinder valves are threaded to suit a particular class of cylinder. The cylinder containing combustible gases have left - hand threads and cylinders containing noncombustible gases have right-handed threads. In this way the use of a valve on a wrong type of cylinder is avoided. This safety feature is also applicable for all connectors and regulators.

11.1.2.4 Pressure Regulators :-

Pressure regulators are required for acetylene and oxygen cylinders. They reduce the pressure of the gas in the cylinder to the pressure used in the torch. Regulators used for acetylene and oxygen are different construction to maintain different pressures. Pressure regulators are mounted on the top of the cylinders. Two gauges are provided on the regulators, one for showing the pressure in the cylinder and the other for pressure being supplied to the torch.

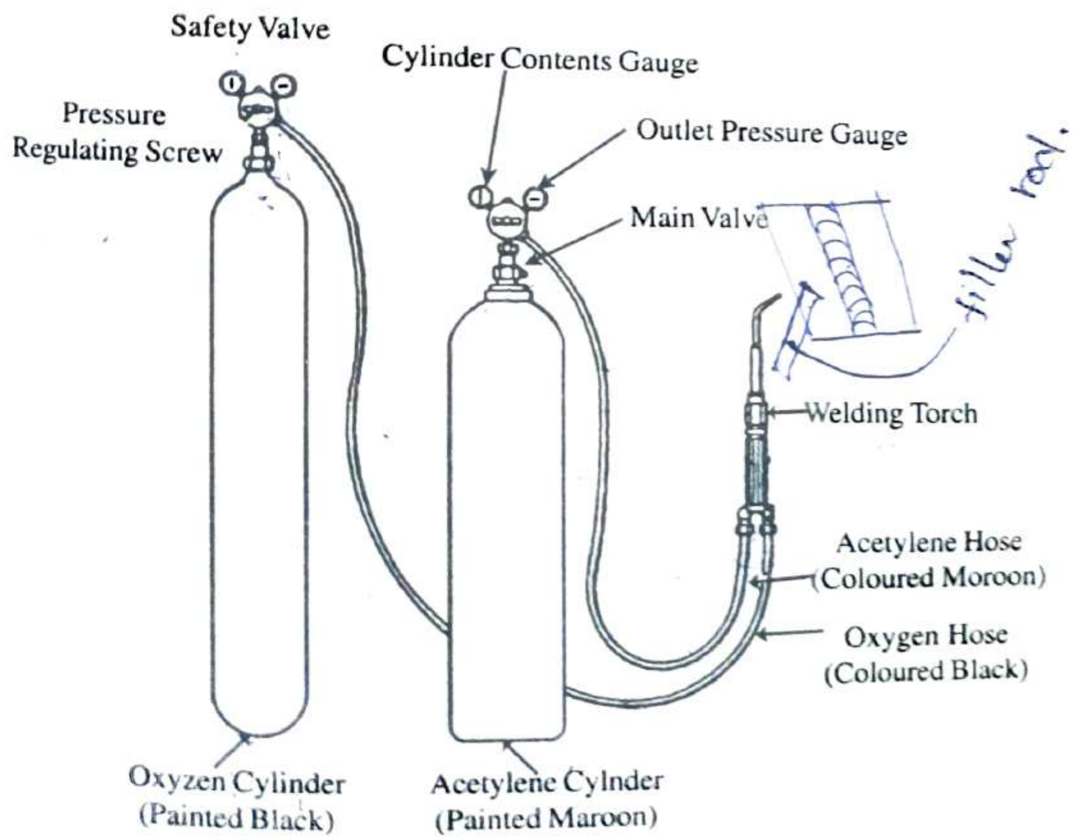


Fig : 11.2 : Oxy - Acetylene Set

11.1.3 Advantages of Gas Welding

The advantages of gas welding are as follows :

1. Low capital cost
2. High portability and convenience; can be easily altered (by changing torch) for brazing cutting and heating
3. Oxy - acetylene flame is more easily controlled and can be used for all metals and alloys.
4. Welding skills are relatively easy.

11.1.4 Disadvantages :

1. Takes longer time to weld .
2. Heat affected zone and distortion are longer
3. Oxygen and acetylene gases are expensive and there are safty problems in handling and storage of these gases
4. Shielding provided by flame is not effective

11.1.5 Applications

Oxy-acetylene welding is a versatile process and can be used for welding all commercial metals and alloys. Due to low temperature of gas flame, the process is employed for welding thin sections. The process is mostly used in sheet metal fabrication workshops, aircraft industries, garages and maintenance shops.

11.2. Types of Oxy - Acetylene Flame :

The type of flame to be used is adjusted according to the work materials. This can be achieved by regulating the supply of acetylene and oxygen. Depending on relative amounts of oxygen and acetylene, the gas flame can be classified into three types;

1. Oxidising flame
2. Neutral flame and
3. Reducing (Carburising) flame

11.2.1 Oxidising flame :- The oxidising flame has an excess of oxygen over the acetylene. Its inner core is shorter and less luminous and outer flame acquires light bluish colour.

11.3. Arc Welding :-

11.3.1 Principle of Arc Welding :-

The source of heat in this process is an electric arc. The electric are develops when current flows across the air gap between the end of metal electrode and the work surface. Thus are is strong stable electric discharge occuring in the air gap between the end of metal electrode and the work surface. This arc is strong stable electric discharge occuring in the air gap between an electrode and the work. The temperature of this arc is about 3600°C which can melt and fuse the metal very quickly to produce joint. The temperature of the arc at the centre is around 6500°C only 60 to 70 percent of the heat is utilised in arc welding to heatup and melt the metal. The remaining 40 to 30 percent is dissipated into surroundings.

The principle of arc welding is based upon the formation of an electric arc between a consumable electrode (bare or coated) and the base metal. The heat of the arc is concentrated at the point of welding; as a result, it melts the electrode and base metal. When the weld metal solidifies, the slag gets deposited on its surface as it is lighter than metal and weld metal is allowed to cool gradually and slowly. After cooling (Solidification) a sound joint is formed. The slag is removed by chipping hammer. The principle of arc welding is shown in Fig 11.5.

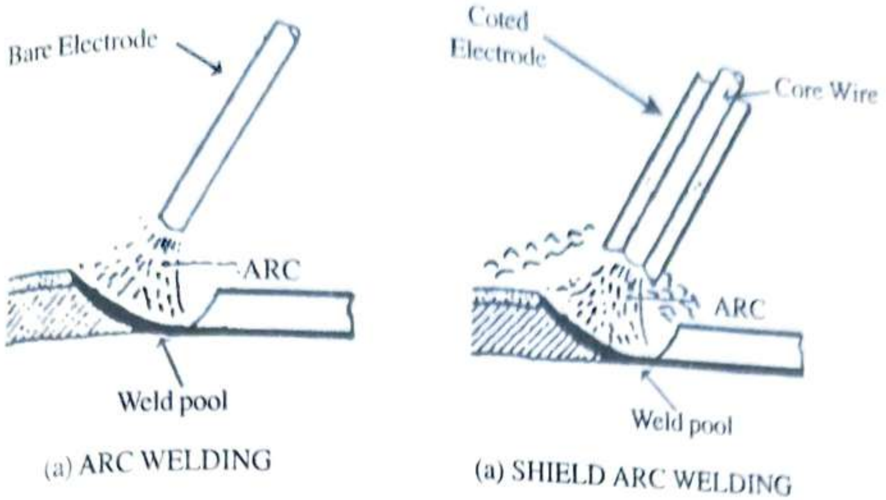


Fig : 11.5 : Principle of arc welding

11.3.2 The sequences of steps involved in arc welding operation :-

1. Preparation of edges
2. Holding the workpiece in a fixture
3. Stricking the arc, and
4. Welding the joint.

11.3.3 Arc welding Equipment and Accessories :-

In arc welding process, the source of heat is electricity. The required electrical energy (high ampere-low voltage) is obtained by an arc welding equipment. The functions of such equipment are.

1. To provide AC or D.C. welding supply for arc welding.
2. To change the high voltage of the main supply (Ac) to low voltage and heavy current (Ac or Dc) suitable for arc welding.
3. To control and adjust the required welding current during arc welding

The equipment and accessories (Fig 11.6) required for electric arc welding usually consists of

1. Equipment to provide the welding current
   a. Transformer (for a.c)
   b. Generator or rectifier (for d.c)

2. Accessories
   - a) Electrodes
   - b) Electrode holder
   - c) Cables
   - d) Safety devics and
   - e) Tools

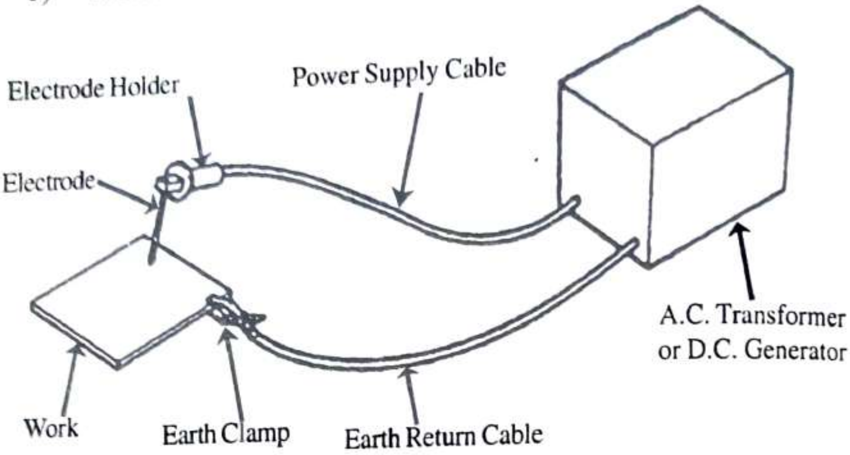


Fig : 11.6 : Manual Metal Arc Welding Equipment

11.3.3.1 Equipment :-

(a) Transformer : The purpose of transformer is to change the high input voltage and low amperage to a low voltage (20 - 80v) and high average (80-500 amps). Its cost is low, and a.c. gives a smoother arc when using high currents. However its use is confined mostly to ferrous metals. It is not suitable for bare electrods and welding special jobs where fine setting of current is required.

(b) Generator : It is driven by a motor or an engine. It generates and supply d.c. for electric arc welding.

(c) Rectifier : The purpose of rectifier is to change the output a.c. of a transformer into d.c. which is required for electric arc welding. The output of stepdown transformer is connected to the rectifier unit which converts A.c. to D.C. output is connected to positive and negative terminals from where it is tapped for welding purpose.

11.3.3.2 Ac Plant and D.C. Plant :-

A.C. and D.C. plants are used in manual metal arc welding. Both plants are suitable for the welding of all metals for some non-ferrous metals which require a d.c. plant. The following are the advantages and disadvantages of alternate and direct currents.

11.3.4 Advantages of Arc Welding

1. Metal arc welding is faster and lower in cost than gas welding.
2. The process is a quite versatile and welds can be made in any position.
3. Suitable for wide range of metals [ferrous and non - ferrous] and their alloys.
4. Less sensitive to weld than other processes.

11.3.5 Disadvantages of arc welding :

1. The process is not suitable for thin sections.
2. The process is not suitable for mechanisation.
3. Electrode replacement is necessary for long joints
4. Not suitable for heavy fabrications because less metal is deposited per hour.
5. Failure to remove the slag when run is interrupted. This will result in slag inclusions in the weld.

11.3.6 Applications of arc welding :

The Manual Metal Arc welding (MMAW) has a wider field of application. It is employed for fabrication of pressure vessels, ships, structural steel work, joints in pipe work, construction and repair of machine parts.

This process can also be used hard facing and repairs of the broken parts.

11.4. Forge Welding :-

Forge welding is smith welding which is the oldest known welding process and its use has been reported from about 1400B.C. By this process the pieces to be welded are heated to above 1000°C and then placed together and given impact blows by hammering. In the more recent form of welding of large components the pressure is applied by rolling, drawing and squeezing to achieve the forging action. The oxides are exclude by virtue of design of the workpieces and or by the use of appropriate temperature as well as fluxes. Fluxes commonly used for forge welding low carbon steels are sand, fluorspar, and borax. They help in melting the oxides, if formed.

Proper heating of the workpieces is the major welding variable that controls the joint quality. In sufficient heating may not affect a joint while overheating results in a brittle joint of low strength. Also, the overheated pieces tend to be oxidised which shows itself by spongy appearance. The joints most commonly employed are scarf, cleft and lap types, as shown in Fig 11.7

Forge welding is now mainly used in under - developed countries for welding small agriculture implements and chains, etc..

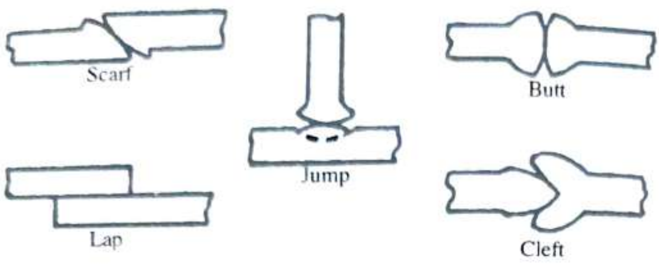


Fig : 11.7 Types of joints used in forge or smith welding

11.4.1 Advantages :-

If made correctly, a forge - welded joint has every quality of the original metal and is as good in strength as an arc or oxy-acetylene welded joint.

11.4.2 Disadvantages :-

1. It is usually limited to the joining together of pieces of solid steel stock.
2. There is the danger of sulphur pick - up by the metal from the coke of the furnace

11.4.3 Applications :-

1. Forge welding finds use in blacksmith shops, rail - road shops and repair shops of general character.

2. It is also used for making pipes from plates by rolling the plate to cylindrical form and making the longitudinal junction by forge welding. Strip/plate is pulled through dies to form a rolled cylinder, the long edges being butted together in the dies at the high temperature required to form a forge weld.

11.5. Resistance Welding :-

All of us know that when electric current flows through a wire, it generates heat due to the resistance offered by the metal of the wire to the flow of electrons. In resistance welding, the heat required for welding is produced by means of the electrical resistance between the two members to be joined. This process is also known as electric welding.

The heat generated in resistance welding is given by

$$H = I^2 R\, t\, K$$

where H = heat generated, in joules

I = current in amperes

R = resistance in ohms

T = time of current flow in seconds

K = constant to account for losses due to radiation and conduction.

The value of K is normally less than one

There are five basic methods of resistance welding, viz.

1. Spot welding
2. Seam welding
3. Projection welding
4. Flash Butt welding
5. Upset Butt welding

11.5.1 Advantages of Resistance Welding :-

1. Fast rate of production
2. No filler rod is needed
3. Semi - automatic equipments
4. Less - skilled workers can do the job.
5. Both similar and dissimilar metals can be welded.
6. High reliability and reproducibility are obtained
7. More general elimination of warping or distortion of parts.

11.5.2 Disadvantages of Resistance Welding :-

1. The initial cost of equipment is high.
2. Skilled persons are needed for the maintenance of equipment and its controls.
3. In some materials, special surface preparation is required
4. Bigger job thickness cannot be welded.

11.5.3 Applications of Resistance Welding :-

Resistance welding is used for

1. Joining sheets, bars, rods and tubes.
2. Making tubes and metal furniture
3. Welding aircraft and automobile parts.
4. Making cutting tools.
5. Making fuel tanks of cars, tractors etc.
6. Making wire fabric grids, grills, mesh weld, containers etc.

11.6. Spot Welding

It is the simplest and most commonly used method of overlap welding of strips, sheets or plates of metal at small areas.

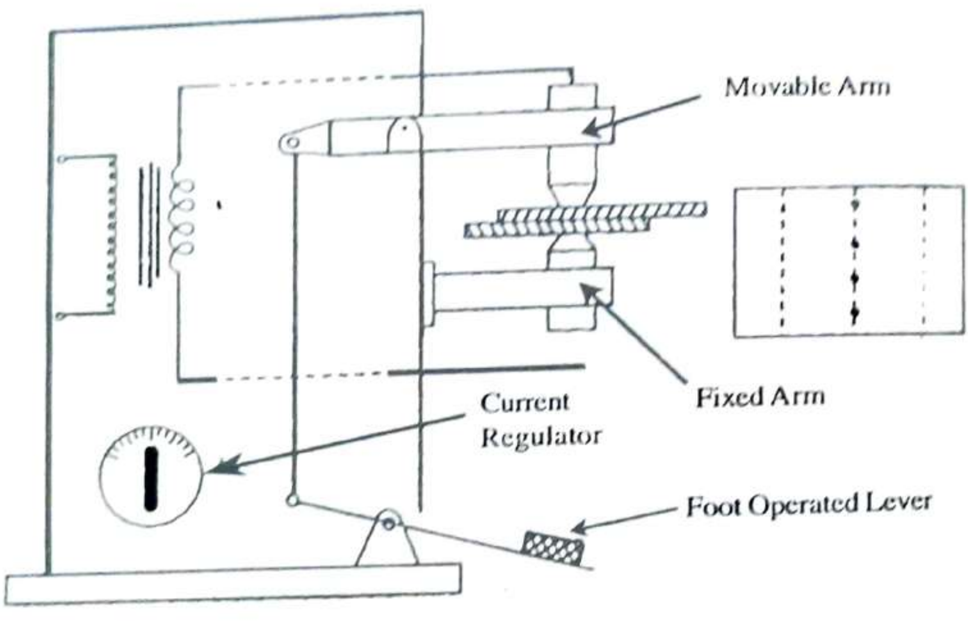


Fig 11.8 : Spot welding machine

In this method sheets of a metal to be welding are held between copper electrode (water cooled) by applying pressure through foot pedal lever. A current of low voltage and sufficient amperage is passed between electrode causing the parts to be brought to welding temperature. The metal under electrode pressure is squeezed and welded. After this the current is turned off while the pressure is still acting. The pressure is applied till the weld cools and produce a solid bond. Now the pressure is released and the work is removed from the machine.

i) No edge preparation is needed.

ii) Low cost.

iii) High speed of welding.

11.6.2 Applications :-

i) This technique is used mostly in thin sheet work like making sheet metal boxes, containers such as receptacles

ii) Thicker metals up to 12.5mm have been successfully spot welded.

iii) It finds application in automobile and air craft industries.

11.7. Thermit Welding

This process besically a fusion welding process in which welding is effected by pouring super heated steel arounds the parts to be welded. In this process neither arc is produced to the parts nor flame is used. In this an exothermic chemical reaction is utilized for developing high temperature.

A mixture of finely divided aluminium and iron oxide called Thermit mixture is kept in crucible hanging over the mould. The thermit mixture is ignited using a megnesium ribbon or highly inflammable poweder having barium peroxide.

The reaction takes about 30 seconds only and heat is liberated which is twice the temperature of melting point of steel. The following reaction takes place as per equation.

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

The resultant is super heated molten iron. The molten iron is made to flow into the mould and fuse with the parts to be jointed.

The Fig. 11.9 shows the method of preparing the mould. The two pieces to be joined are cleaned and gap is left between them. Then wax is poured on the joint and a wax patter is formed. Moulding sand is rammed around the wax patterns and pouring, heating and risering gates are cut. A gas flame is used which melts the wax patterns and at the same time preheats the parts to be welded. Then the preheating gate is plugged with sand.

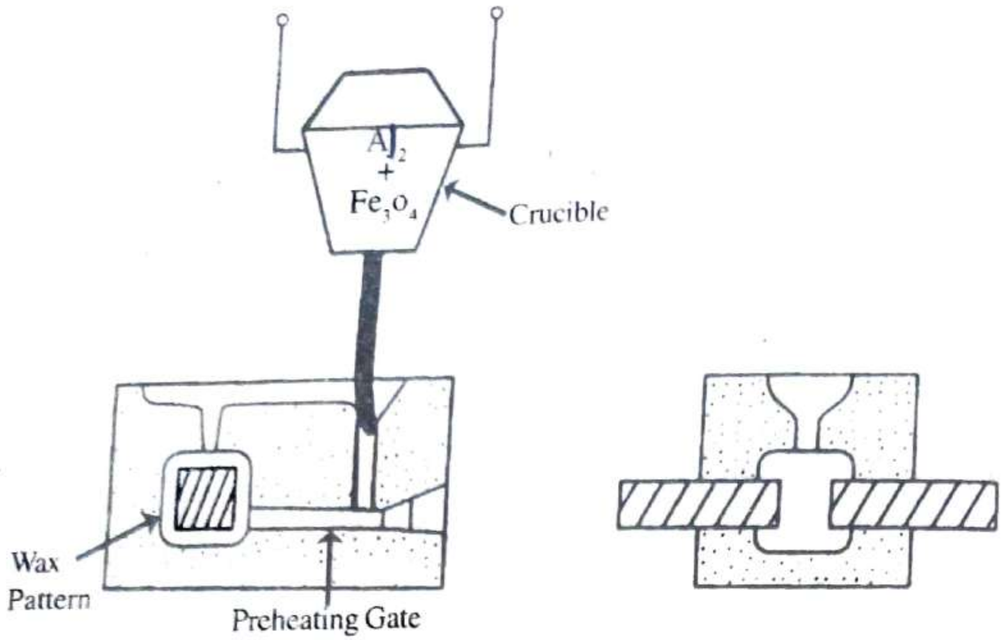


Fig 11.9 : Thermit Welding

11.7.1 Advantages :

i) The welds are sound and free internal residual stresses.

ii) Broken parts can be welded on the site itself.

iii) The heat necessary for welding is obtained from a chemical reaction and thus no costly power - supply is required.

11.7.2 Limitations :

Thermit welding applicable only to ferrous metal parts of heavy sections.

11.7.3 Applications :

It is applicable in the repair of heavy parts such as rail tracks, spokes of driving wheels, broken motor casting, connecting rod etc.

11.8. Plasma Arc Welding :-

Plasma is a flow of ionised gas that is obtained by passing a gas through a high temperature arc which results in spitting the gas molecules to atoms and then to ions and electrons.

In plasma arc welding the arc is created between a tungsten electrode and the workpiece, as in gas tungsten arc welding. However, the plasma arc is constructed by an outer nozzle through which the sheilding gas flows.

Power source used for plasma arc welding is in variably of constant current dc type with an open circuit voltage of 70 to 80 volts and a duty cycle of 60%.

There are two variants of the plasma arc welding process called non-transferred type and transferred type. In the non-transferred type the tungstone electrode is the cathode and the torch tip the anode such a torch is very similar to oxy-acetelene torch as regards its main variability as workpiece is outside the electrical circuit. However, such a plasma arc is less intense compared with the transferred arc wherein the work piece is the anode. The main variabilities of the transferred arc is, however, restricted. But such an arc is very intense and therefore the process results in higher thermal efficiency with consequential higher deposition rates as compared with Gtaw Fig 11.10, Fig 11.11 shows the setups for two modes of the plasma welding arc.

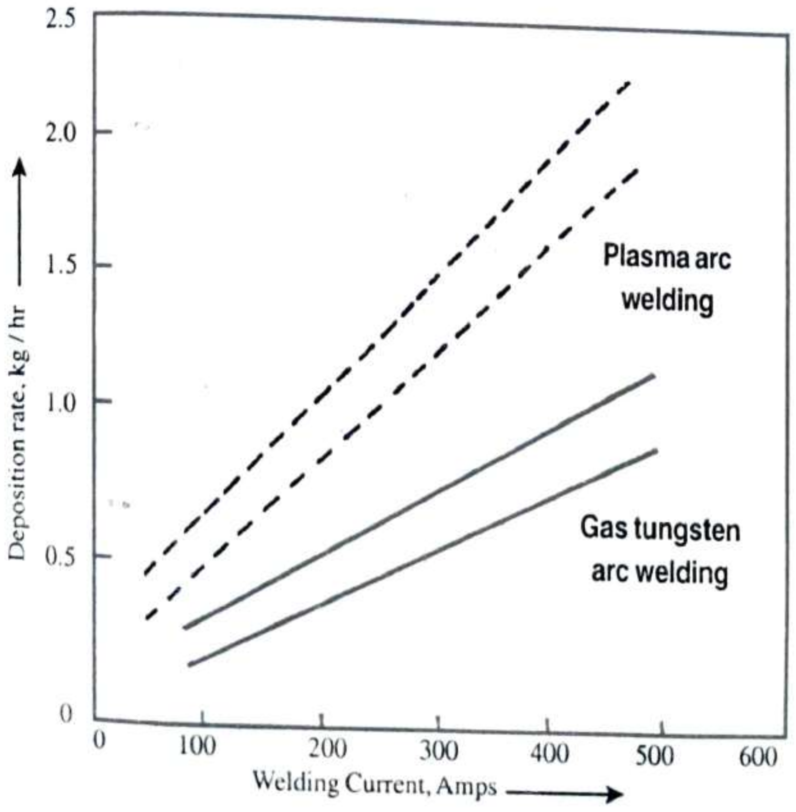
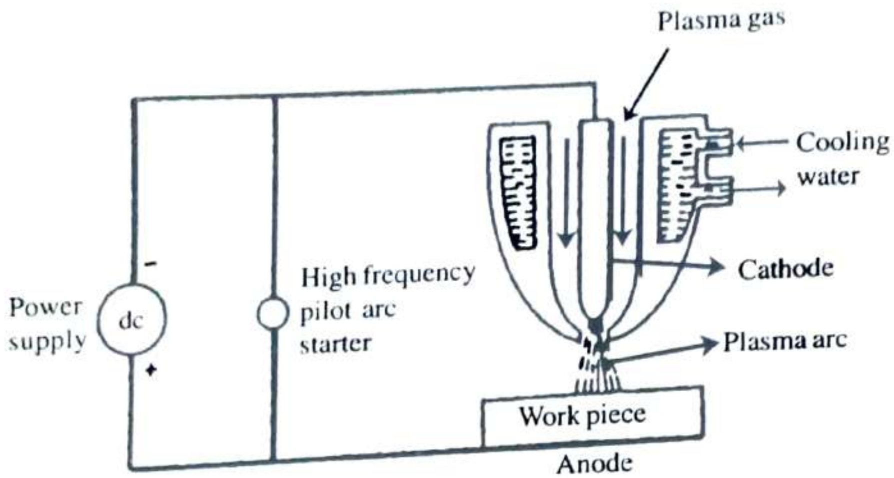
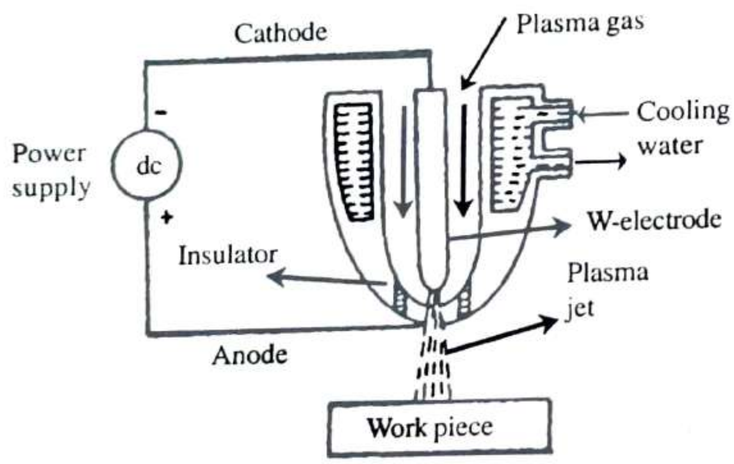


Fig : 11.10 Welding current versus deposition rate of GTAW and plasma arc welding.



(a) Transferred arc



(b) Non-Transferred arc

Fig : 11.11 Two modes of plasma arc welding

Any gas that does not attack the tungsten electrode or the copper nozzle tip can be used for plasma welding. However, argon, and argon-hydrogen mixture are more commonly employed.

11.8.1 Advantages :

Some of the advantages of plasma arc welding in addition to those mentioned under section are listed below :

1. Stability of arc
2. Uniform penetration
3. Simplified fixtures

4. Rewelding of the root of the joint saved
5. It is possible to produce fully penetrated keyhole welds on pieces upto about 6mm thick with square butt joint.
6. Excellent weld quality.
7. Plasma arc welding can produce radiographic quality welds at high speeds.
8. It can weld steel pieces up to about one half inch thick, square butt joint in single run with no filler metal addition.

11.8.2 Disadvantages :

1. Infra - red and ultraviolet radiations necessitate special protection devices.
2. Welders need ear plugs because of unpleasant, disturbing and damaging noise.
3. More chances of electrical hazards are associated with this process.
4. The process is limited to metal thickness of 25mm and lower for butt welds.
5. Plasma arc welding process and equipment are more complicated and require greater knowledge on the part of the welder as compared to TIG welding.
6. Incert gas consumption is high.

11.8.3 Applications :

Plasma arc welding finds applications as follows:

1. Single run autogenous and multi-run circumferential pipe welding.
2. In tube mill applications.
3. Welding cryogenic, aeroscope and high temperature corrosion resistant alloys.
4. Nuclear submarine pipe system (non - nuclear sections, sub assemblies)
5. Welding steel rocket motor cases
6. Welding of stainless steel tubes (thickness 2.6 to 6.3mm)

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13.1 Tungsten-Inert Gas (TIG) Welding :

A Tungsten inert gas welding is shown in Fig 13.1. This process is also known as gas tungsten arc welding (GTAW). It uses a nonconsumable tungsten electrode mounted at the centre of the torch. The inert gas is supplied to the welding zone through operation is done by stricking the arc between the work piece and tungsten electrode in the atmosphere of inert gas.

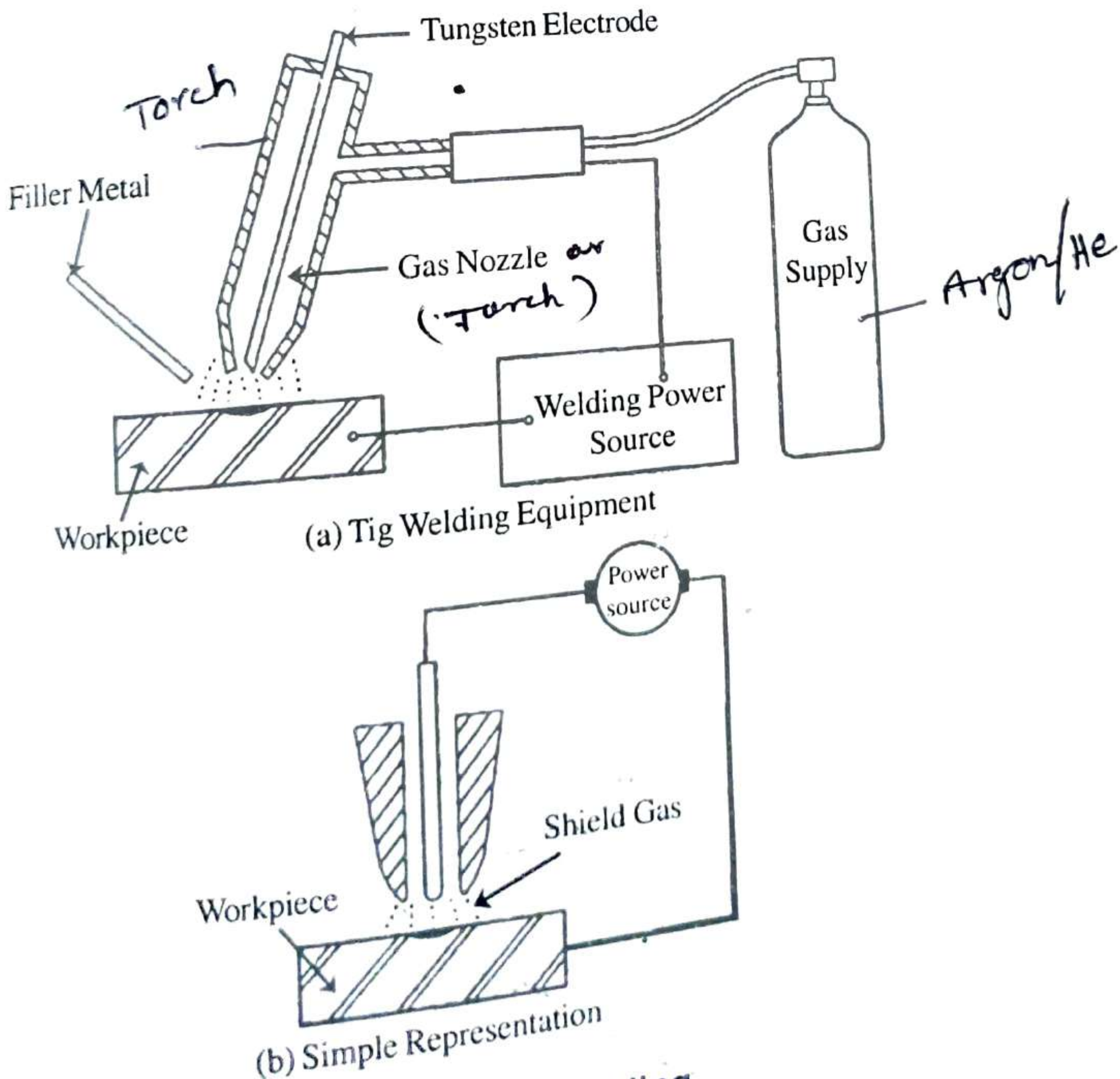


Fig : 13.1 TIG Welding

13.1.1: Advantages :

1. No flux is used so no danger of flux entrapment.
2. Clear visibility of the arc, so better control.
3. It can weld in all positions.
4. High quality welding of thin materials (as thin as 0.125mm).
5. Heat affected zone is very less.
6. Unlike metals can be welded to each other like mild steel to stainless steel, bross to copper etc.

13.1.2: Disadvantages :

1. Tungsten, if transfers can contaminate the weld pool.
2. Filler rod end if be chance comes out of the inert gas shield can cause weld metal contamination.
3. Equipment costs are higher than flux shielded metal arc welding.
4. Electrode is non-consumble, so seperate filler rod is needed, so there is decrease in welding speed.

13.1.3: Applications:

1. Welding of carbon steel, stainless steel, nicked, aluminium. magnesium, brass, copper, bronze, titanium etc.
2. Welding of sheet metal and thinner sections.
3. Used in aircrafts, rocket motor chambers, transistor cases and instrument industries.

13.2: Metal Inert Gas (MIG) Welding: [See Fig 13.2]

MIG welding stands for Metal Inert Gas Welding. In this process, the tungsten electrode is replaced with a consumble electrode. The electrode is continuously fed to the arc at which it is consumed and transferred to the base metal. Arc is shielded by an inert gas, which flows from the holder nozzle through which the electrode also process. It is similar to submerged arc welding in feeding the arc welding in feeding the bare electrode from a reel, it differs in the fact that the shielding is done by an inert gas and the arc is visible during the welding process.

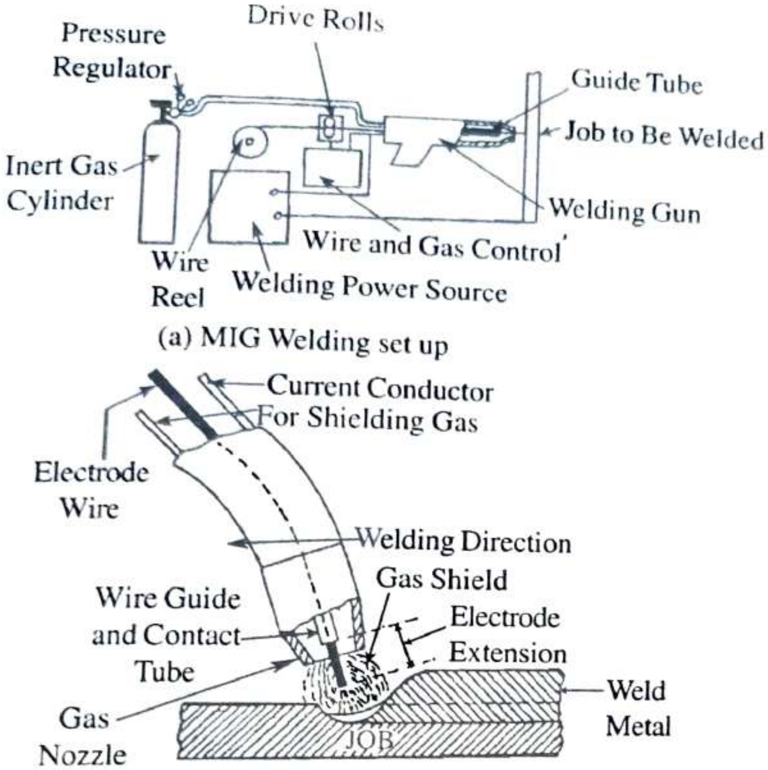


Fig: 13.2 MIG Welding Operation

13.2.1: Advantages:

1. GMAW does not require the high degree of operator skill.
2. Continuous welding at higher speeds and in all positions with deeper penetration is possible.
3. Thick and thin, both types of workpieces can be welded effectively.
4. The process can be easily mechanized.
5. Since no flux is used so more visibility, neatness, cleanliness, spatter free weld.

13.2.2: Disadvantages:

1. Welding equipment is more complex and more costly.
2. The metallurgical and mechanical properties of the joint may be affected due to high cooling rate.
3. It is difficult to weld in small corners.
4. Process variables are more.

13.2.3: Applications:

1. It is suitable for welding variety of ferrous and nonferrous metals.
2. Metal fabrication industries, ship building, automobiles, pressure vessel industries etc.
3. Welding tool steels and dies.

13.3: Friction welding:

13.3.1: Definition:

1. Friction welding is a solid-state welding process wherein coalescence is produced by the heat obtained from mechanically induced sliding motion between rubbing surfaces. The work parts are held together under pressure.

2. Inertia welding is similar to friction welding because both use friction to develop heat. The temperature developed arc below the melting point of the metals being welded but high enough to create plastic flow and intermolecular bonding.

13.3.2: Operational Steps in Friction Welding: [Fig 13.3]

1. The two components to be friction welded are held in axial alignment.
2. One component that is held in the chucking spindle of the machine. is rotated and accelerated to the desired speed.
3. The other component that is stationary and is held in the movable damp is moved forward to come into pressure contact with the rotating component.
4. Pressure and rotation are maintained until the resulting high temperature makes the components metals plastic for welding with sufficient metal behind the interface becoming softened to permit the components to be forged together. During this period metal is slowly extruded from the weld region to form an upset.
5. When sufficient heating has taken place the power drive is uncoupled. a brake is applied to stop rotation and the axial force is usually increased to forge the two components together. This produces further deformation.

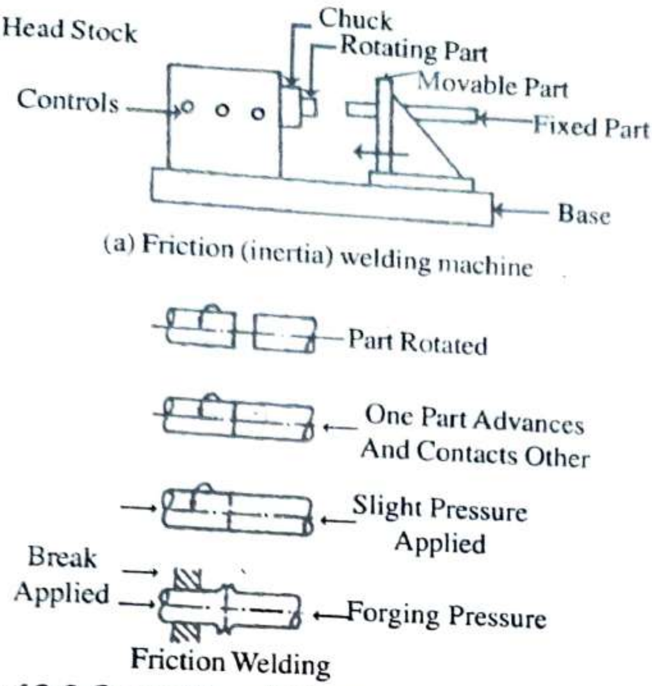


Fig: 13.3 Operational Steps in Friction Welding

13.3.3: Advantages:

1. It is easier process. Any unskilled operator can work on a friction welding machine.
2. The heat generated being small, weld below the melting temperature, so there will be no distortion and warping.
3. Since the joining takes place by diffusion rather than by actual melting, so even dissimilar metals can be joined.
4. The edge cleaning is not a problem, since the oxides and contaminants present would easily be removed during the initial rubbing.

13.3.4: Disadvantages :

1. The use of this process is restricted to flat and angular butt welds where one part is normal to the other part.
2. So far the process has been applied only to the joining of small pieces in the form of bar stock.
3. Sometimes, quite a heavy flash is forced out in all inertia and friction welds.
4. Thrust pressures in inertia welding will range from 700 to 2800 kg/ cm^2, which requires a heavy rigid machine.

13.3.5: Applications :

i) It is used in aerospace industries, automobile industries.

ii) Production of cutting tools etc.

13.4: High Frequency Induction Welding :

High frequency induction welding of tubes is similar to high frequency resistance welding except that the heat generated in the work material is by the current induced into it. Because there is no electrical contact with the work this process can be used only where there is a complete current path or closed loop wholly within the work. The induced current flows not only through the weld area but also through other portions of the work.

A Water - cooled induction coil or inductor made of copper encircles the tube at the open end of the vee as shown in Fig 13.4. High frequency current flown through the coil induces a circulating current around the outside surface of the tube and along the edges of the vee, heating them to welding temperature. Pressure is applied to accomplish the weld.

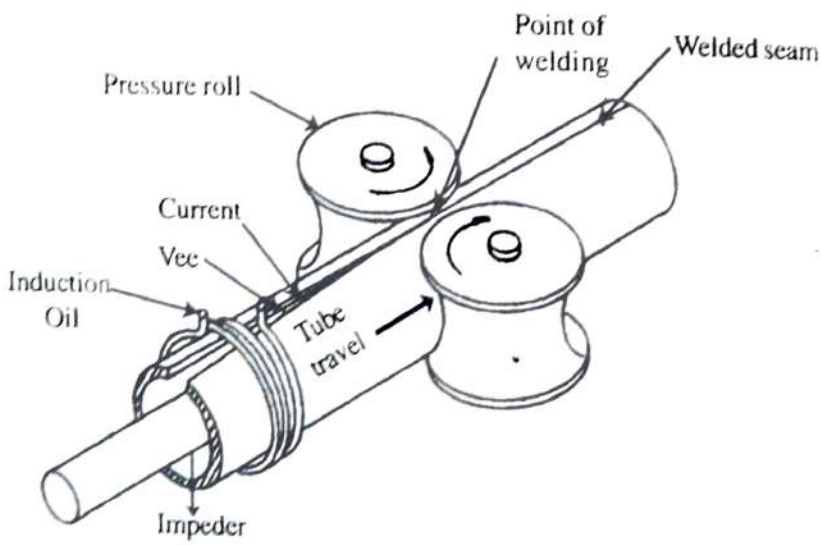


Fig 13.4 : HFIW Process of tube Manufacturing

13.4.1: Advantages :

The process can as well be advantageously used for manufacturing tubing from coated material, small or thin-walled tubing; and it eliminates surface marking by electrical contacts.

13.4.2: Disadvantages :

This process is, however, not suitable for welding high conductivity metals or those which form refractory oxides as there is no effective mechanism for oxide disposal.

13.4.3 : Applications :

HFIW process is suitable for tubing made of any metal within a diameter range of 12 to 150 mm with a wall thickness of 0.15 to 10 mm at a welding speed ranging between 5 and 300 m/min.

HFIW process is not limited to tube manufacture but can also be employed to make circumferential welds for welding cap to tube.

13.5 : Explosive welding :

In this process the weld joint is made with high relative velocity at a high pressure using high explosives. As the plate moves at high velocity and meets the other plate with massive impact, high stress waves created between the plate. Which clears all the oxides and scales present in the interface and make a clean joint. Explosive welding eliminates the problems associated with fusion welding methods such as the heat affected zone etc. Generally low detonation velocity explosives are used in explosive welding. The detonation velocity is depends on the thickness of the plate being welded.

Fig 13.5 illustrates the two common setups used in explosive welding. It contains four basic components. 1) Target plate 2)`flyer plate 3) Buffer plate 4) Explosive and a detonator

The target plate is fixed is an anvil of large mass. When the explosive is detonated. It thrusts the flyer plate towards the target plate. To protect the flyer plate from surface damage due to impact, a thin layer of rubber or PVC sheet is placed between the flyer plate and the explosive. The explosive may be in sheet form or granular form which is spread uniformly over the buffer plate. Welding is completed in microseconds.

13.5.1: Advantages :

i) Simplicity of the process.

ii) Extremely large surface can be bonded.

iii) Welds can be produced on heat - treated metals without affecting their microstructures.

iv) Wide range of thicknesses can be explosively clad together.

v) Explosive bonds have a solid state joint that is free from heat effected zone.

vi) Lack of porosity, phase changes and structural changes impact better mechanical properties to the joints.

13.5.2: Disadvantages :

i) In industrial areas the use of explosives will be severely restricted by the noise and ground vibrations caused by explosion.

ii) The regulations relating to the storage of explosives and the problem of preventing them from falling into unauthorized hands may well prove to be the main obstacle to the use of explosive and welding.

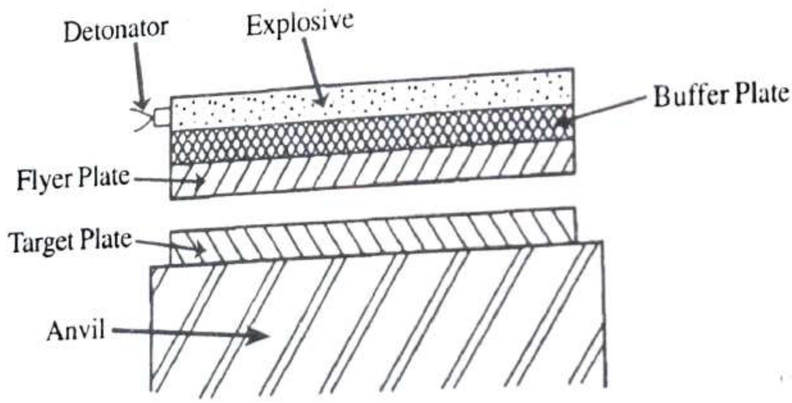
iii) Metals harder than about 50 RC are extremely difficult to weld.

iv) Metal thickness greater than 62 mm of each alloy cannot be joined easily and require high explosive loads.

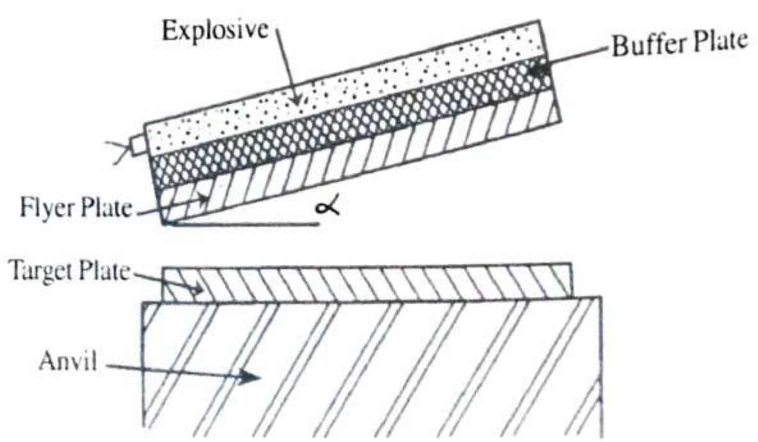
v) Materials such as beryllium, tungsten, boron, glass and ceramics are not normally processed by explosive welding.

13.5.3: Applications :

It is used in lap joints. Aluminium and Copper can be welded to stainless steel, aluminium to nickel alloys, tungsten to steel to nickel. Cladding of plates is one of the major commercial applications.



(a) Parallel Stand Off



(b) Angular Stand Off

Fig : 13.5 Explosive Welding

13.6 : Laser Beam Welding :

The name Laser is acronym (word made up of initial letters) meaning light amplification by stimulated emission of radiation.

The basic function of laser is to amplify light energy. White light consists of all colours of the spectrum. Each having particular wave length. Only a part of the colour band is used. The laser at present is usable to convert more than 1% of given energy into a usable beam. One of the laser uses a cylindrical ruby crystal as depicted in fig. 13.6. Ruby is aluminium oxide with chromium despersed throughout forming about 1/2000th of the crystal. The crystal is optically worked to very fine limits (microns) to keep the true form and square ends. The ends are silvered to form mirrors internally, while one end has a tiny hole in the silver layer through which the laser beam emerges. Around the outside of the crystal is placed an electronic flash tube. This contains the inert gas xenon and when this is subjected to an electric discharge from a capacitor, the gas transforms a high proposition of the electrical energy into white light. The flash has only a short duration (about 1/1000 Sec.)

The intense light flash excites the chromium atoms of the crystal, pumping them to high energy level. Some of the energy out of this is lost as heat, but the light photons are reflected repeatedly from one mirror to the other mirror at the two ends of the ruby crystal, increasing the exitation of the chromium atoms still further, till they all lose their extra energy simultaneously, to form a narrow beam of coherent red light, which leaves the crystal through the small hole in the mirror at one end of the crystal.

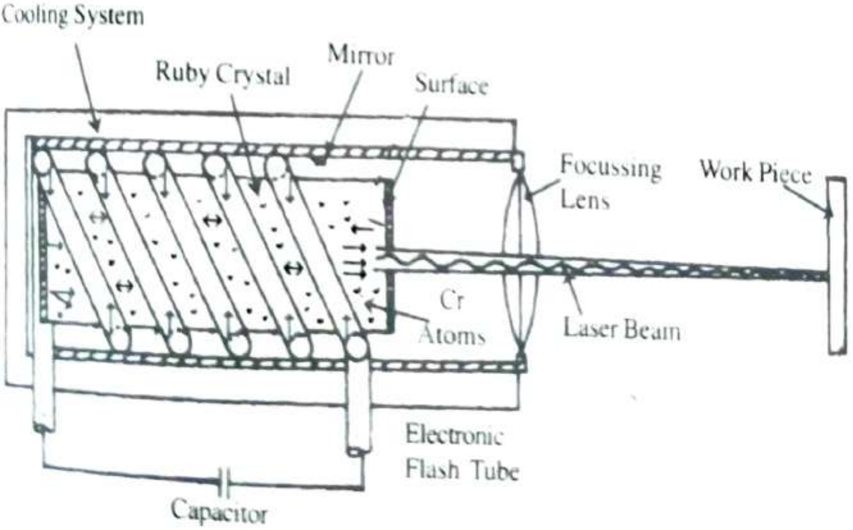


Fig . 13.6 : Laser Beam Welding

The stimulated emission takes place in about a millionth of a second. The beam of red light is very narrow and also it does not spread or diverge, so that it can be easily focussed by an optical lens to a pinpoint area thus producing a power density to nearly 0.15x10w/cm^2 capable of vaporizing diamonds, metals or refractory substances. By suitable focussing, the control of melting for welding can be done. In case of ruby laser, the energy obtained from it is not continuous but is a succession of pulses as the crystal is pumped with light energy. Red light is absorbed by metals up to 100^{0}A of the surface. The concentrated energy of laser beam is similar to that of an electron beam. But where as in electron beam, the heat is transferred by electron penetration in laser beam the heat is transferred by conduction.

13.6.1 : Advantages :

i) Deeper penetration welding can be done even with dissimilar metals.

ii) Heat affected zone is very less.

iii) This process reduces the roughness of the welded surface.

iv) No vacuum is required as in electron beam welding.

v) Welds can be made inside transparent glass of plastic housings.

vi) Because it is light, it can be focussed to microscopic dimensions and directed with great accuracy.

13.6.2 : Disadvantages :

i) Slow welding speed.

ii) Laser is dangerous for the operators eyes.

iii) Laser welding is limited to depth or approximately 1.5mm only.

13.6.3 : Applications :

i) It can be used for joining multi layer materials with different thermal properties.

ii) It can be used for cutting as well as welding.

iii) It can join wire to wire, sheet to sheet, wire to sheet etc.

iv) It is used for the welding of copper, nickel, aluminium, titanium, tungsten, zirconium etc.

Chapter 14

Welding Defects & Testing of Welds

14.1 : Defects In Welding

Many types of defects can be produced in welding. The following defects are more Common) (fig : 14.1)

14.1.1 Lack of Penetration : Lack of weld metal actually entering the parent metal

i) Caused by too long an arc length

ii) Prevented by use of proper welding current for electrode use of large size nozzle in gas welding and slower welding speeds

14.1.2 Under Cut : Groove formed along the edges of welding bead there by reducing the thickness of base metal

i) Caused due to excessive current, excessive speed and wrong electrode position

ii) To prevent this defect, reduce welding current or arc length, alter the angle of electrode. In gas welding use a smaller size nozzle with improved techniques i.e. better control over nozzle and filter rod

14.1.3 : Slag Inclusion : An entrapment of slag or other foreign matter actually inside the weld metal

i) Caused due to inadequate slag removal between runs or electrode replacement.

ii) To prevent slag inclusion, use undamaged coated electrodes. For gas welding keep tip of inner flame cone out of weld pool. Clean base metal and improve welding techniques.

Testing and Inspection is carried out after the jobs have been welded. with a view to

1) Access the properties and quality of the welded joints

2) Access the suitability of the weldment for the intended purpose

All forms of testing and inspection of welds after fabrication can be groped into two basic categories namely

i) Destructive Testing

ii) Non- destructive Testing

14.3 : Destructive Testing of Welds :

Destructive tests are applied to samples representative of the welded joint under review, often made specially for test purpose. In a destructive test, the test piece or specimen is destroyed, in most cases by fracturing after destructive testing the specimen remains no longer useful for further use

The most Commonly used mechanical tests are

1) Tensile Test

2) Compression Test

3) Shear Strength test

4) Bend Test

5) Hardness test

6) Izard impact test

14.3.1 :Testing test :

This is the most Commonly used test for indicating the strength and ductility of a metal. Ductility is the property of a material that enables it to be drawn into wires , involving the use of tensile force. The tensile test is carried out on a tensile testing machine. The tensile testing machine consists of two main parts :

a) The straining device and

b) Load measurement device the straining device is either electrically operated or a plunger may be subjected to oil pressure.

14.4.2: Magnetic particle inspection :

It is used to check surface flows in materials which can be magnetized. The surface to be inspected is coated with a liquid (fine oil) solution containing very tiny coloured magnetic particles, and is then subjected to magnetic field created by either passing a current through it or containing at or near the surface on magnetization creates a local north south and magnetic pole, and attracts the metallic field, the flaws in the solution. On removal of magnetic field, the flaws are detected by concentrations of magnetic particles.

Since best results are obtained when magnetic field flux lines are perpendicular to the crack the object is tested by magnetizing twice, creating magnetic fields at 900 to check all flaws.

UNIT - III

Bulk Forming.

16.1 Introduction :

A component can be produced either by using machining and casting process or by the application of external forces. Shaping of a component by the application of external forces is known as the metal forming process. Metal forming can be described as a process in which the desired size and shape are obtained through the deformation of metals plastically under the action of externally applied forces. Owing to the larger magnitudes of the forces involved, these processes, are also known as bulk deformation processes. Few authors call these processes as plastic working because it involves the deforming of materials in the plastic state.

Typical example of the metal forming process, which is familiar to everyone, is forging operation. You must have seen a blacksmith hammering a heated piece of iron to give it a required shape. In this case, blacksmith is applying compressive forces for shaping the material, which is heated to make it soft. The process of metal forming is carried out on machines called metal forming machines. Metal forming process can be carried out in hot or cold condition.

16.2 Types of Mechanical Working of Metals :

There are two types (i) cold working (ii) hot working. If the mechanical working of metals is carried out above the recrystallisation temperature it is known as hot working and if it is carried out below the recrystallisation temperature it is known as cold working of metals. There crystallisation temperature for steel is 800°C.

16.3 Hot Working :

In hot working of metals the shaping operations are conducted above the recrystallisation temperature. An increase in temperature of metal leads to an

16.3.1 Advantages :

Hot working of metals has the following advantages:

1. At high temperature the metal is soft, plastic and is easily formed and power required for shaping process is less as compared to cold working of metal.

2. A refinement in grain structure is achieved. The grain structure of the metal ingot when it is cast is not uniform. Hot working of metal causes a replacement of original grain structure by one of a more uniform nature. Recrystallisation takes place and strain hardened grains are refined.

3. It welds up cracks and removes porosity in metals.

4. Properties like toughness, ductility, elongation percentage are improved.

5. Thick section can be easily brought into shape without damaging the structure.

6. The ultimate tensile strength, yield point, hardness and resistance to corrosion is not affected in hot working whereas ultimate tensile strength, yield point, and hardness are increased and resistance to corrosion is decreased by cold working.

16.3.2 Disadvantages :

1. It gives poor surface finish and close tolerances cannot be maintained.
2. Expensive tools are needed to work with metal at high temperature.
3. Handling of heated metals is expensive and difficult.
4. It requires a heating device.

16.4 Cold Working

It is defined as any form of mechanical deformation process carried out on the metal below its recrystallisation temperature. Most of the cold working processes are carried out at room temperature. During cold working the grain structure changes. The metal gets deformed and the deformation produced in the metal is brought about only after stress exceeds the elastic limit. Severe stresses known as residual stresses are developed in the metal during cold working. Such stresses are quite harmful and can be removed by suitable heat treatment such as annealing. Cold working can be performed only on a few metals and alloys.

16.4.1 Advantages :

1. Cold working helps to attain better dimentional accuracy.
2. It produces smooth surface finish.
3. Cold working increases the strength, elasticity and hardness of metal parts worked.
4. Small parts may be shaped rapidly and at a lower cost than by most of the other methods.

16.4.2 Disadvantages :

The various disadvantages of cold working are as follows:

1. Some parts cannot be cold working because they are too brittle.
2. It requires to much energy to cold work large sections of most of the metals.
3. Propagation of cracks has greater changes in comparison to hot working.

16.5 Differences between Hot Working and Cold Working :

Hot Working	Cold Working
1. Hot working is done at a temperature above recrystllisation but below its melting point. It can therefore be regarded as a simultaneous process of deformation and recovery. 2. Hardening due to plastic deformation is completely eliminated by recovery and recrystallisation 3. Mechanical properties such as elongation, reduction of area and impact values are improved. Ultimate tensile strength, yield point, fatigue strength, hardness are not affected by hot working.	1. Cold Working is done at temperature below recrystllisation temperature. So no appreciable recovery can take place during deformation. 2. Hardening is not eliminated since working is done at a temperature below recrystallisation. 3. Cold working decreases elongation, reduction of area. Increases ultimate tensile strength, yield point and Hardness. 4. Good surface finish is obtained. 5. Crystallisation does not occur. Grains are only elongated.

Hot Working	Cold Working
4. Surface finish of hot worked metal is not nearly as good as with cold working because of oxidation and scaling. 5. Refinement of crystals occurs. 6. Cracks and blowholes are welded up. 7. Internal or residual stresses are not developed in the metal. 8. Oxide forms rapidly on metal surface. 9. Less force is required. 10. Equipment used in hot working is light. 11. Handling and maintenance of hot metal is difficult and troublesome. 12. Hot working processes: a) Hot forging b) Hot rolling c) Hot spinning d) Hot extrusion e) Welded pipe and tube manu facturing f) Roll piercing g) Hot drawing	6. Possibility of crack formation and propagation is great. 7. Internal and residual stresses are developed in the metal. 8. Cold parts posses less ductility. 9. Higher forces are required for deformation. 10. More powerful and heavier equipment's are required for cold working. 11. Easier to handle cold parts. 12. Cold working processes: a) Cold rolling b) Cold extrusion c) Press work i) Drawing ii) Squeezing iii) Bending iv) Shearing

16.6 Recovery :

It is the initial stage in which internal stresses are eliminated and there is not appreciable reduction in strength and hardness. Further, it will not effect the structure.

16.7 Recrystallisation :

A cold worked metal is in a state of considerable stress because during cold working the grains are distorted and broken up thus resulting in an unhomogeneous structure which contains high residual stresses. For this reason the material is often heated to a sufficiently high temperature to get strain free grains. The softened material so obtained will have approximately original structure and will be capable of further deformation.

Formation of new grains is called recrystallisation. The crystallisation does not produce new structures but produces new crystals of the same structure.

16.8 Recrystallisation Temperature :

When a metal is heated to high temperature after being cold worked, new equiaxed, unstrained crystals will be formed. This temperature is called a recrystallisation temperature. Recrystallisation temperature greatly depends on the degree of cold work which the material has undergone and severe cold work results in a lower crystallisation temperature. Recrystallisation temperature is lowest of pure metals and is generally raised by the presence of other elements. Recrystallisation temperature is different for different conditions in same metal. Recrystallisation temperature for some of the metals is shown in table.

Metal	Recrystallisation Temperature
Lead	0^0C
Tin	0^0C
Gold	200^0C
Copper	200^0C
Aluminium	150^0C
Iron	450^0C
Nickel	620^0C
Platinum	450^0C
Magnesium	150^0C
Tungsten	1200^0C
Zinc	Room Temperature

16.9 Grain Growth :

Grain growth results due to further increasing the temperature or keeping the structure at high temperature for longer duration. Large grain size metals are highly ductile but of low strength and hardness. Therefore coarse grains are not desirable in the final structure.

16.10 Stages of Recovery, Recrystallisation and Grain Growth :

Recrystallisation follows recovery:

The grain size after recrystallisation depends on the amount of cold work prior to recrystallisation. The greater the amount of cold work the finer the resulting grain size. However, smaller (but greater than minimum) deformation results in large grain size. The effect of these of these stages are illustrated in Fig 16.1

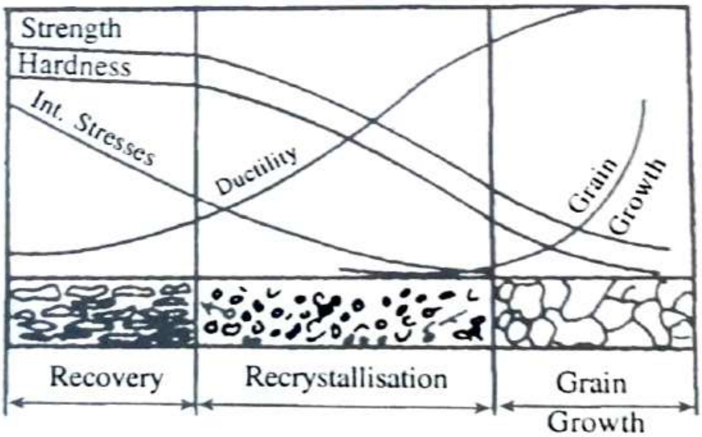


Fig.16.1

16.11 Work Hardening or Strain Hardening :

(i) Strain hardening or work hardening is a phenomenon which results in an increase in hardness and strength of metal (specimen) subjected to plastic deformation (cold working) at temperatures lower than the crystallisation range.

(ii) An important characteristic of plastic deformation of metals is that the shear stress required to produce slip continuously increases with shear strain.

This increased in the stress required to cause slip because of previous plastic deformation or the increase of strength of material due to mechanical working is known as strain hardening or work hardening.

(iii) Strain hardening is very commonly employed both on pure metals and on alloys, as a means of improving the useful mechanical properties such as strength and hardness.

(iv) Strain hardening, however, reduces ductility (formability) and plasticity.

(v) The principle of work hardening can be illustrated by considering the stress - strain diagram of Fig.16-2

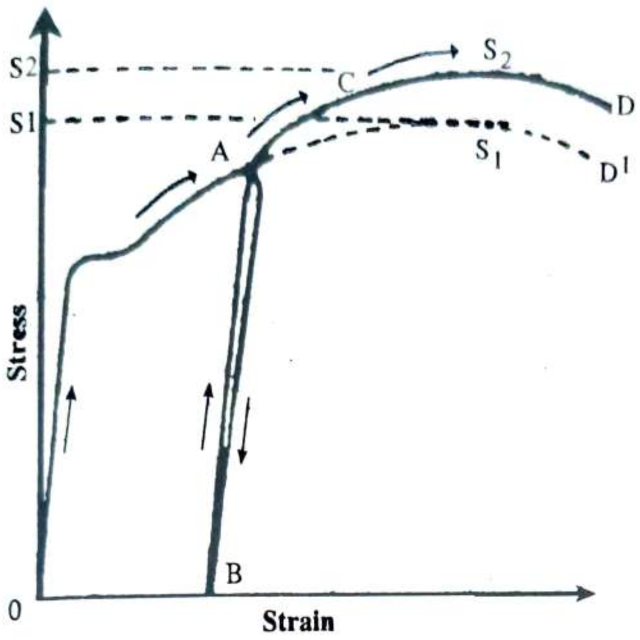


Fig.16-2 Work Hardening

(vi) When loaded, the strain increases with stress and the curve reaches point A in the plastic range. If at this stage, the specimen is unloaded, the strain.does not recover along the original path Ao, but moves along AB. If the specimen is reloaded immediately, the curve again rises from B to A, but via another path and reaches, the point C, after which it will follow the curvature, if loading is continued.

If the specimen would not have been unloaded, after point A, the stress - strain curve would have followed the dotted path AD|.

A comparison of paths ACD and AD| show that the cold working (plastic deformation) has increased the yield strength and ultimate strength. (S2 > S1) of the metal.

Theory of Work Hardening :

Naturally, the stress (T) necessary to move a dislocation in the stress field of other dislocations surrounding it, will have to have a higher value; that is why the curve ACD (Fig.16-2) is above that AD|, and the value of S_2 greater than that of S_1.

17.2 Rolling Operation :

In this process, the ingot (piece of metal to be rolled) is passed through two rolls rotating in the opposite directions at a uniform peripheral speed. The space between the rolls is adjusted to confirm to the desired thickness of the rolled section. The rolls squeeze the ingot and it comes out of the rolls, its thickness or cross-section is reduced and its width and length are increased.

The structural changes that occur in the material during the rolling process are illustrated in Fig.17-1. Because of squeezing, the grains are elongated 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 start refining in the case of hot rolling. In the cold rolling, grains retain the shape acquired by them during rolling.

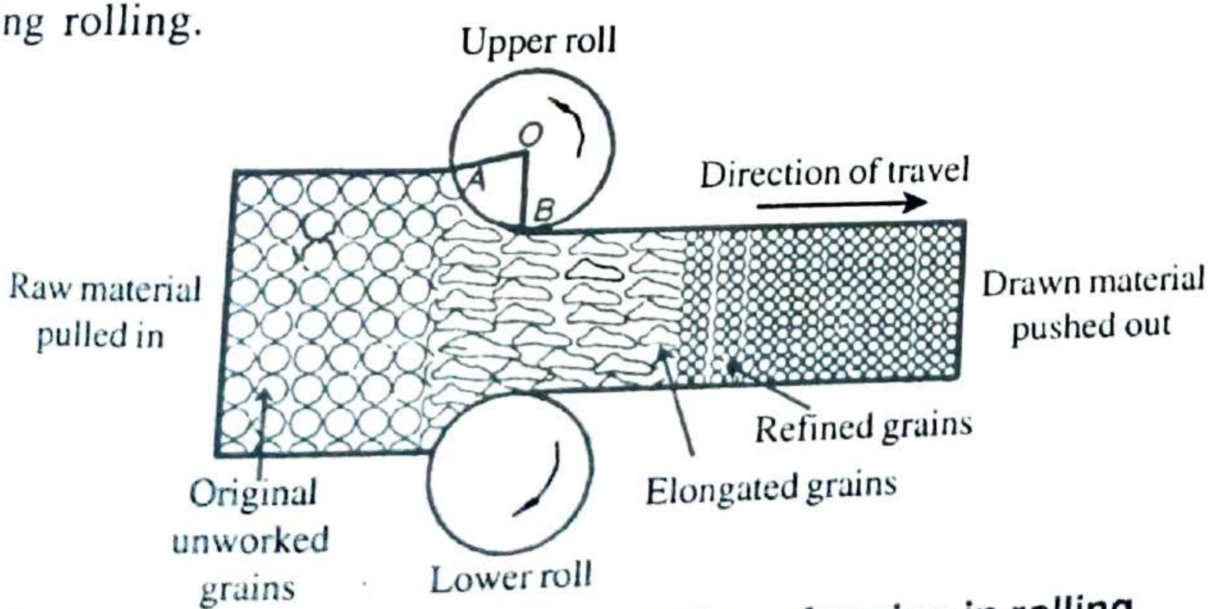


Fig.17.1 Rolling process and deformation of grains in rolling

17.3.5 Sheet :

A sheet is a thin portion of plate with a maximum thickness of 6.35mm

17.3.6 Strip :

A strip is a narrow sheet and has a maximum width of 600mm with a maximum thickness of 6.35mm. Since it is normally handled in coil form, its length can be considerable and is limited only by the manufacturing and handling facilities.

17.3.7 Foil :

It is a thin strip with a maximum width of 300mm and a maximum thickness of 1.5mm. It is a available in coil form.

17.3.8 Bar :

It is a long, straight, symmetrical piece of uniform cross-section. It may be round, square or of another configuration. A circular bar is called a rod.

17.3.9 Wire :

A wire is a thin variety of bar, available in coil form and not normally so identified over 9.5mm cross-section.

17.4 Types of Rolling Mills :

The arrangement of rolls at a rolling station is called a rolling mill. Rolling mills are commonly of the following types :

1. Two high rolling mill
2. Three high rolling mill
3. Four high rolling mill
4. Continuous mills
5. Planetary rolling mills
6. Universal rolling mills

17.4.1 Two-high Rolling Mill :

It consists of two heavy horizontal rolls, placed exactly one over the other. The rolls are supported on bearings housed in study upright side frames, called stands. The space between the rolls can be adjusted by raising or lowering the upper roll. The position of the lower roll is fixed. Both the rolls rotate in opposite directions to one another, as shown in Fig.17-2. Their direction of rotation is fixed and cannot be reversed. Thus, the work can be rolled by feeling from one direction only.

There is another mill of two-high mill which incorporates a drive mechanism that can reverse the direction of rotation of the rolls. This facilities rolling of the workpiece continuously through back-and-forth passes between the rolls. This type of rolling mill is known as a two high reversing mill. They are normally employed for the initial rolling of an ingot.

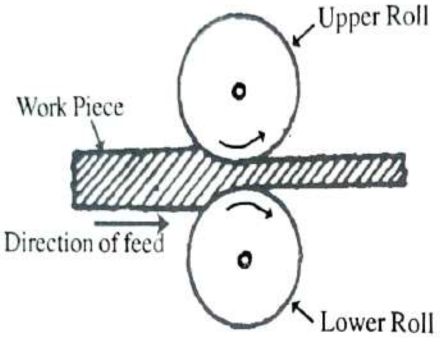


Fig.17.2 : A Two High Mill

17.4.2 Three High Rolling Mills :

It consists of three horizontal rolls, positioned directly one over the other, as shown in Fig.17-3. The directions of rotation of the upper and lower rolls re the same, but the intermediate roll rotates in a direction opposite to both of these. All the three rolls reversed. The work piece is fed in one direction between the upper and middle rolls and in the reverse direction between the middle and lower rolls. Many pieces may be passed through the rolls simultaneously. This results in a higher rate of production than the two-high mill. This mill may be used for blooming, billet rolling or finish rolling.

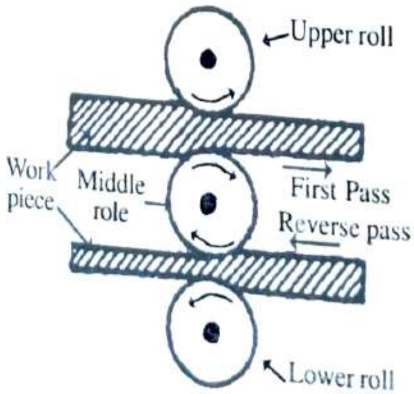


Fig.17.3 : Roll positions in a three-high rolling mill

17.4.3 Four High Rolling Mills:

It consists four horizontal rolls, two of smaller diameter arranged directly one over the other as shown in Fig.17-4. The larger diameter rolls are called back-up rolls and their main function is to prevent the deflection of the smaller rolls, which otherwise would result in thickening of rolled plates or sheets at the centre. The smaller rolls are known as working rolls and they are the rolls which concentrate the total rolling pressure over the metal. These mills are generally used for subsequent rolling of slabs. The common products of these mills are hot or cold rolled sheets and plates.

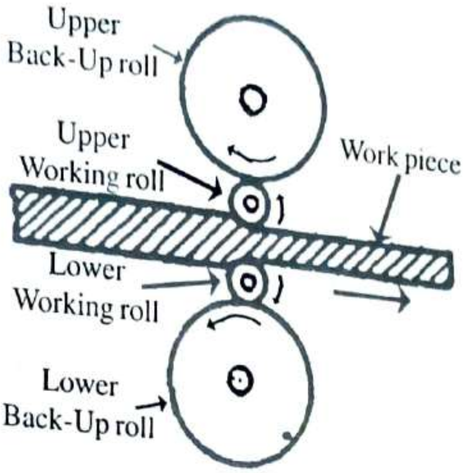


Fig.17.4 : Arrangement rolls in a four-high rolling mill

17.4.4 Cluster Mill :

It consists of two working rolls of smaller diameter and four or more back-up rolls or larger diameter. The arrangement of rolls for this mill is shown in Fig.17-5. The number of back-up rolls may go up as high 20 or more, depending upon the amount of support needed for the working rolls during the operation. This type of mill is generally used for cold rolling.

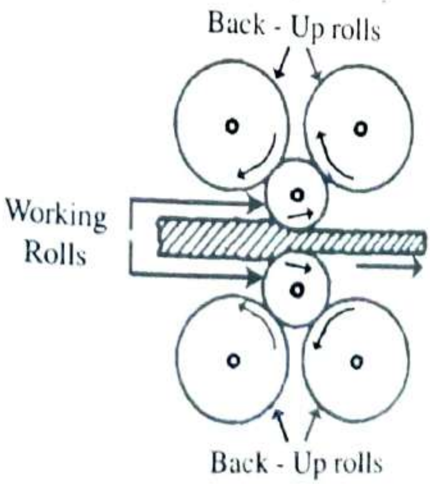


Fig.17.5 : Arrangement of rolls in a cluster mill

17.4.5 Continuous Rolling Mill :

This is also known as tandem mill. Continuous mill is commonly used for the high production. Each set of rolls is called as stand or rolling mill stand. The continuous mill is shown in Fig.17-6

Since a different reduction takes place at each stand, the strip will move at different velocities at each stage in the mill. Thus, the rolls at stand 2 should run at exit velocity of material at stand 1 and rolls at stand 3 should run at exit velocity of material at stand 2 and so on. The speed of each set of rolls must be synchronized so that each successive stand takes the strip at a speed equal to the delivery speed of the preceding stand. The uncoiler and the windup reel accomplish the functions of feeding the stock of the rolls and coiling up the final product.

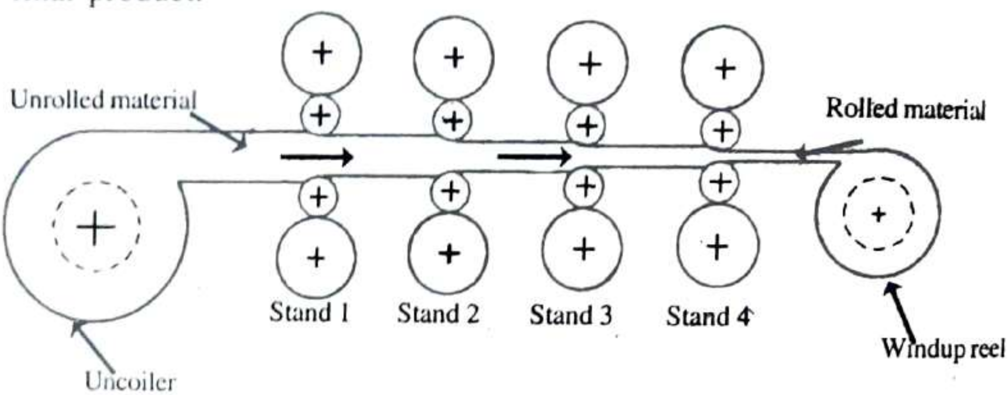


Fig.17.6 : Continuous rolling mill with four rolling mill stands

17.4.6 Planetary Rolling Mill :

Planetary rolling mill is used to reduce slabs to coiled hot rolled strips in a single pass. The work piece material is passed through the planetary mill having multiple rollers of small diameter backed up by a larger roll and equispaced on its periphery. The smaller rolls revolve about the axis of the larger roll as planets revolve around the sun. The mill is shown in Fig.17-7.

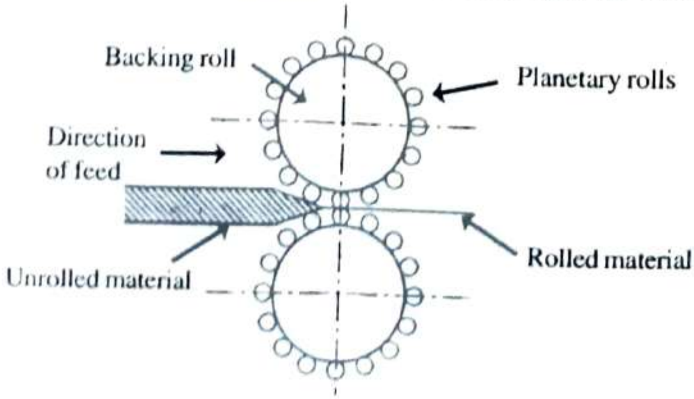


Fig.17.7 : Planetary rolling mill

17.4.7 Universal Rolling Mill :

Universal mill consists of two pairs of rolls, axes of one pair are horizontal and the axes of other pair are vertical, mounted on a common roll stand. The horizontal rolls roll the material as in a two-high rolling mill and vertical mill does the function of giving a perfect edge to the rolled product. This type of rolling mill is used for the rolling of beams, I-section, and plate products that require rolled (finished) edges. This type of rolling mill is illustrated in Fig.17-8.

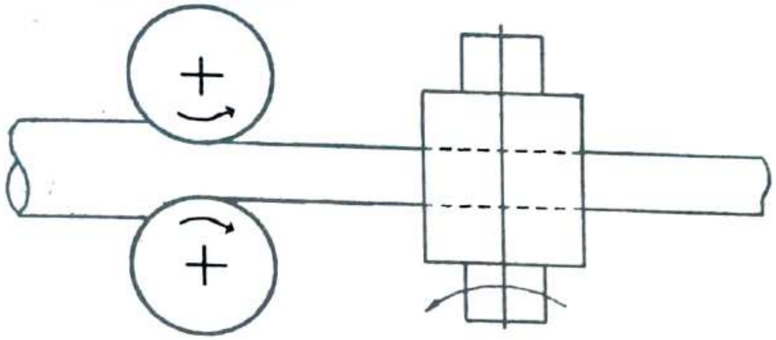


Fig.17.48 : Universal rolling mill

17.5 Forces In Rolling :

17.5.1 Frictional Forces:

The rolls pull the material into the roll gap through a net frictional force on the material. It can be seen that this net frictional force must be to the right in Fig.17-9; consequently, the frictional force to the left of the neutral point must be higher than the friction force to the right.

Although friction is necessary for rolling materials, energy is dissipated in overcoming friction; thus, increasing friction means increasing forces and power requirements. Further more, higher friction could damage the surface of the rolled product. A compromise has to be made, one which induces low coefficients of friction by using effective lubricants.

The maximum possible draft, defined as the difference between the initial and final thickness, $(h_0 - h_f)$ is a function of the coefficient of friction, m, and the roll radius, R:

$$h_0 - h_f = \mu^2 R \quad \text{\_ \_(I)}$$

Thus, the higher the friction and the larger the roll radius, the greater the maximum possible draft (and reduction in thickness) becomes. This situation is similar to the use of large tires (High R) and rough tires (high, μ) on form factors and on off-road earth-moving equipment, which permit the vehicles to travel over rough terrain without skidding.

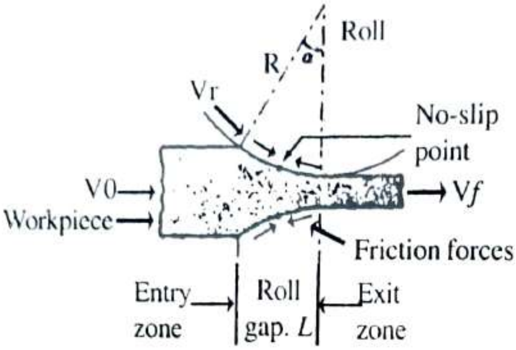


Fig.17.9 : Friction forces acting on strip surfaces

17.5.2 Roll Force :

Because the rolls apply pressure on the material in order to reduce its thickness, a force perpendicular to the arc of contact (Fig.17-10) is needed. Note, in Fig 17.10 that this roll force, F, is shown as perpendicular to the plane of the strip rather than as at an angle. This alignment is used because the arc of contact is generally very smaller compared to the roll radius, so we can assume the roll force to be perpendicular without causing significant error.

The roll force in flat rolling can be estimated from the formula

$F = LWY_{avg}$, ... (II)

Where L is the roll-strip contact length, W is the width of the strip, and Yavg is the average true stress of the strip in the roll gap. Equation (II), ideally, is for a frictionless situation. The higher the coefficient of friction is between the rolls and the strip, the greater becomes and divergence, and the formula predicts a lower roll force than the actual force.

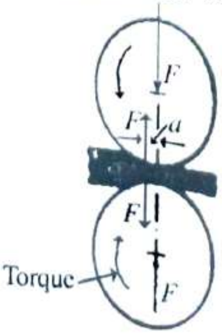


Fig.17.10 : The roll force, F, and the torque acting on the rolls

17.5.3 Roll Power :

The power required per roll can be estimated by assuming that the force F acts in the middle of the arc of contact: In Fig 17.10 a = L/2. Torque per roll is the product of F and a. Therefore, the power per roll in S.I. Units is

$$\text{Power} = \frac{2\pi LFN}{60{,}000\text{KW}}$$

Where F is in Newtons, L is in meters, and N is the rpm of the roll.

Summary

In a single stage drawing operation, a cup may be obtained of a diameter from 1.8 to 2 times less than that of the initial that blank. Upon more deformation, the drawing force required increases to such an extent that the metal is ruptured. A further reduction in cup diameter is possible only by subsequent forming operation called redrawing.

19.2 Wire Drawing :

Wire is made by cold-drawing hot rolled wire rod through one or more dies as shown in fig 19.2 to decrease it size and increase the physical properties.

The wire rod is rolled from a single billet and cleaned in an acid to remove scale, rust and immersed in a lime solution to neutralize the acid.

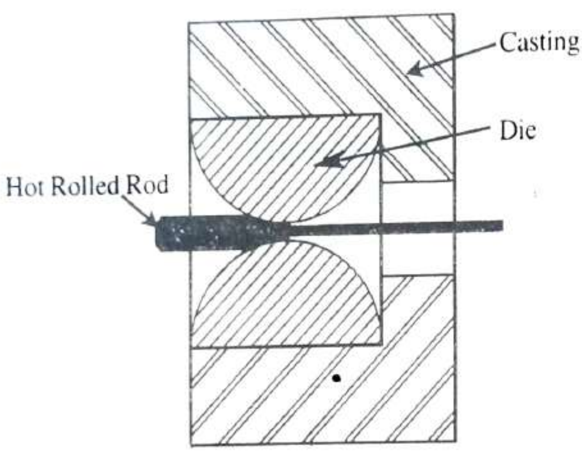


Fig 19.2 wire drawing process

Both single draft or continuous drawing processes may be used. In the first method, a coil is placed on the rod or frame and the end of the rod is pointed so that it will enter the die. The end is grasped by tongs on a draw bench and pulled out and wound around the reel. After the enter coil has passed through one die, the process of drawing wire through holes of small size is repeated until the desired diameter of the wire is obtained. A typical draw bench of this type with three sets of dies in shown in Fit 19.3. After the wire has passed through several dies, it becomes brittle due to strain hardening. It should therefore be annealed.

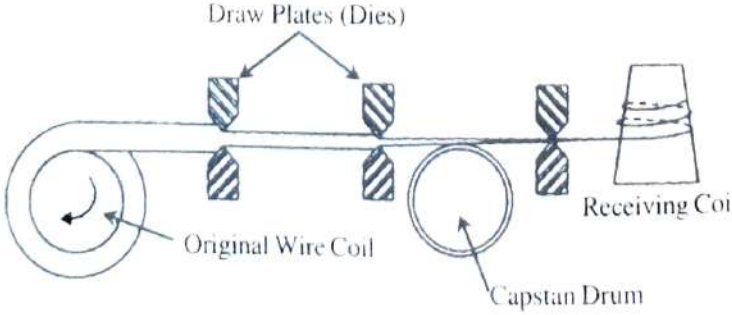


Fig : 19.3 A multi die draw Bench

If continuous drawing, the wire is fed through several dies and draw block, which are arranged in series. The number of dies depends upon the reduction required and also on the kind of material being drawn.

19.3 : Tube Drawing :

The three common methods of drawing are : Tube sinking, Tube drawing with a plug and tube drawing with a moving mandrel, the last two methods being more widely used because in tube sinking (Fig 19.4(a) the inside of the tube is not supported and so during drawing operation, the inner surface becomes uneven and there will be tendency for the wall thickness to increase slightly. In plug drawing and movable mandrel drawing, both the inner and outer surfaces are controlled and we get tubes of better dimensional accuracy as compared to tube sinking. In plug drawing, the plug (which may either cylindrical or conical) can either be fixed, (Fig 19.4(b)(i)), or floating. (Fig 19.4(b)(ii))The friction with a fixed plug will be more than with a floating plug, so the reduction in areas seldom exceeds 30% in this method with a floating plug, this figure can be approximately 45% or with the same reduction, the drawing loads will be less than floating plug than with a fixed plug. The friction is minimized in tube drawing with a movable mandrel (Fig 19.4(c)). However, after tube drawing, the mandrel has to be removed by rolling which results in slightly increased tube diameter and reduced dimensional tolerances.

Tube sinking is used to only reduce the outside diameter of tube. If the wall thickness of the tube is also to be reduced, an internal die is also needed, which may be in the form of a plug or a mandrel. Mandrels are used for tubes from about 12.7mm to 250 mm in diameter. Heavy walled tubes and those with less than 12.7mm dia are drawn without a mandrel. This is the procedure used for drawing hypodermic needles (starting from a 50 mm dia tube) with outside diameter less than 0.02 mm and with inside diameter half of the outside diameter

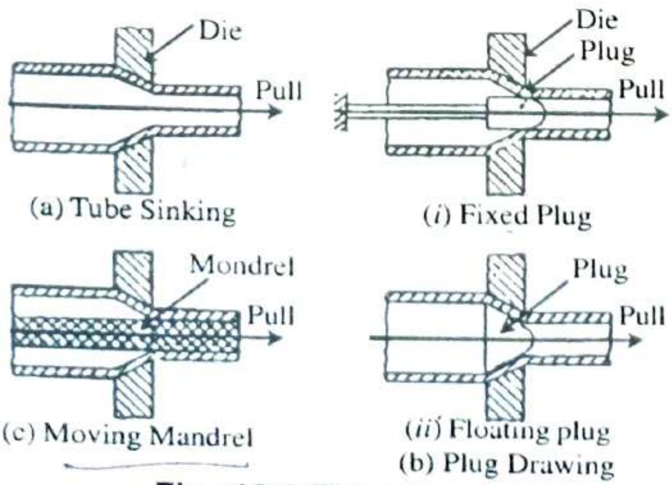


Fig : 19.4: Tube drawing

21.4 : Cold Extrusion

Cold extrusion process is classified as follows.

1. Forward cold extrusion

    a) Hydrostatic extrusion

2. Backward cold extrusion

    b) cold extrusion forgiving

    a) Impact extrusion

21.4.1 : Forward cold extrusion

The forward cold extrusion is similar to that of forward hot extrusion process except for the fact that the extrusion ratios possible are lower and extrusion pressures higher (table 21.1) than that of hot extrusion. It is normally used for simple shapes requiring better surface finish and to improve technical properties. Examples of the applications are cans, various aluminium brackets, shock absorber cylinders, rocket motors and heads, etc.

Table : 21.1. Cold extrusion pressures

Material	Extrusion pressure MPa
pure aluminium	600 to 1100
soft brass	450 to 800
soft copper	400 to 1100
C10 steel	800 to 2500
C20 steel	900 to 3100

21.4.1.1 : Hydrostatic Extrusion :

Another extrusion process that is being used for special applications is the hydrostatic extrusion. In this the metal billet is compressed from all sides by a liquid rather than the ram. The presence of liquid inside the container eliminates the need for any lubricant and also the material is more uniformly compressed from all sides throughout the deformation zone. Because of this, highly brittle materials such as grey cast iron can also be extruded. A typical hydrostatic extrusion operation is shown in Fig 21.6. Some of the pressure transmitting fluids used are castor oil with 10% alcohol, SAE 30 mineral lubricating oil, glycerine, ethyl glycol and iso pentane. The hydrostatic pressure range is from 1110 to 3150 MPa. The commercial applications of the process are limited to the extrusion of reactor fuel rods, cladding of metals and making wires of less ductile materials.

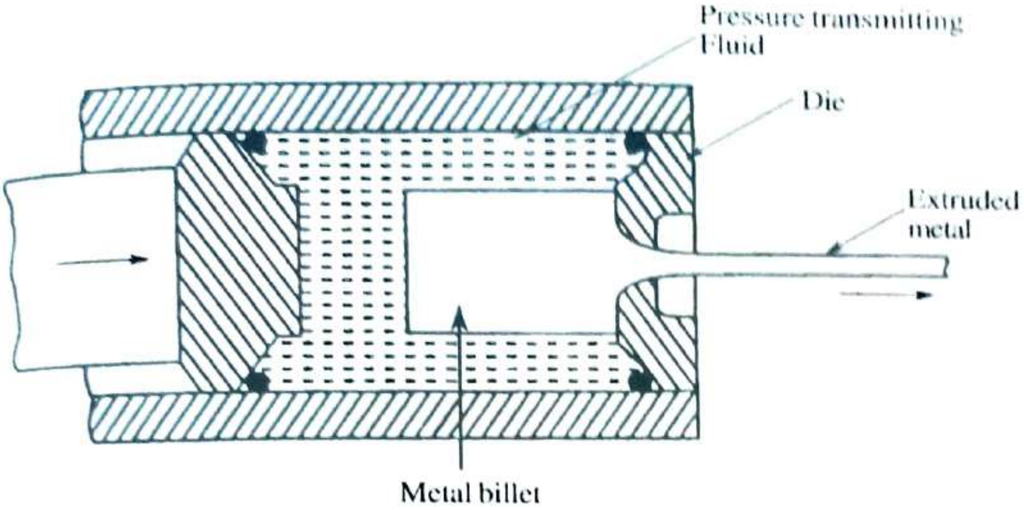


Fig : 21.6 : Hydrostatic Extrusion

21.4.2 : Backward Cold Extrusion :

Backward cold extrusion divided into two types.

1) Cold extrusion forging

2) impact extrusion

21.4.2.1 : Cold extrusion forging :

The cold extrusion forging is similar to impact extrusion but with the main difference that the side walls are much thicker and their height is smaller. This also contains a die and punch set as shown in Fig 21.7. The punch slowly descends over the slug kept on the die, thus forging some metal between the punch and the die and the rest being extruded through the clearance between the punch and die side walls. The side wall thus generated are short and thick with any profile in the end unlike the impact extrusion. Afterwards, the component is ejected by means of the ejector pin provided in the die.

The backward cold extrusion processes are different from other extrusion processes in that each stroke of the punch prepares a directly unable single component which may not necessarily have a uniform cross-section over its entire length. Also, these are limited to smaller sizes and for non-ferrous alloys only.

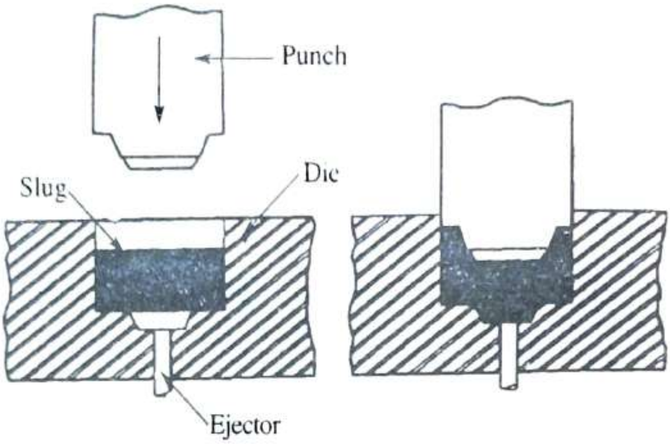


Fig : 21.7 : Cold extrusion forging

21.4.2.2 : Impact extrusion :

This is a cold extrusion process, similar to backward extrusion process, but carried out at higher speeds. The punch strikes a single blow with considerable force causing the metal to squirt up around the punch as shown in Fig 21.8. A small amount of unheated slug of metal is placed in the die cavity, the punch is driven rapidly into the die cavity and because of high pressure, metal immediately fills the cavity

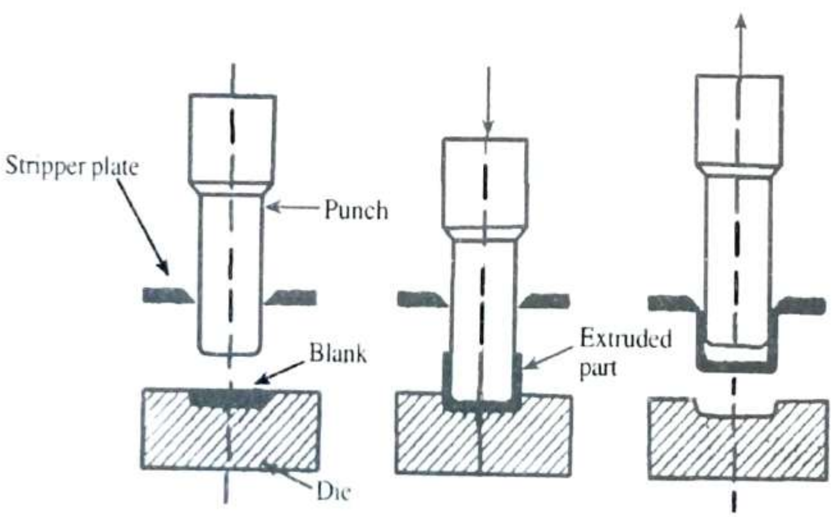


Fig : 21.8: Impact extrusion process

As there is no more space for the metal deformation in the cavity, the metal deformation in the cavity, the metal is forced upwards through the gap between the punch and the die, forming a tube-shaped part.

Applications of impact extrusion process are in the manufacture of collapsible tubes for toothpaste, ointments, shell cases, soft drink cans, etc. Fit 21.9 illustrates impact extrusion of a collapsible tube with a nozzle.

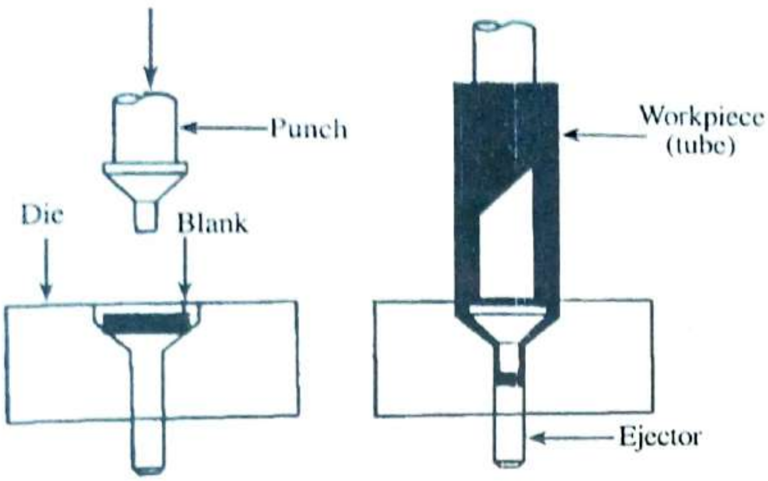


Fig 21.9 : Impact extrusion of collapsible tube with a nozzle.

For producing toothpaste tubes, a shall hole is punched in the centre of the blank and the die cavity is shaped to form the neck of the tube. Upon the completion of the stroke, the tube is blown from the ram with compressed air. The tubes are then threaded, trimmed, enamelled and printed.

Impact extrusions are low in cost, have excellent surface quality, and can give production rates of the order 100,000 to 20 million parts per year.

21.5 : Tube extrusion :

The usual method for extruding tubes is shown in fig 21.10. It is a form of direct extrusion, but uses a mandrel to shape the inside of the tube. After the billet is placed inside, the die containing the mandrel is pushed through the ingot. The press stem then advances, extrudes the metal through the die and around the mandrel, as shown in Fig.

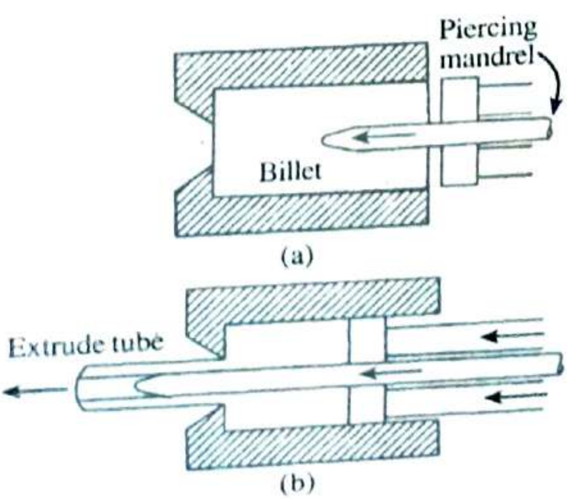


Fig : 21.10 : Tube extrusion process

22.5 : Types of forging operations :

The different types of forging operations are

1) Smith forging
2) Drop forging
3) Press forging
4) Machine or upset forging

22.5.1 : Smith Forging :

The term hand forging reminds us of a muscular blacksmith. The process consists of forming the desired shape of a heated metal by applying repeated blow of a hand held hammer. A flat die or an anvil is used. The desired shape of the metal piece is maintained by the smith during the forging process as the desired length and cross-section are adjusted manually by positioning and turning the part on the flat surface of the anvil. While hammering, the red-hot metal is held with a pair of tongs and a well-rounded chisel - shaped edge, called fuller is used to draw out the metal. Fuller is held on the metal by a helper while the smith strikes the metal with a hammer.

The quality of the forging is wholly dependent on the skill of the smith. Only relatively simple shapes can be forged by this technique and this method of metal working will continue to be used in its present form for many years to come. Fig22.17 illustrates a hand forging operation.

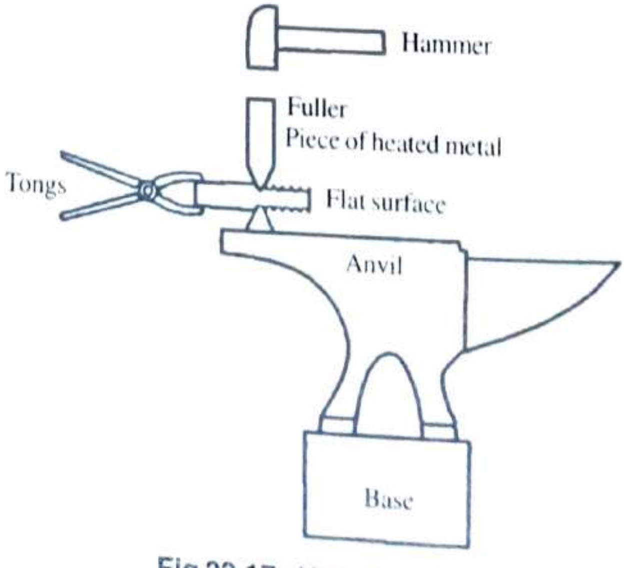


Fig 22.17 : Hand forging operation

22.5.2 : Drop forging :

Drop forging is a process of forming parts by hammering a heated bar or billet into die cavities. In its simplest form, a drop forge raises a massive weight and allows it to fall. It is essentially a mechanized form of the blacksmith's hammer. Dies are made in sets or halves; one half of the die is attached to ram and the other to a stationary anvil. The drop hammer uses compressed air to lift the ram and then falls under gravity. The ram is a lifted by a steel rod connected to a piston, a separate air circuit operates the ram to move it up and then the ram falls down under gravity on to the red-hot billet. Thus, the required shape on the billet is achieved.

Drop hammers are the choice for work pieces made of copper alloys, steel, titanium and refractory alloys. Fig 22.18 illustrates a drop forging operation using a hydraulic hammer.

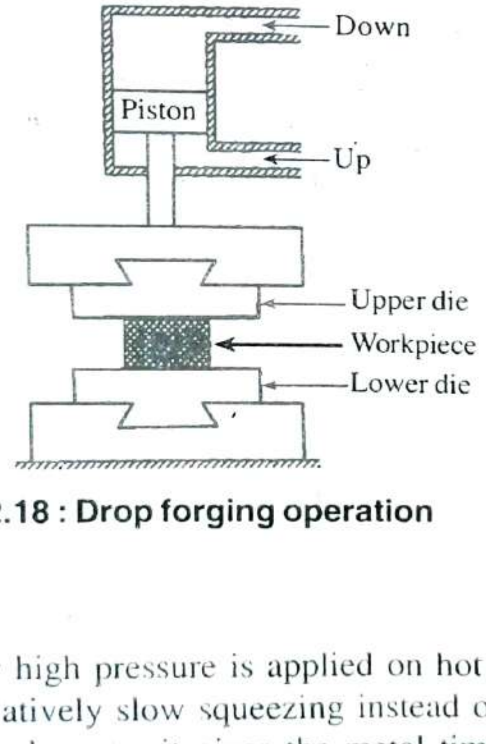


Fig 22.18 : Drop forging operation

22.5.3: Press Forging :

In press forging steady high pressure is applied on hot metal work piece. In this case the action is relatively slow squeezing instead of delivering heavy blows and penetrates deeply because it gives the metal time to flow. Usually only one stroke is needed to complete a particular forging operation. Press forgings are generally more accurate dimensionally than drop forgings.

The manner in which the metal deformation takes place in press forging substantially differs from that of hammer forging one blow of the hammer works the metal only in the surface layers of the forging so that deformation does not effectively penetrate into the volume of the metal. The push or squeeze of a press applied to the stock gradually increases and penetrates deep into the metal, involving its whole volume. This feature of press forging is taken into consideration in designing die equipment.

22.8 Defects in forgings :

Defects in forgings occur due to many reasons like poor quality of the stock improper heating, improper forging conditions, uneven cooling of stock poor die design wrong forging methods etc. Some common defects in forgings are discussed below

22.8.1 pitting :

This defects occur on the surface of a forging that is caused by scales which is not fully removed from the die cavities is worked into the surface of the forging. Sometimes the scales stick with the upper die and when the forging operation is carried out it forms a depression on the work piece. pitting can be avoided by prorer control of forging temperature and frequent cleaning of dies.

22. 8.2 Cold shuts or laps

These are short cracks that occur at the corners of the surface that are at right angles to each other. Cold shuts are caused due to the in ward folding of metal surface to minimise these defects. Sharp corners should be avoided i,.e by rounding them off.

22.8.3 : Die shift :

This defect is caused due to misalignment between two halves of forging dies. The die shift many also occur due to loose wedger. To avoid it the alignment of dies should be proper and wedges rigidly fixed.

22.8.4 Dents :

These are caused due to careless working

22.8.5 Fins and rags

Fins and rags are small projections or loose metal driven into the surface of the forging. It can be controlled by proper die design and workman ship.

22.8.6 : Incomplete filling of dies

This defect is caused due to many reasons like wrong amount of stock. Insufficient number of blows during forging. In correct die design or too low working temperature resulting in poor plastic flow of metal.

Explosive Forming

- ✓ Explosive forming, is distinguished from conventional forming in that the punch or diaphragm is replaced by an explosive charge.

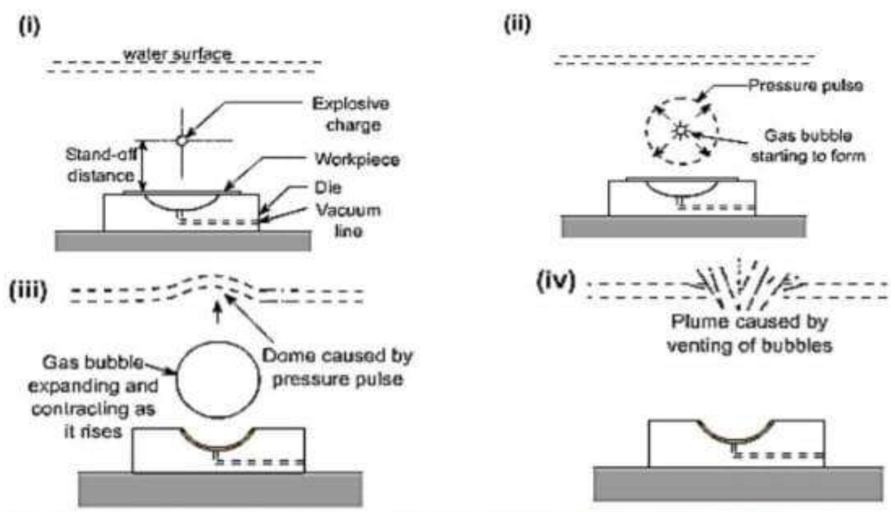
- ✓ Explosives used are generally high – explosive chemicals, gaseous mixtures, or propellants.

There are two techniques of high – explosive forming:

- Stand – off technique
- Contact technique

Standoff Technique

- ➢ Sheet metal work piece blank is clamped over a die and the assembly is lowered into a tank filled with water.
- ➢ Air in the die is pumped out.
- ➢ Explosive charge is placed at some predetermined distance from the work piece.
- ➢ On detonation of the explosive, a pressure pulse of very high intensity is produced.
- ➢ Gas bubble is also produced which expands spherically and then collapses.
- ➢ When the pressure pulse impinges against the work piece, the metal is deformed into the die with as high velocity as 120 m/s.



Sequeuce of underwater explosive forming operations.(i) explosive charge is set in position (ii) pressure pulse and gas bubble are formed as the detonation of charge occurs, (iii) workpiece is deformed, and (iv) gas bubbles vent at the surface of water.

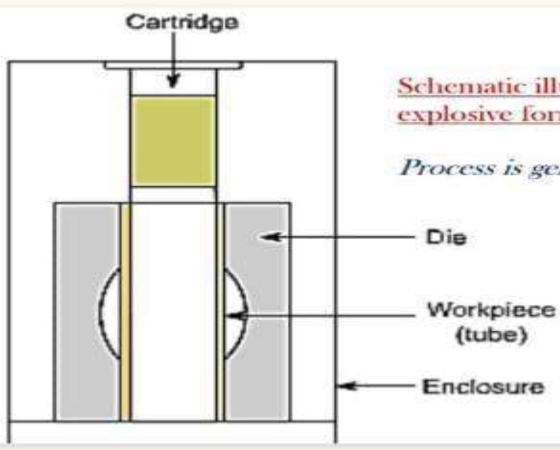
Use of water as the energy transfer medium ensures a uniform transmission of energy and muffles the sound of the explosive blast.

Process is versatile – a large variety of shapes can be formed, there is virtually no limit to the size of the work piece, and it is suitable for low – quantity production as well.

Process has been successfully used to form steel plates 25 mm thick x 4 m diameter and to bulge steel tubes as thick as 25 mm.

Contact Technique

- ✓ Explosive charge in the form of cartridge is held in direct contact with the work piece while the detonation is initiated.
- ✓ Detonation builds up extremely high pressures (upto 30,000MPa) on the surface of the work piece resulting in metal deformation, and possible fracture.
- ✓ Process is used often for bulging tubes



Schematic illustration of contact technique of explosive forming.

Process is generally used for bulging of tubes

Applications

- Explosive forming is mainly used in the aerospace industries but has also found successful applications in the production of automotive related components.
- Process has the greatest potential in limited – production prototype forming and for forming large size components for which conventional tooling costs are prohibitively high.

Explosives used can be:

- High energy chemicals like TNT, RDX, and Dynamite.
- Gaseous mixtures
- Propellants.

Factors to be considered while selecting an HERF process:

- Size of work piece
- Geometry of deformation
- Behavior of work material under high strain rates
- Energy requirements/ source
- Cost of tooling / die
- Cycle time
- Overall capital investment
- Safety considerations.

Role of water:

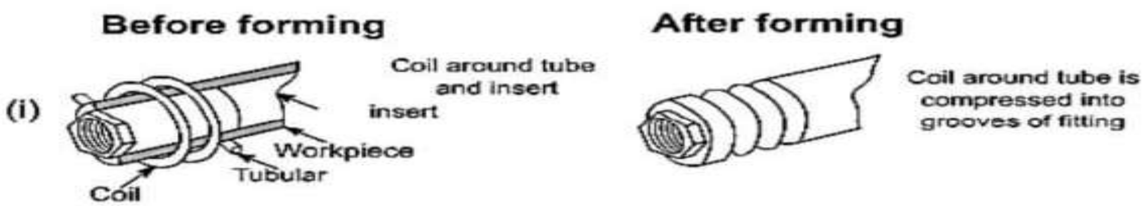
- ➢ Acts as energy transfer medium
- ➢ Ensures uniform transmission of energy
- ➢ Muffles the sound of explosion
- ➢ Cushioning/ smooth application of energy on the work without direct contact.

Process Variables

- ❑ Type and amount of explosive: wide range of explosive is available.
- ❑ Stand off distance – SOD- (Distance between work piece and explosive): Optimum SOD must be maintained.
- ❑ The medium used to transmit energy: water is most widely used.
- ❑ Work size
- ❑ Work material properties
- ❑ Vacuum in the die

Electro Magnetic Forming

- ✓ Process is also called *magnetic pulse forming* and is mainly used for swaging type operations, such as fastening fittings on the ends of tubes and crimping terminal ends of cables.
- ✓ Other applications are blanking, forming, embossing, and drawing.



Various applications of magnetic forming process. (i) Swaging

Process details/ Steps:

- The electrical energy is stored in the capacitor bank
- The tubular work piece is mounted on a mandrel having the die cavity to produce shape on the tube.
- A primary coil is placed around the tube and mandrel assembly.
- When the switch is closed, the energy is discharged through the coil
- The coil produces a varying magnetic field around it.
- In the tube a secondary current is induced, which creates its own magnetic field in the opposite direction.
- The directions of these two magnetic fields oppose one another and hence the rigidly held coil repels the work into the die cavity.
- The work tube collapses into the die, assuming its shape.

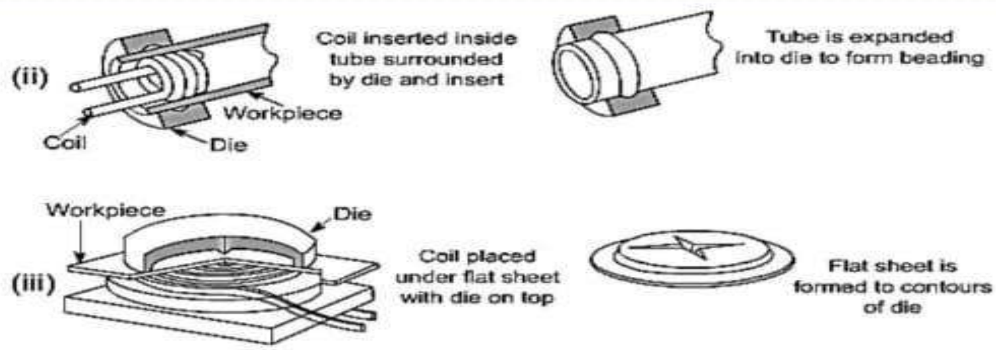
- ✓ A high charging voltage is supplied for a short time to a bank of capacitors connected in parallel. (The amount of electrical energy stored in the bank can be increased either by adding capacitors to the bank or by increasing the voltage).
- ✓ When the charging is complete, which takes very little time, a high voltage switch triggers the stored electrical energy through the coil.
- ✓ A high – intensity magnetic field is established which induces eddy currents into the conductive work piece, resulting in the establishment of another magnetic field.

✓ A high charging voltage is supplied for a short time to a bank of capacitors connected in parallel. (The amount of electrical energy stored in the bank can be increased either by adding capacitors to the bank or by increasing the voltage).

✓ When the charging is complete, which takes very little time, a high voltage switch triggers the stored electrical energy through the coil.

✓ A high – intensity magnetic field is established which induces eddy currents into the conductive work piece, resulting in the establishment of another magnetic field.

✓ The forces produced by the two magnetic fields oppose each other with the consequence that there is a repelling force between the coil and the tubular work piece that causes permanent deformation of the work piece.



Various applications of magnetic forming process. (ii) Expanding, and (iii) Embossing or blanking.

Magnetic forming can be accomplished in any of the following three ways, depending upon the requirements.

- Coil surrounding work piece:- When a tube – like part x is to fit over another part y, coil is designed to surround x so that when energized, would force the material of x tightly around y to obtain necessary fit.
- Coil inside work piece:- Consider fixing of a collar on a tube – like part. The magnetic coil is placed inside the tube – like part, so that when energized would expand the material of the part into the collar.
- Coil on flat surface:- Flat coil having spiral shaped winding can also be designed to be placed either above or below a flat work piece.These coils are used in conjunction with a die to form, emboss, blank, or dimple the work piece.

- Either permanent or expandable coils may be used. Since the repelling force acts on the coil as well the work, the coil itself and the insulation on it must be capable of withstanding the force, or else they will be destroyed.

- Expandable coils are less costly and are also preferred when high energy level is needed.

Advantages:

i) Suitable for small tubes

ii) Operations like collapsing, bending and crimping can be easily done.

iii) Electrical energy applied can be precisely controlled and hence the process is accurately controlled.

iv) The process is safer compared to explosive forming.

v) Wide range of applications.

Limitations:

i) Applicable only for electrically conducting materials.

ii) Not suitable for large work pieces.

iii) Rigid clamping of primary coil is critical.

iv) Shorter life of the coil due to large forces acting on it.

Applications

- It has found extensive applications in the fabrication of hollow, non – circular, or asymmetrical shapes from tubular stock.
- Compression applications involve swaging to produce compression, tensile, and torque joints or sealed pressure joints, and swaging to apply compression bands or shrink rings for fastening components together.
- Flat coils have been used on flat sheets to produce stretch (internal) and shrink (external) flanges on ring and disc – shaped work pieces.
- Electromagnetic forming has also been used to perform shearing, piercing, and rivettting.

Electro Hydraulic Forming

- Electro hydraulic forming (EHF), also known as electro spark forming, is a process in which electrical energy is converted into mechanical energy for the forming of metallic parts.
- A bank of capacitors is first charged to a high voltage and then discharged across a gap between two electrodes, causing explosions inside the hollow work piece, which is filled with some suitable medium, generally water.

- These explosions produce shock waves that travel radially in all directions at high velocity until they meet some obstruction.
- If the discharge energy is sufficiently high, the hollow work piece is deformed.
- The deformation can be controlled by applying external restraints in the form of die or by varying the amount of energy released.

ELECTRO HYDRAULIC FORMING

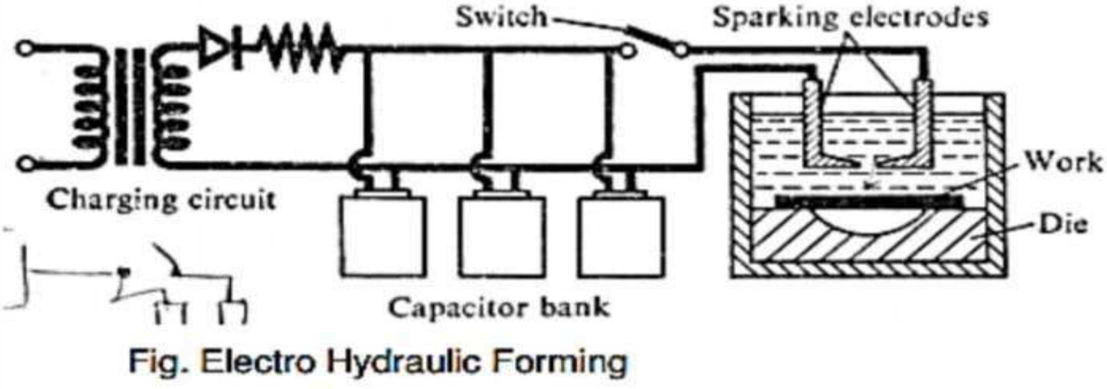
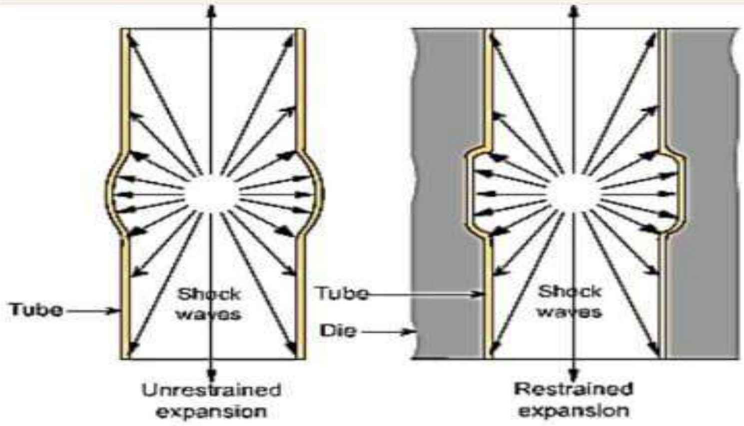


Fig. Electro Hydraulic Forming



Unrestrained and restrained electro-hydraulic forming process.

Principle

A sudden electrical discharge in the form of sparks is produced between electrodes and this discharge produces a shock wave in the water medium.
This shock wave deforms the work plate and collapses it into the die.
Characteristics of this process are similar to those of explosive forming.
Major difference, however, is that a chemical explosive is replaced by a capacitor bank, which stores the electrical energy.

Capacitor is charged through a charging circuit.

When the switch is closed, a spark is produced between electrodes and a shock wave or pressure pulse is created.

Energy released is much lesser than that released in explosive forming.

Process Characteristics:

- Stand off distance: It must be optimum.
- Capacitor used: The energy of the pressure pulse depends on the size of capacitor.
- Transfer medium: Usually water is used.
- Vacuum: the die cavity must be evacuated to prevent adiabatic heating of the work due to a sudden compression of air.
- Material properties with regard to the application of high rates of strain.

Advantages

- ✓ EHF can form hollow shapes with much ease and at less cost compared to other forming techniques.
- ✓ EHF is more adaptable to automatic production compared to other high energy rate forming techniques.
- ✓ EHF can produce small – to intermediate sized parts that don't have excessive energy requirements.

- ✓ Better control of the pressure pulse as source of energy is electrical- which can be easily controlled.
- ✓ Safer in handling than the explosive materials.
- ✓ More suitable if the work size is small to medium.
- ✓ Thin plates can be formed with smaller amounts of energy.
- ✓ The process does not depend on the electrical properties of the work material.

Limitations:

- Suitable only for smaller works
- Need for vacuum makes the equipment more complicated.
- Proper SOD is necessary for effective process.

Applications:

- They include smaller radar dish, cone and other shapes in thinner and small works.

UNIT V

Introduction to Additive Manufacturing (AM): Fundamentals of additive Manufacturing, Need for Additive Manufacturing, Generic AM process, Distinction between AM and CNC, Classification of AM Processes, Steps in AM process, Advantages of AM, standards on AM, Major Applications.

Vat Photo polymerization AM Processes: Stereo lithography (SL), Materials, SL resin curing process, Micro-stereo lithography, Process Benefits and Drawbacks, Applications of Photo polymerization Processes.

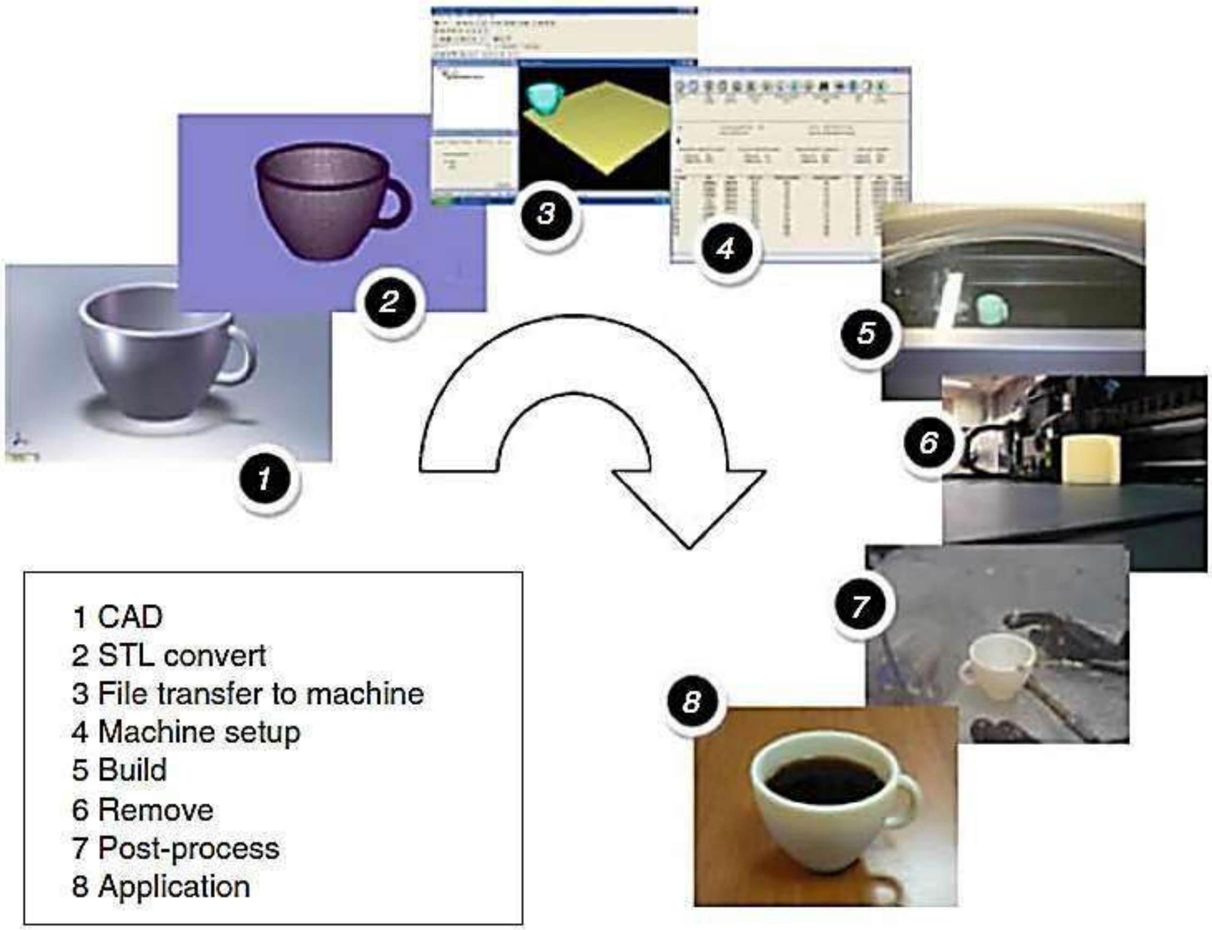
Introduction

Manufacturing is a process in which raw materials are transformed into finished goods.

Additive Manufacturing

• Technology that can make anything.
• Eliminates many constraints imposed by conventional manufacturing
• Leads to more market opportunities.
• Increased applications such as 3D faxing sender scans a 3D object in cross sections and sends out the digital image in layers, and then the recipient receives the layered image and uses an AM machine to fabricate the 3D object

Additive Manufacturing Process chain



Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

1. Conceptualization and CAD
2. Conversion to STL
3. Transfer and manipulation of STL file on AM machine
4. Machine setup
5. Build
6. Part removal and clean-up
7. Post-processing of part
8. Application

Conceptualization and CAD

• The generic AM process starts with 3D CAD information.
• There may be a many of ways as to how the 3D source data can be created.
• The model description could be generated by a computer.
• Most 3D CAD systems are solid modeling systems with some surface modeling components.

Conversion to STL

• The term STL was derived from STereoLithograhy.
• STL is a simple way of describing a CAD model in terms of its geometry alone.
• It works by removing any construction data, modeling history, etc., and approximating the surfaces of the model with a series of triangular facets.
• The minimum size of these triangles can be set within most CAD software and the objective is to ensure the models created do not show any obvious triangles on the surface.

The process of converting to STL is automatic within most CAD systems.

• STL file repair software is used when there are problems with the file generated by the CAD system that may prevent the part from being built correctly.
• With complex geometries, it may be difficult to detect such problems while inspecting the CAD or the subsequently generated STL data.
• If the errors are small then they may even go unnoticed until after the part has been built.

STL is essentially a surface description, the corresponding triangles in the files must be pointing in the correct direction; (in other words, the surface normal vector associated with the triangle must indicate which side of the triangle is outside vs. inside the part).

• While most errors can be detected and rectified automatically, there may also be a requirement for manual intervention.

Transfer to AM Machine and STL File Manipulation

• Once the STL file has been created, it can be sent directly to the target AM machine.
• Ideally, it should be possible to press a “print” button and the machine should build
• The part straight away.

• However there may be a number of actions required prior to building the part.
• The first task would be to verify that the part is correct.
• AM system software normally has a visualization tool that allows the user to view and manipulate the part.
• The user may wish to reposition the part or even change the orientation to allow it to be built at a specific location within the machine.
• It is quite common to build more than one part in an AM machine at a time.
• This may be multiples of the same part (thus requiring a copy function) or completely different STL files.

Machine Setup

• All AM machines will have at least some setup parameters that are specific to that machine or process.
• Some machines are only designed to run perhaps one or two different materials and with no variation in layer thickness or other build parameters.
• In the more complex cases to have default settings or save files from previously defined setups to help speed up the machine setup process and to prevent mistakes.
• Normally, an incorrect setup procedure will still result in a part being built.

Build Setup

• The first few stages of the AM process are semi-automated tasks that may require considerable manual control, interaction, and decision making.
• Once these steps are completed, the process switches to the computer controlled building phase.
• All AM machines will have a similar sequence of layer control, using a height adjustable platform, material deposition, and layer cross-section formation.
• All machines will repeat the process until either the build is complete or there is no source material remaining.

Removal and Cleanup

• The output from the AM machine should be ready for use.
• More often the parts still require a significant amount of manual finishing before they are ready for use.

• The part must be either separated from a build platform on which the part was produced or removed from excess build material surrounding the part.
• Some AM processes use additional material other than that used to make the part itself (secondary support materials).

Post Process

• Post-processing refers to the (usually manual) stages of finishing the parts for application purposes.
• This may involve abrasive finishing, like polishing and sandpapering, or application of coatings.

Application

• Following post-processing, parts are ready for use.
• Although parts may be made from similar materials to those available from other manufacturing processes (like molding and casting), parts may not behave according to standard material specifications.
• Some AM processes create parts with small voids or bubbles trapped inside them, which could be the source for part failure under mechanical stress.
• Some processes may cause the material to degrade during build or for materials not to bond, link, or crystallize in an optimum way.

ADVANTAGES

I. Freedom of design
II. Complexity for free
III. Potential elimination of tooling
IV. Lightweight design
V. Elimination of production steps

DISADVANTAGES

I. Slow build rates
II. High production costs
III. Considerable effort required for application design
IV. Discontinuous production process
V. Limited

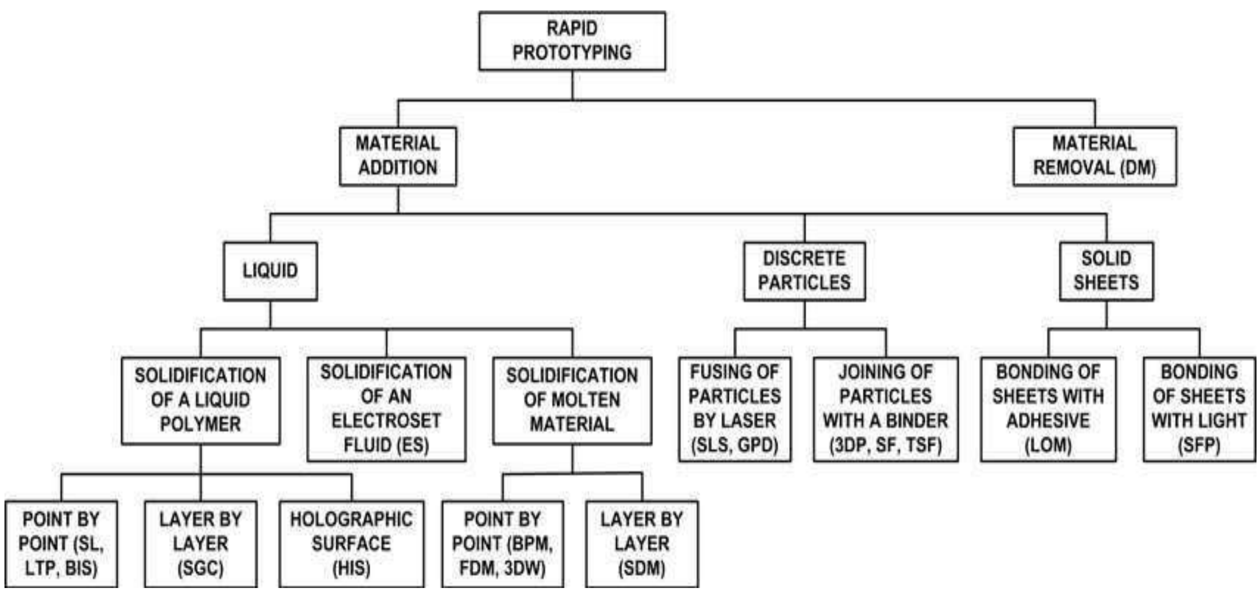
Applications

AM has been used across a diverse array of industries, including;

- ✓ Automotive
- ✓ Aerospace
- ✓ Biomedical
- ✓ Consumer goods and many others

AM processes are classifying:
Major Seven types

1) Vat Photopolymerisation/Steriolithography
2) Material Jetting
3) Binder jetting
4) Material extrusion
5) Powder bed fusion
6) Sheet lamination
7) Directed energy deposition



1) Vat Photopolymerisation/Steriolithography

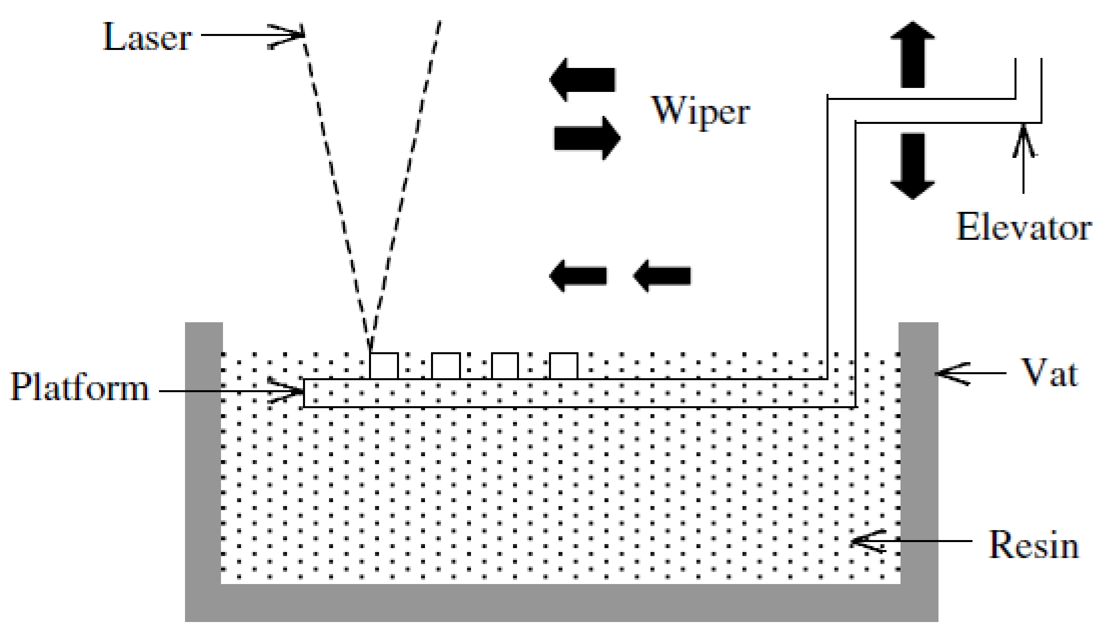
Stereolithography Apparatus (SLA) Process

- 3D Systems was founded in 1986 by inventor Charles W. Hull and entrepreneur Raymond S. Freed and its first commercial system marketed in 1988.
- It has been awarded more than 40 United States patents and 20 international patents, with additional patents filed or pending internationally.

Principle

The SLA process is based on the following principles
• Parts are built from a photo-curable liquid resin that cures when exposed to a laser beam (photopolymerization process) which scans across the surface of the resin.
• The building is done layer by layer, each layer being scanned by the optical scanning system and controlled by an elevation mechanism which lowers at the completion of each layer.

Stereolithography Apparatus (SLA) Process



Stereolithography process creates 3D plastic objects directly from CAD data.

• The process begins with the vat filled with the photo-curable liquid resin and the elevator table set just below the surface of the liquid resin.
• 3D CAD solid model file is loaded into the system by the operator.
• Supports are designed to stabilize the part during building.
• The translator converts the CAD data into a STL file.
• The control unit slices the model and support into a series of cross sections from 0.025 to 0.5 mm thick.
• The optical scanning system directs and focuses the laser beam to solidify a 2D cross section corresponding to the slice on the surface of the photo-curable liquid resin.
• The elevator table drops enough to cover the solid polymer with another layer of the liquid resin.
• A leveling wiper or vacuum blade moves across the surfaces to recoat the next layer of resin on the surface.
• The laser then draws the next layer.
• The process continues building the part from bottom up, until the system completes the part.
• The part is then raised out of the vat and cleaned of excess polymer.

Applications

• Models for conceptualization, packaging and presentation.
• Prototypes for design, analysis, verification and functional testing.
• Parts for prototype tooling and low volume production tooling.
• Patterns for investment casting, sand casting and molding.
• Tools for fixture and tooling design, and production tooling.

Extrusion-Based AM Processes: Fused Deposition Modelling (FDM), Principles, Materials, Plotting and path control, Bio-Extrusion, Process Benefits and Drawbacks, Applications of Extrusion-Based Processes

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Extrusion-Based AM Processes

What is it

- Obtaining the desired model or prototype from a semi solid material, when this material is extruded from a selected nozzle.
- These technologies can be visualized as similar to cake icing, in that material contained in a reservoir is forced out through a nozzle when

pressure is applied.

- If the pressure remains constant, then the resulting extruded material (commonly referred to as “roads”) will flow at a constant rate and will remain a constant cross-sectional diameter.
- The material that is being extruded must be in a semi-solid state when it comes out of the nozzle.
- This material must fully solidify while remaining in that shape.
- Furthermore, the material must bond to material that has already been extruded so that a solid structure can result.
- Once a layer is completed, the machine must index upwards, or move the part downwards, so that a further layer can be produce.
- There are two primary approaches when using an extrusion process.
- The most commonly used approach is to use temperature as a way of controlling the material state.
- Molten material is liquefied inside a reservoir so that it can flow out through the nozzle and bond with adjacent material before solidifying.
- An alternative approach is to use a chemical change to cause solidification.

- In such cases, a curing agent, residual solvent, reaction with air, or simply drying of a “wet” material permits bonding to occur.
- Parts may therefore cure or dry out to become fully stable.
- This approach may be more applicable to biochemical applications where materials must have biocompatibility with living cells and so choice of material is very restricted.

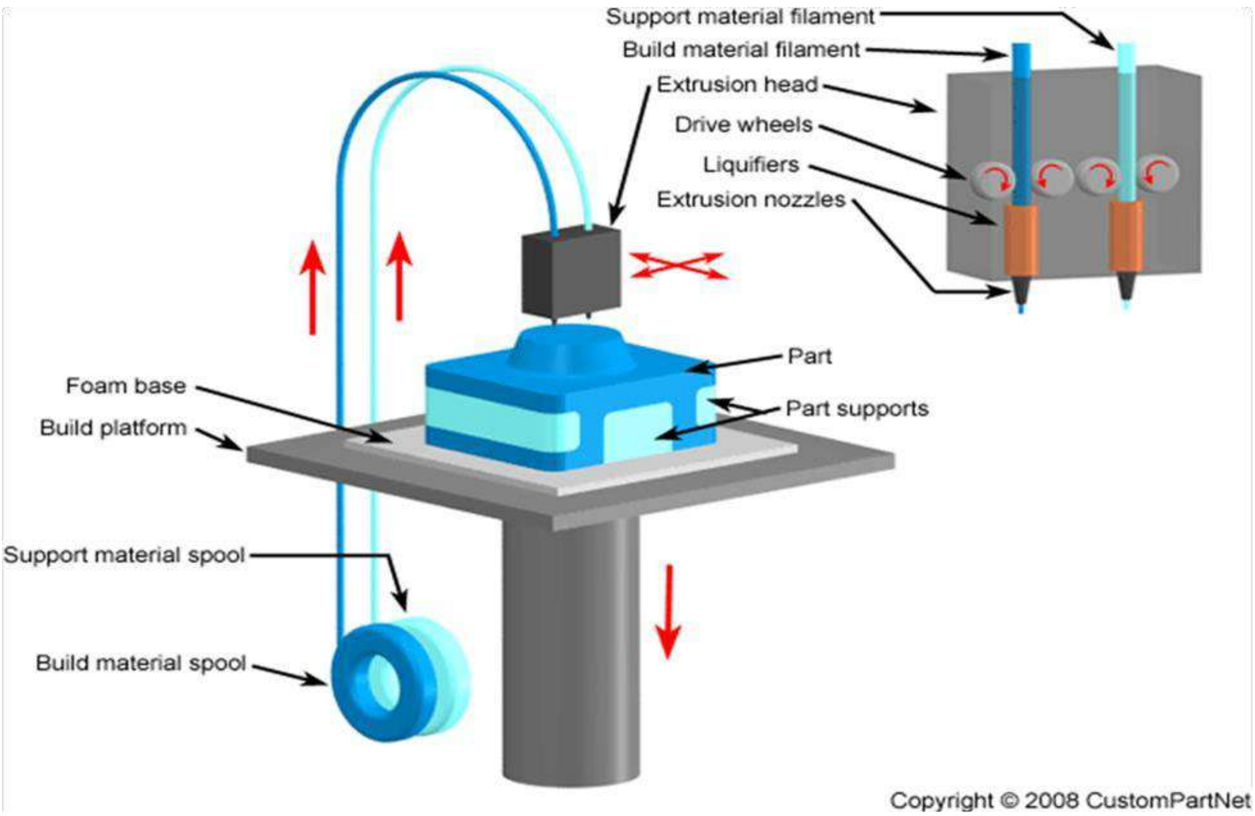
Fused Deposition Modeling (FDM)

Basic principles

There are a number of key features that are common to any extrusion-based system:

- Loading of material
- Liquification of the material
- Application of pressure to move the material through the nozzle
- Extrusion
- Plotting according to a predefined path and in a controlled manner
- Bonding of the material to itself or secondary build materials to form a coherent
- Solid structure
- Inclusion of support structures to enable complex geometrical features
- FDM is the second most widely used rapid prototyping technology, after stereolithography.
- A plastic filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off.
- The nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical directions.

- As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer.
- The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic.



Build Materials

The FDMs can be equipped to build with investment casting wax, acrylonitrile butadiene styrene (ABS) plastic, medical grade ABS thermoplastic, and/or Elastomer. Currently ABS is used in most of the cases ABS is an opaque engineering thermoplastic widely used in electronic housings, auto parts, consumer products, pipe fittings, lego toys and many more.

Acrylonitrile: It is a synthetic monomer produced from propylene and ammonia. This component contributes to ABS chemical resistance & heat stability

Butadiene: It is produced as a by-product of ethylene production from steam crackers. This component delivers toughness & impact strength to ABS polymer

Styrene: It is manufactured by dehydrogenation of ethyl benzene. It provides rigidity & processability to ABS plastic

How ABS is Made?

ABS is produced by emulsion or continuous mass technique. The chemical formula of Acrylonitrile Butadiene Styrene is $(C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)_n$. The natural material is an opaque ivory color and is readily colored with pigments or dyes.

ABS is a strong & durable, chemically resistant resin but gets easily attacked by polar solvents. It offers greater impact properties and slightly higher heat distortion temperature than HIPS.

Acrylonitrile Butadiene Styrene has a broad processing window and can be processed on most standard machinery. It can be injection-molded, blow-molded, or extruded. It has a low melting temperature making it particularly suitable for **processing by 3D printing** on an FDM machine.

ABS falls between standard resins (PVC, polyethylene, polystyrene, and so on) and engineering resins (acrylic, nylon acetal…) and often meets the property requirements at a reasonable price-cost effectiveness.

Benefits of FDM

- FDM is the most cost-effective way of producing custom thermoplastic parts and prototypes.
- The lead times of FDM are short (as fast as next-day-delivery), due to the high availability of the technology.(A dimensional accuracy of ± 0.5% with a lower limit of ± 0.5 mm (± 0.020"))
- A wide range of thermoplastic materials is available, suitable for both prototyping and some non-commercial functional applications.
- All support material is removed such that the supported surface has a consistent finish.
- All parts are printed with 3 outline / perimeter shells or a wall thickness of 1.2 mm.

Limitations of FDM

- FDM has the lowest dimensional accuracy and resolution compared to other 3D printing technologies, so it is not suitable for parts with intricate details. they have a layer thickness option of 0.078 mm, but this is only available with the highest-cost machine and use of this level of precision will lead to longer build times.

- FDM parts are likely to have visible layer lines, so post processing is required for a smooth finish. it is impossible to draw sharp external corners; there will be a radius equivalent to that of the nozzle at any corner or edge. Internal corners and edges will also exhibit rounding. The actual shape produced is dependent on the nozzle, acceleration, and deceleration characteristics, and the visco elastic behavior of the material as it solidifies.
- Feed rate is also dependent on the ability to supply the material and the rate at which the liquefier can melt the material and feed it through the nozzle.
- The layer adhesion mechanism makes FDM parts inherently anisotropic.
- the anisotropic nature of a part's properties. Additionally, different layering strategies result in different strengths

Applications of Extrusion-Based Processes

- Low-volume production of complex end-use parts

Prototypes for form, fit and function testing

- Prototypes directly constructed in production materials
- Extrusion is widely used in production of tubes and hollow pipes.
- Aluminum extrusion is used in structure work in many industries.
- This process is used to produce frames, doors, window etc. in automotive industries.
- Extrusion is widely used to produce plastic objects.

Powder Bed Fusion AM Processes: Selective laser Sintering (SLS), Materials, Powder fusion mechanism, SLS Metal and ceramic part creation, Electron Beam melting (EBM), Process Benefits and Drawbacks, Applications of Powder Bed Fusion Processes.
Directed Energy Deposition AM Processes: Process Description, Laser Engineered Net Shaping (LENS), Direct Metal Deposition (DMD), Electron Beam Based Metal Deposition, Benefits and drawbacks, Applications of Directed Energy Deposition Processes.
Wire arc based additive manufacturing methods, Advantages and disadvantages, comparison with conventional AM and WAAM.

- SLS is a rapid prototyping (RP) process that builds models from a wide variety of materials using an additive fabrication method
- The build media for SLS comes in powder form, which is fused together by a powerful carbon dioxide laser to form the final product

HISTORY

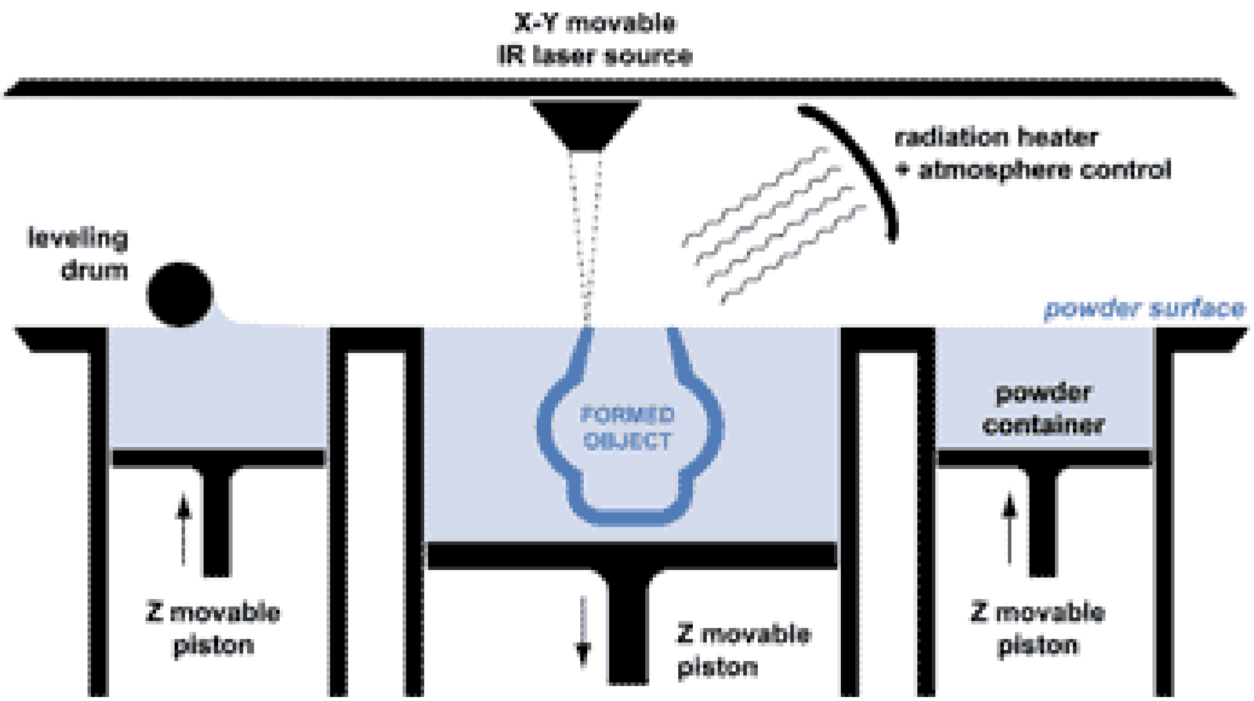
- The Selective Laser Sintering (SLS) process was developed by The University of Texas in Austin, and was commercialized by DTM, Corporation out of Austin, TX in 1987 with support from B.F. Goodrich
- The first SLS system was shipped in 1992, and there are currently several systems in use worldwide.
- The build media for SLS comes in powder form, which is fused together by a powerful carbon dioxide laser to form the final product.

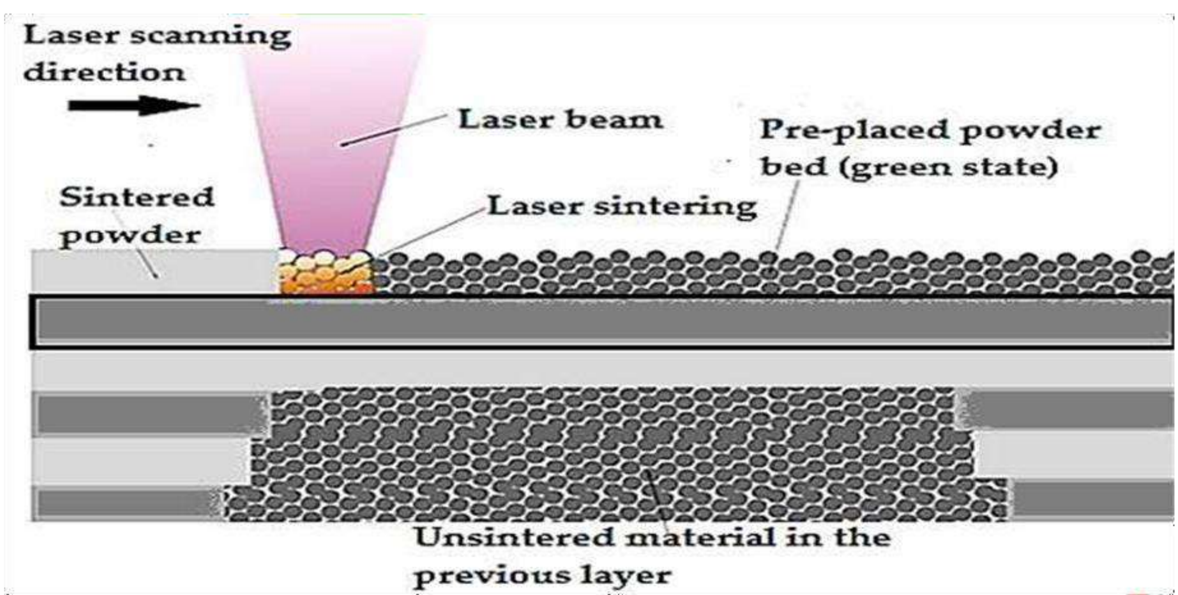
- SLS currently has 10 different build materials that can be used within the same machine for a wide variety of applications.
- The SLS process begins, like most other RP processes, with the standard .STL CAD file format, which is exported now by most 3D CAD package.

SLS – MECHANISM

- Moving laser beam sinters heat-fusible powders in areas corresponding to the CAD geometry model one layer at a time to build the solid part.

- After each layer is completed, a new layer of loose powders is spread across the surface.
- Layer by layer, the powders are gradually bonded by the laser beam into a solid mass that forms the 3-D part geometry.
- In areas not sintered, the powders are loose and can be poured out of completed part





MATERIALS THAT CAN BE USED

- Plastic powders
- Metal powders (direct metal laser sintering),
- Ceramic powders
- Glass powders

Patented in 1989.

- Considerably stronger than SLA; sometimes structurally functional parts are possible.
- Advantage over SLA: Variety of materials and ability to approximate common engineering plastic materials.
- Process is simple: Thereis no milling or masking steps required
- Living hinges are possible with the thermoplastic-like materials
- Powdery, porous surface unless sealant is used
- Sealant also strengthens part
- Uncured material is easily removed after a build by brushing or blowing it off.

PROCESS PARAMETERS

1. Part bed temperature
2. Layer thickness
3. Laser power The longer the laser dwells in a particular location, the deeper the fusion depth and the larger the melt pool diameter. Typical layer thicknesses range from 0.1 to 0.15 mm
4. Laser scan speed
5. Energy density
6. Powder shape

Process parameters can be lumped into four categories:

- (1) laser-related parameters (laser power, spot size, pulse duration, pulse frequency, etc.),
- (2) scan-related parameters (scan speed, scan spacing, and scan pattern),
- (3) powder-related parameters (particle shape, size and distribution, powder bed density, layer thickness, material properties, etc.), and
- (4) temperature-related parameters (powder bed temperature, powder feeder temperature, temperature uniformity, etc.)

Part bed temperature:

- The part bed is the central region of the SLS machine (DTM Sinterstation 2000) where the part is built
- The part bed temperature is controlled primarily by the heater underneath the build area
- the temperature should be lower than melting temperature of the powder
- The higher the temperature is set, the less the incident energy is required during the SLS process

Layer thickness: is a measure of the thickness of each layer during the SLS process

- It is also the depth by which the part piston is lowered after the laser scanning of each layer
- A thicker layer requires greater incident energy
- Thicker layers will not give us very good **surface finish because of 'stair stepping'**

Energy density is defined as the amount of energy input per unit area

- It is dependent upon laser power, scan speed and scan spacing and is determined by the following equation
- ED = LP / (BS x SS)
- where ED is the energy density, LP is the laser power, BS is the beam

scan speed and SS is the scan spacing. The laser power, scan speed and scan spacing need to be optimized according to the amount of input energy required to fuse the particles in the layer

- **Selective Laser Sintering Applications Rapid Manufacturing**
  - Aerospace Hardware
  - UAS, UAV, UUV, UGV Hardware
  - Medical and Healthcare
  - Electronics; Packaging, Connectors
  - Homeland Security
  - Military Hardware
- **Rapid Prototypes:**
  - Functional Proof of Concept Prototypes
  - Design Evaluation Models

- (Form, Fit & Function)
- Product Performance & Testing
- Engineering Design Verification
- Wind-Tunnel Test Models

- **Tooling and Patterns:**
  - Rapid Tooling (concept development & bridge tools)
  - Injection Mould Inserts
  - Tooling and Manufacturing Estimating Visual Aid
  - Investment Casting Patterns
  - Jigs and Fixtures
  - Foundry Patterns - Sand Casting

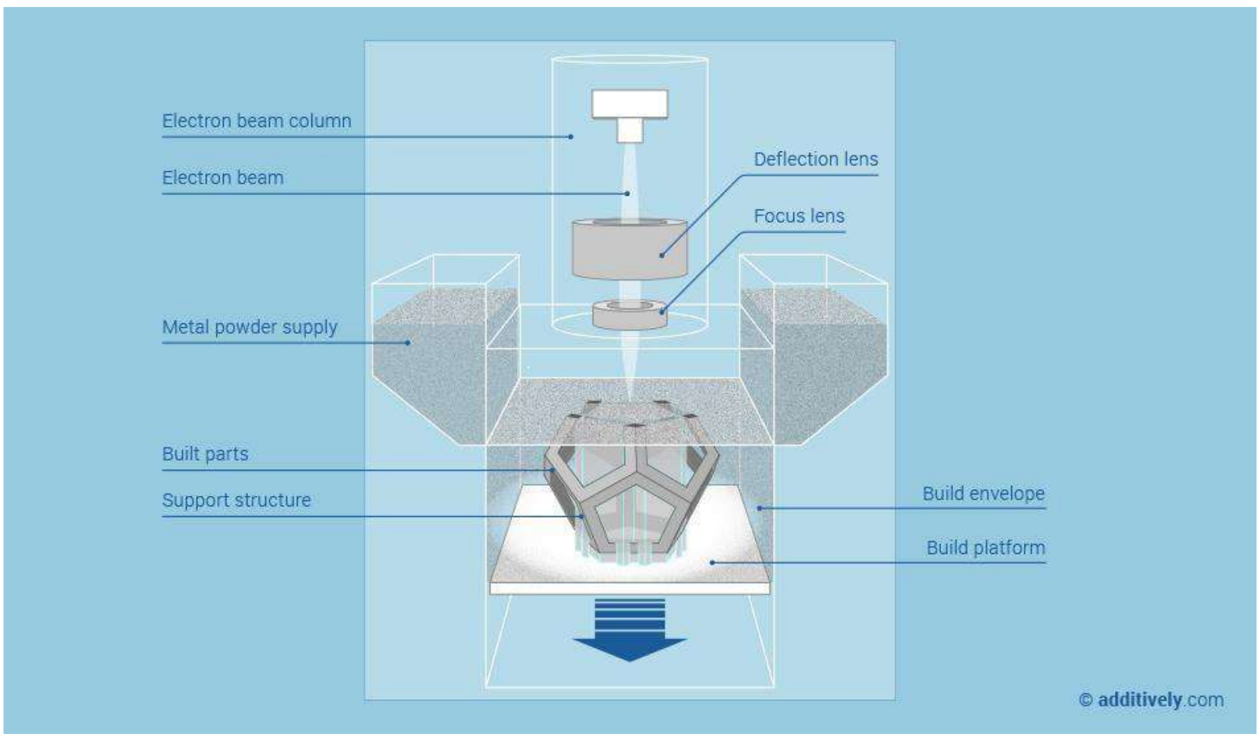
ADVANTAGES

- Stereolithography offers a lot of advantage to a variety of business situations.
- SLA parts have probably the best surface quality of all other RP systems, and are also highly competitive in dimensional accuracy.
- Also, the latest SLA systems have significantly increased the speed at which parts can be produced, which is ultimately the goal of RP.
- Finely detailed features, like thin vertical walls, sharp corners, and tall columns can be fabricated with ease even on older SLA systems, and the growing list of available resins are pushing the envelope on temperature and strength characteristics as well

DISADVANTAGES

- The main disadvantage of the SLA process is most likely the Post processing requirements.
- Although significant advances have been made to make working materials safer and easier to work with, procedures to handle raw materials for the SLA still require careful and aware practices.
- Another disadvantage, which may decrease as resin competition increases, is the relatively high cost of photocurable resins, weighing in at around $600 to $800 per gallon.

Electron Beam melting (EBM)



Process description

EBM is a powder metallurgical process which includes the following main steps:

• Design of part   CAD drawing

- Positioning of part(s) within build space, addition of support structures (if needed)
- Slicing of 3D part into 2D layers
- Building the part layer-by-layer
- Removal of part from the machine, blow off surplus powder

  ✓ A thin layer of metal powder is selectively melted by an electron beam. The parts are built up layer by layer the in the powder bed.

  ✓ Electron beam melting is similar to laser melting, but working with an electron beam instead of a laser. The machine distributes a layer of metal powder onto a build platform, which is melted by the electron beam. The build platform is then lowered and the next layer of metal powder will be coated on top. The process of coating powder and melting where needed is repeated and the parts are built up layer by layer in the powder bed.

  ✓ Electron beam melting requires support structures, which anchor parts and overhanging structures to the build platform. This enables the heat transfer away from where the powder is melted. Therefore, it reduces thermal stresses and prevents wrapping. The build envelope can be filled by several parts which are built in parallel as long as they are all attached to the build platform. Parts are built under vacuum.

Advantages / disadvantages

✓ Parts can be manufactured in some standard metals with high density by electron beam melting. However, the availability of materials is limited and the process is rather slow and expensive.

✓ The technology manufactures parts in standard metals with high density (above 99%) and good mechanical properties (comparable to traditional production technologies). Compared to laser melting, EBM produces less thermal stress in parts and therefore requires less support structure. Further, it builds parts faster.

- ✓ Electron beam melting is still a slow and expensive process that only works with a limited set of metals. Parts usually require quite a lot of post-processing. Compared to laser melting, the technology does not achieve equally good surface finishes.

Material Systems

- ✓ In principle all metal powders can be used as long as they can be adapted to the process in terms of particle size distribution and shape. The following materials have been qualified for EBM:
- ✓ • Grade 2 Titanium
- ✓ • Ti-6Al-4V
- ✓ • CoCr
- ✓ Other possible materials which can be developed for EBM within the frame of further R&D work :
- ✓ • Aluminium and its alloys
- ✓ • Steels
- ✓ • Superalloys
- ✓ • Intermetallics
- ✓ • Refractory metals and alloys

Application areas

- Small series parts down to one of a kind are produced directly by electron beam melting (post-processing to achieve better tolerances and surface finish might be required).
- Prototypes are produced for form / fit and functional testing.
- Support parts (jigs, fixtures, helps) are produced directly by EBM

Process chain

When planning an EBM build, critical tolerances, surface finishes and overhangs need to be taken into consideration. After the build, parts often need to be thermally processed and support structure needs to be mechanically removed. Electron beam melting parts can be further post-processed as any welding part.

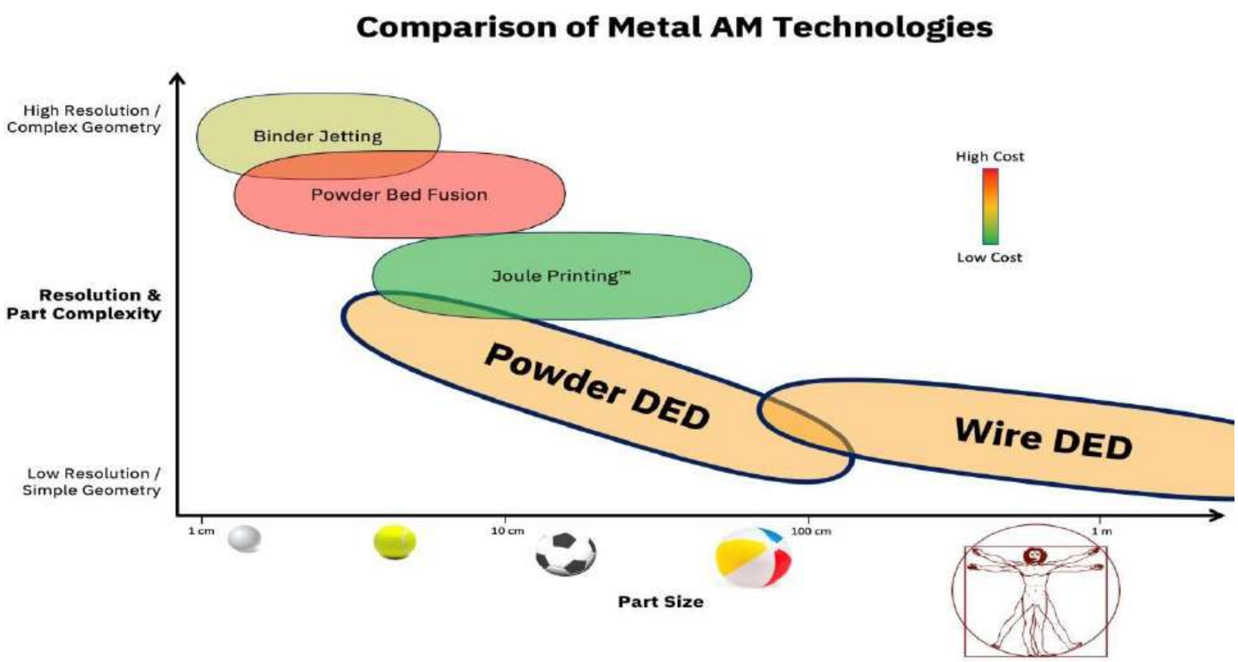
Pre-build planning

The production of parts is planned in a build preparation software. One or several parts are placed in the build using the digital 3D files (typically in the STL file format). Important decision during the set-up phase is the orientation of the part in the build envelope and what support structures are required. This depends on:

- ✓ Geometry, overhangs and inclination
- ✓ Location of most critical tolerances and surface finishes
- ✓ Areas where post-processing is required and additional material needs to be added
- ✓ **Post-processing**
- ✓ **Removal of build envelope:** The build cylinder is removed from the machine
- ✓ **Remove powder:** Build platform with the parts attached is taken out of the loose powder. Excess loose powder is removed by sand balsting. This is usually straight forward, however might require some extra effort for parts with complex geometric features (e.g. trapped powder)
- ✓ **Thermal processing:** After the build parts, are often thermally processed to release residual stresses and improve part characteristics and metallurgical structure. Which regime is best depends on the application, desired part characteristics and the material used. Typical processes include vacuum heat treatment, heat treatment under inert gas or hot isostatic pressing (HIP).

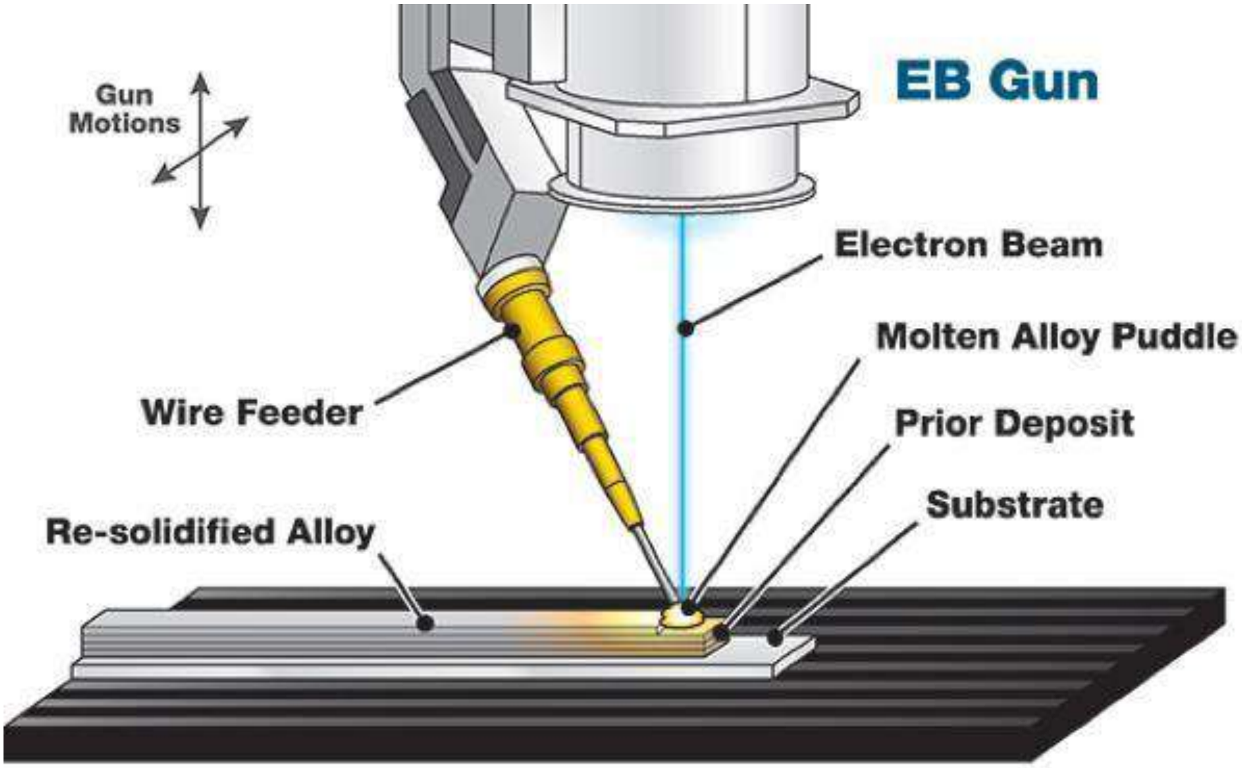
- ✓ **Removal of supports and post-machining:** Afterwards, parts are taken off the build platform, typically through wire cutting EDM or machining. Further, support structures are mechanically removed. Parts might be partially post-machined in order to fulfil critical tolerances.
- ✓ **Surface finish:** Often parts need to be further processed to improve surface finish – either mechanically (e.g. polishing, grinding, peening) or chemically (e.g. plating, electro polishing).

Directed Energy Deposition AM Processes



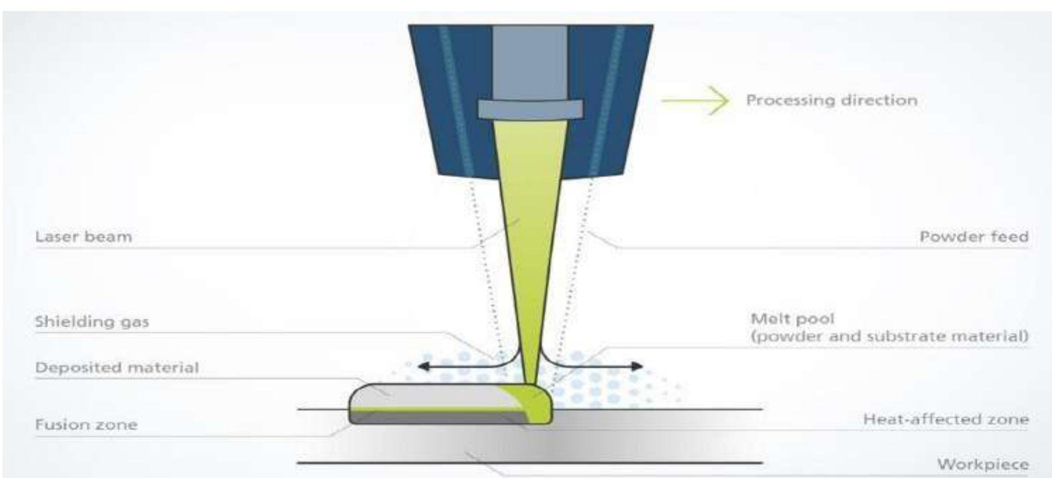
Directed Energy Deposition (DED): is a category of metal additive manufacturing (AM) that utilizes robotic welding processes to print at high deposition rates but with relatively low resolution. DED systems use an electric arc, plasma, laser or electron beam to melt metal feedstock (wire or powder) into a molten deposit pool. The DED process is typically used for prototyping, low volume production of large, simple parts, and feature addition and repair

Directed Energy Deposition (DED)



Wire DED Diagram

Powder DED Diagram:



- Four key elements of DED systems influence design, part quality, and economics:

1) The Core Printing Process

There are four different heat sources utilized in DED: electric arc, plasma, laser and electron beam. It is called “directed energy deposition” because the heat source is directed at the feedstock, at or near the point of deposition. The feedstock, either wire or powder, is then fed into the path of the heat source which melts it, causing the feedstock to drip or spray into a comparatively large melt pool. By controlling the motion of the heat source and material feed, the melt pool is directed around a toolpath where it eventually freezes into a solid metal bead. In wire-based DED, this bead is much wider than the input feedstock. The melting mechanisms are the same as conventional welding processes and require a large amount of energy to maintain the melt pool and successfully bond the deposited material to the part.

- The high energy input has important design and metallurgical implications. To borrow a welding term, there is a “heat affected zone” around the melt pool which is subjected to large thermal gradients that cause residual stresses which can lead to part distortion. These stresses, coupled with the cyclical nature of the thermal process, can adversely affect the grain structure and strength of the printed metal. The residual stresses in DED can be so severe that sometimes the print must be interrupted and stress relieved. This involves monitoring the print, stopping it when distortion surpasses an acceptable limit, allowing it to cool, and then moving the build (which can be very large and heavy) to a furnace to perform a lengthy heat treatment. All of these steps need to be completed before the part can be returned and realigned in the printer to continue the build.
- The speed of the printing process directly affects the throughput and economics. In DED processes, the print speed is correlated to the resolution, measured by the width of the deposition. Powder DED processes tend to be higher resolution and thus have lower print speeds than wire-based DED. Below is a chart representing various DED processes and their approximate print speed vs resolution

2) Geometric Capability

- Pushing a large liquid melt pool to produce a part layer does not allow much ability to do overhangs or complex internal geometries. Some DED processes can achieve overhang angles by tilting the print bed, but this approach requires advanced hardware and software, and produces only simple shapes of uniform wall thickness (e.g. a hollow sphere or curved tube).
- Design of DED parts must also consider the residual stresses induced by the process. A large XY footprint or lack of part symmetry can exacerbate this issue. Toolpaths can be optimized to reduce thermal gradients and residual stresses, but this requires advanced software and simulation expertise.

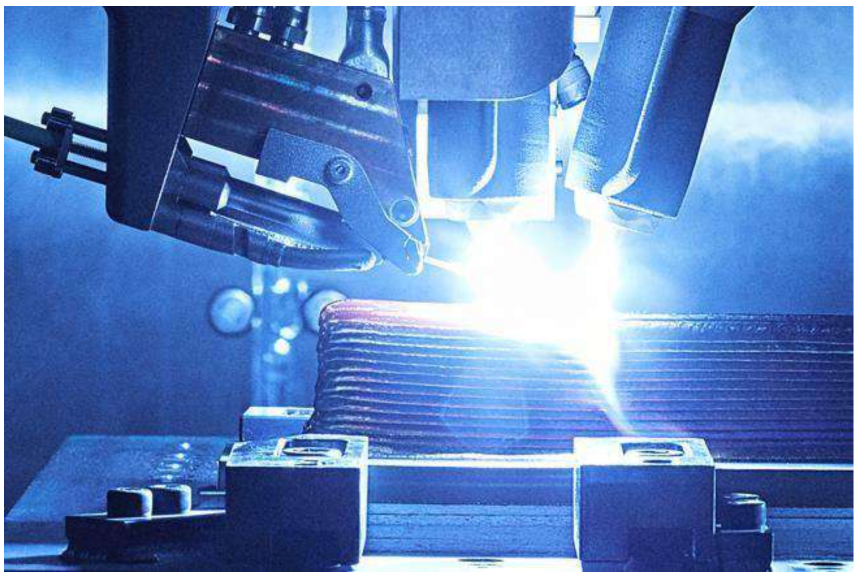
3) Environment and Power Handling

DED processes create molten pools of metal that require special environments to prevent oxidation and fire. This is especially important for reactive metals like Titanium. DED systems print in a vacuum or inert gas chamber, or locally shield the molten metal with inert gas. There are many pros and cons to each of these solutions. To highlight a few:

<u>Vacuum</u> – This provides the highest quality environment but requires a heavy, expensive, reinforced chamber to withstand vacuum forces (see system

pictured above). Also, the chemical composition of the metal can be compromised if the low-pressure environment causes elements in the melt pool to evaporate (as an example, aluminum evaporates when printing Ti6Al4V in a vacuum).

Inert Chamber –Purging the print environment with an inert gas creates a high-quality environment, but requires an enclosed system (chamber). This is the most common approach. *Purging a large chamber with inert gas (usually Argon) can be cost and time prohibitive.*



Local Shielding – This method directs inert gas directly at the melt pool through fluidic equipment attached to the print head. Local shielding provides less atmosphere purity and consistency but may eliminate the need for an expensive enclosed environment. Local shielding is typically used for very large parts where quality compromises may be acceptable and enclosed environments are prohibitively expensive

Most DED processes use high heat loads which require large, expensive power supplies. The heat source usually requires active cooling, further increasing power requirements. The large power supplies used in DED systems contribute significantly to machine cost, and expensive electrical infrastructure is often needed to run them.

4) Build Size

DED build envelopes range in size from a 150 mm cube to multiple meters on each dimension. Some DED printer OEMs custom-build extra-large printers for specific applications. The print envelope is related to the resolution and speed of the equipment – the largest printers produce simple, very low-resolution parts. It is also important to note that larger parts and systems are more susceptible to issues with the residual stresses referenced earlier

Materials

DED systems utilize either wire or powder as the feedstock. Most systems use commercial off the shelf (COTS) materials developed for welding or powder metallurgy. This has advantages in material selection as well as availability, quality and price. The wire typically ranges from 1-3 mm in diameter (the deposition width is usually many multiples of the wire diameter). Powder particle sizes are similar to those used in powder metallurgy processes, 50-150 micron.

Industries & Applications

- These fall into three high-level categories: near-net-shape parts, feature addition, and repair:

Improved

DED's limitations result in it being employed for applications like brackets, enclosures, ribs, tanks, etc. These geometries tend to be low-complexity, but are slow and expensive to machine from billet, cast, or forge at low volumes. An example is the part below – the first FAA-certified DED part flying on a commercial plane (Boeing 787). product designs, time savings, and production cost reduction.

Using DED for Near-net-shape parts has mostly been confined to the aerospace and defense, energy, marine, and industrial industries. DED's fixed cost structure, post-processing requirements, and low resolution haven't made sense for the smaller, higher volume applications that are typical in other industries.

What are the Advantages of DED

- ➢ The ability to control the grain structure.

- It allows the process to be used for the repair of high quality functional parts.
- It can balance between accuracy and speed.
- It allows for the production of relatively large parts with minimal tooling.
- The creation of components with composition gradients or hybrid structures using multiple materials with differing compositions.
- Fast builds with rapid material deposition
- Fully dense parts
- No need for supports
- Best process for part repair

What are the Disadvantages of DED?

- The finish created will vary depending on the material.
- It may require some post processing to achieve the desired effect.
- The material use for DED is still relatively limited and fusion-based processes still require further research to move them into mainstream use.
- Poor surface finish
- Wire process is less accurate

Directed Energy Deposition vs Powder Bed Fusion

- Directed Energy Deposition is ten times faster and five times less expensive than Powder Bed Fusion (PBF) when creating mid-size metal parts. The study tested the two methods in building a 150mm diameter, 200mm tall metal part from Inconel. The geometry of the part was designed to be built without support structures in order to ensure comparable parameters.

- The advantages of DED are evident in that material use as well as cooling and build times are greatly reduced compared to PBF.

Applications

- Directed Energy Deposition can be used to fabricate parts,
- **Generally used for repair or to add material to existing components**.
- the applications for DED fall into three categories;

1) near-net-shape parts.

2) feature additions

3) repair.