ANNAMACHARYA UNIVERSITY

EXCELLENCE IN EDUCATION; SERVICE TO SOCIETY

(ESTD UNDER AP PRIVATE UNIVERSITIES (ESTABLISHMENT AND REGULATION) ACT, 2016)

RAJAMPET-516126:A.P; INDIA

DEPARTMENT OF MECHANICAL ENGINEERING

LECTURE NOTES

B.Tech

(II YEAR – I SEM) (2025-26)

MANUFACTURING PROCESSES

[24AMEC327]

Prepared by
Dr.P.V.Sanjeeva Kumar
Associate Professor, MED

ANNAMACHARYA UNIVERSITY

EXCELLENCE IN EDUCATION; SERVICE TO SOCIETY

(ESTD, UNDER AP PRIVATE UNIVERSITIES (ESTABLISHMENT AND REGULATION) ACT, 2016)

Title of the Course:	Manufacturing Processes
Category:	PCC
Semester:	III Semester
Course Code:	24AMEC32T
Branch/es:	Mechanical Engineering

Lecture Hours	Tutorial Hours	Practice Hours	Credits
3	0	0	3

Course Objectives:

1. To know the working principle of different metal casting processes and gating system.
2. To classify the welding processes, working of different types of welding processes and welding defects.
3. To know the nature of plastic deformation, cold and hot working process, working of a rolling mill and types, extrusion processes.
4. To understand the principles of forging, tools and dies, working of forging processes.
5. To know about the Additive manufacturing and processing of plastics

Course Outcomes:

At the end of the course, the student will be able to

1. Explain casting processes, including pattern making, molding, solidification, and evaluate casting defects with appropriate remedies.
2. Analyze welding processes, joint characteristics, defects, their causes, and evaluate suitable remedies.
3. Analyze bulk forming processes, including metal behavior, and evaluate the effects of forging, rolling, and extrusion techniques.
4. Analyze sheet metal forming techniques, including deep drawing, bending, and evaluate defects and remedies in these processes
5. Explain additive manufacturing and plastic processing techniques, evaluate their advantages, limitations, and applications.

Unit 1 Casting & Special Casting Processes 08

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. 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 2 Welding Processes 08

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

Unit 3 Bulk Metal Forming Processes 07

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 4 Sheet Metal Forming Processes 06

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

Unit 5 Additive Manufacturing and Polymer Processing Techniques 08

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

Plastics: Classification – Properties – Plastics as engineering materials – Method of processing plastics –

Injection moulding –Blow moulding -extrusion compression and transfer moulding

Prescribed Textbooks:

1. S. Kalpakjian and S.R. Schmid, Manufacturing Engineering and Technology, Pearson Education, 2007, 7th Edition. ISBN-13- 978-9332587908
2. P.N. Rao, Manufacturing Technology: Volumes I, 5/e, McGraw Hill Education, 2018, ISBN-13-978-9353160500

Reference Books:

1. Mikell P. Groover, Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, Wiley
2. Amitabha Ghosh and Asok Kumar Mallik, Manufacturing Science, Affiliated East-West Press
3. R.K. Rajput, Manufacturing Technology, Laxmi Publications
4. P.C. Sharma, A Textbook of Production Engineering, S. Chand & Company

Web Resources:

1. https://archive.nptel.ac.in/courses/112/107/112107219/
2. https://archive.nptel.ac.in/courses/112/107/112107145/
3. https://www.youtube.com/playlist?list=PLpW2AOg7zoagjrDiiUac0lSIEP734DwNj
4. https://www.youtube.com/watch?v=gvynYCsGh14
5. https://www.youtube.com/watch?v=iy-AuAC_hOg

CO-PO Mapping:

Course Outcomes	Engineering Knowledge	Problem Analysis	Design/Development of solutions	Conduct investigations of complex problems	Engineering Tool usage	The Engineer and The World	Ethics	Individual and Collaborative team	Communication	Project management and finance	Life-long learning	PSO1	PSO2
24AMEC32T.1	2	2	1	1	-	-	1	-	-	-	-	1	1
24AMEC32T.2	1	3	2	1	-	-	1	-	-	-	-	2	1
24AMEC32T.3	1	3	2	1	-	-	1	-	-	-	-	1	2
24AMEC32T.4	1	3	2	1	-	-	1	-	-	-	-	2	1
24AMEC32T.5	3	1	-	-	-	-	-	-	-	-	-	1	2

Unit 1 - Casting & Special Casing Processes

[Casting: Steps involved in making casting– Advantages of casting and its applications-Patterns and pattern making-Types of patterns–Materials used for pattern —Pattern allowances and their Construction – Molding-different types of cores - Principles of Gating- Risers- Casting design considerations - Solidification of casting – Casting defects –Causes and remedies - Basic principles and applications of Special casting processes: Centrifugal casting - Die casting-Investment casting – shell moulding]

INTRODUCTION

Improved civilization is due to improved quality of products, proper selection of design as well as manufacturing process from raw materials to finished goods. Manufacturing engineering is defined as **the branch of engineering which the raw materials are converted in to finished products for the needs of human or society**.

Classification of manufacturing processes:-

I.Primary Manufacturing processes:- (a) Casting (b) Forming
II.secondary Manufacturing processes:-(c) Fabrication (d) Material Removal

Metal Casting Process:- Virtually nothing moves, turns, rolls, or flies without the benefit of cast metal products. The metal casting industry plays a key role in all the major sectors of our economy. There are castings in locomotives, cars, trucks, aircraft, office buildings, factories, schools, and homes. **Metal Casting is one of the oldest materials shaping methods known. Casting means pouring molten metal into a mold with a cavity of the shape to be made, and allowing it to solidify. When solidified, the desired metal object is taken out from the mold either by breaking the mold or taking the mold apart. The solidified object is called the casting. The department of the workshop, where castings are made is called foundry**. By this process, intricate parts can be given strength and rigidity frequently not obtainable by any other manufacturing process. The mold, into which the metal is poured, is made of some heat resisting material. Sand is most often used as it resists the high temperature of the molten metal. Permanent molds of metal can also be used to cast products.

Advantages: - • Any intricate shape can be produced. • Possible to cast both ferrous and non-ferrous materials • Tools are very simple and expensive • Useful for small lot as well as mass production • Weight reduction in design • No directional property • Extremely large, heavy metal objects can be made • most favorable mechanical properties can be attained such as machinability, vibration damp capacity etc,.

Limitations:- • Accuracy and surface finish are not very good for final application • Difficult to remove defects due to presence of moisture

Application:- Cylindrical bocks, wheels, cylinder liners, gears, pipes, bells, pistons, piston rings, machine tool beds ,turbine blades, agriculture parts, pump housings, mill rolls , etc.

Casting terms:-

Moulding Box or Flask- It holds the sand mould intact. It is made up of wood for temporary application and metal for long term use. There are three types of flasks such as (i) Drag- Lower moulding flask (ii) Cope – Upper moulding flask (iii) Cheek – Intermediate moulding flask used in three piece moulding.
Pattern - Replica of final object to be made with some modifications. Mould cavity is made with the help of pattern.
Parting line – Dividing line between two moulding flasks.
Bottom board – Board used to start mould making (wood)
Facing sand - Small amount of carboneous material sprinkled on the inner surface of the mould cavity to give better surface finish to casting.
Moulding sand – Freshly prepared refractory material used for making the mould cavity. (Mixture of silica, clay & moisture)
Backing sand – used and burnt sand Core – Used for making hollow cavities in the casting
Pouring basin – Funnel shaped cavity on the top of the mould into which molten metal is poured
Sprue – Passage from pouring basin to the mould cavity. It controls the flow of molten metal into the mould. Figure 1 Cross-section of a sand mould ready for pouring
Runner – Passage ways in the parting plane through which molten metal flow is regulated before they reach the mould cavity
Gate – Actual entry point through which molten metal enters the mould cavity
Chaplet – Used to support the core to take of its own weight to overcome the metallostatic force.
Chill – Metallic objects to increase cooling rate of casting
Riser – Reservoir of molten metal in the casting so that hot metal can flow back into the mould cavity when there is a reduction in volume of metal due to solidification

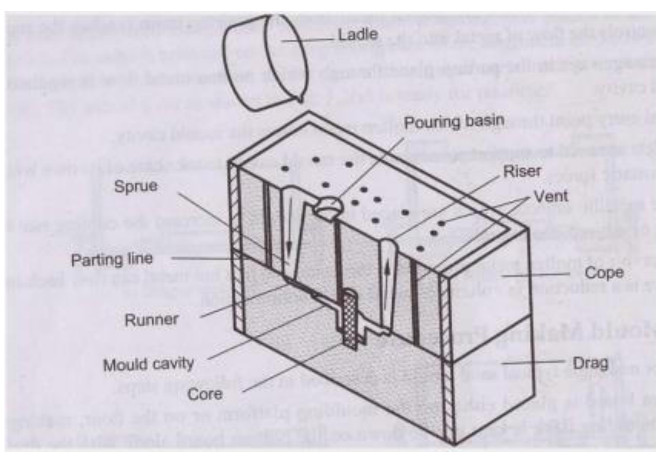


Figure 1 Cross-section of a sand mould ready for pouring

Moulding sand : The moulding sand is the principle material used in foundry because it possess the properties vital for casting process.

The moulding sand consist of the following main constitutes: (i) Silica (ii) Clay (iii) Binder (iv) additives.

Properties of Moulding Sand:

- Compressive Strength
- Permeability
- Refracteriness
- Addhessiveness
- Cohessiveness
- Bondability
- Hardness
- Collapsibility

Types of Moulding Sands:

(i) Green Sand
(ii) Dry Sand
(iii) Loam Sand
(iv) Facing sand
(v) Backing Sand
(vi) Parting Sand
(vii) Core Sand
(viii) System Sand

Tools Used in Foundry

(i) Moulding Flask/Boxes (ii) Pattern (iii) Shovel (iv) Riddle (v) Rammers (vi) Trowels (vii) Slick (viii) Lifters (ix) Strike off Bar (x) Sprue pin (xi) Riser (xii) Bellow/Blower (xiii)Swab (xiv) Gate Cutter (xv) Draw Spike (xvi) Vent Rod (xvii) Rapping Plate (xviii) Gaggers (xix) Clamps (xx) Pouring Weight (xxi) Moulding Board (xxii) Mallet

Steps in Involved in making of casting:

There are FIVE basic steps in making sand castings:

1. Patternmaking 2. Core making 3. Molding 4. Melting and pouring 5. Cleaning or Fettling 6.Testing.

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

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

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

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

5.Cleaning or Fettling:- Cleaning or Fettling refers to all operations necessary to the removal of sand, scale, and excess metal from the casting. Burned-on sand and scale are removed to improve the surface appearance of the casting. Excess metal, in the form of fins, wires, parting line fins, and gates, is removed.

6. Testing:-Inspection of the casting for defects and general quality is performed.

Pattern

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

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

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

To be suitable for use, the pattern material should be:-
1. Easily worked, shaped and joined 2. Light in weight 3. Strong, hard and durable 4. Resistant to wear and abrasion 5. Resistant to corrosion, and to chemical reactions 6. Dimensionally stable and unaffected by variations in temperature and humidity 7. Available at low cost .
The usual pattern materials are wood, metal, and plastics. The most commonly used pattern material is wood, since it is readily available and of low weight. Also, it can be easily shaped and is relatively cheap. The main disadvantage of wood is its absorption of moisture, which can cause distortion and dimensional changes. Hence, proper seasoning and upkeep of wood is almost a prerequisite for large-scale use of wood as a pattern material.

Pattern Allowances:-

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

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

1. Shrinkage or Contraction:- Shrinkage is defined as reduction is the dimension of the cast during the cooling or solidification process. This is a general property of all materials. The magnitude of shrinkage varies from material to material but every material shrinks. Shrinkage or Contraction Allowance to view various rate of contraction of various materials. All most all cast metals shrink or contract volumetrically on cooling. The metal shrinkage is of two types

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

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

Shrinkage allowances for various metals

Material (Non Ferrous)	Shrinkage allowance (mm/mm)
Aluminium	0.0130
Aluminium Bronze	0.0200 to 0.0230
Brass	0.0155
Copper	0.0100 to 0.0160
Lead	0.0260
Magnesium	0.0130
Magnesium alloys	0.0160
White metal	0.0060
Zinc	0.0100 to 0.0150

Material (Ferrous)	Shrinkage allowance (mm/mm)
Grey cast iron	0.0105
White cast iron	0.0160 to 0.0230
Plain carbon steel	0.0210
Chromium steel	0.0200
Manganese steel	0.0250 to 0.0380

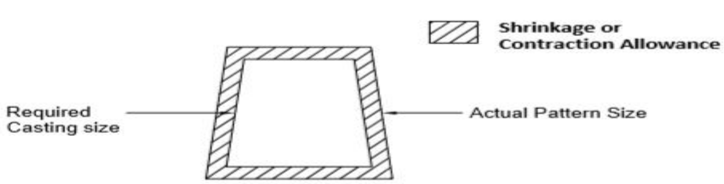


Figure. Shrinkage or contraction Allowance

Shrinkage Allowances

2. Draft or Taper Allowance:- By draft is meant the taper provided by the pattern maker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the sand mold and without excessive rapping by the molder. Figure (a) shows a pattern having no draft allowance being removed from the pattern. In this case, till the pattern is completely lifted out, its sides will remain in contact with the walls of the mold, thus tending to break it. Figure (b) is an illustration of a pattern having proper draft allowance. Here, the moment the pattern lifting commences, all of its surfaces are well away from the sand surface. Thus the pattern can be removed without damaging the mold cavity. Draft allowance varies with the complexity of the sand job. But in general inner details of the pattern require higher draft than outer surfaces. The amount of draft depends upon the length of the vertical side of the pattern to be extracted; the intricacy of the pattern; the method of molding; and pattern material.

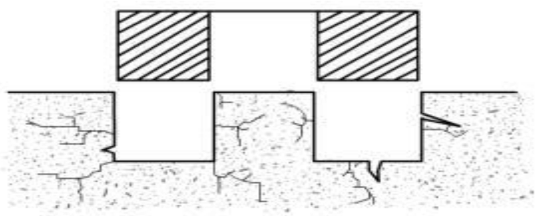


Figure (a): Pattern having no draft on vertical edges

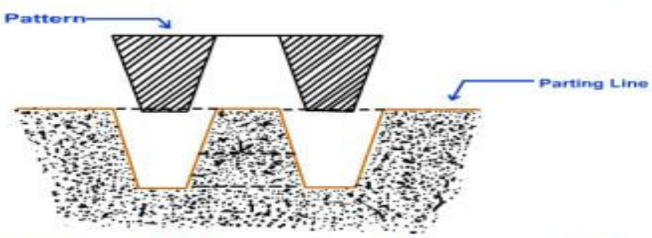
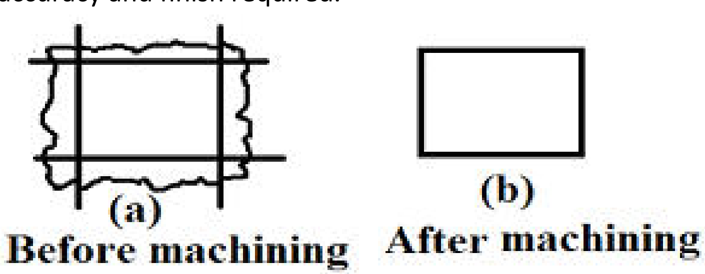


Figure (b) Pattern having draft on vertical edges

Pattern	Outer Draft Angle (in degrees)	Inner Draft Angle
Plastic	0.25 to 1.00	0.35 to 2.25
Wood	0.25 to 3.00	0.50 to 3.00
Metal	0.35 to 1.50	0.50 to 3.00

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



Dimensions (mm)	Bore allowance	Surface allowance (mm)	Cope side Allowance
Non – ferrous metals			
Less than 200	2.0	1.5	2.0
200 to 300	2.5	1.5	3.0
300 to 900	3.0	2.5	3.0
Cast Iron			
Less than 300	3.0	3.0	5.5
300 to 500	5.0	4.0	6.0
500 to 900	6.0	5.0	6.0
Cast steel			
Less than 150	3.0	3.0	6.0
150 to 500	6.0	5.5	7.0
500 to 900	7.0	6.0	9.0

4**. Distortion or Camber Allowance**:- Sometimes castings get distorted, during solidification, due to their typical shape. For example, if the casting has the form of the letter U, V, T, or L etc. it will tend to contract at the closed end causing the vertical legs to look slightly inclined. This can be prevented by making the legs of the U, V, T, or L shaped pattern converge slightly (inward) so that the casting after distortion will have its sides vertical (Figure .4). The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different section of the casting and hindered contraction. Measure taken to prevent the distortion in casting include:

i. Modification of casting design ii. Providing sufficient machining allowance to cover the distortion affect iii. Providing suitable allowance on the pattern, called camber or distortion allowance (inverse reflection)

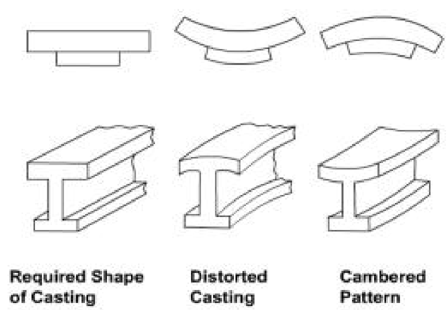


Figure 4: Distortions in castings

5. Rapping Allowance:- Before the withdrawal from the sand mold, the pattern is rapped all around the vertical faces to enlarge the mold cavity slightly, which facilitate its removal. Since it enlarges the final casting made, it is desirable that the original pattern dimension should be reduced to account for this increase. There is no sure way of quantifying this allowance, since it is highly dependent on the foundry personnel practice involved. It is a negative allowance and is to be applied only to those dimensions that are parallel to the parting plane.

Types of Patterns:-

Various types of patterns depends on

- Complexity of the job
- No of castings required
- Molding procedure adopted

(a) Single piece pattern or Solid pattern – It is Inexpensive and simplest one. A Single piece pattern made in one piece only and have no joints or lose pieces. Simple job Useful for Small scale production. Pattern will be entirely in the drag box only. One surface is flat and at the parting line. These patterns are cheap in cost. When using this pattern, the moulder has to cut his own runners, risers and feeding gates.

(b) Split or two piece pattern – Many patterns cannot be made in a single piece because of the difficulties encountered in molding them such patterns are then made as a split or two piece or three piece patterns. The upper and lower parts of the split pattern are accommodated in the cope and drag boxes of the mold separately.

(c) Multipiece pattern: - Patterns for still more intricate castings are made in more than two pieces for facilitating their moulding and withdrawing. A pattern having three pieces required a three piece flask for the moulding processes. The center flask is known as "Cheek". This type of pattern is called the Multipiece pattern. If the pattern have the third piece, the center flask is required and it is called as cheek box. It is used for intricate casting Split along the parting line. It is used where depth of job is too high. The alignment between the pieces of the pattern is with dowel pins fitted to them.

(d) Gated pattern – Gating and runner system are integrated with the pattern is called gated pattern. This can Improves productivity. Usually the gated patterns are made with metal which increases their strength and reduces the tendency to wrap. The gated pattern can manufacture many casting at one time and thus it is used in mass production.

(e) Cope and drag pattern - In the production of large castings, the complete moulds are too heavy to handle by a single operator. Therefore the cope and drag patterns are used to ease this problem to efficient operation. It is similar to split pattern. For cope and drag, separately attached gating system to metal plate. Where ever the patterns are Heavy and inconvenient for handling, this patterns is recommended. It is also useful for Continuous production

(f) Match plate pattern – These patterns are molded with the machines. It consists of a match plate on either side of which each half a number of split patterns are fastened .Similar to cope and drag patterns with gating and risering system mounted on a single matching plate Pattern and match plate are made up of metal (Al) Useful for small casting with high dimensional accuracy Suitable for large scale production Gating system is attached to the match plate Expensive. Piston rings of IC engines are produced with the help of match plate patterns.

(g) Loose piece pattern – Withdrawing of the pattern from the mold is difficult, then it is preferred by lose piece pattern. In this case the main pattern is removed first. Then separate pieces, which may have to be moved or turned before they can be taken out are removed. Useful for highly skilled job Expensive. They require more maintenance.

(h) Follow board pattern – Used for structurally weak portions Bottom board is modified as follow board.

(i) Sweep pattern – The sweep patterns are useful for axi-symmetrical and cylindrical shape Suitable for large scale production. The sweep pattern consists of a board having a shape corresponding to the shape of desired casting and arranged to rotate about the central axis.The sand is rammed in the place and sweep board is moves around its axis of rotation to give the molding sand the desired shape.

(j) Shell pattern- These are used largely for drainage fittings and pipe works. The shell pattern is a hollow construction like a shell and the outside shape is used as a pattern to make the mold, while the inside is used as a core box for making cores. The pattern is usually made of metal mounted on a plate and parted along the center line. The two sections are being accurately doweled together.

(k) Skeleton pattern – Stripes of wood are used for building final pattern Suitable for large casting. The patterns for very large castings would require a large amount of timber for full pattern. In such cases skeleton pattern may be employed. This is a ribbed construction with a large number of square or rectangular openings between the ribs which form a skeleton outline of the pattern to be made. The framework is filled with sand or loam or clays. The excess sand out of the spaces between the ribs is scraped by tool strike of board known as "stickle board". It is usually built in two parts such that one is for cope and another is for drag.

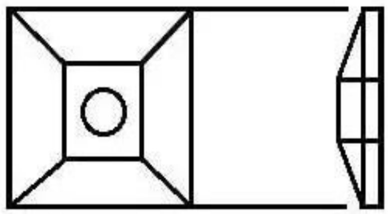
(l) Segmental pattern-The segmental patterns or part patterns are generally applied to make circular works such as rings, wheel rims, gears etc. They are sections of the pattern so arranged as to form a complete mould being moved to form each section of the mould. When making a mould by using this pattern, a vertical spindle is firmly fixed in the center of the drag box.

(m) Right hand and Left hand patterns- many patterns are required to be made in pairs and when their form is such that they cannot be reversed and they have the centers of hubs, bosses etc., and opposite in line. They must be made right and left hand. "J" hangers for overhead shaft line, legs for garden benches / sewing machine/ lathe and brackets for luggage carriers in train coaches are the few examples.

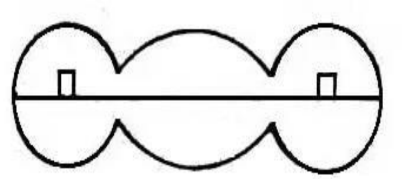
(n) Built-up pattern- As the name implies are composed of two or more pieces. Patterns for special pulleys/flanges are built up segments of wooden strips. These segments are made by cutting stripes of wood to the curvature required and the thickness desired is built up by gluing them by layers. The building up is sometimes necessary because it is difficult to make an intricate shape on a block of wood for constructing a pattern, but easier to build up the shape by gluing or joining number of segmental pieces together.

(o) Boxed-up pattern:- In a boxed up pattern the planks or strips of wood are so joined together either by glue, nails or screws that a pattern is made like a box. Not only this method economizes wood for large patterns but makes them lighter on weight.

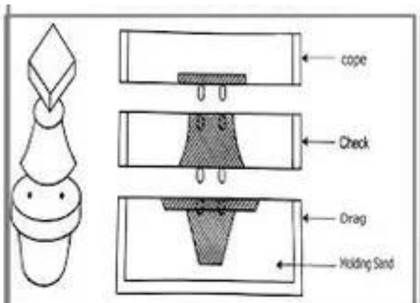
(p) Lagged-up pattern:- Cylindrical works such as cylindrical pipes or columns are built up with lag or stave construction which ensures the performance of the form. Lags or Staves are longitudinal strips of wood which are beveled on each side to make the joint tight outside and glued and nailed or screwed to the end pieces of the wood called heads.



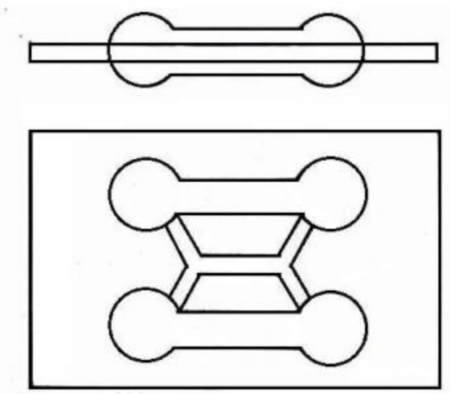
Single Piece or Solid Pattern



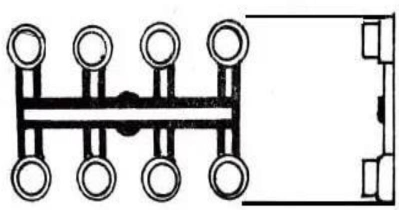
Split Pattern



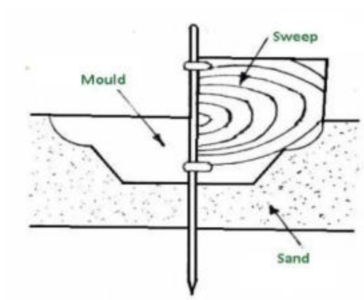
Multi Piece (Cope Drag) Pattern



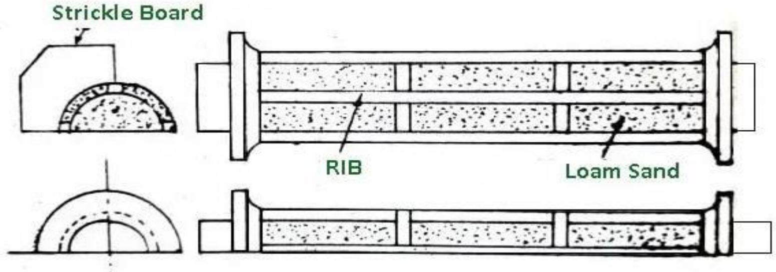
Match Plate Pattern



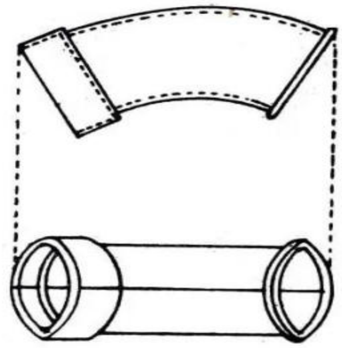
Gated Pattern



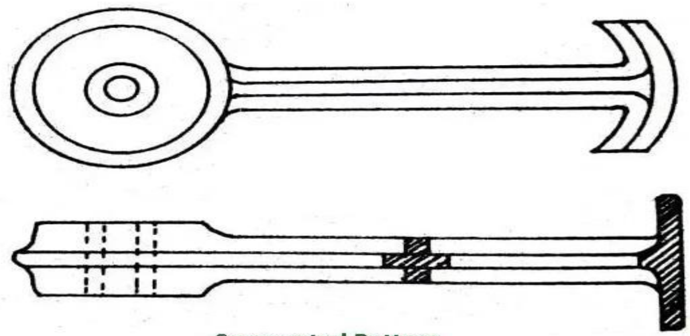
Sweep Pattern



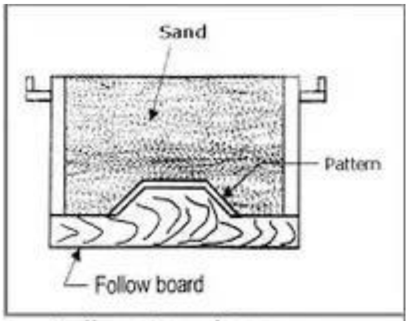
Skeleton Pattern



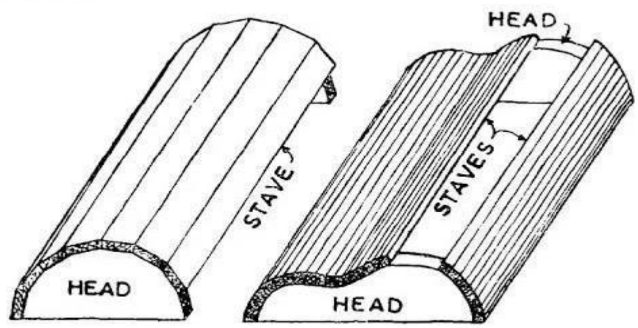
Shell Pattern

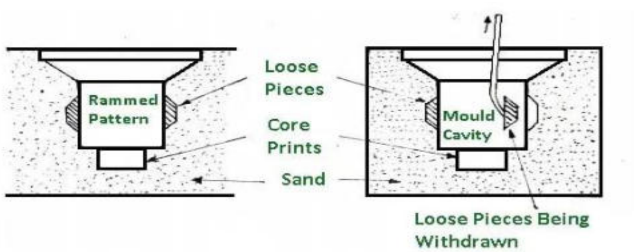


Segmented Pattern



Follow Board Pattern





Loose Piece Pattern

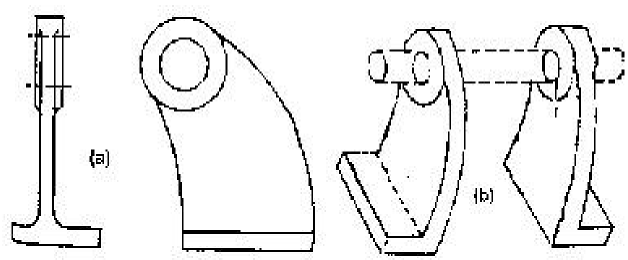


Fig. 6.8 Left and right pattern

COMMON PATTERN MATERIALS: common materials used for making patterns are wood, metal, plastic, plaster, wax or mercury.

Pattern material should be: 1. Easily worked, shaped and joined 2. Light in weight 3. Strong, hard and durable 4. Resistant to wear and abrasion 5. Resistant to corrosion, and to chemical reactions 6. Dimensionally stable and unaffected by variations in temperature and humidity 7. Available at low cost.
The some important pattern materials are discussed as under.
Wood: Wood is the most popular and commonly used material for pattern making. It is cheap, easily available in abundance, repairable and easily fabricated in various forms using resin and glues. It is very light and can produce highly smooth surface. Wood can preserve its surface by application of a shellac coating for longer life of the pattern. But, in spite of its above qualities, it is susceptible to shrinkage and warpage and its life is short because of the reasons that it is highly affected by moisture of the molding sand. After some use it warps and wears out quickly as it is having less resistance to sand abrasion. It cannot withstand rough handily and is weak in comparison to metal. In the light of above qualities, wooden patterns are preferred only when the numbers of castings to be produced are less.
The main varieties of woods used in pattern-making are **shisham, kail, deodar, teak,maple,cherry, and mahogany**.
Advantages of wooden patterns:-1 Wood can be easily worked. 2 It is light in weight. 3 It is easily available. 4 It is very cheap. 5 It is easy to join. 6 It is easy to obtain good surface finish. 7 Wooden laminated patterns are strong. 8 It can be easily repaired.
Disadvantages:-1 It is susceptible to moisture. 2 It tends to warp. 3 It wears out quickly due to sand abrasion. 4 It is weaker than metallic patterns.

1. **Metal Metallic patterns** are preferred when the number of castings required is large enough to justify their use. These patterns are not much affected by moisture as wooden pattern. The wear and tear of this pattern is very less and hence possess longer life. Moreover, metal is easier to shape the pattern with good precision, surface finish and intricacy in shapes. It can withstand against corrosion and handling for longer period. It possesses excellent strength to weight ratio. The main disadvantages of metallic patterns are higher cost, higher weight and tendency of rusting. It is preferred for production of castings in large quantities with same pattern. The metals commonly used for pattern making are cast iron, brass and bronzes and aluminum alloys.

   Cast Iron;-It is cheaper, stronger, tough, and durable and can produce a smooth surface finish. It also possesses good resistance to sand abrasion. The drawbacks of cast iron patterns are that they are hard, heavy, and brittle and get rusted easily in presence of moisture. Advantages 1. It is cheap 2. It is easy to file and fit 3. It is strong 4. It has good resistance against sand abrasion 5. Good surface finish Disadvantages 1 It is heavy 2 It is brittle and hence it can be easily broken 3 It may rust.

   Brasses and Bronzes:- These are heavier and expensive than cast iron and hence are preferred for manufacturing small castings. They possess good strength, machinability and resistance to corrosion and wear. They can produce a better surface finish. Brass and bronze pattern is finding application in making match plate pattern Advantages 1. Better surface finish than cast iron. 2. Very thin sections can be easily casted. Disadvantages 1. It is costly 2. It is heavier than cast iron.

Aluminum Alloys:- Aluminum alloy patterns are more popular and best among all the metallic patterns because of their high light ness, good surface finish, low melting point and good strength. They also possesses good resistance to corrosion and abrasion by sand and thereby enhancing longer life of pattern. These materials do not withstand against rough handling. These have poor repair ability and are preferred for making large castings. Advantages 1. Aluminum alloys pattern does not rust. 2. They are easy to cast. 3. They are light in weight. 4. They can be easily machined. Disadvantages 1. They can be damaged by sharp edges. 2. They are softer than brass and cast iron. 3. Their storing and transportation needs proper care.

White Metal:- (Alloy of Antimony, Copper and Lead) Advantages 1. It is best material for lining and stripping plates. 2. It has low melting point around 260°C 3. It can be cast into narrow cavities. Disadvantages 1. It is too soft. 2. Its storing and transportation needs proper care 3. It wears away by sand or sharp edges.

3.Plastic :-Plastics are getting more popularity now a days because the patterns made of these materials are lighter, stronger, moisture and wear resistant, non-sticky to molding sand, durable and they are not affected by the moisture of the molding sand. Moreover they impart very smooth surface finish on the pattern surface. These materials are somewhat fragile, less resistant to sudden loading and their section may need metal reinforcement. The plastics used for this purpose are thermosetting resins. Phenolic resin plastics are commonly used. These are originally in liquid form and get solidified when heated to a specified temperature. To prepare a plastic pattern, a mould in two halves is prepared in plaster of paris with the help of a wooden pattern known as a master pattern. The phenolic resin is poured into the mould and the mould is subjected to heat. The resin solidifies giving the plastic pattern. Recently a new material has stepped into the field of plastic which is known as foam plastic. Foam plastic is now being produced in several forms and the most common is the expandable polystyrene plastic category. It is made from benzene and ethyl benzene.

4. Plaster:-This material belongs to gypsum family which can be easily cast and worked with wooden tools and preferable for producing highly intricate casting. The main advantages of plaster are that it has high compressive strength and is of high expansion setting type which compensate for the shrinkage allowance of the casting metal. Plaster of paris pattern can be prepared either by directly pouring the slurry of plaster and water in moulds prepared earlier from a master pattern or by sweeping it into desired shape or form by the sweep and strickle method. It is also preferred for production of small size intricate castings and making core boxes.

5. Wax:-Patterns made from wax are excellent for investment casting process. The materials used are blends of several types of waxes, and other additives which act as polymerizing agents, stabilizers, etc. The commonly used waxes are paraffin wax, shellac wax, bees-wax, ceresin wax, and micro-crystalline wax. The properties desired in a good wax pattern include low ash content up to 0.05 per cent, resistant to the primary coat material used for investment, high tensile strength and hardness, and substantial weld strength. The general practice of making wax pattern is to inject liquid or semiliquid wax into a split die.

Principles of gating system

The term gate is defined as one of the channels which actually led in to the mould cavity. The term gating system refers to all channels by means of which molten metal is delivered to the mould cavity.

In order to provide defect-free casting the gating system should make certain provisions while designing the gating system.

1. The mould should be completely filled in the smallest time possible without having to raise the metal temperature or use high metal heads.
2. The metal should flow smoothly into the mould without any turbulence. A turbulence metal flow tends to form dross in the mould.
3. Unwanted material such as slag, dross and other mould material should not be allowed to enter the mould cavity
4. The metal entry into the mould cavity should be properly controlled in such a way that aspiration of the atmospheric air is prevented.
5. A proper thermal gradient be maintained so that the casting is cooled without any shrinkage cavities or distortions.
6. Metal flow should be maintained in such a way that no gating or mould erosion takes place.
7. The gating system should ensure that enough molten metal reaches the mould cavity
8. The gating system design should be economical and easy to implement and remove after casting solidification.
9. Ultimately, the casting yield should be maximized

Elements of gating system

Gating system refers to all those elements which are connected with the flow of molten metal from the ladle to the mould cavity. The various elements that are connected with the gating system are:

- **Pouring Basin**
- **Sprue**
- **Sprue-base well**
- **Runner**
- **Runner Extension**
- **In-gate**
- **Riser**

- **Pouring Basin**: In order to avoid mould erosion, molten metal is poured into a pouring basin, which acts as a reservoir from which it moves smoothly into the sprue. The pouring basin stops the slag from entering into the mould cavity by the help of skimmer or skim core. It holds the slag and dirt which floats on top and only allows the clean metal. It should be always full during pouring and one wall should be inclined 45^0 to the horizontal.

Function:-This will reduce the momentum of liquid flowing into mould Design:- Pouring basin should be deep enough. Entrance into sprue be a smooth radius of 25mm. pouring basin depth should be 2.5 times the sprue entrance diameter. A strainer core restricts the flow of metal into the sprue and thus helps in quick filling of the pouring basin. It is a ceramic coated screen with many small holes.

- **Sprue:** It is a channel through which molten metal is pours into the parting plane where it enters into the runner and gates to reach the mould cavity. When molten metal is moving from top to the cope, it gains velocity and requires a smaller amount of area of cross-section for the same amount of metal to flow. If the sprue is straight and cylindrical, then a low pressure area will be created at the bottom of the sprue. Since the sand is permeable, it will aspire atmospheric air into the mould cavity causing defects in the casting. That is why the sprue is generally made tapered to gradually reduce the cross section.
- **Sprue Base Well**: This is the reservoir for the metal at the bottom of sprue to reduce the momentum of the molten metal. Sprue base well area should be 5 times the sprue choke area and well depth should be approximately equal to that of the runner.
- **Runner:** The runner takes the molten metal from sprue to the casting. It is located at the parting plane which connects the sprue to its ingates. It traps the slag & dross from moving into the mould cavity. This is normally made trapezoidal in cross section. For ferrous metals, the runners should be kept in cope and ingates in drag.
- **Runner Extension** This is provided to trap the slag in the molten metal.
- **In gate:** This is the final stage where the molten metal moves from the runner to the mold cavity. These are the opening through which molten metal enters into the mould cavity. Depending on the application, the various types of gates are:

  Top gate:- The molten metal enters into the mould cavity from the top. These are only used for ferrous alloys. Suitable for simple casting shape. There may be chance of mould erosion.

  Bottom gate:- This type of gating system is used for very deep moulds. It takes higher time for filling of the mould cavity.

  Parting gate:- This is most widely used gate in sand casting. The metal enters into the mould at the parting plane. This is easiest and most economical.

  Step gate:- These types of gates are used for heavy and large casting. The molten metal enters into the mould cavity through a number of ingates arranged in vertical steps. The size of ingates are increased from top to bottom ensuring a gradual filling of mould cavity
- **Riser**:- Riser is a source of extra metal which flows from riser to mold cavity to compensate for shrinkage which takes place in the casting when it starts solidifying. Without a riser heavier parts of the casting will have shrinkage defects, either on the surface or internally.

  Most alloys shrink during solidification. As a result of this volumetric shrinkage, voids are formed which are known as hot spots. So a reservoir of molten metal is maintained from which the metal can flow steadily into the casting. These reservoirs are known as risers.

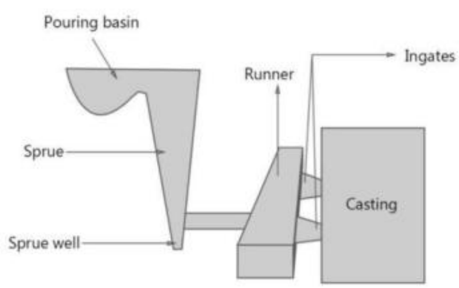
  Design considerations: - The metal in riser should solidify at the end and the riser volume should be sufficient for compensating the shrinkage in the casting. To solve this problem, the riser should have higher volume. The types of risers are:

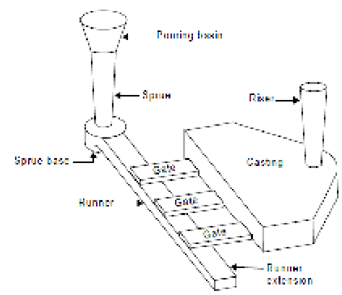
(a) Top riser- This type of riser is open to the atmosphere. It is very conventional & convenient to make. It loses heat to the atmosphere by radiation & convention. To reduce this, insulation is provided on top such as plaster of paris and asbestos sheets.

(b) Blind riser: - This type of riser is surrounded by the moulding sand and looses heat very slowly.

(c) Internal riser:- It is surrounded on all sides by casting such that heat from casting keeps the metal in the riser hot for a longer time. These are used for cylindrical shapes or hollow cylindrical portions casting.

Skim Bob: A skim bob is an enlargement along the runner, whose function is to trap heavier and lighter impurities such as dross or eroded sand. It thus prevents these impurities from going into the mould cavity.





Gating Ratio

The rate of flow of molten metal through the mould cavity is a function of the cross sectional area of the sprue, runners and gates. The dimensional characteristics of gating system can be expressed in terms of gating ratio. The gating ratios refers to the proportion of the cross-sectional areas between sprue, runner and gates. Generally in gating system, the sprue base area taken as unity, followed by the total runner area and finally total ingate area. For example a gating system having a sprue of $1cm^2$, a runner of $3cm^2$ and three gates each having $1cm^2$ cross-sectional area will have a gating ratio of 1:3:3.

The gating ratio reveals that whether the total cross section decreases or increases towards the mould cavity. According, There can be Two types of gating system.

(a) **Non pressurized gating system**:- In this the cross sectional area of the sprue is less than the total area of the runner and then that of the ingates. This has a choke at bottom of the sprue having total runner area and in gates area, sprue area. This reduces the turbulence. This is useful for Al and Mg alloys. These have tapered sprue, sprue base well and pouring basin.

Sprue : runner : ingate :: 1:4:4 or 1:3:3 Disadvantages :- -Air inspiration -casting yield- less

(b) **Pressurized gating system**:- This system has less cross sectional area at the ingates to the mould cavity than at the sprue base. In this type, the in gate areas are smallest, thus maintaining a back pressure. Because of this, the metal is more turbulent and flows full with a minimum air aspiration. This has a higher casting yield. Mostly useful for ferrous and brass castings.

Sprue : runner : ingate :: 1:0.75:0.5 or 2:1:1

Design of Gating System

Sprue:-In the design of gating system , the sprue is main and are designed in tapered shape to reduce the aspiration of air due to increased velocity as the metal flows down the sprue. This is obtained by applying the Bernoulli's equation and the Law of continuity.

The Liquid metal that runs through various channels, obeys Bernoulli's equation according to which the total energy head remains constant.

$$\frac{p}{w} + \frac{v^2}{2g} + h = Cons\tan t$$

h = Potential head[m]; P = pressure[Pa]; V = liquid velocity [m/s]; W= sp. wt. of liquid [N/m^3]
g = gravitational constant, 9.8 m/s^2

Another law of fluid mechanics which is useful in understanding the gating system behavior is law of continuity. According to the Law of continuity, the volume of metal flow at any section is constant.

$$Q = A_1 V_1 = A_2 V_2$$

Q= rate of flow, m3 /s A = Area, m2 V = Velocity, m/s

Pouring time: - One of the important objectives in the design of gating system is pouring time. It is the time required for complete filing of mould cavity. If it is too long, then it requires a higher pouring temperature and if is too short, there will be turbulent flow, which will cause defective casting. So the pouring time depends on casting material, complexity of casting, section thickness and casting size. Ferrous material requires less pouring time whereas non-Ferrous materials require higher pouring time.

The following are the some standard methods to calculate the pouring time for different casting materials.

(1) Grey cast iron, mass< 450 kg

$$t = K\left(1.41 + \frac{T}{14.59}\right)\sqrt{W}, \text{ s}$$

K= fluidity of iron, inches/40
T = avg. section thickness, mm
W = Mass of casting, kg

(2) Grey cast iron, mass> 450 kg

$$t = K\left(1.236 + \frac{T}{16.65}\right)\sqrt[3]{w},\ s$$

Pouring time for cast iron	
Casting mass	Pouring time, s
20 kg	6 to 10
100 kg	15 – 30
100000 kg	60 – 180

(3) Steel casting

$$t = (2.4335 - 0.3953 \log W)\sqrt{w},\ s$$

(4) Shell moulded ductile iron, (Vertical pouring)

$t = K_1\sqrt{w}$, s

K_1 = 2.080 for thin section

= 2.670 for 10 – 25 mm thick sections

= 2.970 for heavier section

(5) Cu alloy castings

$t = K_2\sqrt[3]{w}$, s

K_2 = constant given by

Top gating – 1. 30

Bottom gating – 1.80

Brass – 1.90

Tin bronze – 2.80

(6) Intricately shaped thin walled casting – upto 450 kg

$t = K_3\sqrt[3]{w'}$, s

W' =mass of casting with gates and risers, kg

K_3 = constant

T (mm)	K_3
1.5 – 2.5	1.62
2.5 – 3.5	1.68
3.5 – 8	1.85
8 – 15	2.2

(7) Above 450 kg &upto 1000 kg

$t = K_4\sqrt[3]{w'}$, s

T (mm)	K_4
Upto 10	1
10 – 20	1.35
20 – 40	1.4
Above 40	1.7

for mass< 200kg; avg.section thickness – 25mm

grey cast iron	40s
steel	20s
brass	15 – 45s

Choke area:- The control area which meters the metal flow into the mould cavity so that the mould is completely filled up within the calculated pouring time is known as choke area. It is mainly considered at the bottom of the sprue. The choke area by using Bernoulli's equation,

$$A = \frac{W}{dtC\sqrt{2gH}}$$

A = choke area (mm^2); W = casting mass(kg); t = Pouring time (s); d = mass density of molten metal, (kg/mm^3); g = acceleration due to gravity(mm/s^2) ;H = sprue height(mm); C = efficiency factor:
The effective sprue height, H depends on type of gating system;

(i) Top gate, H = h; (ii) Bottom, H = h – C/2 (iii) Parting, H = h – p^2/2C

Where, h = height of sprue P = height of mould cavity in sprue C = total height of mould cavity

Casing Defects

The following are the major defects, which are likely to occur in sand castings

- Gas defects
- Shrinkage cavities
- Molding material defects
- Pouring metal defects
- Mold shift
- Other defects

Gas Defects: A condition existing in a casting caused by the trapping of gas in the molten metal or by mold gases evolved during the pouring of the casting. The defects in this category can be classified into blowholes and pinhole porosity.

- Blowholes are spherical or elongated cavities present in the casting on the surface or inside the casting.
- Pinhole porosity occurs due to the dissolution of hydrogen gas, which gets entrapped during heating of molten metal.

  Causes:- The lower gas-passing tendency of the mold, which may be due to lower venting, lower permeability of the mold or improper design of the casting. The lower permeability is caused by finer grain size of the sand, high percentage of clay in mold mixture, and excessive moisture present in the mold.

  • Metal contains gas • Mold is too hot • Poor mold burnout

Shrinkage Cavities: These are caused by liquid shrinkage occurring during the solidification of the casting. To compensate for this, proper feeding of liquid metal is required. For this reason risers are placed at the appropriate places in the mold. Sprues may be too thin, too long or not attached in the proper location, causing shrinkage cavities. It is recommended to use thick sprues to avoid shrinkage cavities.

Molding Material Defects: The defects in this category are cuts and washes, metal penetration, fusion, and swell.

- Cut and washes: These appear as rough spots and areas of excess metal, and are caused by erosion of molding sand by the flowing metal. This is caused by the molding sand not having enough strength and the molten metal flowing at high velocity. The former can be taken care of by the proper choice of molding sand and the latter can be overcome by the proper design of the gating system.
- Metal penetration: When molten metal enters into the gaps between sand grains, the result is a rough casting surface. This occurs because the sand is coarse or no mold wash was applied on the surface of the mold. The coarser the sand grains more the metal penetration.

- Fusion: This is caused by the fusion of the sand grains with the molten metal, giving a brittle, glassy appearance on the casting surface. The main reason for this is that the clay or the sand particles are of lower refractoriness or that the pouring temperature is too high.
- Swell: Under the influence of metallostatic forces, the mold wall may move back causing a swell in the dimension of the casting. A proper ramming of the mold will correct this defect.
- Inclusions: Particles of slag, refractory materials, sand or deoxidation products are trapped in the casting during pouring solidification. The provision of choke in the gating system and the pouring basin at the top of the mold can prevent this defect.

Pouring Metal Defects: The likely defects in this category are • Mis-runs and • Cold shuts.

- A mis-run is caused when the metal is unable to fill the mold cavity completely and thus leaves unfilled cavities. A mis-run results when the metal is too cold to flow to the extremities of the mold cavity before freezing. Long, thin sections are subject to this defect and should be avoided in casting design.
- A cold shut is caused when two streams while meeting in the mold cavity, do not fuse together properly thus forming a discontinuity in the casting. When the molten metal is poured into the mold cavity through more-than-one gate, multiple liquid fronts will have to flow together and become one solid. If the flowing metal fronts are too cool, they may not flow together, but will leave a seam in the part. Such a seam is called a cold shut, and can be prevented by assuring sufficient super-heat in the poured metal and thick enough walls in the casting design. The mis-run and cold shut defects are caused either by a lower fluidity of the mold or when the section thickness of the casting is very small. Fluidity can be improved by changing the composition of the metal and by increasing the pouring temperature of the metal.

Mold Shift: The mold shift defect occurs when cope and drag or molding boxes have not been properly aligned. The defects in this are: Lifts **and Shifts.**

Other Defects: The following are some other important defects noticed in the castings and they are,

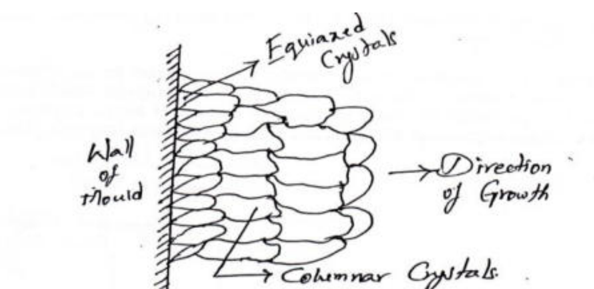
- Sponginess (or) Honey Combing: It is an external defect consists of small number of cavities in close proximity. It is caused by dirt or inclusions held mechanically in suspension in the molten metal.
- Pour-Short: it occurs when the mould cavity is incompletely filled ,because of insufficient molten metal.
- Fins: these are the thin projections metal not intended part of the casting. It is usually occurs at the parting line of the mould or core sections. These are due to loose clamping of boxes or less pouring weight of the mould.
- Hot-tears: These cracks are caused in thin long sections of the casting, if the part of the casting cannot shrink freely on cooling due to intervening sand being too tightly packed, offers resistance to such shrinking. The tear or crack usually takes place when the part is red hot and

has not developed full strength, hence the defect is called “hot tear”. Reason may be excessively tight ramming of sand.

Solidification of casting

Solidification of Metal:-After pouring molten metal into a mold, a series of events takes place during the solidification of the metal and cooling to room temperature. These events greatly influence the size, shape uniformity, and chemical composition of the grains formed throughout the casting, which in turn influence it’s over all properties.

A thorough understanding of the mechanism of solidification, the rate of heat loss from the material to the mould etc… is essential to predict how the casting will solidify and thus avoid casting defects like seams, gas porosity, hot tears etc… Since solidification requires energy to produce a crystalline structure, some super cooling (cooling below the freezing point) is required before the liquid starts to solidify. It is provided by the walls of the mould which provide sites around which crystals can grow initially and subsequently by the solidified particles and the metal itself. So the crystals growing inwards until the whole of the metal has solidified. The crystals near the mould walls are small and equated i.e., their axes randomly oriented. On further solidification, crystals grow with their axes perpendicular to the mould and these are columnar in shape.



Solidification of Pure Metal near mould wall.

Concept of solidification:

To understand the good mechanism of solidification we have to know the basic concept that when the casting solidifies it shrinks or contracts in size. This shrinkage occurs in three stages:

(i) **Liquid Contraction or Shrinkage:** This shrinkage occurs when the metal is liquid. It occurs when the molten metal cools from the temperature at which it is poured to the temperature at which solidification occurs.

(ii) **Solidification Shrinkage:** This occurs when the metal looses its latent heat that is during the metal changes from the liquid state to the solid state.

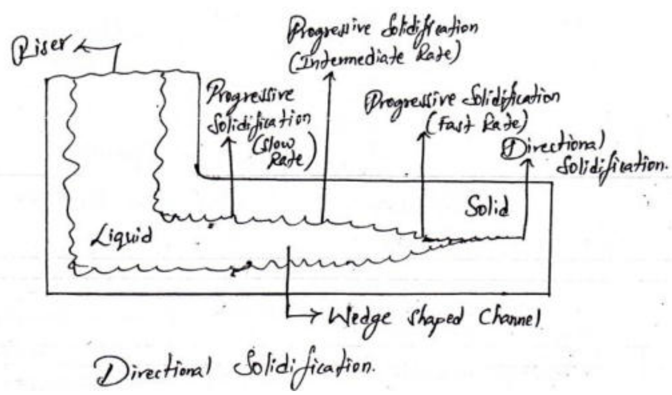
(iii) **Solid Shrinkage:** This occurs when the metal cools from freezing temperature to the room temperature.

Only the first two shrinkages are considered for risering purposes, since the third is accounted for by the pattern makers contraction allowance. Liquid shrinkage is generally negligible, but solidification shrinkage can be substantial.

As already discussed, when the mould cavity is filled with molten metal, the metal adjacent to the walls of the mould cools and solidifies first. This result in the shell of solid metal, with the centre of the section remaining liquid, while there is a zone between the liquid interior and solid exterior where in the metal is in a semi solid or mushy state. The solidification then proceeds inwards towards the same centre of the section. This solidification is called as "Lateral or Progressive Solidification". Longitudinal solidification occurs at right angles to the lateral solidification at the center line (as shown in fig.). The gating should be designed in such a manner that it permits solidification and cooling to progress in such a way that the accompanying shrinkage may take place without resulting in voids, cracks, or porosity with in the casting, so as to obtain a sound casting. This type of solidification is called "Directional Solidification". For this to occur, the following two conditions should be satisfied:

(a) The longitudinal solidification must progress from the thinnest faster cooling sections to the heavier hotter sections.
(b) The temperature gradient, in addition to being properly directed, must be sufficiently steep so that the liquid metal can pass through the wedge shaped channel to compensate for shrinkage as it occurs at the centre line. It implies that the progressive solidification is controlled in such a way that no portion of the casting is isolated from liquid metal feeding channels, during the complete solidification cycle.

If the depth of a section is quite large as compared to its cross section, then the progressive solidification rate will exceed the longitudinal solidification and result in fine center line porosity or even a larger or series of large cavities. To prevent such defects, the cross section of the casting should increase towards the hotter sections.



.

Solidification of Casting:

Sound casting is one which is free from defects like porosity, shrinkage and cracks etc. In order to produce a casting free from such defects, it is essential to know cast structure developed during solidification of metals and alloys.

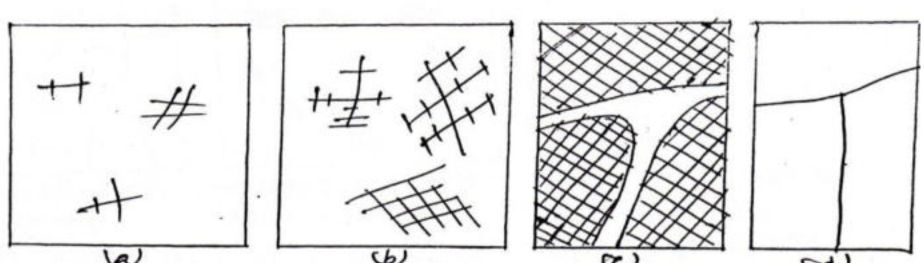
Recrystallization:

(a) In this process, old distorted grains are replaced by new equaixed stress free, strain free grains by a process a nucleation and growth. This is called Recrystallization.
(b) Nucleation occurs at the points of high energy and subsequently these nuclei grow at the expense of old grains. The probability of forming a nucleus is the same at every place a state suitable for homogeneous is said to be in the system.
(c) Nucleation occurs at the surface near the mould wall contains equidistanced grains and the nucleation is based on the volume of the particles formed i.e., free energy and the energy need to join the surface layer of the particle. The microstructure at the end of recrytallization process is similar to the original structure. The grains become equaixed and the dislocation density gets reduced to a value of strain free metal.
(d) Due to change in the microstructure of the casting metal, mechanical properties increases, internal stresses are reduced almost to the original level with increase in corrosion resistance.
(e) The grain size of the material obtained at the end of recrystallization depends on the temperature of heating, time of heating, heating rate and type end level of impurities.
(f) Insoluble particles lock the grain boundaries and prevent their migration. They also reduce the energy of grain boundaries. Due to this, a fine grain size rate sharply decreases.

Formation of Grains:

All the metals are crystalline and crystals are made up of several atoms. The individual crystals or grains together form the visible mass of a solid metal.

A grain is a crystal with almost external shape, but with an internal atomic structure based on the space lattice with which it was formed. The mechanical property of the metal varies with the arrangement of grains. The solidification process is shown in below fig.



Formation of Crystal Grains.

The metal begins to solidify when the temperature of the liquid metal drops below the critical temperature. When two or more atoms associated to form a small crystal called “Nucleus’. It happens in number of locations through out liquid metal. They are simultaneously cooled. Slow cooling favours growth of crystals uniformly in all directions of growth and give equaixed crystals i.e., the crystals with equal dimensions in all the direction. Rapid cooling always favours tree like crystals called “dendrites” which consisting of unit cells, with straight line branches.

Crystal grows until it come in contact with the adjacent crystal of proper geometrical form and having different orientations. They can be distorted by interface of each crystal with its neighbors’.

The boundary formed between two adjacent crystalline growths because of different orientations of the grain is known as boundary.

- As shown in above figure the formation of nucleus in straight line branches is shown in (a).
- Crystals having the same geometrical from but different in orientations can be seen in (b) & (c).
- Grain boundaries formed between adjacent crystals can be seen in (d).

Grain Size:

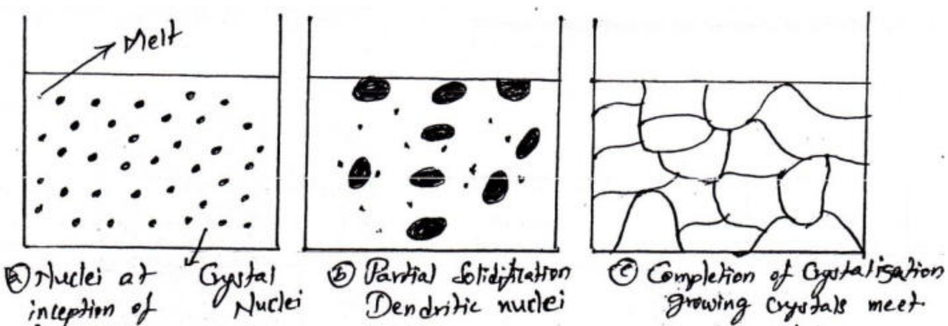
The rate of whole crystallization process is determined by the rate of nucleation (N) and rate of crystal growth (G). The size of the grain is determined by the rate of crystal growth (G) and rate of nucleation (N). At high value of G and low value of N, coarse grains are formed. Besides rate of cooling, the grain size also depends on factors.

- Temperature of liquid metal
- Impurities in metal
- Chemical composition

Solidification of Pure Metals:

Solidification process differs from pure metal to the alloys as it is the transformation of the molten metal back to the solid state.

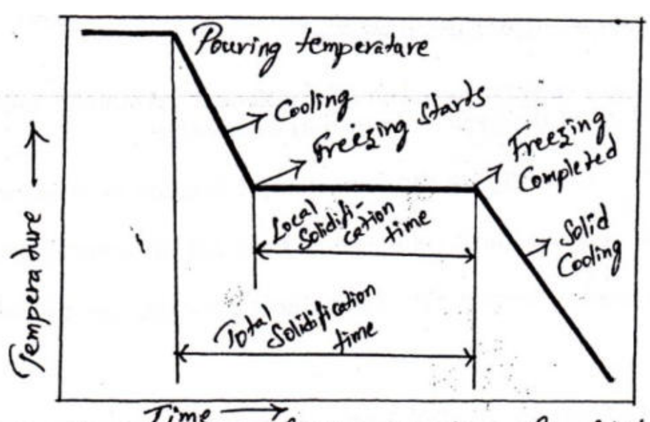
As the pure metal have sharply defined freezing temperature which is the same melting point composed of the small group of atoms oriented into common crystal pattern (See below figure). The process occurs in the overtime called a cooling curve. During the process of solidification nuclei spring up, each nucleus grow and able to form the crystal which is visible to the eye.



→ Progressive Freezing of a Uniformly Cooled Metal.

As each nucleus grows, the atoms within it are having the same orientation. When the nucleus has grown to the point, they absorb all the liquid atoms and come in contact with each other along their boundaries. The boundaries do not line up the plan of atoms, change direction from one crystal to other so solid state composed of a number of crystals of different orientation i.e., mixed crystals.

The actual freezing takes time called "Local Solidification Time" in casting during which the metals latent heat of fusion is released into the surrounding mould. The total solidification time is the time taken between pouring and complete solidification. After the casting is completely solidified, cooling gradually increases by decreasing the slope of the cooling curve as shown in below figure.

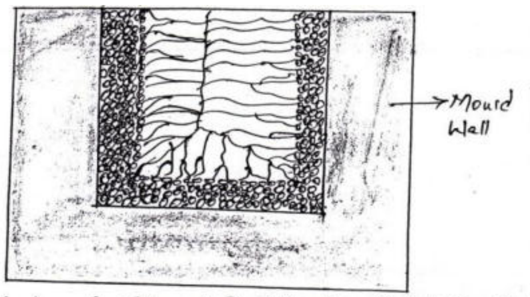


→ Temperature as a function of time for Solidification of pure metal

Because of the chilling action of the mould wall, a thin skin (a thin layer) is formed at the interface immediately after pouring. Thickness of the skin increases to form a shell around molten metal as solidification progress inward toward the centre of the cavity. The rate of freezing depends on the heat transfer in the mould.

As the conductivity of the mould is high, fine, equiaxed, random orientation atoms of small crystal grows neat the mould face. As the cooling progress, the grain formation in the direction away from the heat transfer gradually long columnar crystals, with the axis perpendicular to the mould face are formed.

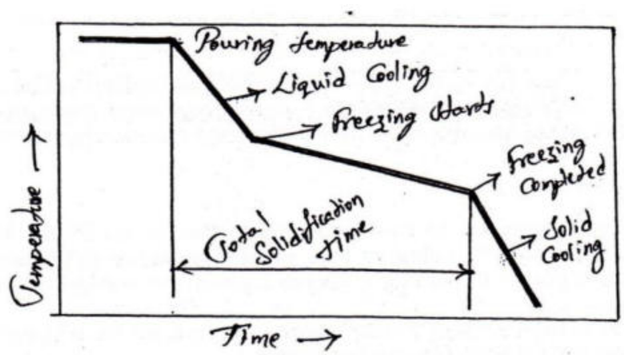
The beginning of solidification and end of solidification takes place at constant temperature in pure metals. These two points are called congruent melting points. Perfect crystals of proper external shape can be obtained only if crystallization develops under the degree of super cooling is very low and the metal is having high purity. In most of the cases it leads to the formation of branches form at right angles to the first branch (Tree like crystals) called dendrites as shown in below figure.



→ Grain Structure of Casting of Pure Metal Showing Randomly Oriented Fine, Equiaxed Grains near the Mould wall and Large Columnar Grains Oriented towards Centre of Casting.

Solidification in Alloys:

Most alloys freeze over a temperature range rather than at a single temperature. The exact range depends on the alloy stem and the particular composition. This can be explained with reference to the phase diagram as shown in below figure.

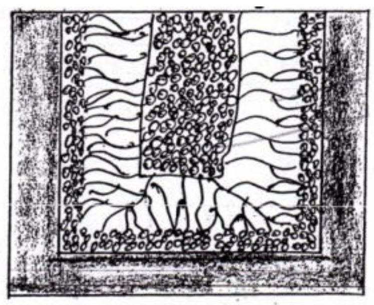


→ Temperature as a function of Time for Solidification of an Alloy.

Just below the solidification starts the solid phase start separating out from the liquid. As the temperature decreases, the freezing begins from the liquids line and is completed when the solidus is reached. As similar to the pure metal the freezing starts by forming a thin skin at the mould wall due to large temperature gradient at the surfaces and dendrites grow away from the surface of the mould wall where both liquid and solid metal together. This solid region has a sort of consistency leading to its name as "Mushy Zone". As the freezing progress the mushy zone is relatively narrow, and exists throughout casting. As the temperature difference increases the dendrite matrix solidify as casting drops to the solidus line for the given alloy composition.

Metals having the higher melting points favour the formation of the dendrites composition in the solidification of alloys.

Composition imbalance can be seen in dendrites growth depending upon the segregation of the elements as shown in figure.



→ Grain Structure in an Alloying Casting showing Segregation of Alloying Components in the Centre of Casting.

The segregation is of two types,

(a) Microscopic Level
(b) Macroscopic Level

Microscopic level: Composition varies throughout each individual grain. Each dendrite has a higher portion of one of the elements in the alloy.

Macroscopic level: Composition varied throughout the casting as the regions of the casting freeze first and richer in one component than the other.

Solidification Time

During the early stages of solidification, a thin solidified skin begins to form at the cool mould walls and as the time passes the skin thickens. With respect to flat mould walls, this thickness is proportional to the square root of time. Thus doubling the time will make the skin $\sqrt{2}$ time thicker i.e 41% thicker.

According to Chvorinov's rule, the solidification time is a function of a volume of the casting and its surface area.

$$\textbf{Solidification Time} = C\,(\text{Volume / Surface area})^2$$

Where:- C= Constant [min/cm^{2}], that reflects mould material ,metal properties like latent heat and temperature.

The Cube shaped solids are solidify fastest than cylindrical shape than spherical shape.

⇨ $t_{cube} = 0.028C < t_{cylinder} = 0.035C < t_{sphere} = 0.043C$

Solidification time for various cases are :

(i) In case of large castings in an insulating mould [sand castings]

Solidification Time = C (Volume / Surface area)^2

(ii) When the heat flow is controlled by the thermal resistance of mould metal interface [permanent mould metal castings].

Solidification Time (t) = $\left[\frac{\rho L}{h(\theta_1 - \theta_2)}\left(\frac{V}{A}\right)\right]$

Where h= Film heat transfer coefficient; ρ=Density of the metal;

θ_1=Temperature of liquid metal; θ_2=Temperature of mould surface;

L=Latent heat of the metal

Riser

Riser:-Riser is a source of extra metal which flows from riser to mold cavity to compensate for shrinkage which takes place in the casting when it starts solidifying. Without a riser heavier parts of the casting will have shrinkage defects, either on the surface or internally. Risers are known by different names as metal reservoir, feeders, or headers. Shrinkage in a mold, from the time of pouring to final casting, occurs in three stages. 1. during the liquid state 2. during the transformation from liquid to solid 3. during the solid state First type of shrinkage is being compensated by the feeders or the gating system. For the second type of shrinkage risers are required. Risers are normally placed at that portion of the casting which is last to freeze. A riser must stay in liquid state at least as long as the casting and must be able to feed the casting during this time.

Functions of Risers

- Provide extra metal to compensate for the volumetric shrinkage
- Allow mold gases to escape
- Provide extra metal pressure on the solidifying mold to reproduce mold details more exact

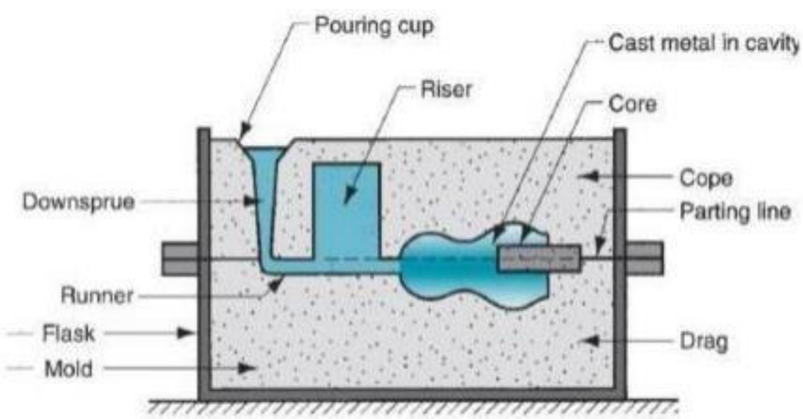
Design Requirements of Risers:-

- Riser size: For a sound casting riser must be last to freeze. The ratio of (volume / surface area)2 of the riser must be greater than that of the casting. However, when this condition does not meet the metal in the riser can be kept in liquid state by heating it externally or using exothermic materials in the risers.

- ❖ Riser placement: the spacing of risers in the casting must be considered by effectively calculating the feeding distance of the risers.
- ❖ Riser shape: cylindrical risers are recommended for most of the castings as spherical risers, although considers as best, are difficult to cast. To increase volume/surface area ratio the bottom of the riser can be shaped as hemisphere.

Riser Design:

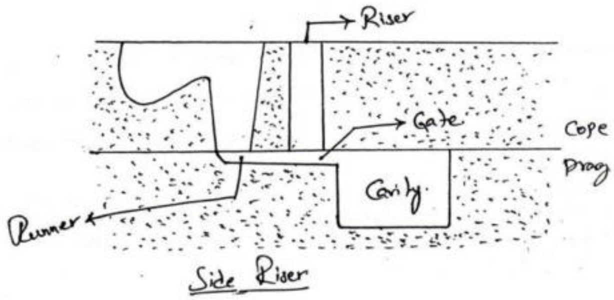
The riser is a reservoir in the mold that serves as a source of liquid metal for the casting to compensate for shrinkage during solidification. The riser must be designed to freeze after the main casting in order to satisfy its function Riser Function As described earlier, a riser is used in a sandcasting mold to feed liquid metal to the casting during freezing in order to compensate for solidification shrinkage. To function, the riser must remain molten until after the casting solidifies. Chvorinov's rule can be used to compute the size of a riser that will satisfy this requirement. The following example illustrates the calculation. The riser represents waste metal that will be separated from the cast part and re-melted to make subsequent castings. It is desirable for the volume of metal in the riser to be a minimum. Since the geometry of the riser is normally selected to maximize the V/A ratio, this tends to reduce the riser volume as much as possible Risers can be designed in different forms. The design shown in Figure below is a side riser. It is attached to the side of the casting by means of a small channel. A top riser is one that is connected to the top surface of the casting. Risers can be open or blind. An open riser is exposed to the outside at the top surface of the cope. This has the disadvantage of allowing more heat to escape, promoting faster solidification. A blind riser is entirely enclosed within the mold, as in Figure below.



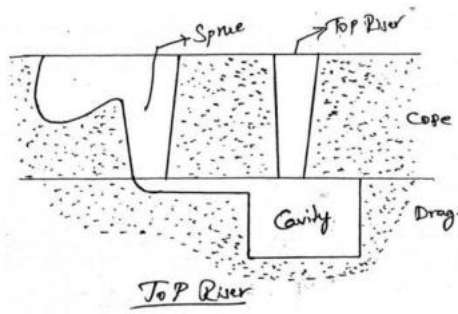
Types of Risers:

Depending upon its location, the riser is described as Side Riser, Top riser,Blind riser.

Side Riser: If the riser is located between runners and casting, it is known as side riser. It is also called a 'live or hot riser' since it is filled last and contains the hottest metal. The side riser receives the molten metal directly from the runner before it enters the mould cavity and is more effective than the top riser.



Top Riser: If a riser must be placed at the top of the casting or at the end of the mould cavity then it is called as Top riser or 'dead or cold riser'. These types of risers fill up with the coldest metal and are likely to solidify before casting.



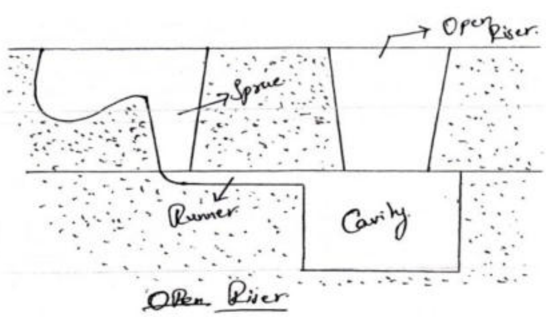
Open risers: These risers are open to the atmosphere at the top surface of the mould.

Advantages:

- (i) It can be easily moulded.
- (ii) As it is open to atmosphere, it will not draw metal from the casting as a result of partial vacuum in the riser.
- (iii) These risers serve as collectors of nonmetallic inclusions floating up to the surface.

Limitations:

- (i) They can be moulded only in the cope i.e., either at the top of the mould cavity or on the side at the parting line.
- (ii) Open risers are holes through which foreign matter may get into the mould cavity.



Blind Risers: A riser which does not break to the top of the cope and is entirely surrounded by moulding sand is known as 'Blind Riser'. Blind risers are setup in high moulding boxes, where the use of open risers would entail a large consumption of molten metal.

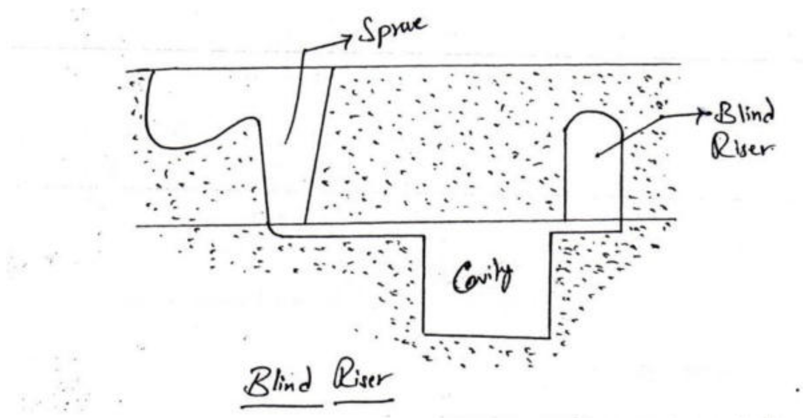
Advantages:

(i) Considerable latitude or flexibility is allowed for positioning the riser, either in a cope or in a drag.

(ii) It is surrounded on all sides by moulding sand. Thus it looses heat slowly which helps in better directional solidification of the casting.

(iii) A blind riser can be smaller than a comparable open riser, there fore more yield is obtained.

The main drawback of the blind riser is that when the metal in it cool, metal skins may quickly form on its walls. This will result in a vacuum in the riser and the riser will not feed and may actually draw metal from the casting.



Special Casting processes:

This process was patent in 20 century to make higher standards hollow castings. The first centrifugal casting machine was invented by a British, A.G. Eckhardt in 1807. This process is widely used for casting hollow pipes, tubes and other symmetrical parts.

1. Centrifugal Casting

Centrifugal Casting: It works on basic principle of centrifugal force on a rotating Component. In this process, the mould is rotated rapidly about its central axis as the metal is poured into it. Because of the centrifugal force, a continuous pressure will be acting on the metal as it solidifies. The slag, oxides and other inclusions being lighter, get separated from the metal and segregate towards the center. This process is normally used for the making of hollow pipes, tubes, hollow bushes, etc., which are axisymmetric with a concentric hole. Since the metal is always pushed outward because of the centrifugal force, no core needs to be used for making the concentric hole. The mould can be rotated about a vertical, horizontal or an inclined axis or about its horizontal and vertical axes simultaneously. The length and outside diameter are fixed by the mould cavity dimensions while the inside diameter is determined by the amount of molten metal poured into the mould.

There are three types of centrifugal casting.

a) True centrifugal casting b) Semi centrifugal casting c) Centrifuging.

True centrifugal casting:

True centrifugal casting is sometime known as centrifugal casting is a process of making symmetrical round hollow sections. This process uses no cores and the symmetrical hollow section is created by pure centrifugal action. In this process, the mould rotates about horizontal or vertical axis. Mostly the mould is rotated about horizontal axis and the molten metal introduce from an external source. The centrifugal force acts on the molten metal which forces it at the outer wall of mould. The mould rotates until the whole casting solidifies. The slag particles are lighter than metal thus separated at the central part of the casting and removed by machining or other suitable process. This process used to make hollow pipes, tubes, hollow bushes etc. which are axi symmetrical with a concentric hole.

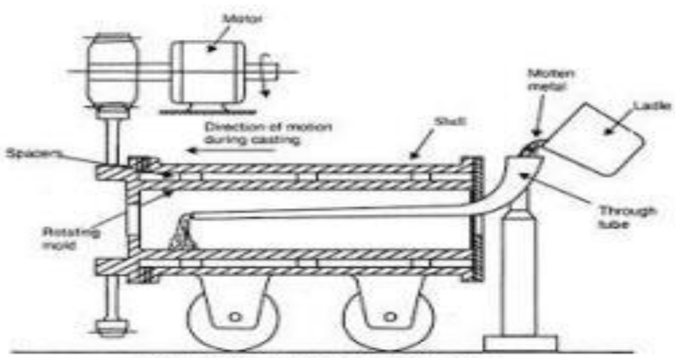


Fig. 4.15. A true centrifugal casting machine.

Semi Centrifugal Casting:

This process is used to cast large size axi symmetrical object. In this process mould is placed horizontally and rotated along the vertical axis. A core is inserted at the center which is used to cast hollow section. When the mould rotates, the outer portion of the mould fill by purely centrifugal action and as the liquid metal approaches toward the center, the centrifugal component decreases and gravity component increase. Thus a core is inserted at center to make hollow cavity at the center without centrifugal force. In this process centrifugal force is used for uniform filling of axi symmetrical parts. Gear blanks, flywheel etc. are made by this process.

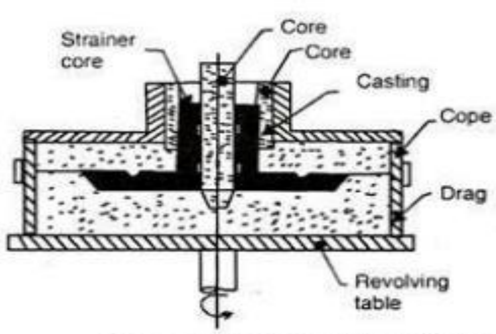


Fig. . Semi-centrifugal Casting.

Centrifuging:

In this process there are several mould cavities connected with a central sprue with radial gates. This process uses higher metal pressure during solidification. It is used to cast shapes which are not axi symmetrical. This is only suitable for small objects.

Application: ♣ It is widely used in aircraft industries to cast rings, flanges and compressor casting. ♣ It is used for cast Steam turbine bearing shell. ♣ Roller for steel rolling mill is another example of centrifugal casting. ♣ It is used in automobile industries to cast gear blank, cylindrical liners, piston rings etc. ♣ It is used to cast bearings. ♣ This process used to cast switch gear components used in electronic industries.

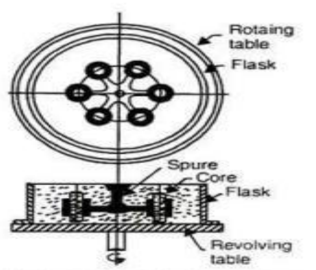


Fig. . Centrifuging casting.

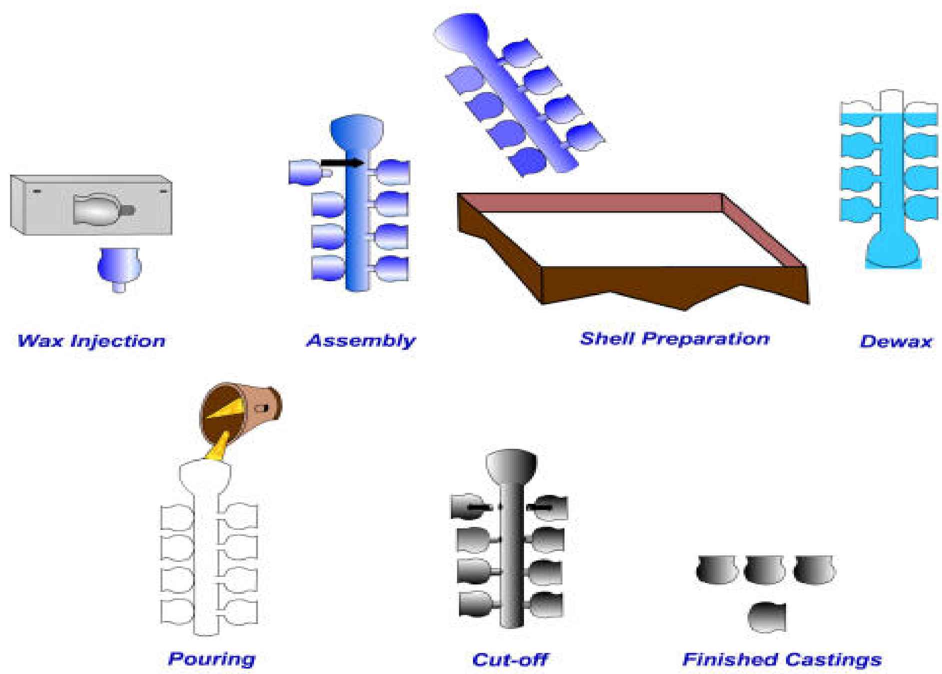
Advantages: ♣ It provides dense metal and high mechanical properties. ♣ Unidirectional solidification can obtain up to a certain thickness. ♣ It can use for mass production. ♣ No cores are required for cast hollow shapes like tubes etc. ♣ Gating system and runner are totally eliminated. ♣ All the impurity like oxide or other slag particles, segregated at center from where it can easily remove. ♣ It required lower pouring temperature thus save energy. ♣ Lower casting defects due to uniform solidification.

Disadvantages: ♣ Limited design can be cast. It can cast only symmetrical shapes. ♣ High equipment or setup cost. ♣ It is not suitable for every metal. ♣ Higher maintenance required. ♣ High skill operator required. ♣ In this casting process, solidification time and temperature distribution is difficult to determine.

2.Investment Casting Process:

The root of the investment casting process, the cire perdue or "lost wax" method dates back to at least the fourth millennium B.C. The artists and sculptors of ancient Egypt and Mesopotamia used the rudiments of the investment casting process to create intricately detailed jewelry, pectorals and idols. The investment casting process alos called lost wax process begins with the production of wax replicas or patterns of the desired shape of the castings. A pattern is needed for every casting to be produced. The patterns are prepared by injecting wax or polystyrene in a metal dies. A number of patterns are attached to a central wax sprue to form a assembly. The mold is prepared by surrounding the pattern with refractory slurry that can set at room temperature. The mold is then heated so that pattern melts and flows out, leaving a clean cavity behind. The mould is further hardened by heating and the molten metal is poured while it is still hot. When the casting is solidified, the mold is broken and the casting taken out. The basic steps of the investment casting process are (Figure 11) :

- ❖ Production of heat-disposable wax, plastic, or polystyrene patterns.
- ❖ Assembly of these patterns onto a gating system .
- ❖ “Investing,” or covering the pattern assembly with refractory slurry.
- ❖ Melting the pattern assembly to remove the pattern material.
- ❖ Firing the mold to remove the last traces of the pattern material.
- ❖ Pouring.
- ❖ Knockout, cutoff and finishing.



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

Disadvantages • More segregation of alloy component during pouring under the forces of rotation • Contamination of internal surface of castings with non-metallic inclusions • inaccurate internal diameter.

Applications : jewellery, surgical instruments, vanes and blades of gas turbine, impellers, claws of movie camera

3. Die Casting

Die casting involves preparation of components by injecting molten metal at high pressure into a metallic dies. It is also known as pressure die casting. Narrow sections, complex shapes, fine surface details can be produced by using this casting process. The dies have two parts. 1st one is a stationary half (cover die) which is fixed to die casting m/c. The other one is a moving half (ejector die) which is moved out for extraction of casting. At the starting of the process, two halves of the die should be placed apart. The lubricant is sprayed on die cavity and then the dies are closed and clamped. The metal is injected into the die. After solidification, the die will be opened and the casting will be ejected. The major problem of die casting is that the air left in the cavity when the die is closed. Also back pressure exists on the molten metal in the die cavity. It can be overcome by evacuating the air from the die after the die is closed and metal is injected. In manufacturing industry, die casting machines are rated on the force with which they can hold the mold closed. Clamping forces for these machines vary from around 25 to 3000 tons.

Advantages:- Metal enters much faster – less filling time- No porosity -Parts exposed to air after solidification so no oxidation-High tolerance- Fine microstructure.

These are of two types: (a) Hot chamber die casting (b) Cold chamber die casting.

a)Hot chamber die casting:- This is also called sometimes known as "submerged plunger die casting process". In hot chamber die casting machine, there is suitable furnace for melting and holding the metal. A plunger is submerged in reservoir of molten metal as shown in below figure. A Gooseneck is used for pumping of the liquid metal in to the die cavity. It is made up of grey C.I., ductile iron, cast steel. A plunger made up of alloy C.I., hydraulic operated moves up in the gooseneck to uncover the entry port for the entry of liquid metal into the gooseneck.

Following are the steps in a casting cycle.

1. As the plunger is raised, opening of cylinder is uncovered and, molten metal enters the cylinder from molten metal reservoir under the force of gravity.
2. The plunger is forced downward, pneumatically or hydraulically, closing the cylinder opening and forcing the molten metal through a nozzle in die.
3. As soon as casting is solidified, the pressure is relieved, dies are opened and casting is ejected by means of knockout pins. As the same time plunger again

moves up uncovering the holes in cylinder and allowing the liquid metal from furnace to cylinder.

The cycle timings and pressure in the machines are set to suit the different metals and castings. The added advantage of hot chamber process is that molten metal is injected from the same chamber, in which it is melted, i.e., there is no handling of molten metal. The limitation of process is that it cannot be used for higher melting point metals. The process can be used for most of low melting temperature alloys such as zinc, lead and tin.

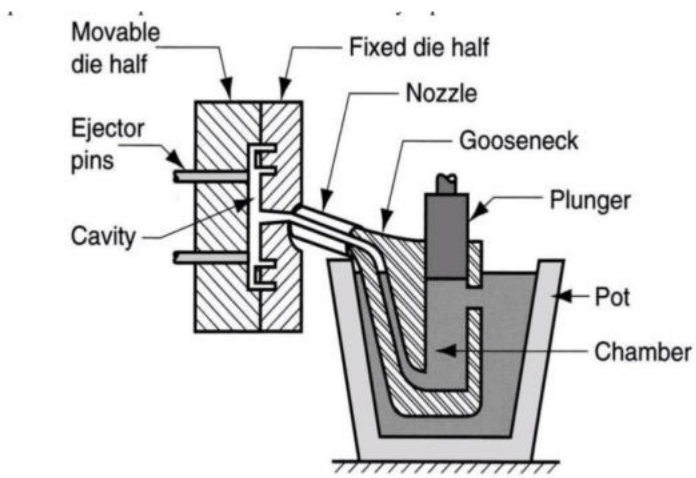


Figure: Hot chamber die casting

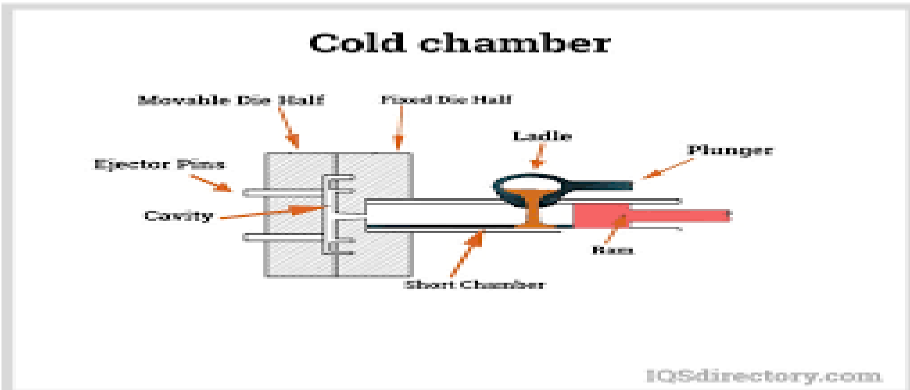
b)Cold chamber process: - In this process, pressures as high as 300 MPa are used. The storing chamber is not heated. In the hot process is suitable for low temperature melting alloys. As cylinders is continuously in contact with liquid metal, aluminium and other high temperature melting alloy will attack the cylinder material. So for these metals cold chamber process is used. In cold chamber processes, holding furnace for liquid metal is not integral with die casting machine. The metal is melted in a separate furnace and then poured into die casting machine with the help of ladle. This process reduces the contact time between liquid metal and shot chamber.

The cold chamber process is shown in below figure.

The cycle starts when,

1. Lubricants are sprayed throughout the dies.
2. Die halves are closed and clamped.
3. Measured quantity of molten is poured in shot chamber of the machine. The metal can be poured either by hand ladle or by means of auto ladle is form of robotic device.
4. Plunger forces the metal into die cavity and maintains the pressure during solidification.
5. Dies are open and casting is ejected.
6. Plunger returns to original position completing the cycle.

Since molten metal is transferred through ladle, cold chamber process has a longer operating cycle than that of hot chamber process. Also during the transportation of liquid metal from furnace to die casting machine, it may loose the super heat and some times may cause defects such as cold shuts.



Advantages of Die Casting Processes:

1. Closer dimensional tolerance and smoother casting surfaces can be achieved since not coating is applied to die casting.
2. Because of high pressure involved in die casting narrow sections and complex shapes can easily produced.
3. Very high production rates can be achieved.
4. Complex casting can be produced because of using the movable cores.
5. Die casting gives better mechanical properties because of fine grained skin formed during solidification.
6. The process is very economical for large scale production.

Limitations of Die Casting Processes:

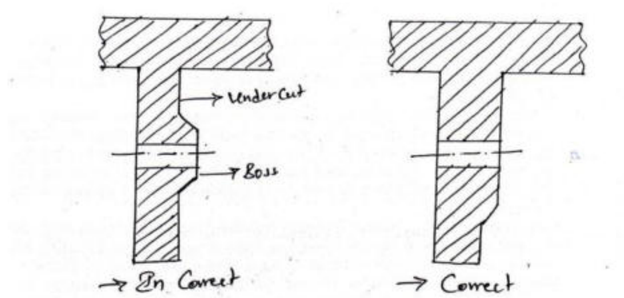
1. The dies and machines are very costly. Therefore economy in production is possible only when large quantities are produced.
2. Not suitable for all materials because of die materials limitations. Normally non ferrous metals like Zn, Mg, Al or Copper alloys are die cast.
3. Maximum size of casting is limited. Normally castings weighing between 4 kg to 15 kg are cast because of machine limitations.
4. The air may get entrapped during the process. It is a usual problem with die castings.

Casting Design Considerations:

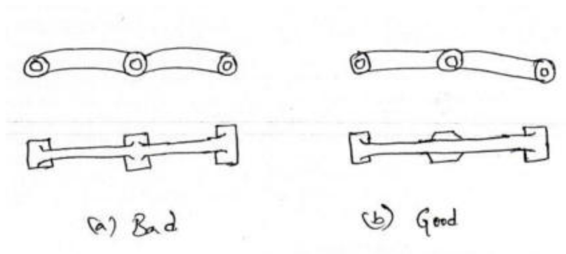
A cast part must have such a design as to ensure a high level of its working characteristics like strength, rigidity, stiffness, tightness, and corrosion resistance at a given mass and shape of the part. Proper attention to design details can minimize casting problems and lower costs. For this a close collaboration between the designer and the foundry engineer is important.

The main feature of the casting process is that the molten metal poured into the mould contracts as it cools and solidifies. The main consideration is that the shape of the casting should allow for directional solidification. Some of the important design considerations are discussed below:

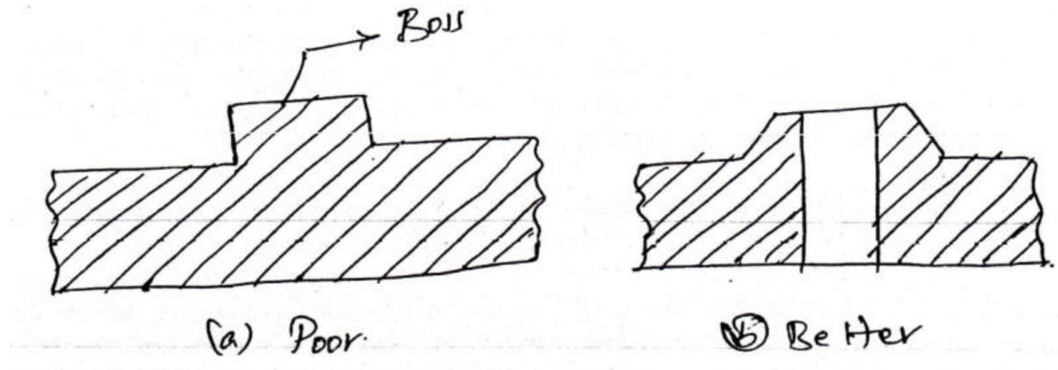
a. The shape of the castings should be as simple as possible. That helps to reduce the cost of patterns, cores and moulds.
b. Castings should be made as compact as possible. Large steel castings of complex shape are divided into two or more castings, which can be easily cast, and then joined by welding to produce a 'cast-weld' construction.
c. Projecting details (bosses, lugs etc…) or undercuts should be avoided, or the pattern elements for them should be made so that they do not hinder the removal of pattern from the mould.



d. To facilitate removal, provision should be made for draft (1/2° to 3°) on the castings vertical surfaces. The draft is greater for the inside surfaces than for the exterior surfaces.
e. Where ever possible, avoid complex parting lines on the pattern, because these increase the cost of moulding operations. Parting lines should be in a single plane, if practicable. The design (b) is better not only because the lines are simpler and the pattern is less costly but also because a plane parting can be used in the process of moulding.

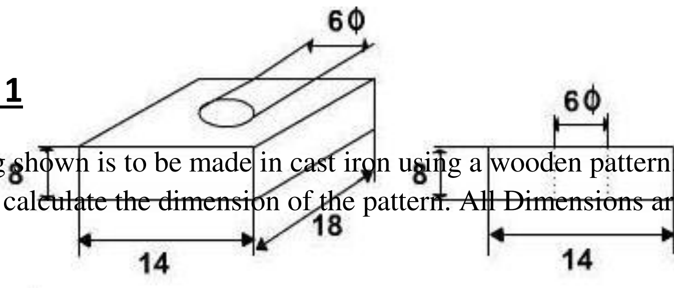


f. Avoid concentration of metal so that no shrinkage cavities are formed. For this reason, bosses, lugs, pads should be avoided unless absolutely necessary. Metal section is too heavy at bosses which are difficult to feed solid.



g. The position of the castings surfaces during metal pouring must be taken into account, since gas blow holes may form on the castings upper horizontal surfaces. Critical surfaces of castings should lie at the bottom part of the mould.
h. Minimum Section Thickness: The thickness of the casting walls is determined depending on the size and mass of the casting, its material and the mass of the casting. Except for cast iron, the minimum section thickness depends mainly upon the fluidity of the molten metal. If a casting section is too thin, or if it is relatively thin and extends too far, a misrun or cold shut defect will occur.
i. The casting design should provide for easy removal of core materials and reinforcements and should make for ease of cleaning and fettling after the shake out operation. In order to remove core material from internal cavities, special bosses with holes should be provided on the casting. After the cleaning, the holes are stopped with plugs. The outer contour of the casting should be free of deep blind pockets and recesses. The cavities should have openings of sufficient size to facilitate stripping.
j. A material that has a large solidification shrinkage will result in hot shortness if the moulding material does not collapse sufficiently to allow shrinkage or the moulds should be of simple shape so as not to develop tensile stress during solidification. If possible the casting design should be changed to allow deformation without moving large mould masses.

Exercise 1



The casting shown is to be made in cast iron using a wooden pattern. Assuming only shrinkage allowance, calculate the dimension of the pattern. All Dimensions are in Inches

The shrinkage allowance for cast iron for size up to 2 feet is o.125 inch per feet (as per Table 1)
For dimension 18 inch, allowance = 18 X 0.125 / 12 = 0.1875 inch » 0.2 inch
For dimension 14 inch, allowance = 14 X 0.125 / 12 = 0.146 inch » 0.15 inch
For dimension 8 inch, allowance = 8 X 0.125 / 12 = 0.0833 inch » 0. 09 inch
For dimension 6 inch, allowance = 6 X 0.125 / 12 = 0.0625 inch » 0. 07 inch
The pattern drawing with required dimension is shown below:

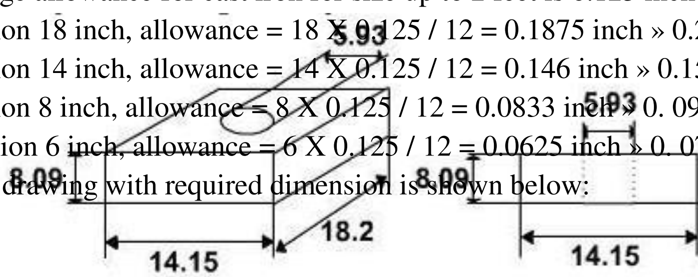


Table 1: Rate of Contraction of Various Metals

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

Shell – Moulding Method

Shell – Moulding Method: It is a modification of the sand mould process. In this process, the mould is made up of mixture of dried silica sand and phenolic resin, formed into a thin half mould shells which are clamped together for pouring metal.

The sand is first mixed with either urea or phenol formaldehyde resin in a muller. Metal pattern is heated to 200^0 to 230˚C in an oven and sprayed with silicon grease and kept on the top of the dump box. The dump box contains sand mixed with thermo plastic resin. The box is inverted, causing the sand mix to fall on the hot pattern. The resin melts and flow in between the grains of sand, acting as a bond. After 30 seconds, a hard layer of sand is formed over the pattern. Then the dump box is inverted back to its original position. The pattern with a thin shell is cured for two minutes at 315˚C. The shell is finally removed from the pattern by ejector pins. The two shells are clamped together to form the mould and placed in the flask with backing sand.This process can produce complex parts with good surface finish 1.25 μm to 3.75 μm, and dimensional tolerance of 0.5 %. A good surface finish and good size tolerance reduce the need for machining. The process overall is quite cost effective due to reduced machining and cleanup costs. The materials that can be used with this process are cast irons, and aluminium and copper alloy

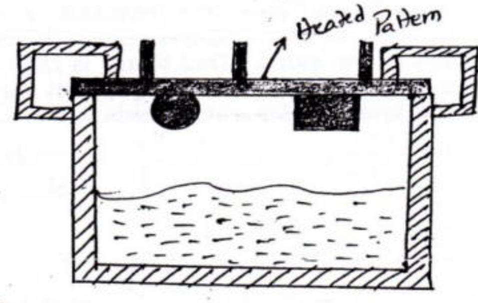
Advantages:

1. High dimensional accuracy and good surface finish.
2. The chances of blow holes or pockets are reduced since the shells are highly permeable.
3. Thin wall sections can be produced.
4. Shells can be stored for long time.

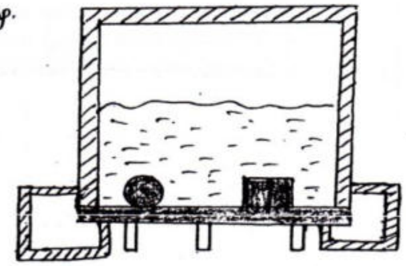
Disadvantages:

1. The metal patterns are costly than wood pattern.
2. Resin is an expensive binder.
3. Specialized equipments are to be used.

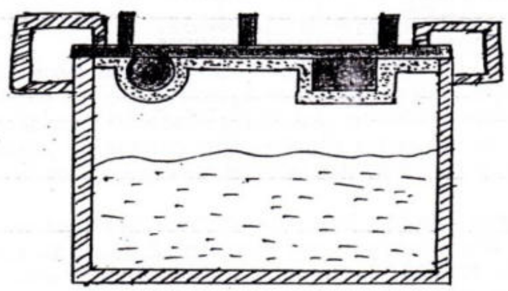
Applications: cylinders Break beam Transmission planet carrier Refrigerator valve plate Small crank shaft



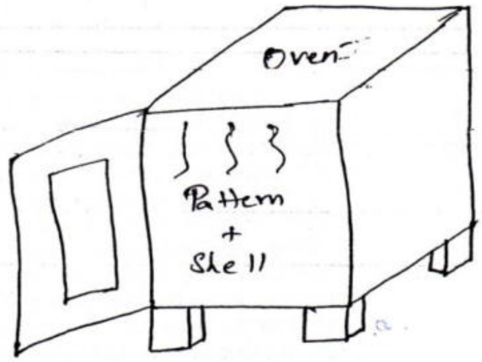
(a) Sand with resin binder in dump box



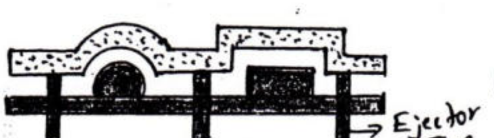
(b) Sand with dumped over the heated Pattern.



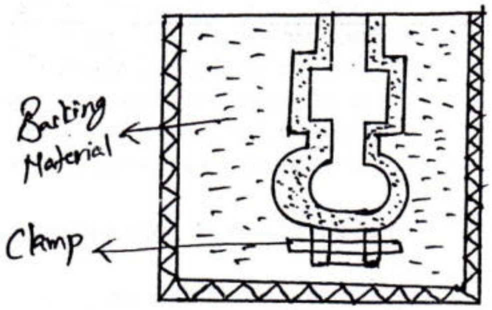
(c) Shell formed over the Pattern



(d) Shell is Curved in oven.



(e) Shell Lemoving from the pattern



(f) Two shells joined to form a Mould

Shell Moulding Process

2.4. CORE

A **core** *is a body made of refractory material (sand or metal, metal cores being less frequently used), which is set into the prepared mould before closing and pouring it, for forming the holes, recesses, projections, undercuts and internal cavities.*

- The cores are subject to much more severe thermal and mechanical effects than the moulds, because they are surrounded on all sides (except for the ends) by molten metal. Consequently core sands should meet more stringent requirements.
- *Refractoriness or thermal stability of core can be increased by giving a thin coating of graphite or similar material to the surface of the core.*

Characteristics of cores. A core should have the following *characteristics* :

(*i*) Core must have dry strength or be capable of being handled after drying. It must be able to withstand force of molten metal.

(*ii*) It should produce minimum amount of gas when in contact with molten metal.

(*iii*) It should be highly refractory, and able to withstand high temperatures of molten metal.

(*iv*) It should be more permeable than the mould itself and for this reason, coarse sand with large grain size mixed with *molasses* is used for core making.

(*v*) It should be capable of collapsing shortly after the molten metal has solidified around the core. Collapsibility provides freeness in the contraction of metal.

(*vi*) The surface of core should be smooth so as to provide a good finish to the casting.

2.4.1. Core Making

- Cores are made in simple wooden, metallic or plastic core boxes. These core boxes are part of the pattern equipment for the castings. The complicated shapes may require support of sand or metal formers until these are baked.
- The *simple method of core making is similar to that of mould making.* The sand mixture is rammed into the core box with a wooden rammer. Sometimes the cores may need reinforcement with wire or nails in order to provide internal support so that they may not collapse while handling. The core-sand mixture is rammed by hand or pneumatic rammers. Venting and other necessary operations are performed during construction of the core.
- For *production work, machines are used for core makings* where core-sand mixture is rammed by *jolting, squeezing or blowing* by *means of suitable machines*. The most common core making machine is the *core blower*. Venting, reinforcing and other necessary operations are performed by hand during core construction.

Sometimes cores may be made by *extruding a core-sand mixture through a suitable die opening and called* **"stock cores"** which are of symmetrical cross-section.

The cores are removed from the core box placed in metal trays and are baked in an oven at a suitable temperature varying from 150°C to 400°C for the required duration of time. The source of heat may be the burning of gas, oil, coke, or electric heating.

2.4.3. Core Prints

For supporting the cores in the mould cavity an impression in the form of a recess is made in the mould with the help of a projection on pattern. This projection is known as **core print.**

2.4.2. Types of Cores

A *core is a specially designed shape employed to take the place of metal in a mould.*

The cores may be *classified* as follows :

I. According to the state of the core :

(*i*) Green sand cores.

(*ii*) Dry sand cores.

(*iii*) Oil sand cores.

(*iv*) Loam cores.

(*v*) Metal cores.

(*i*) **Green sand cores :**

- These are made from ordinary moulding sand, mixed with floor-sand, thoroughly vented and not too damp.
- They are restricted to *simple shapes,* reinforced with substantial core irons for handling, and *not dried before using.*

(*ii*) **Dry sand cores :**

- These cores consist of moulding sand with controlled conditions of such opening materials as horse manure, sawdust or chopped straw, blended together in a mill with either water, clay water, molasses or any other suitable binding agent. Ample core irons are used for strengthening.
- The interiors of large cores are filled with coke to facilitate venting, and to overcome contraction strains.
- They are baked until perfectly dry.

(*iii*) **Oil sand cores :**

- They consist chiefly of sea shore or other silica sands, to which has been added a binding medium ; a few typical binders being linseed oil, resin, molasses and cereal flour.
- All cores of this type are baked before handling.

(*iv*) **Loam cores :**

- Loam cores are perforated cast-iron or steel barrels on to which has been wound straw or a hayband and then coated with loam. The whole is then baked perfectly dry.

(*v*) **Metal cores :**

- These cores are usually made of steel (see Fig. 2.16) and are mostly used in the making of non-ferrous castings, acting as densers, and they also impart a fine finish.
- They are also used for the production of iron castings, they produce a *white hard skin.*

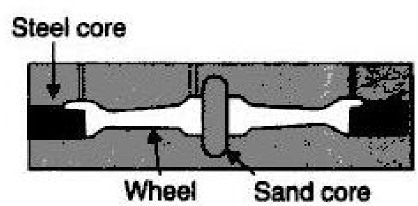


Fig. 2.16. Steel cores in a sand casting.

II. According to the position of the core in the mould :

(*i*) Horizontal core.
(*ii*) Vertical core.
(*iii*) Balanced core.
(*iv*) Cover core.
(*v*) Hanging core.
(*vi*) Wing core.

(*i*) **Horizontal core :** Refer to Fig. 2.17 (*i*) :

- The core is usually cylindrical in form and is laid horizontally at the parting line of the mould.
- The ends of the core rest in the seats provided by the core prints on the pattern.

(*ii*) **Vertical core :** Refer to Fig. 2.17 (*ii*) :

- The core is placed vertically in the mould.
- Usually top and bottom of the core are provided with a taper, but the amount of taper on the top is greater than that at the bottom.

(*iii*) **Balanced core :** Refer to Fig. 2.17 (*iii*) :

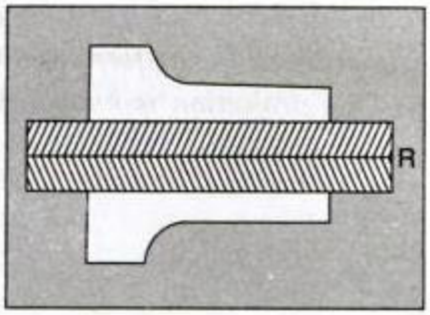
- This core is similar to horizontal core, but it is supported at one end only.
- The core print in such cases should be large enough to give proper bearing to the core.

(*iv*), (*v*) **Cover core and hanging core :** Refer to Fig. 2.17 (*iv*) and (*v*) :

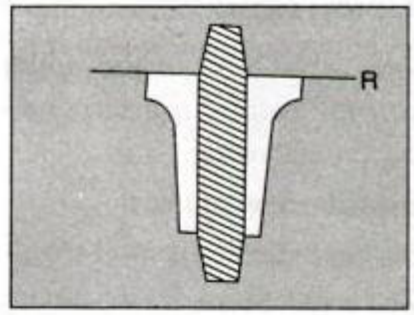
- The cover core, as shown in Fig. 2.17 (*iv*), is used when the entire pattern is rammed in the drag and the core is required to be supported from the top of the mould. This type of core usually requires a hole through the upper part to permit the metal to reach the mould.
- If the core hangs from the cope and does not have any support at the bottom in the drag, then it is called *hanging core* [Fig. 2.17 (*v*)].

(*vi*) **Wing core :** Refer to Fig. 2.17 (*vi*) :

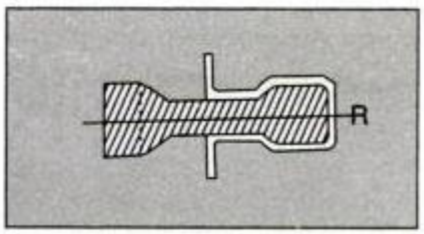
- A wing core is used when a hole or recess is to be obtained in casting either above or below the parting line. In this case, the side of the core point is given sufficient amount of taper so that the core can be placed readily in the mould.
- The core is sometimes designated by other names such as *tail core, drop core, chair core* and *saddle core* according to its shape and position in the mould.



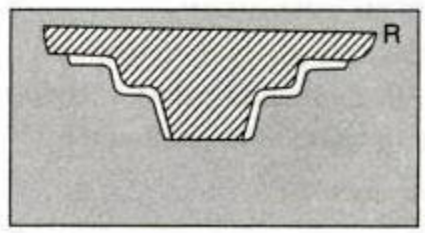
(*i*) Horizontal core



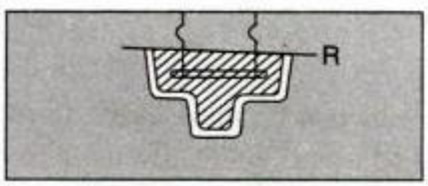
(*ii*) Vertical core



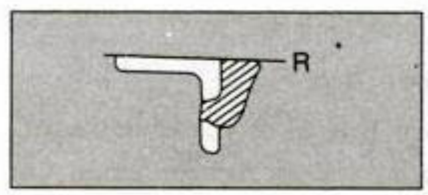
(*iii*) Balanced core



(*iv*) Cover core



(*v*) Hanging core



(*vi*) Wing core

Fig. 2.17. Types of cores.

Unit -2. Welding Processes

[Classification of welding process, 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, Inert Gas welding, TIG & MIG welding- Electro-slag welding,Resistance welding, Friction welding, Friction stir Welding,Forge welding, Thermit welding and Plasma Arc ,Laser welding ,Electron beam welding –. Soldering & Brazing. Heat affected zones in welding; Pre and Post heating, welding defects – causes and remedies]

Introduction

Fabrication is often known as secondary manufacturing process as the method relies on the raw material obtained from the manufacturing process like extrusion and rolling. Fabrication is a process of joining two or more elements to make a single part. Most common examples are aircraft, ship bodies, bridges, building trusses, welded machine frames, sheet metal parts, etc.

Fabrication process can be classified as follows.

- Mechanical joining by means of bolts &nuts, screws, rivets etc,.
- Adhesive bonding by employing synthetic glues such as epoxies.
- Welding, brazing and soldering.

History of welding:- Welding which is the process of joining two metallic components for the desired purpose, can be defined as the process of joining two similar or dissimilar metallic components with the application of heat, with or without the application of pressure and with or without the use of filler metal. Heat may be obtained by chemical reaction, electric arc, electrical resistance, frictional heat, sound and light energy. If no filter metal is used during welding then it is termed as ‘Autogenous Welding Process'. During ‘Bronze Age' parts were joined by forge welding to produce tools, weapons and ornaments etc, however, present day welding processes have been developed within a period of about a century. First application of welding with carbon electrode was developed in 1885 while metal arc welding with bare electrode was patented in 1890. However, these developments were more of experimental value and applicable only for repair welding but proved to be the important base for present day manual metal arc (MMAW) welding and other arc welding processes. In the mean time resistance butt welding was invented in USA in the year 1886. Other resistance welding processes such as spot and flash welding with manual application of load were developed around 1905. With the production of cheap oxygen in 1902, oxy – acetylene welding became feasible in Europe in 1903. When the coated electrodes were developed in 1907, the manual metal arc welding process become viable for production/fabrication of components and assemblies in the industries on large scale.

Applications: Although most of the welding processes at the time of their developments could not get their place in the production except for repair welding, however, at the later stage these found proper place in manufacturing/production. Welding is extensively used in automobile industry, aircraft machine frames, structural work, tank repair work, ship building, etc. It is also useful method for repairing of broken castings and defective metal parts. Presently welding is widely being used in fabrication of pressure vessels, bridges, building structures, aircraft and space crafts, railway coaches and general applications. It is also being used in shipbuilding, automobile, electrical, electronic and defense industries, laying of pipe lines and railway tracks and nuclear installations etc.

Advantages: The wide spread use of welding at the present time is due to its following advantages:

1. Welding results in a good saving of material and reduced labour content of production.
2. Welded joints are strong, especially under static loading.
3. The welded joints are very tight.
4. Low manufacturing costs.
5. Dependability of the medium, that is, the weldments are safer.
6. It gives the designer great latitude in planning and designing.
7. Welding is also useful as a method for repairing broken, worn or defective metal parts. Due to this, the cost of reinvestment can be avoided.
8. Without welding techniques, the light weight methods of fabrication, so vital to the automotive and aircraft industries, would be unthinkable.

Disadvantages:

1. They have poor fatigue resistance due to stress concentration.
2. There are induced residual stresses and various weld defects, such as cracks, incomplete fusion, slag inclusions and the like.
3. Not all metals are satisfactorily weldable.
4. The weldments are less readily machinable, as compared to castings.

Classification of welding processes:

Welding processes may be classified according to the source of energy employed for heating the metals and the state of metal at the place being welded. These may be divided into two groups as follows:

I.According to the application of Pressure.

(a) Pressure Processes: In this processes the parts to be joined are heated to a plastic state (fusion may occur to a limited extent) and forced together with external pressure to make the joint. Some of the more common processes in this group are mentioned below:

1. Forge Welding
2. Thermit Pressure welding
3. Pressure Gas welding
4. Electric Resistance welding

(b) Fusion processes: In these processes, the material at the joint is heated to the molten state and allowed to solidify to make the joint, without the application of pressure. Here some joints may be made without the addition of a filler metal, but in general, a filler metal must be added to the weld to fill the space between the parts being welded. The filler metal deposited should ordinarily be of the same composition as the base metal.
Some of the common welding processes in this group are listed below:

1. Gas welding
2. Electric Arc welding
3. Thermit Fusion welding

II. According to the with or without Filler matal .

(a)Autogeneous: In 'Autogeneous' processes, no filler metal is added to the joint interface, for example, cold and hot pressure welding processes and electric resistance welding.
(b)Homogeneous: In 'Homogeneous' processes, filler metal is added and is of the same type as the parent metal, for example, welding of plain low C steel with a low C welding of 70 – 30 brass with a 70 – 30 brass welding rod etc.
(c)Hetrogeneous: In 'Hetrogeneous' processes, a filler metal is used but is of a different type from the parent metal, for example, brazing and soldering processes. Brazing and soldering are not strictly the welding processes in view of the definition of welding process given above. However these processes also belong to the family of welding processe

III.According to the source of heat energy.

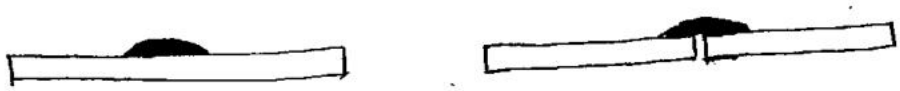
1. Gas Welding
   (a) Oxyacetylene Welding (b) Oxyhydrogen Welding

2. Arc Welding
   (a) Carbon Arc Welding (b) Metal Arc Welding
   (c) Submerged Arc Welding (d) Inert Gas Welding-[(i) TIG (ii) MIG]
   (e) Plasma Arc Welding (f) Electric Slag Welding
3. Resistance Welding
   (a) Spot Welding (b) Seam Welding
   (c) Projection Welding (d) Butt Welding
4. Solid State Welding
   (a) Friction Welding (b) Ultrasonic Welding
   (c) Explosive Welding
5. Thermo Chemical Welding
   (a) Thermit Welding (b) Atomic Hydrogen Welding
6. Radiant Energy Welding Process
   (a) Electron Beam Welding (b) Laser Beam Welding

Types of Welds:

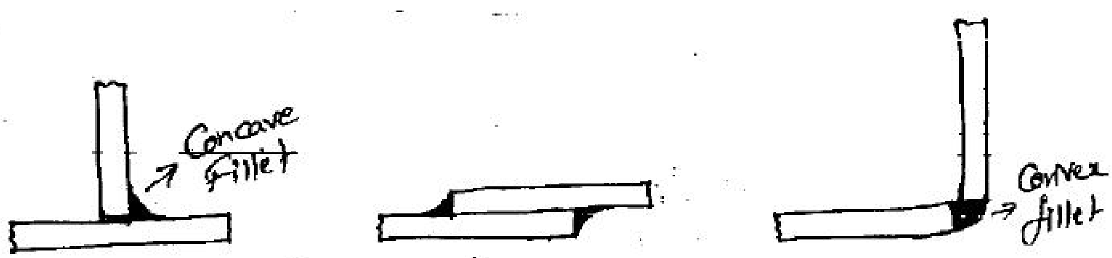
The following are the different types of welds used in making a joint.

(i) Bead Weld: 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. The below figure shows the type of bead weld.



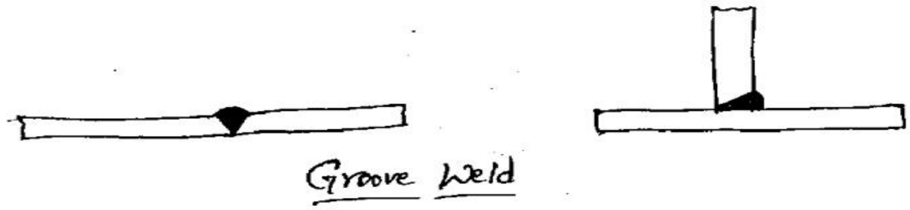
Bead Weld

(ii) Fillet Weld: A 'Fillet' weld is one in which the filler metal is deposited at the corner of two intersecting surfaces, such as T or Lap joint.

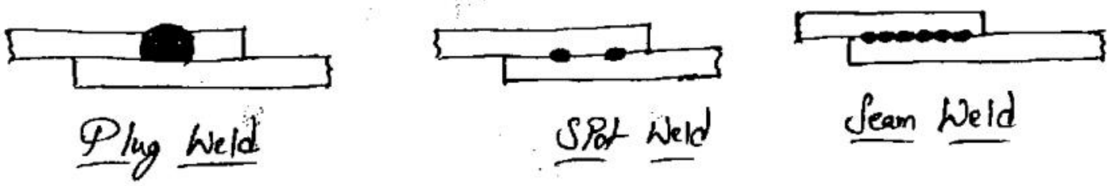


Fillet Weld

(iii) Groove Weld: A 'Groove' weld is one in which the filler material is deposited in a groove formed by edge preparation of one member or of both the members.



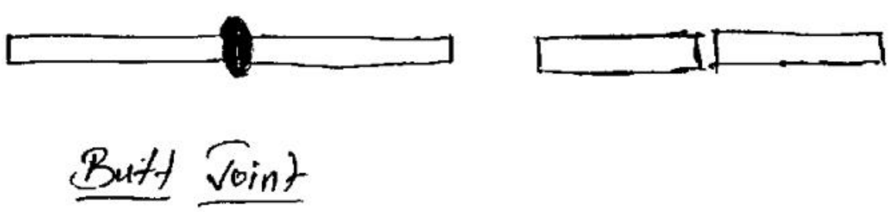
(iv) Plug or Slot Weld: A 'Plug' or 'Slot' weld is one in which a hole is formed through one of the pieces to be welded and the filler material is then deposited into this hole and fused with the mating part.



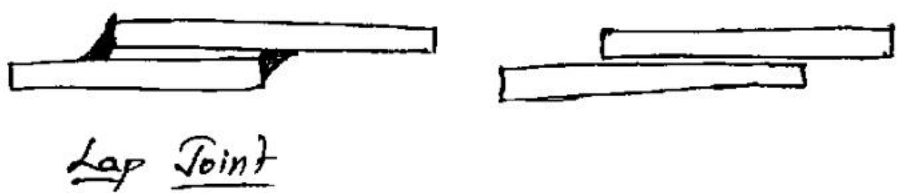
Types of Welded Joints:

The relative positions of the two pieces being welded determine the type of joint. There are five basic types of joints which are used in fusion welding. These are,

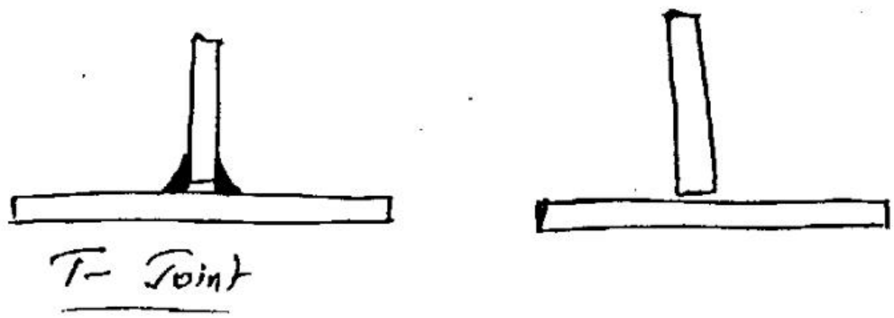
(a) Butt Joint: The butt–joint is used to join the ends of two plates or surfaces located approximately in the same plane.



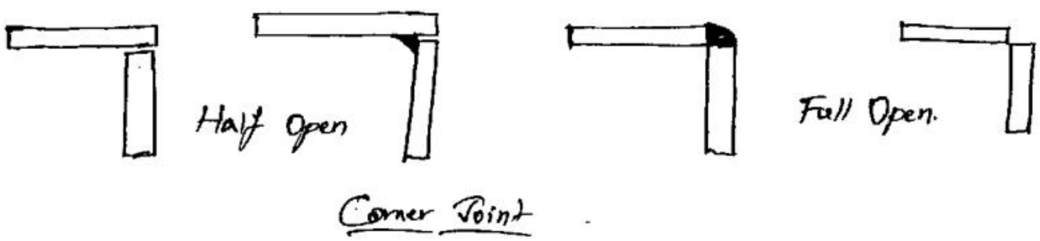
(b) Lap Joint: The lap-joint is used to join two overlapping plates so that the edge of each plate is welded to the surface of the other.



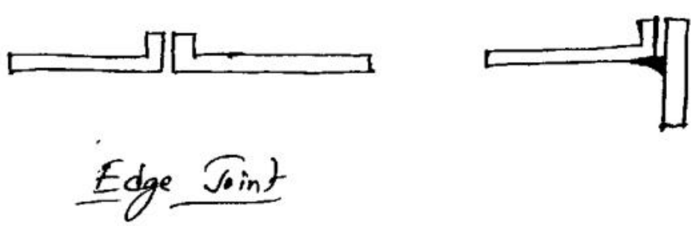
(c) T – Joint: The T-joint is used to weld two plates or sections whose surfaces are at right angles to each other.



(d) Corner Joint: The corner-joint is used to join the edges of two sheets or plates whose surfaces are at 90° to each other.



(e) Edge Joint: The edge joint is used in joining the sheet metal work.



Edge Preparation for Welding:

The preparation of the edges of the pieces to be welded depends upon the thickness of metal being welded. Edge preparation is necessary when thickness increases so that heat would be able to penetrate the entire depth. This ensures formation of sound welds. The edge preparation is done by beveling the edges of the pieces after the rust, grease, oil or paint are completely removed from their surfaces.

There are five basic types of chamfer put on the mating edges prior to welding; they are Square, V, Bevel, U and J.

These five basic types of edge preparation are applied to the different types of weld joints.

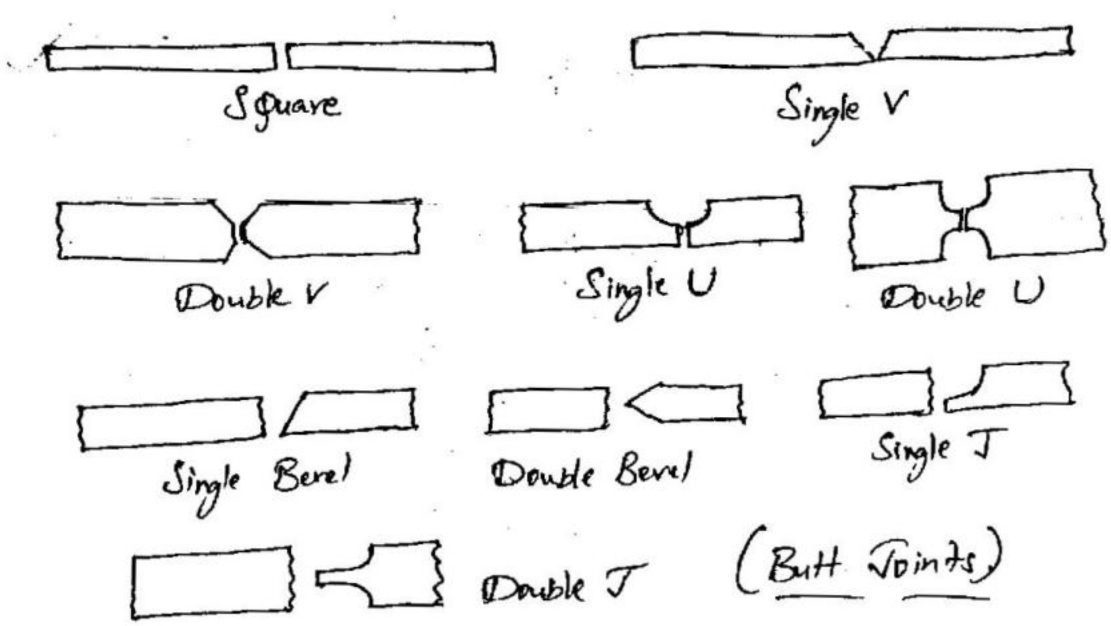
Butt joints: The straight square butt joints with no special edge preparation are used when the thickness of the two joints to be welded is small so that heat of welding penetrates the full depth of joint. These joints are suitable from 3 to 8 mm. However, if the plate thickness is more than 4.5 mm. edge preparation is recommended.

Single V: For thickness up to 16mm

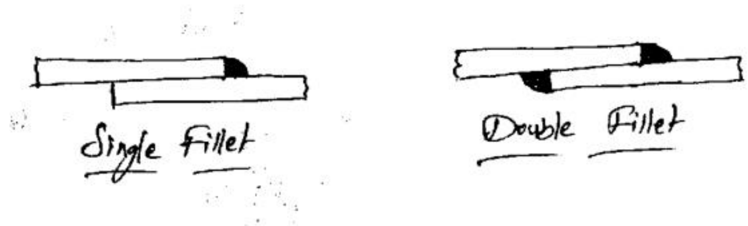
Double V: For thickness > 16mm

Single and Double U: For thickness greater than 20mm.

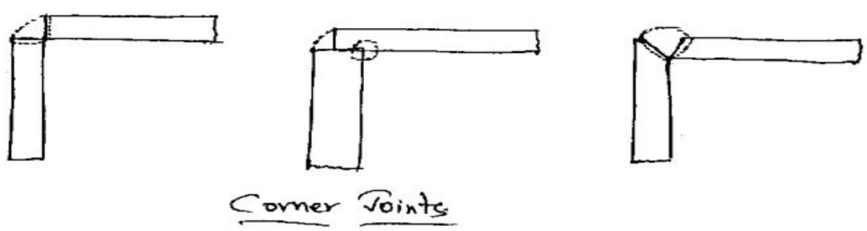
Other edge preparations for a butt joint are: Single bevel, Double bevel, Single J, Double J. Butt joints are made by bead or groove welds.



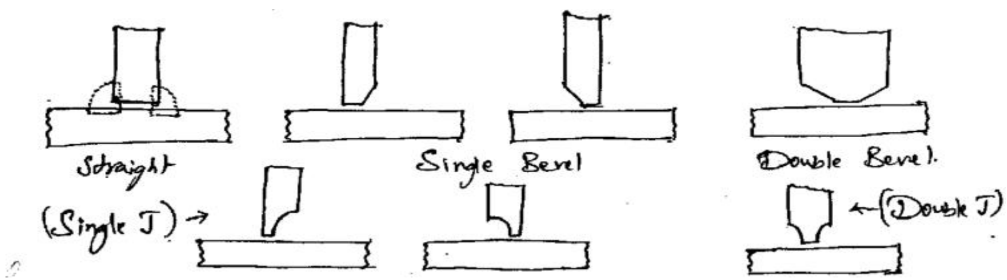
Lap Joints: These joints are used to join thin sheets, usually less than 3 mm thick. These joints do not need any special edge preparation. The joint is produced by fillet welds.



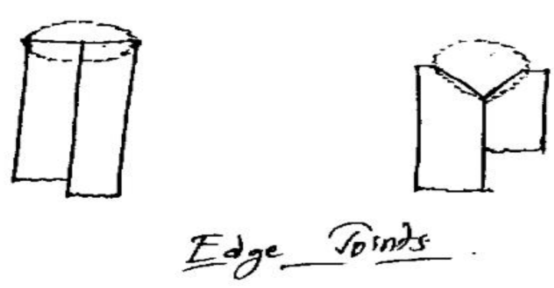
Corner Joints: These joints are used to join sheets upto 5mm thick. These joints are welded with or without edge preparation, with the help of fillet or groove welds.



Tee Joints: Only structures subjected to low static loads can be welded without edge preparation. Single bevel joints are employed for critical structures in which the members are from 10 to 20 mm thick and Double bevel designs are used for thicker metals. Single J and Double J joints can also be used thicker metals. Tee joints are made by using fillet or groove welds.



Edge Joints: Edge joints are used for metals upto 3 mm thick. The height of flange should be twice the thickness of the sheet. These joints are made by Bead or Groove welds.



Characteristics of Welding Process:

I. <u>Vital Welding Characteristis/Properties</u>

a. Deposition Rate:

Weight of metal deposited (Kg) in a given period of time (hour).

b. Deposition Efficiency (Also Called Electrode Efficiency in Arc Welding):

It is the ratio of deposited weight to melted weight. It is of order of 60—75% for shielded metal arc welding, 85—90% for flux cored arc welding, 90—95% for gas metal arc welding, 90—100% for gas tungsten arc welding, and around 95% for submerged arc welding.

c. Operation Factor:

It is the ratio of total actual welding time to time the operator spends in executing welding. If is of the order of 20—30% for shielded metal arc welding and gas tungsten arc welding, 50% for gas metal arc welding (manual), and 100% for automatic gas metal arc welding and submerged arc welding.

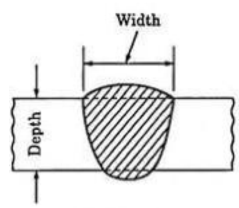


Fig. 9.15

d. Penetration:

It is an important characteristic of fusion welding and is the ratio of width of the weld to its depth. It is of the order of 1.25 for gas metal arc welding, 2.5 for shielded metal arc welding, 5 for plasma arc welding, and 15 for electron beam welding.

A welding process having greater penetrating power calls for a narrow groove, lesser heat affected zone and distortion, and lesser filler metal consumption.

e. Welding Speed:

Speed at which electrode moves or deposition takes place.

f. Heat Input:

It is expressed as:

$$\left\{\frac{V \times I}{s}\left(\frac{\text{Voltage} \times \text{Current}}{\text{Welding speed}}\right)\right\}, \frac{\text{Volt} \times \text{amp. sec.}}{\text{mm}} \text{ or joule/mm}$$

or as MJ/m.

It is of the order of 0.1—0.6 for electron beam welding and laser beam welding, 0.3 to 1.5 for gas tungsten arc welding, 0.5 to 3 for gas metal arc welding and shielded metal arc welding, 1—10 for submerged arc welding and 5—50 for electro slag welding.

g. Power Density:

It is the heat intensity expressed in Watts/m^2. Penetration of weld is proportional to power density.

It is of the order of 5 x 10^6 to 5 x 10^8 W/m^2 for shielded metal arc welding and gas metal arc welding, 5 x 10^6— 5 x 10^{10} W/m^2 for plasma arc welding, 10^{10} to 10^{12} W/m^2 for electron beam and laser beam welding processes.

II. Mechanical Characteristis/Properties

Strength:

A crucial property, indicating the weld's ability to withstand applied forces. Includes tensile strength (resistance to pulling apart), yield strength (the point at which permanent deformation begins), and compressive strength (resistance to crushing).

Ductility:

The ability of the weld to deform under tension without fracturing. A ductile weld can absorb energy and is less prone to brittle failure.

Toughness:

A measure of a material's ability to absorb energy before fracture, indicating resistance to impact and cracking.

Hardness:

The resistance of a material to localized deformation, such as indentation or scratching.

Fatigue Resistance:

The ability of the weld to withstand cyclic loading (repeated stress) without failure.

Corrosion Resistance:

The ability of the weld to withstand degradation from environmental factors like moisture, chemicals, or pollutants.

III. Metallurgical Characteristis/Properties

Melting Point:

The temperature at which a material transitions from solid to liquid, influencing the welding process and the resulting weld pool.

Thermal Expansion:

The tendency of a material to change size with temperature variations. Differences in thermal expansion between materials can create residual stresses in the weld.

Grain Size and Structure:

Welding can alter the microstructure of the base metal, affecting its mechanical properties. Heat-affected zone (HAZ) is an area where the microstructure is modified due to the heat input during welding.

Alloying Elements:

The presence and concentration of alloying elements in the filler and base metals can significantly influence the mechanical and corrosion resistance of the weld.

Weldability:

A measure of how easily a material can be welded. This is influenced by factors like melting point, thermal conductivity, and the material's tendency to form brittle phases during welding.

Gas Welding:

Gas welding is a fusion welding process. It joins metals using the heat of combustion of an oxygen/air and fuel gas i.e., acetylene, hydrogen, butane mixture. The intense heat (flame) thus produced melts and fuses together the edges of the parts to be welded, generally with the addition of a filler metal.

1. Oxy – Acetylene Welding:

Oxy – acetylene is used for welding almost all metals and alloys. When acetylene is mixed with oxygen in correct proportions in the welding torch and ignited, the flame resulting at the tip of the torch is sufficiently hot to melt and join the parent metal. The flame reaches a temperature of about 3000°C. A filler metal rod is generally added to the molten metal pool to built up the seam slightly for greater strength.

Oxygen is produced by either electrolysis or liquification of air. Electrolysis separates water into hydrogen and oxygen by passing an electric current through it. Most commercial oxygen is made by liquefying air and separating the oxygen from the nitrogen. It is stored in the steel cylinders. Acetylene gas (C2H2) is obtained from the chemical reaction of water and calcium carbide.

$$CaC_2 \quad + \quad 2H_2O \quad \text{-------->} \quad C_2H_2 \quad + \quad Ca\,(OH)_2$$

[Calcium Carbide] + [Water] --------> [Acetylene] + [Hydrated Lime]

The reaction provides acetylene gas and hydrated lime as sludge. A special hopper of dropping the calcium carbide into a tank of water at controlled rate is referred as acetylene generator. Acetylene cylinders are also readily available.

The chemical reaction between acetylene gas and oxygen is represented by the equation

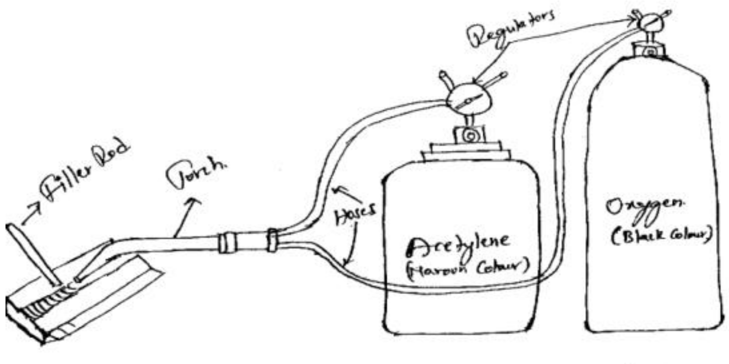
The primary combustion process, which occurs in the inner core of the flame involves the following reaction.This reaction dissociates the acetylene into carbon monoxide and hydrogen and produces about one-third of the total heat generated in the flame.

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

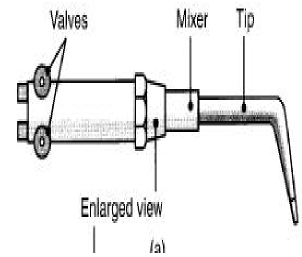
The secondary combustion process is

$$2CO + H_2 + 1.50_2 \text{ -> } 2CO_2 + H_20 + \text{Heat.}$$

This reaction consists of the further burning of both the hydrogen and the carbon monoxide and produces about two-thirds of the total heat.Note that the reaction also produces water vapor. The temperatures developed in the flame can reach 3300°C.



Equipment for Oxy-Acetylene Welding.



Equipment for Oxy – Acetylene Welding: Oxy – acetylene welding equipment consists of the following:

- **(i) Oxygen Cylinder:** Oxygen is filled in the cylinder at a pressure of 150 kg/cm^2. This cylinder is made of steel and it is in black colour.
- **(ii) Acetylene Cylinder:** Acetylene is dissolved in acetone in a cylinder containing porous calcium silicate filler. These cylinders are usually filled to a pressure of 16 kg/cm^2. The cylinder is made of steel and it is in maroon colour.
- **(iii) Welding Torch:** It is used to mix the gases in the right proportions to control the volume of gases burned at the welding tip and to direct the flow. It has a handle to carry it and two inlet connections for gases at one end. Each inlet has a valve to control the volume of oxygen or other gases. The two gases mix up in a mixer and flame is produced by igniting the mixture at the tip of the torch.
- **(iv) Pressure Regulator:** It is located on the top of the gas cylinder. Its function is to reduce the pressure from the cylinder and to maintain it at constant value. The pressure regulator located on the oxygen cylinder is called oxygen pressure regulator and the other one located on the top of the acetylene cylinder is called the acetylene pressure regulator.
- **(v) Hose and Hose Fittings:** The hose is a rubber tube which permits the flow of gas. Two hoses to carry oxygen and acetylene separately are required. They connect the regulator mounted on cylinders to the torch. Generally, green colour is adopted for oxygen hose and red colour for acetylene. The hose should be strong, durable, flexible and light in weight.
- **(vi) Goggles:** Goggles fitted with coloured lenses should be provided to protect the eyes from harmful heat and ultraviolet and infrared rays.
- **(vii) Gloves:** These are used to protect hands from heat and the metal splashes during welding.
- **(viii) Spark Lighter:** It is used to provide a convenient and instant means for lighting the welding torch.
- **(ix) Wire Brush:** Its function is to clean the surfaces of joints before and after welding.

Other Equipments:

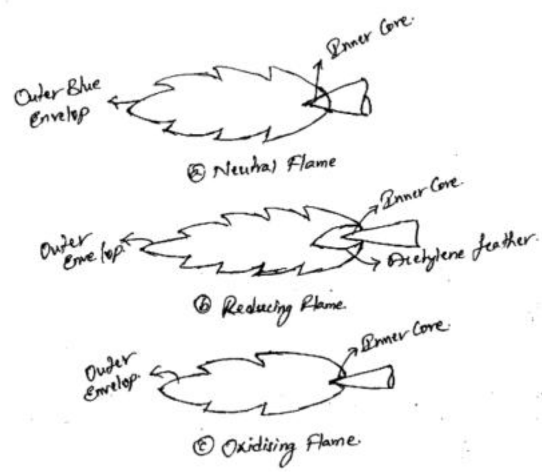
Welding Rods: These are used for providing extra metal to the weld. These are also known as filler rods. The filler rod should have the same composition and properties as that of parent metal. The filler rods are available in 1, 1.25, 1.6, 2, 2.25, 3, 4.5, 6, 8 and 10 mm diameter. The selection of filler rod depends on the welding technique and thickness of the base metal. Steel rods are generally employed when welding ferrous metals. They have a higher carbon content and more manganese and silicon than the base metal. The last two components act as deoxidizing agents and prevent the inclusions of oxide in the weld. Rods containing chromium and vanadium are used for welding alloy steels.

Flux: When the metal to be welded is heated by oxy – acetylene flame, the oxygen of the atmosphere combines with the heated metal and forms metal oxides. These metal oxides have higher melting point than the parent metal. Therefore it is essential that these oxides are removed otherwise slag inclusions will result in poor quality of weld. These oxides can be removed from the weld location by the use of certain fluxes which react chemically with the oxides of most metals and from fusible slag and floats at the top of the molten puddle and do not interfere with the deposition of filler metal. Besides it also protects the molten puddle from atmospheric oxygen. Fluxes are available in several forms such as dry powder, paste or in the form of coating on the welding rod. For ferrous metal, borax, sodium carbonate and sodium bicarbonate are used as suitable fluxes. For copper and copper alloys, mixture of sodium and potassium borates, carbonates, chlorides and boric acid are suitable.

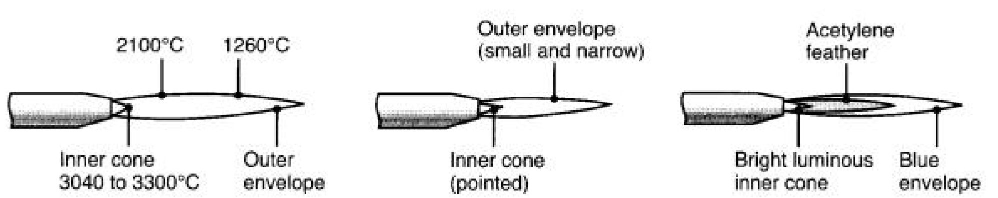
Types of Flames:

The correct adjustment of the flame is important for the production of satisfactory welds. The flame must be of proper size, shape and condition in order to operate at maximum efficiency. The three types of oxy – acetylene flames, which are used in engineering works, are as follows;

(a) Neutral flame.
(b) Reducing or carburising flame.
(c) Oxidising flame.



Section 30.2 Oxyfuel-gas Welding



(a) Neutral flame (b) Oxidizing flame (c) Carburizing (reducing) flame

(a) Neutral Flame: A neutral flame is produced when approximately equal volumes of oxygen and acetylene are supplied to the torch. The temperature of the neutral flame is in order of about 3260°C.The neutral flame consists of sharp brilliant inner cone extending a short distance from the tip of the torch and an outer cone or envelop. The first one develops heat and second protects the molten metal from oxidation, because the oxygen in the surrounding atmosphere is consumed by gases from flame.The neutral flame is commonly used for welding most of the metals such as mild steel, stainless steel, cast iron, copper, aluminium etc…

(b) Reducing or Carburising Flame: If the volume of oxygen supplied to the neutral flame is reduced, the resulting flame will be reducing flame. The temperature of the reducing flame is of order of 3038°C.This flame has three zones (i) Inner core (ii) An intermediate of whitish colour (iii) The bluish outer cone. The outer flame envelop is longer than the other two flames. Being rich in carbon, this flame is suitable for welding steel. It is also used for surface hardening.

(c) Oxidising Flame: If the volume of oxygen to the neutral flame is increased, the result will be oxidising flame. The temperature of the oxidising flame is of the order of 3300°C to 3500°C. It is hotter than neutral flame.The oxidising flame consists of one smaller core which is more pointed than the neutral flame. The outer envelop is shorter. Oxidising flame is used in welding brass, copper base metals, zinc base metals and few ferrous metals such as manganese, steels and cast irons.

Advantages of Oxy – Acetylene Welding:

1. The equipment is comparatively in expensive.
2. Low maintanenance cost.
3. The oxy – acetylene flame is generally more easily controlled and not as piercing as metallic are welding. Therefore, it is used extensively for sheet metal fabrication and repair works.
4. The equipment is versatile. Besides gas welding, the equipment is used for preheating, brazing, metal cutting etc…
5. With proper technique, practically all metal can be welded.
6. Since the source of heat and filler metal are separate, the welder has controlled over the filler material deposition rates.

Disadvantages of Oxy – Acetylene Welding:

1. It takes considerable longer for the metal to heat up than in arc welding.
2. Prolonged heating of the joint in gas welding results in larger heat affected area. This often results in increased growth, more distortion.
3. These are safety problems involved in handling and storing of gases.
4. Flame temperature is less than the temperature of the arc.
5. Heavy sections cannot be joined economically.
6. Flux shielding in gas welding is not so effective as an inert gas shielding in TIG or MIG welding.

Applications of Gas Welding:

1. For joining thin materials.
2. For joining most ferrous and non – ferrous metals.
3. In automatic and aircraft industries and sheet metal fabrications.

2. Oxy – Hydrogen Welding:

Oxy – Hydrogen welding is used for aluminium, magnesium, lead etc. In this process hydrogen is used in place of acetylene and the flame temperature is very low 2000°C. An advantage of this process is that no oxides are formed on the surface of the weld.

Gas welding techniques

I. Based on the Direction of travel welding rod and welding torch:

Gas welding techniques are classified as: 1. Left ward welding or forehand welding technique, and 2. Right ward or backhand welding technique. 3. Vertical welding. The position of welding torch, filler rod and direction of welding for these techniques is shown in Fig.

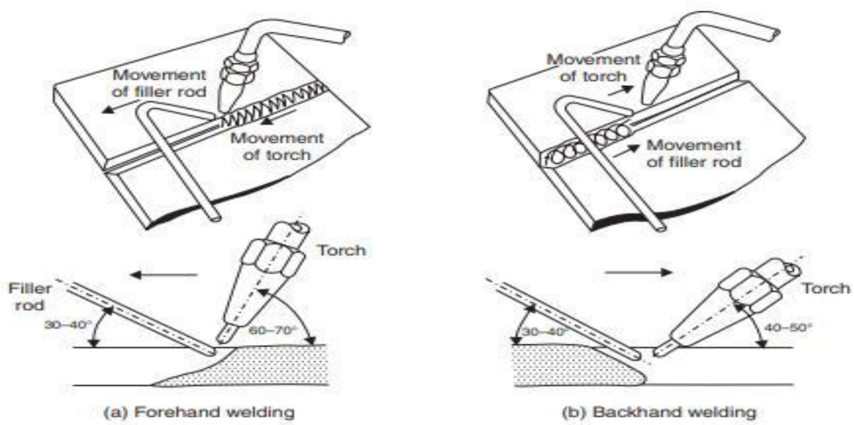
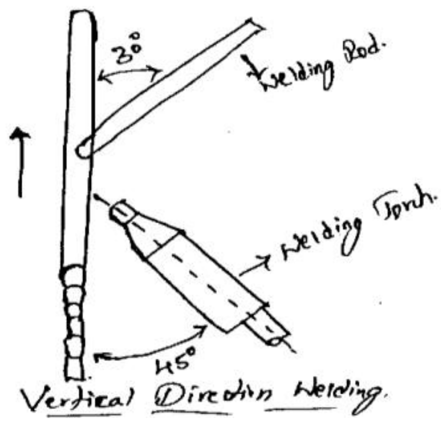


Fig. . . Welding techniques

1. **Left ward welding or forehand welding technique:-**It will be noticed that in the left ward welding technique, the flame from the torch preheats the material yet to be welded. The welder holds torch in the right hand and filler rod in the left hand. The weld is made working from right to left as shown in below figure. Since the flame is pointed in the direction of the welding, it preheats the edges of the joint. This method is suitable for mild steel, cast iron, aluminium, brass etc…
2. **Right ward or backhand welding technique:-** In the right ward welding, the flame post heats the weld-bead. It is carried out from left to right as shown in below figure. Thicker materials can be welded by this method.
3. **Vertical Welding:** It starts at the bottom of the weld joint and gives an oscillating movement to the welding torch which points slightly upwards as shown in below figure.

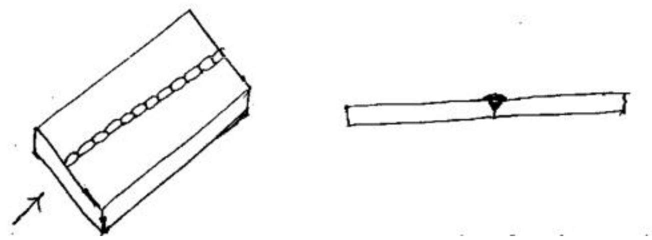


II.Based on the Position of Welding:

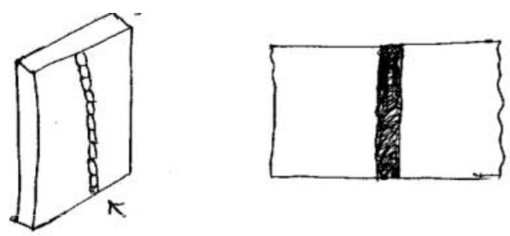
(a) Down Hand Welds (b) Vertical Welds (c) Inclined Welds

(d) Horizontal Welds (e) Overhead Welds

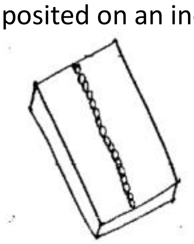
(a) Down Hand Welds (flat): These welds are deposited in any direction on a horizontal surface so that the flame is above the face of the weld.



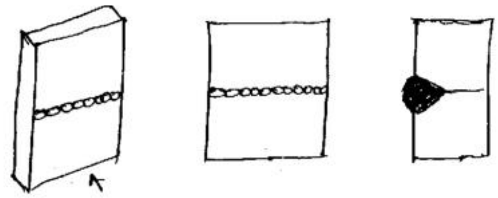
(b) Vertical Welds: These welds are deposited on a vertical surface in a vertical direction as shown in below figure.



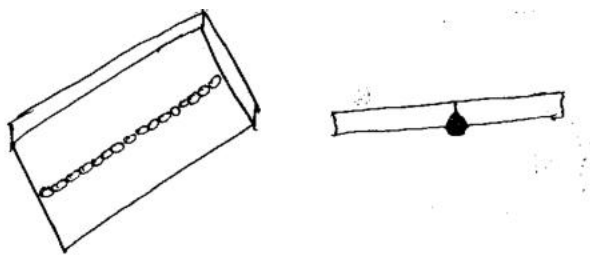
(c) Inclined Welds: These welds are deposited on an inclined surface as shown in below figure.



(d) Horizontal Welds: These welds are deposited on vertical surface in a horizontal direction as shown in fig.



(e) Overhead Welds: These welds are deposited on a horizontal surface in any direction so that the face of welds is above the flame as shown in fig.



Cutting of Metals: [Oxy-Acetetylene Cutting

The welding equipments are not only used for welding that is joining the work pieces but some of the equipments are also used for cutting of the metals. This is the most frequently employed thermal cutting process used for low carbon and low alloy steel plates and often referred to as 'flame cutting' or 'gas cutting'. It can be used to cut steel upto 2 m thick.

Oxy – Acetylene Cutting:

It is a chemical process in the sense that the metal, at the portion where it is to be cut is actually made to oxidize under the action of flame with the following reaction.

$$3Fe + 2O_2 \longrightarrow Fe_3O_4 + 26{,}691 \text{ cal}$$

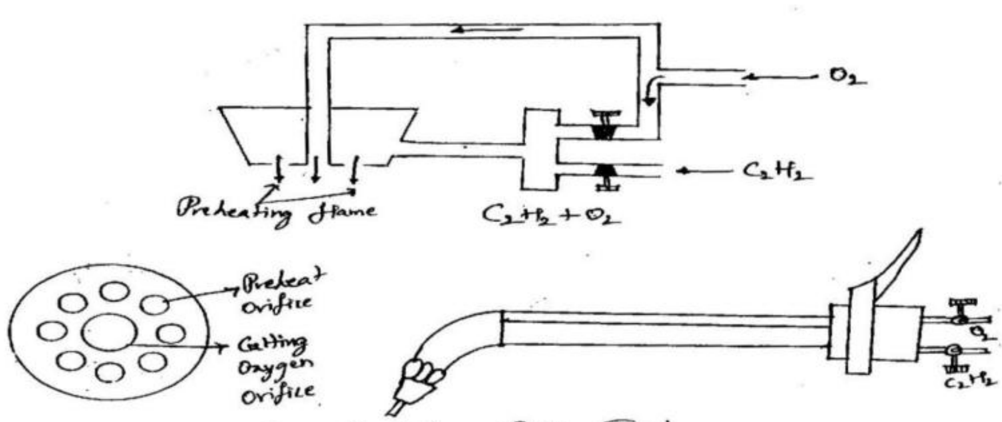
Iron Oxygen Black Iron Oxide Heat

All ferrous metals can be cut by means of oxy-acetylene flame cutting. The oxy-acetylene flame cutting process makes use of cutting torch. The torch mixes the acetylene and oxygen in the correct proportions to produce preheating flame and also the torch supplies a uniformly, concentrated stream of high purity oxygen to the reaction zone. The tip has a central hole for pure oxygen jet with surrounding holes for preheating flames as shown in below figure.

To produce a cut, the steel is heated to ignition temperature (900°C) i.e., reddish yellow color by preheating flame, keeping the torch 3 mm above the surface of material to be cut. A jet of pure oxygen is directed at this heated area. This forms the iron oxide there and the same melted immediately (burning the steel in its path). It is then blown off by the oxygen jet, thus providing a narrow slit along the cutting line.

This method is suited for cutting of ferrous metals and its alloys.

Oxygen cutting can be accomplished manually or by machine (automatic).



Oxy-Acetylene Cutting Torch.

Oxygen cutting machines are further divided two classes:

1. Portable machine
2. Stationary machine

On a portable machine, the carriage supports the torch. It is usually run by an electric motor on a straight track. The speed of the motor is adjustable to the size of the metal being cut.

The stationary type of cutting machines is designed on two different mechanical principles for cutting torch. One is the pantograph design and the other uses a cross carriage mechanism.

Cutting of Ferrous and Non-Ferrous Metals: Metal Powder Cutting: It is an oxygen cutting process in which metal powder (iron or aluminum) is employed to facilitate cutting. This process is used for cutting cast iron, chromium-nickel, stainless steel and some high alloy steels. The working principle of powder cutting is lite injection of metal powder into the oxygen stream well before it strikes the metal to be cut. The powder is heated by its passage through the oxy-acetylene preheat flames and almost immediately ignites in the stream of cutting oxygen. The powder from a powder dispenser is carried to the lip of the cutting torch by the use of compressed air or nitrogen as shown in Fig. The ignited powder provides much higher temperature in the stream and that helps in culling the metal in almost the same manner as cutting of low carbon steel. Preheating is not essential for powder cutting.

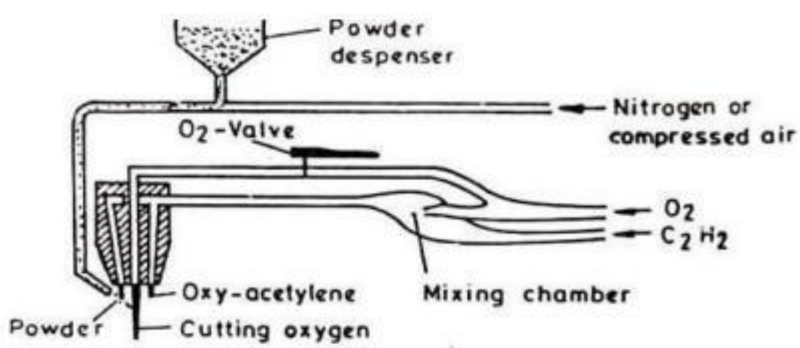
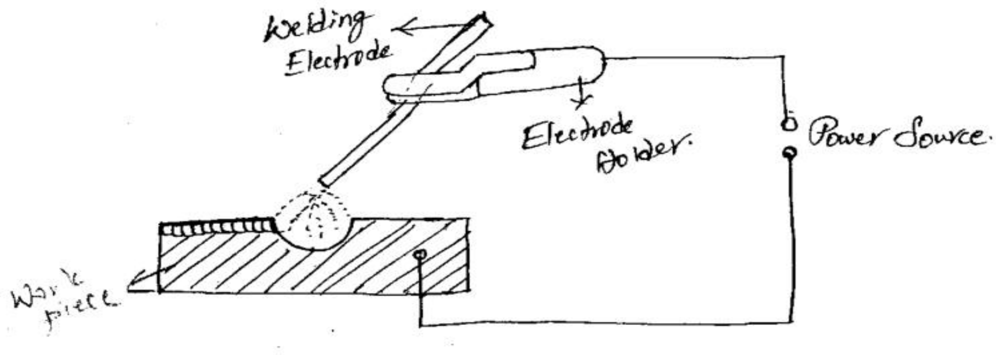


Fig. [illegible] Cutting torch for metal powder cutting.

Metal powder culling was initially introduced for cutting stainless steel but has been successfully used for cutting alloy steels, cast iron, bronze, nickel, aluminium, steel mill ladle spills, certain 60 refractories, and concrete. The same basic process can also be used for gouging and scarfing to condition billets, blooms, and slabs in steel mills.

Arc Welding:

In arc welding process, the welding temperature is produced by an electric arc, established between an electrode and the metal being welded. The temperature of the arc is 7000°C. The arc welding set up is shown in below figure.



Arc Welding Setup

Arc Welding Equipments:

The equipments required for arc welding consists of:

(a) Arc welding Power Sources
(b) Electrode
(c) Electrode Holder
(d) Cables, Cable connectors
(e) Earthing Clamps
(f) Chipping Hammer
(g) Helmet
(h) Safety Goggles
(i) Apron
(j) Hand Gloves

(a) Arc Welding Power Source: The power source is required to maintain the arc between the electrode and base metal is available in (i) DC generator (ii) AC transformer

(i) DC Generator: DC Generator is run either by an electric motor or diesel engine. These generator supplies voltage in the range of 15 to 50 volts and output current 200 to 600 Amps. These produce DC in either straight or reverse polarity. The heat generated is split into two parts in the ratio of 66 percent at positive pole and 33 percent at negative pole. For welding thin materials, the work is made negative and the electrode positive. This is called reverse polarity. For welding heavy sections the electrode is made negative and the work to be positive, this is called straight polarity. It can be used for welding ferrous and non – ferrous metals. The disadvantage of the generator is the high investment and maintenance cost. Its operation is noisy.

(ii) AC Transformer: AC Transformer changes high voltage, low amperage to low voltage, high amperage. The main advantage of transformer over generator is low cost and ease of operation. Since there are no moving parts in the equipment, the operation is noiseless. The disadvantage of the transformer is that the polarity cannot be changed.

(b) Electrodes for Arc Welding: Electrodes for arc welding may be broadly classified as:

1. Non – consumable electrodes
2. Consumable electrodes

Non – Consumable electrodes are usually made of carbon, graphite or tungsten. These electrodes do not get consumed during the arc welding. These are used in carbon arc welding like TIG welding, atomic hydrogen welding.

Consumable electrodes get consumed during the welding. These are made of various metals depending upon the purpose and chemical composition of patent metals being welded. These electrodes are further classified into, (1) Bare Electrodes (2) coated electrodes.

Bare electrodes are used in submerged arc welding and metal inert gas welding (MIG) welding.

Coated electrodes are again subdivided into (1) Light coated electrodes (2) Heavy coated electrodes.

Light coated electrodes are used for welding non–essential jobs. The primary purpose of light coated is to increase are stability. These produce poor mechanical properties welds due to the lack of protection of the weld.

Heavy Coated electrodes are used to produce high quality welds.

Functions of Coated Electrode:

The coating on electrodes performs the following function:

1. Protects the weld from atmospheric oxygen and nitrogen by producing a shield of gas around the arc and weld pool.
2. Stabilize the arc.
3. Provide the slag so as to protect the weld from rapid cooling.
4. Remove oxides and impurities.
5. Add alloying elements to the weld metal.
6. Increase deposition efficiency.

STRIKING AN ARC:- To strike an arc, the electrode should be shorted by touching the work. At the moment of contact, a very heavy current starts flowing through the circuit, while voltage drops. Now, the electrode is lifted slowly so that a gap of 2–3 mm between the tip of the electrode and the work piece is maintained. The voltage across the arc rises to about 15–20 volts and the amperage drops. Due to heat generated in the arc, the tip of the metal electrode starts melting and the gap increases. Unless the electrode is slowly moved towards the work at the same rate at which the tip of the electrode is melting maintaining the gap at 2–3 mm, the arc will extinguish. If the gap increases too much the machine voltage will not be able to maintain the arc. A great amount of heat (and intense light) is generated by the arc. It not only melts the electrode tip, but also melts the work piece at the location of the arc maintaining a pool of molten metal as shown in Fig. Without some manner of shielding, this metal will oxidizeoxidise. The metal electrodes are therefore, given a layer of coating throughout its length (except for about 35–40 mm at the stub end, where the metal core of electrode is exposed and held in the electrode holder). Under the action of heat, this coating at the tip of the electrode vaporises and creates a gaseous shield around the molten metal pool and saves it from oxidation. The electrode coating also contains flux (which reacts with impurities to form slag) and other ingredients which help stabilise the arc. As the electrode is slowly moved over the joint, the molten metal pool solidifies creating a joint. The joints produced by this process are often stronger than the parent metals being joined.

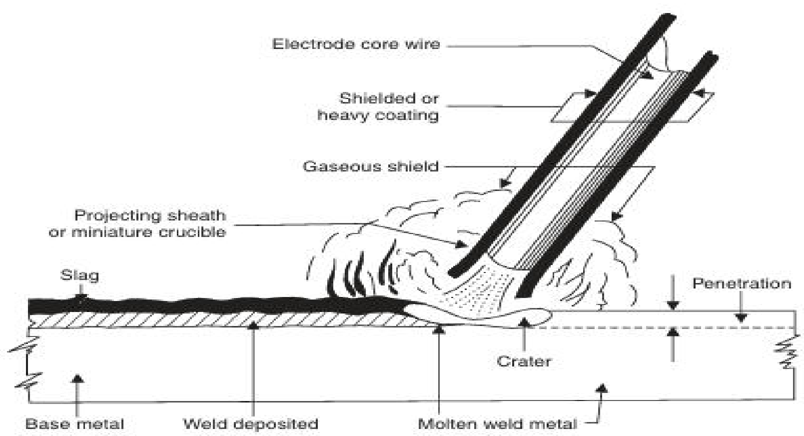


Fig. Welding action of a cellulosic-coated stick electrode

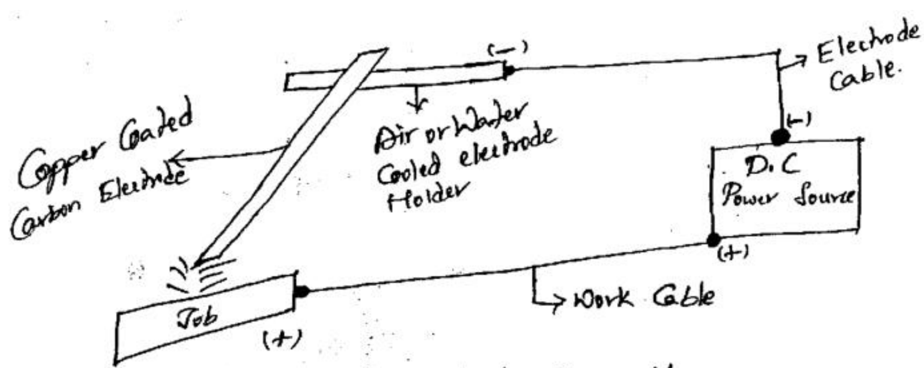
Types of Arc Welding:

(a) Carbon arc welding
(b) Metal arc welding
(c) Submerged arc welding
(d) Inert gas welding
    (i) TIG welding (ii) MIG Welding
(e) Plasma arc welding
(f) Electro Slag welding

(a) Carbon Arc Welding:

In carbon arc welding process the arc is obtained between the carbon electrode and the work piece or between two carbon electrodes. This welding is suitably used in welding of steel sheets, copper alloys and brass etc…

In this, coalescence is produced by heating with an electric arc between a carbon electrode and the work. Shielding is generally not used. Pressure is not used, and filler metal may or may not be used. The electric are can also be struck by the "twin arc method" that is between two carbon electrodes. Filler metal, when used is fed into the arc and allows a fairly high rate of weld metal deposition. Sometimes a filler rod is placed into the joint groove, and the carbon arc is passed slowly along the joint until fusion is completed.



Single Carbon Electrode Arc welding.

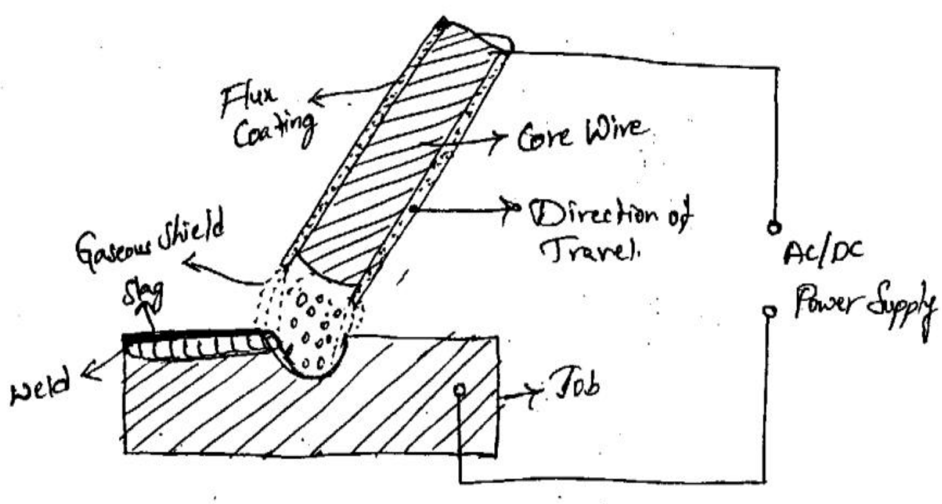
The weld metal is not shielded from contamination of oxygen and nitrogen in the atmosphere. More ever, very little if any carbon is picked up by the weld from the carbon electrode. Thus this process is generally limited to those materials which are not sufficiently contaminated by these elements, that are copper alloys, brass, bronze, aluminium alloys etc… It will be better if the filler metal incorporates deoxidizer.

Manual Metal Arc welding[Shield Metal Arc Welding]

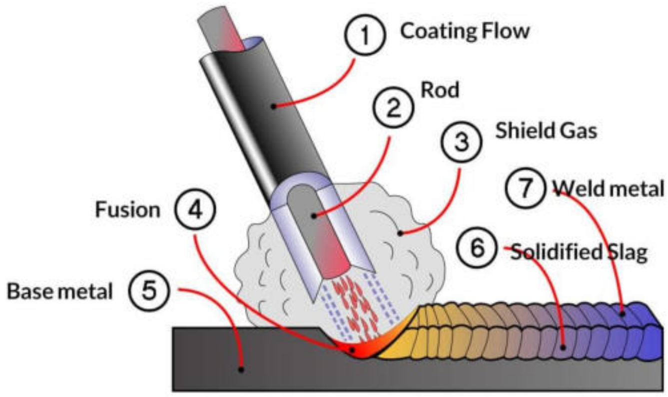
In this process, the heat is generated by an electric arc between base metal and a consumable electrode. As the electrode movement is manually controlled hence it is termed as manual metal arc welding. This process is extensively used for depositing weld metal because it is easy to deposit the molten weld metal at right place where it is required and it doesn't need separate shielding. This process is commonly used for welding of the metals, which are comparatively less sensitive to the atmospheric gases. This process can use both AC and DC..This is also called Shield Metal Arc Welding (SMAW) or Stick welding. Heat required for the welding is obtained from the arc struck between the coated electrode and the work piece. The material droplets are transformed from the electrode to the work piece through the arc and deposited along the joint to be welded. The coating produces a gaseous shield and slag to protect from atmosphere.

During the process of welding, the electrode is given three movements. The electrode is continuously fed downward along its axis to maintain the arc length. It is progressively fed along the weld and thirdly the electrode tip is given an oscillating movement across the weld. The side ways oscillating movement of the electrode tip is given to:

(i) Obtain and maintain proper bead width.
(ii) Float out slag.
(iii) Secure good penetration at the edges of the weld.
(iv) Allow gases to escape and there by avoid porosities.



Metal Arc Welding.



Advantages:

1. It is the simplest of all the arc welding processes.
2. The equipment is portable and less cost.
3. Wide range of metals and their alloys can be welded.

Disadvantage:

1. Mechanization is difficult due to limited length of the electrode.

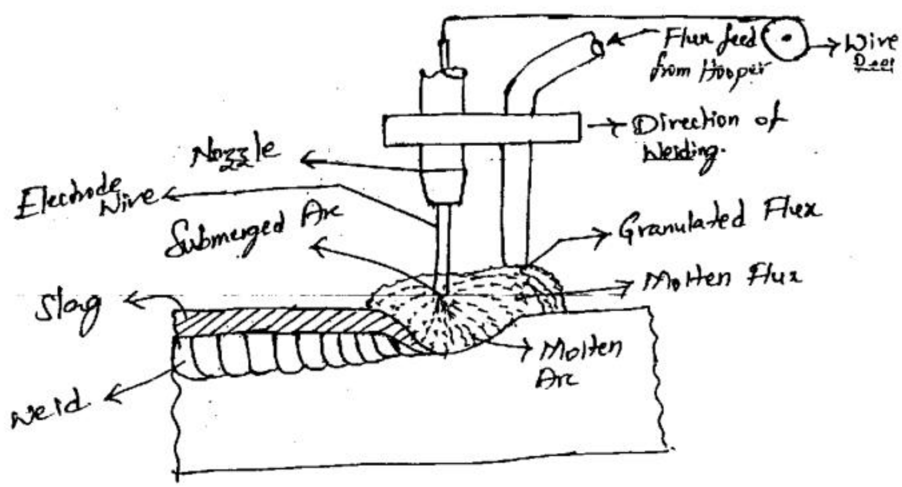
Applications:

1. All commonly used metals and their alloys can be welded.
2. This process finds application on ship building, aircraft industries, automobile industries etc…

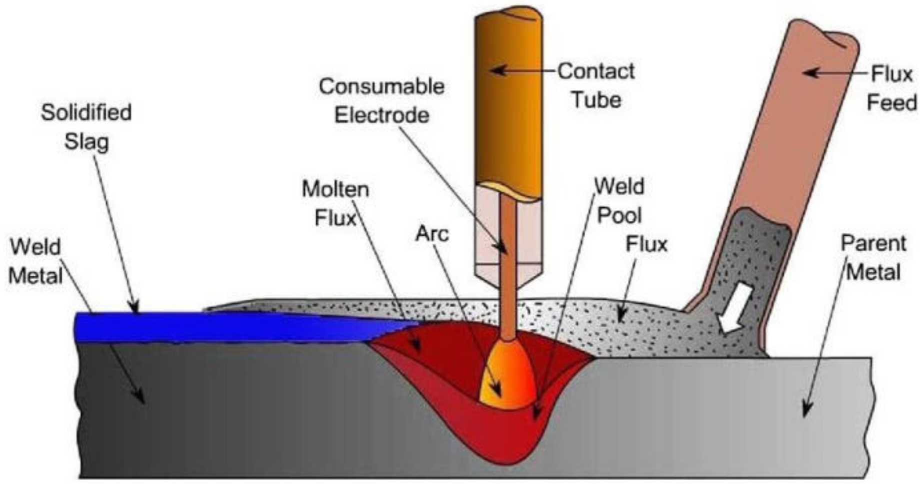
Submerged Arc Welding:

This process is so named because of metal arc is shielded by a blanket of flux as shown in figure. In this process instead of flux covered electrode, granular flux and a bare electrode is used. Flux is deposited continuously in front of the electrode and the flame feeder and the electrode feeder together move as the welding proceeds. The flux is sufficient depth to submerge completely the arc column so that there is no smoke or splatter and the weld is shielded from the effect of all atmospheric gases. As a result of this unique protection, the welds are exceptionally smooth.

The arc is started either by striking the electrode beneath the flux on the work or by placing the steel wool between the electrode and the work piece before switching on the welding current. The intense heat of the arc immediately produces a pool of molten metal in the joint and at the same time the flux adjacent to the arc column melts and floats on top of the molten metal. This forms a blanket that eliminates spatter losses and protects the welded joint from oxidation. The current density is 300 to 400 amps which is 5 to 6 times than that of metal arc welding. Submerged arc welding is done manually or automatic and semi-automatic. The manual and the automatic submerged arc welding process are most suited to the flat welding position, or slightly vertical, down hill welding position. Backing strip of steel, copper or some refractory material is used under the joint to avoid loosing some of the molten metal.This process is used to weld low alloy, high tensile steels as well as mild steel, low carbon steels.



Submerged Arc Welding.



Advantages:

- Deep penetration is obtained due to the high current, density which is 5 to 6 times than that of metal arc welding.
- Welding is fast due to high melting rate of electrodes.
- Minimum distortion due to high speed.
- Quality of the weld is excellent and uniform.

Applications:

The submerged arc welding process has many industrial applications. It is used for fabricating pipe, boiler vessels, structural shapes and practically any job where straight line welding is required.

Inert gas welding:

In this coalescence is produced by heating with an electric arc between a suitable electrode and the work. Shielding is obtained form an inert gas such as carbon dioxide, helium and argon. Pressure is not used, and the filler metal may or may not be used. Inert gas welding is done either with nonconsumable electrode or with consumable metal electrode.

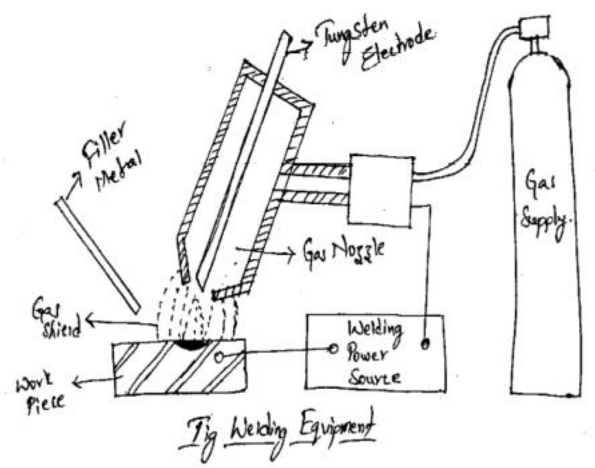
In conventional arc welding, the fluxes are used to shield the atmosphere around the molten metal. In inert gas welding, inert gases such as argon, helium, carbon dioxide are used for surrounding the electric arc and thus keeping atmospheric air and other contaminations away from the molten metal pool.

Two methods are employed.

1) Tungsten-inert Gas (TIG) Welding
2) Metal-inert Gas (MIG) Welding

(1) Tungsten – inert Gas Welding:

A tungsten inert gas welding equipment is shown in below figure. This process is also known as gas tungsten arc welding (GTAW). It uses a non-consumable tungsten electrode mounted at the centre of the torch. The inert gas is supplied to the welding zone through the angular path surrounding the tungsten electrode. Welding operation is done by striking the arc between the work piece and tungsten electrode in the atmosphere of inert gas.



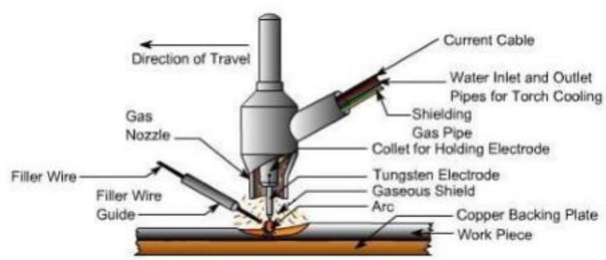


Fig [illegible]: Principle of TIG Welding.

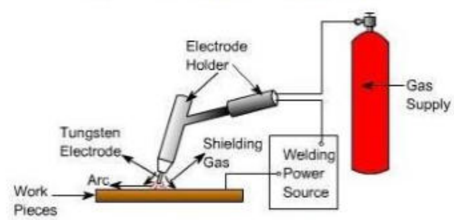


Fig [illegible]: Schematic Diagram of TIG Welding System.

Advantages:

(i) No flux is required.
(ii) TIG welds are stronger, more ductile and more corrosion resistance than welds made with ordinary shield arc welding.
(iii) Welding is easily done in all the position.

Disadvantages:

(i) Equipment is costlier.
(ii) Separate filler rod is needed.

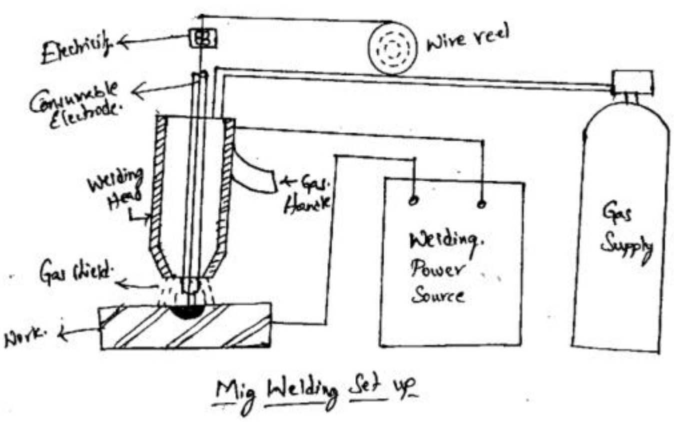
(iii) Decrease in welding speed.

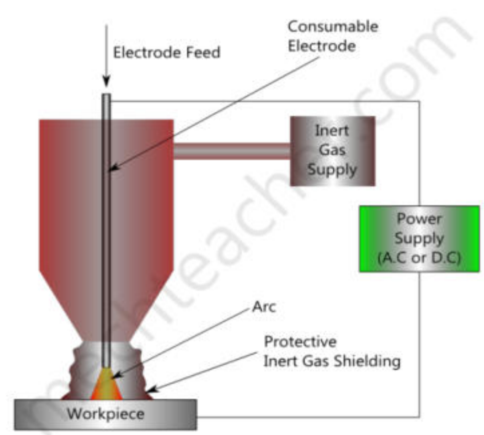
Applications:

(i) It is used for fusion welding of aluminium, magnesium alloys, stainless steel, low alloy steel high alloy steel, brass, bronze, silver, molybdenum and a wide range of other metals.
(ii) It can also be used to weld many dissimilar metals.
(iii) The TIG process can be used to braze and to supply the heat source for brazes welding.
(iv) It can also be used as heat source for the hard surfacing of the metals.

(2) Metal Inert Gas (MIG) Welding:

MIG welding stands for Metal Inert Gas Welding. In this process, the tungsten electrode is replaced with a consumable electrode. The electrode is continuously fed to the arc at the rate 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 passes. It is similar to submerged 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.





Components used in Metal Inert Gas Welding (MIG Welding):

Advantages:

(i) No flux is required.
(ii) High quality welds are produced.
(iii) Less operator skill is required.
(iv) High welding speed.
(v) It is suitable for ferrous and non-ferrous metals.

Disadvantages:

(i) Welding equipment is more complex and costly.
(ii) It is difficult to weld in small corners.

Applications:

(i) It can be done on most of the commercial metals.
(ii) It is used for welding carbon and low alloy steels, stainless steels nickel and its alloys, copper alloys.
(iii) MIG welding is used in aircraft and automobile industries.

Electro Slag Welding:

In this process, electrode wire is fed into a molten slag pool. An arc is drawn initially, but is then snuffed out by the slag, and the heat of fusion is provided by resistance heating in the slag.

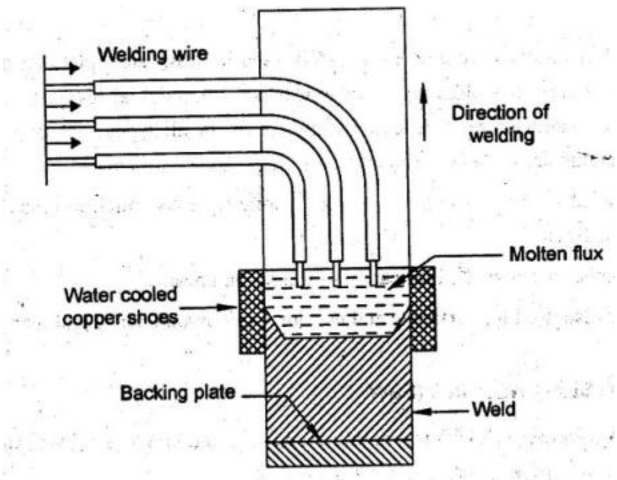


Figure 2.16 Electroslag welding

The pieces to be welded are positioned vertically with necessary gap between them. Two copper shoes (water cooled) sides on either side of the gap form a well in which flux is deposited. An electric arc is stuck between the electrode and the joint bottom with the help of a piece of steel wool. The arc melts the electrode and flux and forms the molten slag. When enough slag accumulate, the arc action stops and further requirement heat is provided by the resistance offered by the slag to the current flowing through it. The molten metal temperature is 2000°C. This heat is sufficient to fuse the edges of the work pieces and the welding electrode. The heated metal collects in the pool beneath the slag slowly solidifies there by forming the weld bead joining the two work pieces.

Advantages:

- (i) Thicker plated can be welded in a single pass and economically.
- (ii) High welding speed.
- (iii) Minimum joint preparation.
- (iv) Little distortion.
- (v) The weld metal is totally out of contact with atmosphere and hence the best quality of weld.

Applications:

It is used particularly for welding thickness of 30 mm over plates and structures for turbine shafts, boiler parts and heavy presses.

Resistance Welding:

Resistance welding is "a group of welding processes where in coalescence is produced by the heat obtained from resistance of the work to electric current in a circuit of which the work is a part, and by the application of pressure and without the use of a filler metal".

In this welding, a heavy electric arc current is passed through the metal pieces to be joined, over a limited area, causing them to be locally heated to plastic state and the weld is completed by the application of pressure. In this process two copper electrodes are used. The metal pieces to be welded are pressed between electrodes and current is passed through the electrodes. A transformer in the welding machine reduces the voltage from either 120 or 240 volts to4 to 12 volts and raises the amperage sufficiently to produce a good heat.

The amount of heat (H) generated is given by the following relation:

$$H = KI^2RT$$

Where, H = The heat generated in the work in joules

I = Electric current in amperes

R = Resistance of the joint in ohms

T = Time of current flow in seconds

K = A constant to account for the heat loss from the welded joint

For good resistance welding the following factors are properly controlled.

(i) **Welding Current:** Enough current is required to bring the work pieces to plastic state for welding. It is properly adjusted on the current control device on the machine.
(ii) **Welding Pressure:** Mechanical pressure is required to hold the work pieces and squeeze the pieces to form the weld during plastic state.
(iii) **Cycle Time:** It is the combination of weld time and hold time. The duration of current flowing through the work piece to raise the temperature is called welding time. After this the current is switched off while the pressure is still acting. The pressure is applied till the weld cools and regains sufficient strength. This period is known a hold time.

The types of resistance welding are:

(a) Spot Welding (b) Seam Welding

(c) Projection Welding (d) Butt Welding

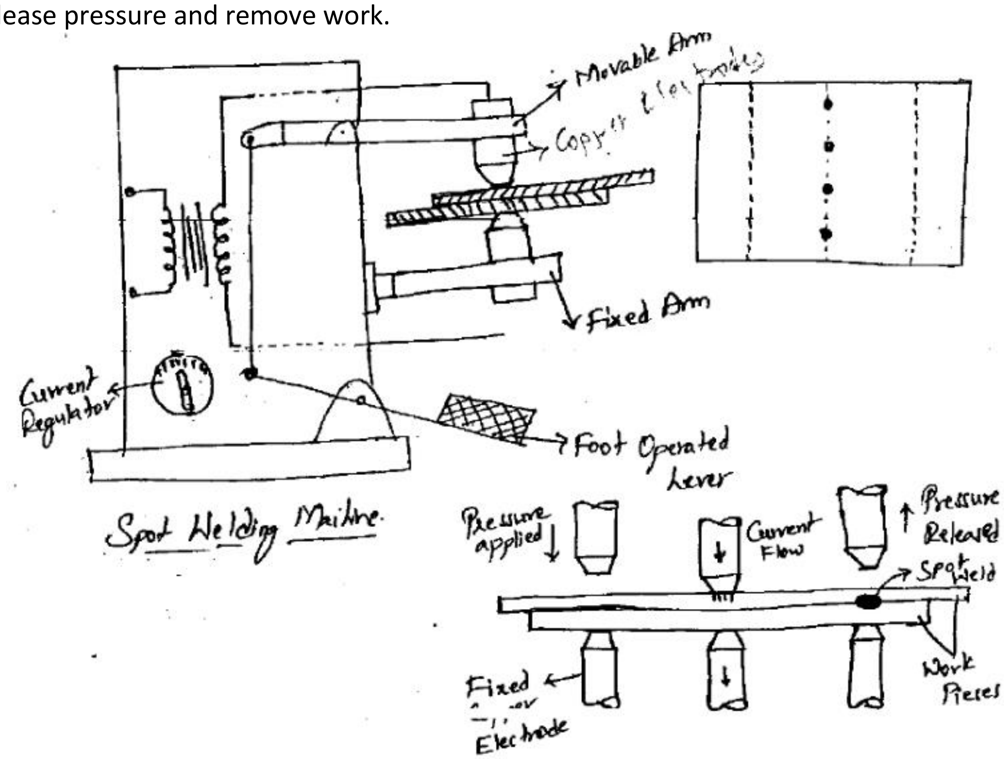
(a) Spot Welding:

This is called as Resistance Spot Welding (RSW). It is the simplest and most commonly used method of overlap welding of strips, sheets or plates of metal at small areas.

In this method, sheets of a metal to be welded are held between copper electrodes (water cooled) by applying pressure through foot pedal lever. A current of low voltage and sufficient amperage is passed between electrodes causing the parts to be brought to welding temperature. The metal under electrodes 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 produces a solid bond. Now the pressure is released and the work is removed from the machine.

The welding cycle to produce one spot can be written as:

(i) Position the work pieces and squeeze between the electrodes.
(ii) Apply a low voltage current to the electrode.
(iii) Hold until the proper temperature is attained.
(iv) Release current, continue pressure.
(v) Release pressure and remove work.



Advantages:

(i) No edge preparation is needed
(ii) Low cost
(iii) High speed of welding

Disadvantages:

The main disadvantage is high cost of equipment, and there are limitations to the types of joints made.

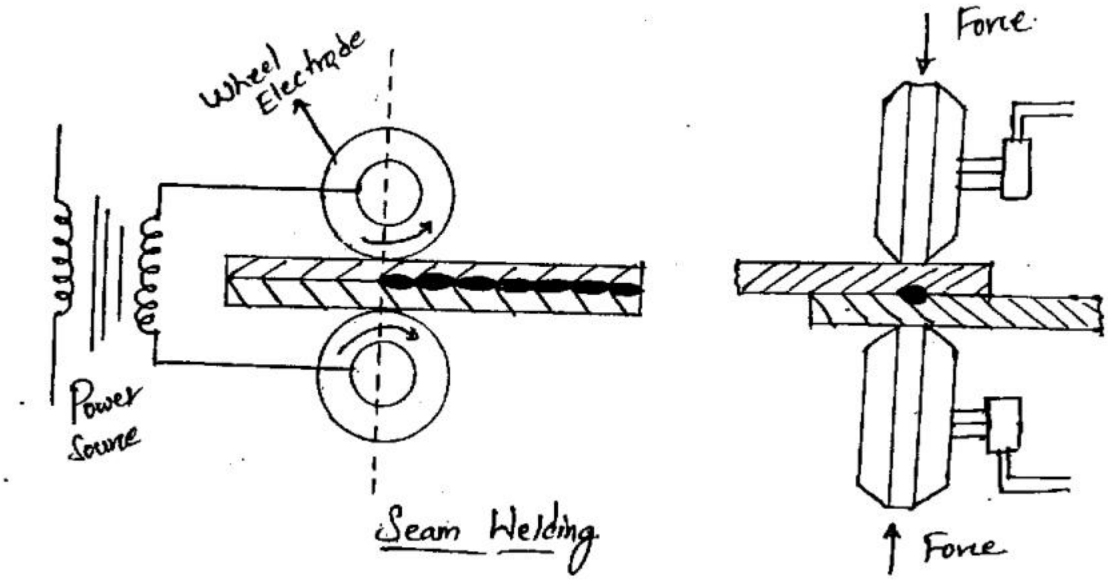
Applications:

(i) This technique is used mostly in thin sheet work like making sheet metal boxes, containers such as receptacles.
(ii) Thicker metals up to 12.5 mm have been successfully spot welded.
(iii) It finds application in automobile and aircraft industries.

(b) Seam Welding:

Seam welding is similar to spot welding, except that the electrodes in spot welding are replaced by copper rollers or wheels. The work pieces to be welded are passed between the rollers as shown in figure. A current impulse is applied through the rollers to the material in contact with them. The heat generated makes the metal plastic and the pressure from the rollers completes the weld.

To obtain a series of spot welds along a line by the RSW (Resistance Seam Welding) method, an interrupt work movement will be necessary. The same result can be achieved much more conveniently and rapidly in the resistance seam welding where the electrodes are in the form of rotating disc electrodes, with the working being welded moving continuously by the electrodes.



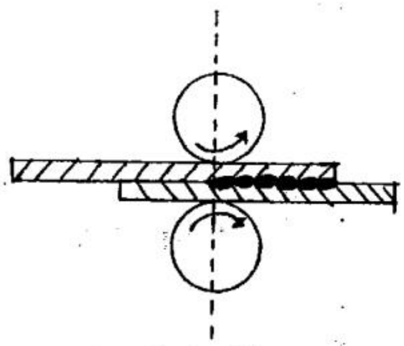
Seam Welding

In Seam welding, there are two types of welds are obtained:

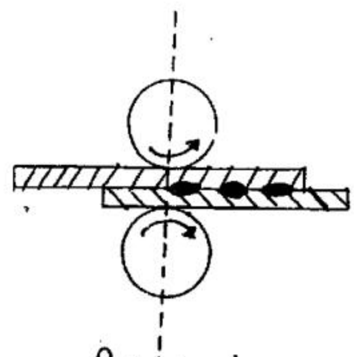
(i) Stitch Welding
(ii) Roll Welding

(i) Stitch Welding: Stitch weld is made by the current on the rollers off and on quickly enough, so that continuous fusion zone made of overlapping nugget is obtained.

(ii) Roll Welding: It is obtained by constant and regular timed interruptions of welding current, which causes individual nuggets to be formed.



Stitch Welding.



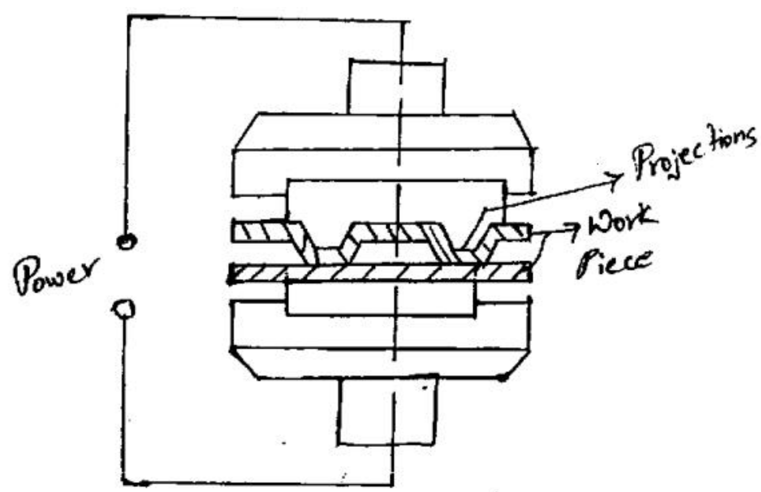
Roll Welding.

Seam welding is used on many types of pressure tight or leak proof tanks for various purposes, exhaust systems, barrels etc…

(c) Projection Welding:

The Resistance Projection Welding process is similar to spot welding except that the current is concentrated at the spots to be welded.

In this welding small projections are raised on one side of the sheet or plate where it is to be welded to another. The projections serve to concentrate the welding heat at these areas and facilitate fusion without the necessity of employing a large current. During the welding process, the heated and softened projections collapse under the pressure of the electrode there by forming the weld. The working principle of projections welding is shown in below figure.



Projection Welding.

Advantages:

(ii) This method of welding gives longer electrode life.

(iii) Outer or top surfaces can be produced with no electrode marks.

Disadvantages:

(i) All projections should be seated in one blow.

(ii) A prior operation is necessary to form the projection.

Applications:

A common use of projection welding is attaching small fasteners, nuts, special blots, studs and similar parts to large components.

(d) Butt Welding:

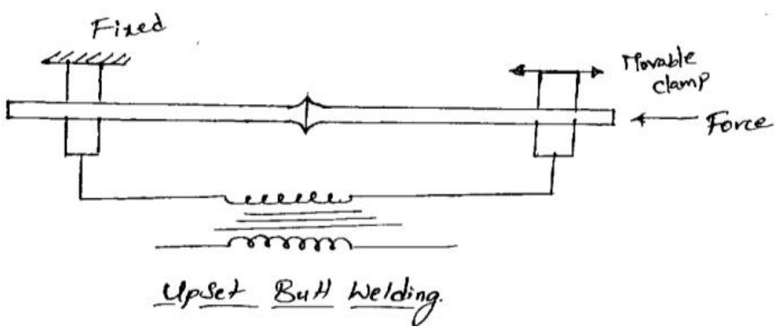
Resistance Butt Welding is used to join the pieces end to end. This process is best suited to rods, pipes and many other parts of uniform cross section.

There are two types of Resistance Butt welding:

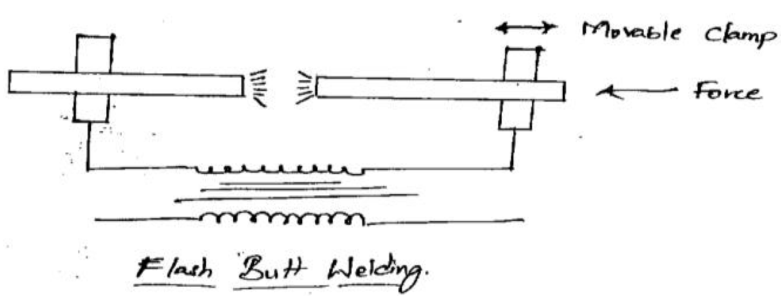
(i) Upset welding

(ii) Flash Welding

(i) Upset Welding: In upset welding, the parts are clamped and brought in solid contact and current is applied so that the heat is generated through the contact area of the parts as illustrated in below figure. At this point, the two parts are pressed together firmly. This action of pressing together is called upsetting. It is used on non-ferrous materials for welding bars, rods, tube formed parts etc…



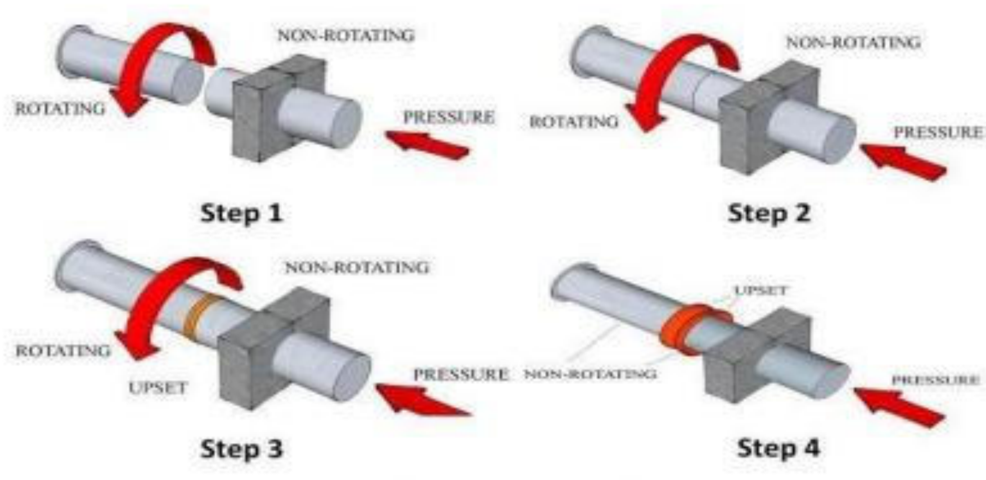
(ii) Flash Welding: Flash welding is similar t upset welding except that the heat is obtained by means of an arc than the simple resistance heating. The two parts are brought together and the power supply is switched on. As the parts moved closer, flashing or arcing raised the temperatures of the parts to a welding temperature. Now power is switched off and the parts are forced together to form a weld.



Friction Welding

Principle: Friction welding works on basic principle of friction. In this welding process, the friction is used to generate heat at the interference surface. This heat is further used to join two work pieces by applying external pressure at the surface of work piece. In this welding process, the friction is applied until the plastic forming temperature is achieved. It is normally 900-1300 degree centigrade for steel. After this heating phase, a uniformly increasing pressure force applied until the both metal work pieces makes a permanent joint. The speed usually in the range of 1500 to 3000 rpm . The pressure to be applied in the range of 40 to 450MPa for a time of 2 to 30 Seconds.This joint is created due to thermo-mechanical treatment at the contact surface. Working: There are many types of friction welding processes which works differently. But all different these processes involves common a working principle which can be summarize as follow.

- First both the work pieces are prepared for smooth square surface. One of them is mounted on a rotor driven chuck and other one remains stationary.
- The rotor allows rotating at high speed thus it makes rotate mounted work piece. A little pressure force is applied on the stationary work piece which permits cleaning the surface by burnishing action.
- Now a high pressure force applied to the stationary work piece which forces it toward rotating work piece and generates a high friction force. This friction generates heat at the contact surface. It is applied until the plastic forming temperature is achieved.
- When the temperature is reached the desire limit, the rotor is stopped and the pressure force is applied increasingly until the whole weld is formed.
- This welding is used to weld those metals and alloys which cannot be welded by other method.



Application: ♣ For welding tubes and shafts. ♣ It is mostly used in aerospace, automobile, marine and oil industries. ♣ Gears, axle tube, valves, drive line etc. components are friction welded. ♣ It is used to replace forging or casting assembly. ♣ Hydraulic piston rod, truck rollers bushes etc. are join by friction welding. ♣ Used in electrical industries for welding copper and aluminum equipment's. ♣ Used in pump for welding pump shaft (stainless steel to carbon steels). ♣ Gear levers, drill bits, connecting rod etc. are welded by friction welding.

Advantages: ♣ It is environment friendly process without generation smoke etc. ♣ Narrow heat affected zone so no change in properties of heat sensitive material. ♣ No filler metal required. ♣ Welding strength is strong in most cases. ♣ Easily automated. ♣ High welding speed. ♣ High efficiency of weld. ♣ Wide variety of metal can be weld by this process.

Disadvantages: ♣ This is mostly used only for round bars of same cross section. ♣ Non-forgeable material cannot be weld. ♣ Preparation of work piece is more critical ♣ High setup cost. ♣ Joint design is limited.

Friction Stir Welding

Friction stir welding **(FSW)**, illustrated in Figure is a solid state welding process in which a rotating tool is fed along the joint line between two work pieces, generating friction heat and mechanically stirring the metal to form the weld seam. The process derives its name from this stirring or mixing action. FSW is distinguished from conventional FRW by the fact that friction heat is generated by a separate wear-resistant tool rather than by the parts themselves. FSW was developed in 1991 at The Welding Institute in Cambridge, UK. The rotating tool is stepped, consisting of a cylindrical shoulder and a smaller probe projecting beneath it. During welding, the shoulder rubs against the top surfaces of the two parts, developing much of the friction heat, while the probe generates additional heat by mechanically mixing the metal along the butt surfaces. The probe has a geometry designed to facilitate the mixing action. The heat produced by the combination of friction.and mixing does not melt the metal but softens it to a highly plastic condition. As the tool is fed forward along the joint, the leading surface of the rotating probe forces the metal around it and into its wake, developing forces that forge the metal into a weld seam. The shoulder serves to constrain the plasticized metal flowing around the probe.

The FSW process is used in the aerospace, automotive, railway, and shipbuilding industries. Typical applications are butt joints on large aluminum parts. Other metals, including steel, copper, and titanium, as well as polymers and composites have also been joined using FSW. Advantages in these applications include (1) good mechanical properties of the weld joint, (2) avoidance of toxic fumes, warping, shielding issues, and other problems associated with arc welding, (3) little distortion or shrinkage, and (4) good weld appearance. Disadvantages include (1) an exit hole is produced when the tool is withdrawn from the work, and (2) heavy-duty clamping of the parts is required

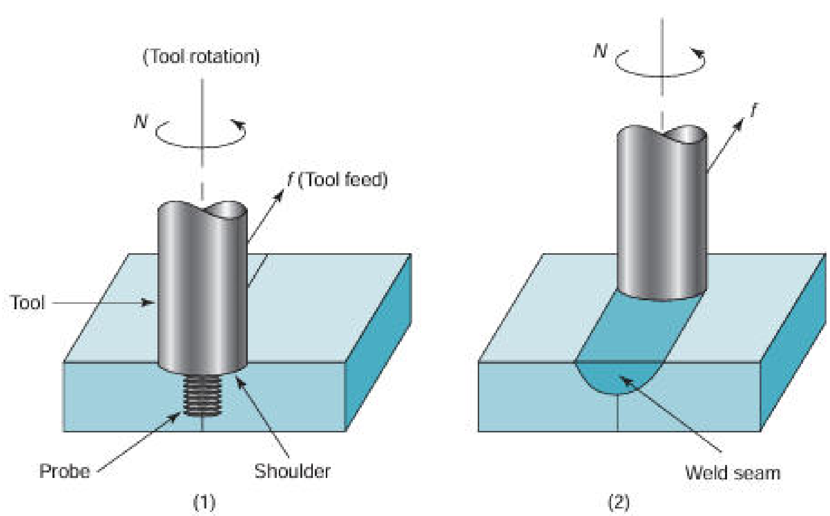


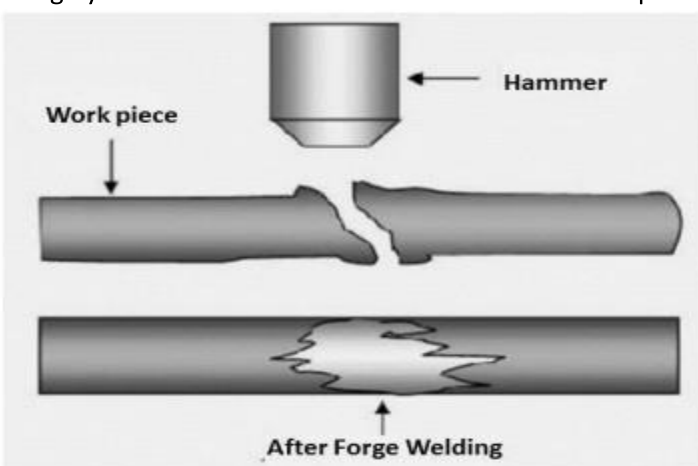
FIGURE Shows the Friction stir welding (FSW): (1) rotating tool just prior to feeding into joint and (2) partially completed weld seam. N ¼tool rotation, f ¼ tool feed.

Forge Welding

Forge Welding Principle As we discussed, forge welding is a solid state welding process in which both the plates are heated quite below its melting temperature. This heating deforms the work pieces plastically. Now a repeated hammering or high pressurize load is applied on these plates together. Due to this high pressure and temperature, inter-molecular diffusion takes place at the interface surface of the plates which make a strong weld joint. This is basic principle of forge welding. One of the basic requirement of this types of welding, is clean interface surface which should be free from oxide or other contaminant particles. To prevent the welding surface from oxidation, flux is used which mixes with the oxide and lower down its melting temperature and viscosity. This allow to flow out the oxide layer during heating and hammering process. The work pieces commonly forge welded and are of wrought iron and steel. The commonly used forge welding processes are : (i) Hammer welding (ii) Die welding, and (iii) Roll welding.

Working:- Forge welding was one of the most applied welding method in ancient time. This is a fundamental welding process of all solid state welding. Its working can be summarized as follow.

- First both the work plates heated together. The heating temperature is about 50 to 90% of its melting temperature. Both the plates are coated with flux.
- Now manual hammering is done by a blacksmith hammer for making a joint. This process is repeated until a proper joint is created.
- For welding large work pieces, mechanical hammering is used which is either driven by electric motor or by using hydraulic mean. Sometime dies are used which provides finished surface.



Application :-

- It is used to join steel or iron.
- It is used to manufacture gates, prison cells etc.
- It is widely used in cookware.

- It was used to join boiler plates before introduction of other welding process.
- It was used to weld weapon like sword etc.
- Used to weld shotgun barrels.

Advantages:-

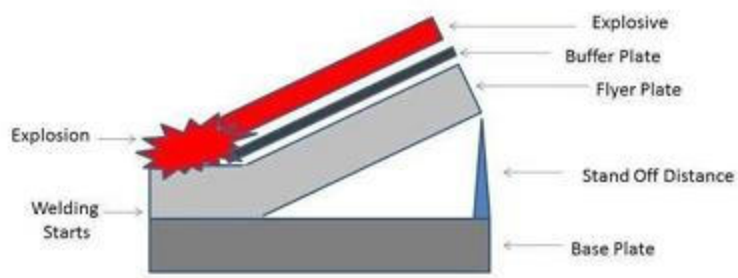
- It is simple and easy.
- It does not require any costly equipment for weld small pieces.
- It can weld both similar and dissimilar metals.
- Properties of weld joint is similar to base material.
- No filler material required.

Disadvantages:-

- Only small objects can be weld. Larger objects required large press and heating furnaces, which are not economical.
- High skill required because excessive hammering can damage the welding plates.
- High Welding defects involve.
- It cannot use as mass production.
- Mostly suitable for iron and steel.
- It is a slow welding process.

Explosive Welding

Explosive Welding: Principle: This welding process works on basic principle of metallurgical bonding. In this process, a controlled detonation of explosive is used on the welding surface. This explosion generates a high pressure force, which deform the work plates plastically at the interface. This deformation forms a metallurgical bond between these plates. This metallurgical bond is stronger than the parent materials. The detonation process occurs for a very short period of time which cannot damage the parent material. This is basic principle of explosion welding. This welding is highly depend on welding parameters like standoff distance, velocity of detonation, surface preparation, explosive etc. This welding is capable to join large area due to high energy available in explosive.



Explosion Welding

Basic terminology:

Base Plate: This is one of the welding plate which is kept stationary on a avail. It involves a backer which supports the base plate and minimizes the distortion during the explosion.

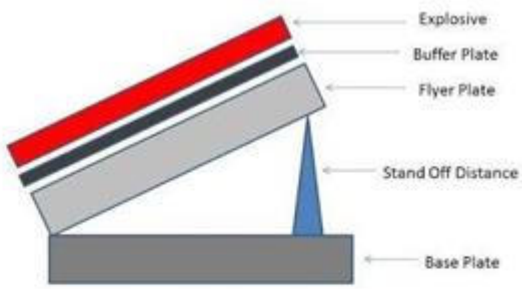
Flyer Plate: This is another welding plate which is going to be weld on base plate. It has lowest density and tensile yield strength compare to base plate. It is situated parallel or at an angle on the base plate. **Buffer Plate:** Buffer plate is situated on the flyer plate. This plate is used to minimize the effect or explosion on upper surface of flyer plate. This protects the flyer plate from any damage due to explosion. **Standoff distance:** Stand-off distance plays a vital role in explosion welding. It is distance between flyer plate and base plate. Generally it is taken double of thickness of flyer plate for thin plates and equal to thickness of flyer plate for thick plates.

Explosive: Explosive is placed over the flyer plate. This explosive is situated in a box structure. This box placed on the flyer plate. Mostly RDX, TNT, Lead azide, PETN etc. used as explosive.

Velocity of detonation: It is the rate at which the explosive detonate. This velocity should be kept less than 120% of sonic velocity. It is directly proportional to explosive type and its density.

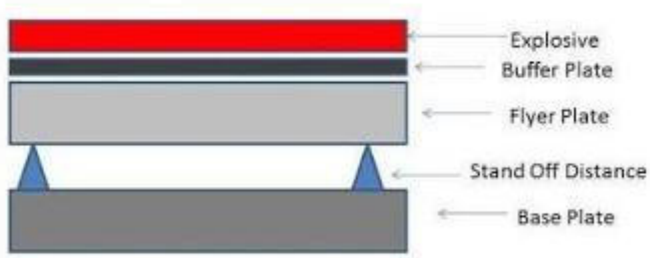
Types: This welding can be classified into two types according to the setup configuration.

Oblique Explosion Welding: In this type of welding process base plate is fixed on an anvil and filler plate makes an angle with the base plate. This welding configuration is used to join thin and small plates.



Oblique Explosion Welding

Parallel Explosion Welding: As the name implies, in this welding configuration filler plate is parallel to the base plate. There is some standoff distance between base plate and flyer plate. This configuration is used to weld thick and large plates.



Parallel Explosion Welding

Working: We have discussed about working principle of explosion welding. Its working can be summarized as follow. First both the flyer plate and the base plate interface surface are cleaned and prepared for good weld. Now the base plate fixed on the avail and the flyer plate place at the top surface of it at a pre- define distance (stand-off distance). The flyer plate may be inclined or parallel according to the welding configuration. The buffer plate is set over the flyer plate. This plate protects the upper surface of flyer place from damage due to high impact force of explosion. The prepared explosive is place into a box of same size of welding surface. This box is placed over buffer plate. There is a detonator at one side of the explosive. This is used to start explosion. Now the detonator ignited the explosive which create a high pressure wave. These waves deforms the interface surface plastically and form a metallurgical bond between base plate and flyer plate. This bond is stronger than parent material.

Application:

Used to weld large structure sheets of aluminum to stainless steel. It is used to weld cylindrical component like pipe, concentric cylinder, tube etc.   Weld clad sheet with steel in a heat exchanger. Join dissimilar metals which cannot be weld by other welding process. For joining cooling fan etc.

Advantages and Disadvantages:

Advantages: It can join both similar and dissimilar material. Simple in operation and handling. Large surface can be weld in single pass. High metal joining rate. Mostly time is used in preparation of the welding. It does not effect on properties of welding material. It is solid state process so does not involve any filler material, flux etc.

Disadvantages: It can weld only ductile metal with high toughness. It creates a large noise which produces noise Pollution. Welding is highly depends on process parameters. Higher safety precautions involved due to explosive. Designs of joints are limited.

Thermit Welding:

This is a casting cum welding process.This is a type of thermo chemical welding process. Thermit welding is “A group of welding processes where in coalescence is produced by heating with superheated liquid metal and slag resulting from a chemical reaction between a metal oxide and aluminium with or with out the application of pressure”. This process is also called as “Exothermic Welding”.

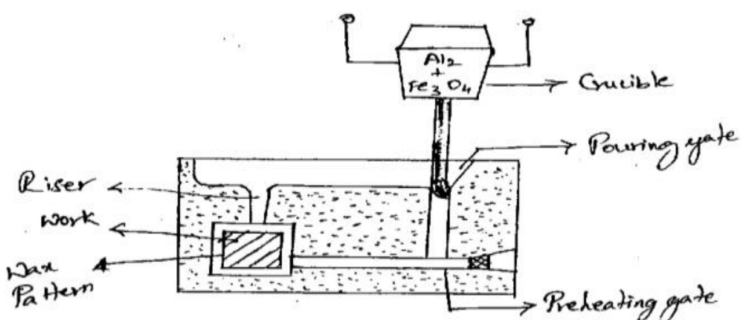
The process is basically a fusion welding process in which welding is effected by pouring super heated steel around the parts to be welded. In this process, neither arc is produced to the parts nor flame is used. In this an exothermic chemical reaction is utilized for developing high temperature.

A mixture of finely divided aluminium and iron oxide called ‘Thermit mixture’ is kept in a crucible hanging over the mould. The Thermit mixture is ignited using a magnesium ribbon or highly inflammable powder having barium peroxide. The reaction takes place about 30 seconds only and heat is liberated which is twice the temperature of melting point of steel (3000 ^{0}C) . Aluminum has greater affinity to react with oxygen; it reacts with ferric oxide to liberate pure iron and slag of aluminum oxide. Aluminum oxide floats on top of molten metal pool in the form of slag and pure iron (steel) settled below, because of large difference in densities.The mixture consists 3 parts of Iron oxide and 1 part Aluminium.The following reaction takes place as per equation:

$$8Al + 3F3O4 \text{ ------------->} 4Al2O3 + 9Fe + \text{heat}$$

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 figure shows the method of preparing the mould. The two pieces to be joined are cleaned and a gap is left between them. Then wax is poured on the joint and a wax pattern is formed. Moulding sand is rammed around the wax pattern and pouring, heating and risering gates are cut. A gas flame is used melt the wax pattern and at the same time it preheats the parts to be welded. Then the preheating gate is plugged with sand. When the ends of the pieces to be welded reach the welding heat, they are forced together by means of clamps to make a pressure butt weld. The mould is then removed and the Thermit iron and slag are knocked off from around the weld.



Thermit Welding.

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.

Limitations:

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

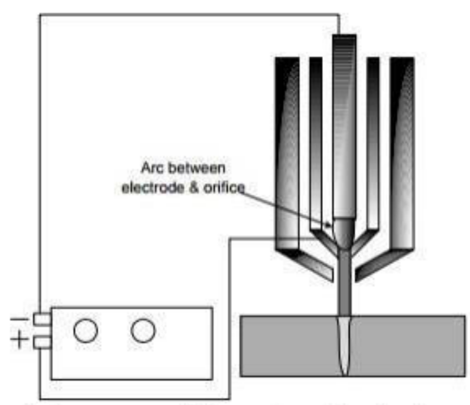
Applications:

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

Plasma Arc Cutting:

The plasma means an ionized gas which contains charged particles like ions and electrons .It conducts electricity, magnetism .The plasma arc welding (PAW) can be considered as an advanced version of TIG welding. Like TIGW, PAW also uses the tungsten electrode and inert gases for shielding of the molten metal. Low velocity plasma and diffused arc is generated in the TIG welding while in case of PAW very high velocity and coherent plasma is generated. Large surface area of the arc exposed to ambient air and base metal in case of TIG welding causes greater heat losses than PAW and lowers the energy density. Therefore, TIG arc burns at temperature lower than plasma arc.

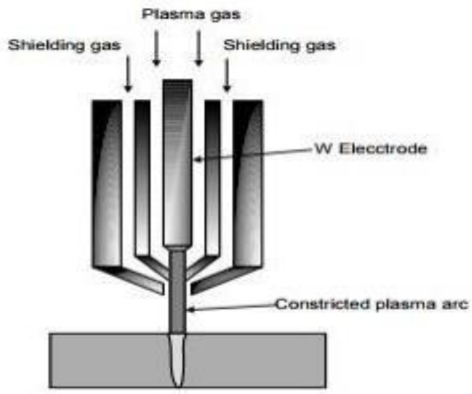
Principle of PAW: In plasma arc welding, arc is forced to pass through nozzle (water cooled copper) which causes the constriction of the arc (Fig.1). Constriction of arc results in (a) reduction in cross-sectional area of arc, (b) increases penetration (d) increases energy density and (c) increases to velocity of plasma approaching to the sound velocity and temperature to about 25000^0 C. these factors together make PAW, a high energy density and low heat input welding process therefore; it poses fewer which in turn reduces problems associated with weld thermal cycle.



Schematic of plasma arc welding system showing important components (Fig.1)

Constriction of arc increases the penetration and reduces the width of weld bead. Energy associated with plasma depends on plasma current, size of nozzle, plasma gas (Fig.2). A coherent, calumniated and stiff plasma is formed due to constriction therefore it doesn’t get deflected and diffused. Hence, heat is transferred to the base metal over a very small area which in turns results in high energy density and deep of penetration and small width of the weld pool / key hole / cut.

Energy density and penetration capability of plasma jet is determined by the various process parameters namely plasma current, nozzle orifice diameter and shape, plasma forming gas (Air, He, Ar) and flow rate of plasma carrying.



Schematic of constriction of arc in PAW (Fig.2)

Types of PAW:- Plasma generated due to the arc between the non-consumable electrode and workpiece is called **transferred plasma** whereasthat due to arc between non-consumable electrode and nozzle is called **non-transferred plasma**. Non-transferred plasma system to a large extent becomes independent of nozzle to work piece distance

following variants of PAW has been developed such as: Micro-plasma (< 15 Amperes) • Melt-in mode (15–400 Amperes) plasma arc • Keyhole mode (>400 Amperes) plasma arc

Advantages of PAW:-

With regard to energy density, PAW stands between GTAW/GMAW and EBW/LBW accordingly it can be used using melt-in mode and key-hole mode. Melt-in mode results in greater heat input and higher width to depth of weld ratio than key-hole mode. Higher energy density associated with PAW than GTAW produces narrow heat affected zone and lowers residual stress and distortion related problems. High depth to width ratio of weld produced by PAW reduces the angular distortion. It generally uses about one tenth of welding current as compared to GTAW for same thickness therefore it can be effectively applied for joining of the thin sheets. Further, nontransferred plasma offers flexibility of variation in standoff distance between nozzle and workpiece without extinction of the arc. Limitation of PA

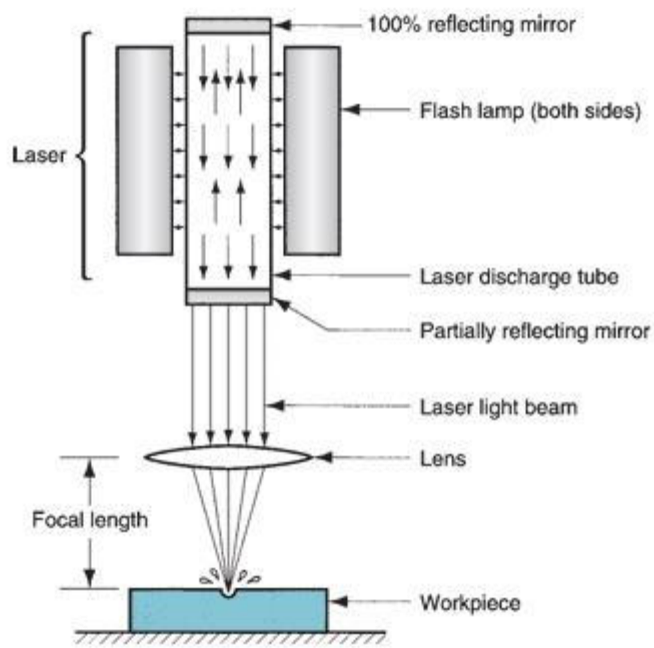
Limitation of PAW:- Infrared and ultra-violet rays generated during the PA welding are found harmful to human being. High noise (100dB) associated with PAW is another undesirable factor.

Laser-Beam Welding

Laser-beam welding (LBW)is a fusion-welding process in which coalescence is achieved by the energy of a highly concentrated, coherent light beam focused on the joint to be welded. The term laser is an acronym for light amplification by stimulated emission of radiation. This same technology is used for laser-beam machining . LBW is normally performed with shielding gases (e.g.,helium, argon, nitrogen, and carbon dioxide) to prevent oxidation. Filler metal is not usually added.

Lasers are being used for a variety of industrial applications, including heat treatment , welding, measurement, as well as scribing, cutting, and drilling.A laser is an optical transducer that converts electrical energy into a highly coherent light beam. A laser light beam has several properties that distinguish it from other forms of light.

LBW produces welds of high quality, deep penetration, and narrow heat-affected zone. These features are similar to those achieved in electron-beam welding, and the two processes are often compared. There are several advantages of LBW over EBW: no vacuum chamber is required, no X-rays are emitted, and laser beams can be focused and directed by optical lenses and mirrors. On the other hand, LBW does not possess the capability for the deep welds and high depth-to-width ratios of EBW. Maximum depth in laser welding is about 19 mm (0.75 in), whereas EBW can be used for weld depths of 50 mm (2 in) or more; and the depth-to-width ratios in LBW are typically limited to around 5:1.Because of the highly concentrated energy in the small area of the laser beam, the process is often used to join small parts.



How it works:

Heat Source:A laser beam, generated by a solid-state laser, fiber laser, or CO_2 laser, is focused onto the joint between the materials.

Melting: The concentrated laser energy melts the material at the joint, creating a molten pool.

Fusion: As the laser beam moves along the joint, the molten material solidifies, fusing the two pieces together.

Precision: Laser welding offers high precision due to the focused beam and can be used for both keyhole welding (deeper welds) and heat conduction welding (shallower welds).

Automation: Laser welding is often automated using robots, allowing for high-volume production and consistent quality.

Shielding: While often performed in atmospheric conditions, reactive materials may require shielding with inert gas to prevent contamination.

Advantages of Laser Welding

1. Small Heat Affected Zone (HAZ)
2. Good Mechanical Properties
3. Ability to Weld Small Components
4. Fast Process
5. Easy to Automate
6. High-Quality Welds

Disadvantages of Laser Welding

1. Laser Safety Needs to be Ensured
2. Safety is Complicated with Large Parts
3. High Initial Investment
4. Reflective Materials

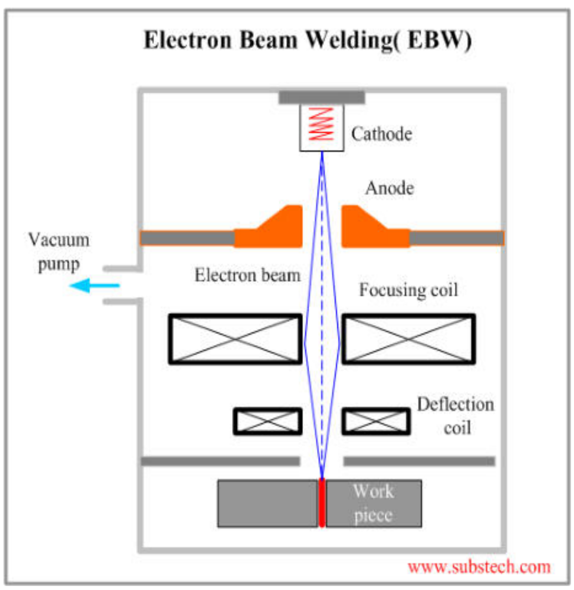
ELECTRON BEAM WELDING

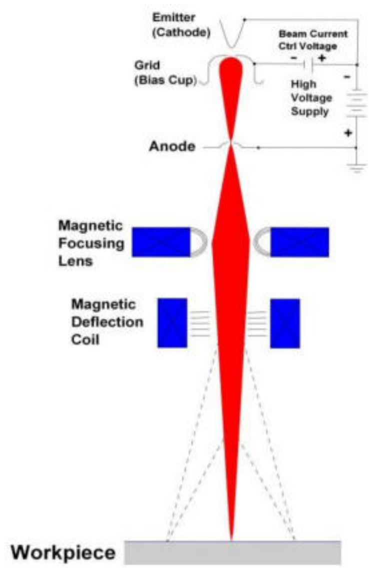
Electron Beam Welding (EBW) is a fusion welding in which coalescence is produced by heating the work piece due to impingement of the concentrated electron beam of high kinetic energy on the work piece. As the electron beam impinges the work-piece, kinetic energy of the electron beams converts into thermal energy resulting in melting and even evaporation of the work material. Principles: In general, electron beam welding process is carried out in vacuum. In this process, electrons are emitted from the heated filament called electrode. These electrons are accelerated by applying high potential difference (30 kV to 175 kV) between cathode and anode. The higher the potential difference, the higher would be the acceleration of the electrons. The electrons get the speed in the range of 50,000 to 200,000 km/s. The electron beam is focused by means of electromagnetic lenses. When this high kinetic energy electron beam strikes on the work-piece, high heat is generated on the work piece resulting in melting of the work material. Molten metal fills into the gap between parts to be joined and subsequently it gets solidified and forms the weld joint.

EBW Equipment: An EBW set up consists of the following major equipment:

i) Electron gun ii) Power supply iii) Vacuum Chamber iv) Work piece handling device.

<u>I)Electron -Gun</u>: An electron gun generates, accelerates and aligns the electron beam in required direction and spots onto the work piece. The gun is of two types:(I) Self accelerated (ii) work accelerated. The work accelerated gun accelerates the electrons by providing potential difference between the work-piece and cathode. In the self accelerate gun,the electrons are accelerated by applying potential difference between cathode and anode. The anode and cathode are enclosed within the gun itself. The control of electron density is better in this type of electron gun.





A schematic of an electron beam gun used in EBW is shown in Fig.

Major parts of an electron gun are briefly introduced in the following sections.

Emitter/Filament: It generates t he electrons on direct or indirect heating. Anode: It is a positively charged element near cathode, across which the high voltage is applied to accelerate the electrons. The potential difference for high voltage equipment ranges from 70-150 kV and for low voltage equipment from 15-30 kV.

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

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

II)Electron gun power supply: It consists of mainly the high voltage DC power supply source, emitter power supply source, electromagnetic lens and deflection coil source. In the high voltage DC power supply source the required load varies within 3-100 kW. It provides power supply for acceleration of the electrons. The potential difference for high voltage equipment ranges from 70-150 kV and for low voltage equipment 15-30 kV. The current level ranges from 50-1000 mA. In emitter power supply, AC or DC current is required to heat the filament for emission of electrons. However DC current is preferred as it affects the direction of the beam. The amount of current depends upon the diameter and type of the filament. The current and voltage varies from 25-70 A and 5-30 V respectively. The power to the electromagnetic lens and deflection coil is supplied through a solid state device.

III)Vacuum Chamber: In the vacuum chamber pressure is reduced by the vacuum pump. It consists of a roughing mechanical pump and a diffusion pump. The pressure ranges from 1 bar for open atmosphere to 10^{-2} to 10^{-3} milli bar for partial vacuum and 10^{-4} to 10^{-5} milli bar for hard vacuum. As the extent of vacuum increases, the scattering of the electrons in the beam increases. It causes the increase in penetration.

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

Advantages of EBW:

- High penetration to width can be obtained, which is difficult with other welding processes.
- High welding speed is obtained and Material of high melting temperature can be welded.
- Superior weld quality due to welding in vacuum.
- High precision of the welding is obtained.
- Distortion is less due to less heat affected zone.
- Dissimilar materials can be welded.
- Low operating cost and Cleaning cost is negligible.
- Reactive materials like beryllium, titanium etc. can be welded.
- Materials of high melting point like columbium, tungsten etc. can be welded. Inaccessible joints can be made.
- Very wide range of sheet thickness can be joined (0.025 mm to 100 mm)

Disadvantages of EBW:

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

Applications of EBW:

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

Soldering

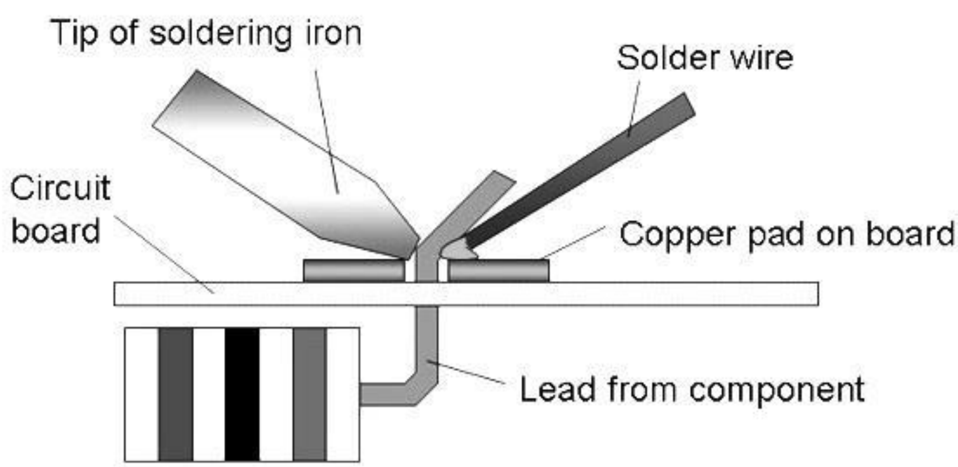
It is a method of joining two pieces of metal by means of a fusible alloy called solder, applied in the molten stage. The melting point of the filler metal is below 420°C. The solder is usually an alloy of Lead and Tin, Lead and Silver. A suitable flux is used in soldering to prevent oxidation of the joint. Fluxes are available in the form of powder, past or liquid.

A good soldering process involves: (i) Pre Cleaning (ii) Fluxing (iii) Heating

(i) **Pre-Cleaning:** Cleaning is done to provide chemically clean surface to obtain proper bond and may be done by means of acid pickling, solvent cleaning etc…

(ii) **Fluxing:** Fluxing is done to remove the oxides from joint surface and to prevent the filler metal from oxidizing. Fluxes are in form of powder, paste or liquid.

(iii) **Heating:** The most common source of heating is the electrical resistance heating with soldering iron. Other methods of soldering are disoldering, wave soldering, oven soldering, induction soldering and infra red soldering.



Soldering is done in the following ways:

(i) **Hand Soldering:** The soldering iron is heated by keeping in a furnace or by means of electrically. The joint is heated by soldering iron and solder is applied which melts and flows the joint by capillary action.

(ii) **Dip Soldering:** In dip soldering, the parts to be soldered are first cleaned and dipped in flux bath and finally dipped in the molten solder bath and lifted after the soldering is completed.

(iii) **Wave Soldering:** In this method, parts are not dipped into the solder tank, but a wave is generated in the tank so that the solder comes up and makes necessary joint. This is used in electronic printed circuit board, PCB.

Brazing

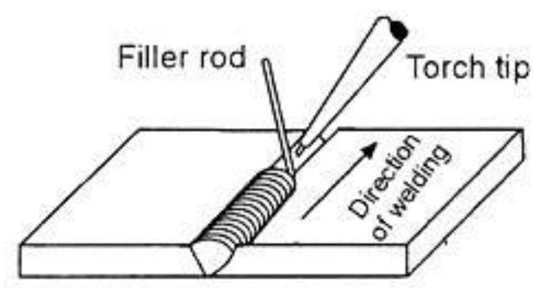
It is a process of joining two pieces of metals in which a non-ferrous filler metal or alloy is introduced between the pieces to be joined. The melting point of the filler metal is above 420°C but lower than the melting temperature of parent metal. The filler metal is distributed between surfaces by capillary action. The copper base alloys and silver base alloys are commonly used as filler metal in brazing. A suitable flux such as borax is used.

Steps in Brazing:

(i) The surfaces to be joined are cleaned and subsequently rinsed and dried and fitted closely together.

(ii) A flux is applied to all surfaces where the filler metal is to flow.

(iii) After that, the joint is heated to the proper brazing temperature. Solid filler metal may be replaced on the metal pieces and thus melted as the metal pieces are heated, or it may be applied to the metal pieces after the brazing temperature is reached. Only a small amount of filler metals needed to fill the joint completely.



Fluxes: Fluxes are used to prevent oxidation of the base metal and the filler metal during brazing, form a fusible slag of any oxides which may be present or formed, and promote the free flowing of the filler metal by capillary attraction.

Common fluxes are: compositions of borates, fluorides, chlorides, borax and boric acid in various proportions according to specific requirements. Fluxes are used in form of powder, paste or slurry. Borax is used as fused borax, because water in it will cause bubbling during heating.

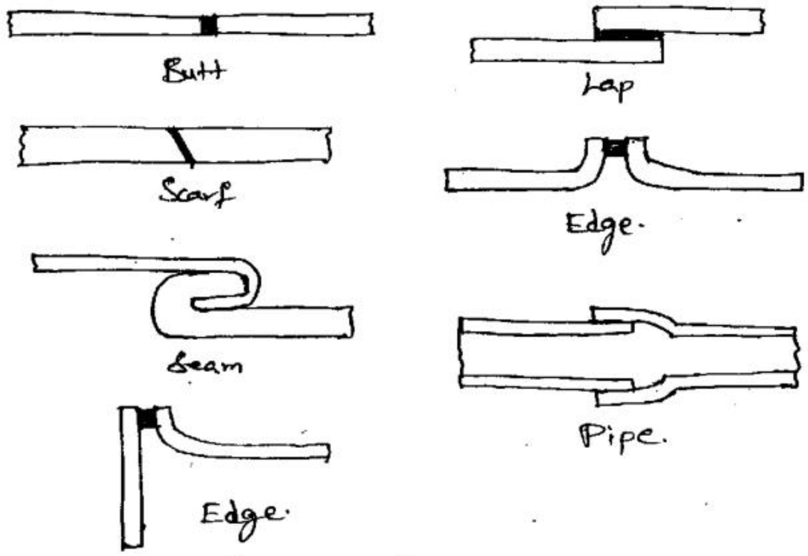
Filler Materials: The filler metal or braze metal must:

1. Wet the surfaces of the base metals at the joint.
2. Have high fluidity to penetrate crevices. For capillary attraction to exist, the clearance between the parts being joined must be quite small, other wise the filler metal would run out of the joint. A wider clearance in a joint leads to its reduced strength.
3. Preferably have a narrow melting range.
4. Not lead to galvanic corrosion during service.

The filler metal is applied in the form of wire, strip, performs, powder or paste to the joint area as noted above in step (iii) under 'steps in brazing'. Alternatively the filler metals pre applied to the surface of one of the contacting parts as a coating or cladding, often by rolling, electrolyte deposition or hot dipping.

Brazing Joints:

The following are the different type of Brazing joints which are regularly used at different applications.



Brazing Joints

Brazing Methods:

The selection of brazing method is based on the size and shape of the components to be joined, the base metal and the production rate.

(a) Torch Brazing: Torch brazing is the most versatile method. It is similar to oxy-acetylene welding. In this process, reducing flame is used to heat the joint area. A flux is applied and as soon as it melts, the filler metal is hand fed to the joint area. When the filler metal melts, it flows into the clearance between the base metal components by capillary action. This method finds applications in fabrication industry and repair work.

(b) Furnace Brazing: In this method the atmosphere of the furnace is controlled to prevent oxidation by hydrogen, dissociated ammonia, nitrogen or any gas, thus allowing the molten brazing metal to flow smoothly and uniformly around the joint.

(c) Induction Brazing: In these metals, the metals to be welded are surrounded by metallic coils through which high frequency current is passed. This induces eddy current which produces localized heating. The parts to be brazed are pre-fluxed and the brazing is placed in the joint before switching on the current.

(d) Dip Brazing: In dip brazing, the parts to be brazed are dipped into a bath of molten filler metal covered by a layer of molten flux. Surface not required to be coated with the brazing alloy must be protected by molasses or by lamp black. This process is used for small parts.

(e) Salt Bath Brazing: The source of heating in salt bath brazing is a molten bath of fluoride and chloride salts. This salt bath removes thin oxide films from the metals to be joined. The filler metal replaced in the joint area and is also sometimes cladded before dipped in the salt bath.

(f) Resistance Brazing: It is similar to spot welding. Electrical resistance is used for joining parts. The parts to be joined are placed between the electrodes of the welding machine with the filler metal and flux preloaded at the joint area. Current is then applied until the filler metal melts and flows around the joint.

Advantages:

(i) It gives a stronger joint than soldering
(ii) Joint is clean
(iii) Any metal can be brazed
(iv) Less distortion and residual stress
(v) The process can be done more quickly and more economically

Limitations:

(i) Limited size of parts.
(ii) Machining of the joint edges for getting the desired fit is costly.
(iii) Degree of skill required to perform the brazing operations is high.

Applications:

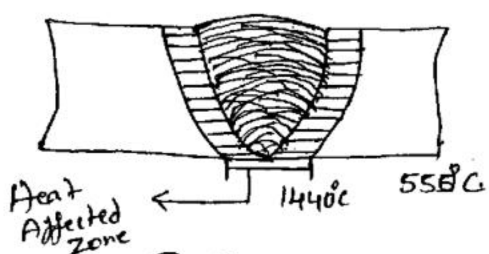
Brazing is used for the assembly of pipe fittings, carbide tips to tool shank, radiators, heat exchangers and the repair of castings.

Uses of Brazing: Assembly of pipes to fittings, carbide tips to tools, radiators, heat exchangers, electrical parts and repair of castings. Leak-tight joints for pressurized and vacuum systems are readily joined by brazing.

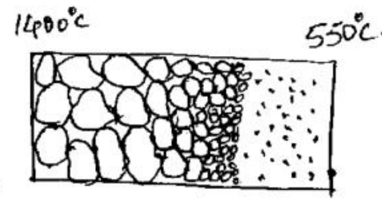
Heat Affected Zone (HAZ):

Heat Affected Zone is the zone where in the base metal is metallurgically affected by the heat of welding, but is not melted.

Heat affected zone is the zone where the base metal is affected metallurgically due to the heat of welding. It is the region closed to the weld, where large thermal fluctuations are encountered due to the fusion welding. This leads to changes in mechanical properties and structure.



(a) Fusion Welding.



(b) Grain Growth in Heat Affected Zone.

Heat Affected Zone contains three regions.

(a) The grain growth zone (1150°C)
(b) The grain refined zone (1150°C to 950°C)
(c) The transition zone (950°C to 750°C)

- **(a) The grain growth zone:** It is immediately adjacent to the fusion zone. In this zone, parent metal has been heated to a temperature above upper critical temperature. This resulted in grain growth.
- **(b) The grain refined zone:** Adjacent to the grain growth zone is the grain refined zone. In this zone, parent metal has been heated just above the transition temperature where grain refinement is completed.
- **(c) The transition zone:** In this zone, base metal temperature is below the transition temperature.

Welding Defects

Welding Defects can be defined as the irregularities formed in the given weld metal due to wrong welding process or incorrect welding patterns, etc. The defect may differ from the desired weld bead shape, size, and intended quality. Welding defects may occur either outside or inside the weld metal. Some of the defects may be allowed if the defects are under permissible limits but other defects such as cracks are never accepted.

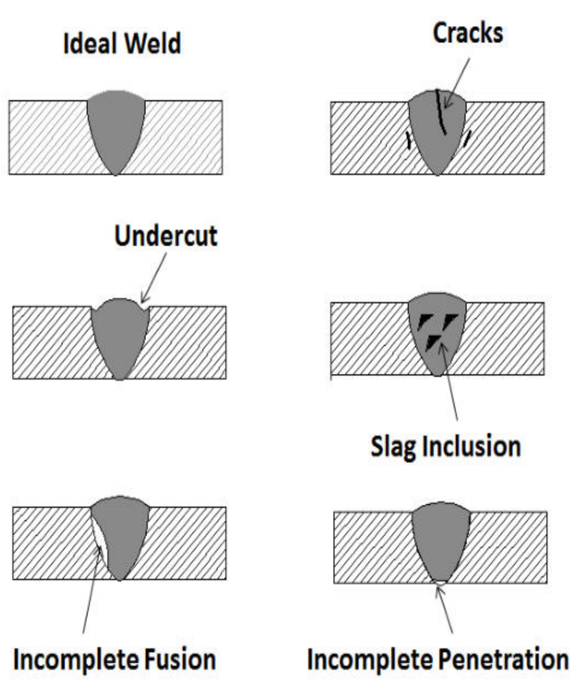
Welding defects can be classified into two types as external and internal defects:

External Welding Defects:

1. Weld Crack
2. Undercut
3. Spatter
4. Porosity
5. Overlap
6. Crater

Internal Welding Defects:

1. Slag Inclusion
2. Incomplete Fusion
3. Necklace cracking
4. Incompletely filled groove or Incomplete penetration

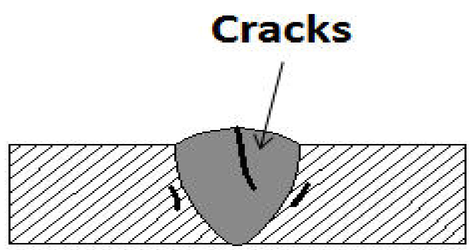


External Welding Defects

The various types of external defects with their causes and remedies are listed below:

1. Weld Crack

This is the most unwanted defect of all the other welding defects. Welding cracks can be present at the surface, inside of the weld material or at the heat affected zones.



Crack can also appear at different temperatures:

Hot Crack – It is more prominent during crystallization of weld joints where the temperature can rise more than 10,000-degree Celsius.

Cold Crack – This type of crack occurs at the end of the welding process where the temperature is quite low. Sometimes cold crack is visible several hours after welding or even after few days.

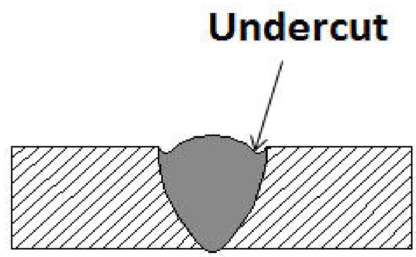
Causes Of Weld Crack:

1. Poor ductility of the given base metal.
2. The presence of residual stress can cause a crack on the weld metal.
3. The rigidity of the joint which makes it difficult to expand or contract the metals.
4. If there is high content on sulfur and carbon then also the cracks may appear.
5. Using hydrogen as a shielding gas while welding ferrous materials.

Remedies for Weld crack:

1. Using appropriate materials may decrease the chances of crack.
2. Preheating the weld and reducing the cooling speed joint helps in reducing crack.
3. Reduce the gap between the weld joints by using reasonable weld joints.
4. While welding releases the clamping force slowly which increases fill to capacity of welding material.

2. Undercut



When the base of metal melts away from the weld zone, then a groove is formed in the shape of a notch, then this type of defect is known as Undercut. It reduces the fatigue strength of the joint.

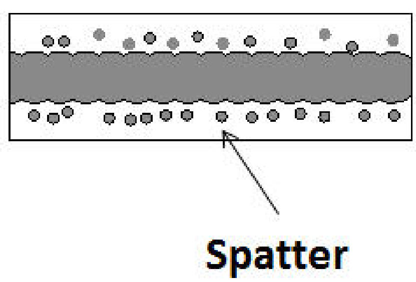
Causes of Undercut:

1. If the arc voltage is very high then this defect may occur.
2. If we use the wrong electrode or if the angle of the electrode is wrong, then also the defect may form.
3. Using a large electrode is also not advisable.
4. High electrode speed is also one of the reasons for this defect.

Remedies for Undercut:

1. Reduce the arc length or lower the arc voltage.
2. Keep the electrode angle from 30 to 45 degree with the standing leg.
3. The diameter of the electrode should be small.
4. Reduce the travel speed of the electrode.

3. Spatter



When some metal drops are expelled from the weld and remain stuck to the surface, then this defect is known as Spatter.

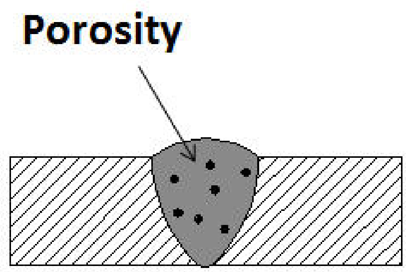
Causes Of Spatter:

1. High Welding current can cause this defect.
2. The longer the arc the more chances of getting this defect.
3. Incorrect polarity.
4. Improper gas shielded may also cause this defect.

Remedies for Spatter:

1. Reducing the arc length and welding current
2. Using the right polarity and according to the conditions of the welding.
3. Increasing the plate angle and using proper gas shielding.

4. Porosity



Porosity in the condition in which the gas or small bubbles gets trapped in the welded zone.

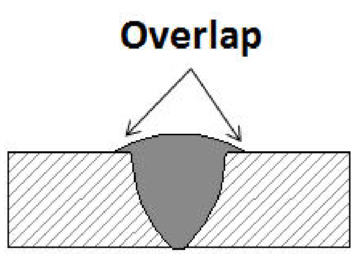
Causes of Porosity:

1. It occurs when the electrode is not coated properly.
2. Using a longer arc may also increase its chances.
3. Increased welding currents.
4. Rust or oil on the welding surface.

Remedies for porosity:

1. Proper selection of the electrode.
2. Decreasing the welding current.
3. Using smaller arc and slowing the process to allow the gases to escape.
4. Remove rust or oil from the surface and use a proper technique.

5. Overlap



When the weld face extends beyond the weld toe, then this defect occurs. In this condition the weld metal rolls and forms an angle less than 90 degrees.

Causes of Overlap:

1. Improper welding technique.
2. By using large electrodes this defect may occur.
3. High welding current

Remedies for Overlap:

1. Using a proper technique for welding.
2. Use small electrode.
3. Less welding current.

6. Crater

It occurs when the crater is not filled before the arc is broken, which causes the outer edges to cool faster than the crater. This causes a stress and then crack is formed.

Causes of the crater:

1. Incorrect torch angle.
2. Use of large electrode:
3. Improper welding technique

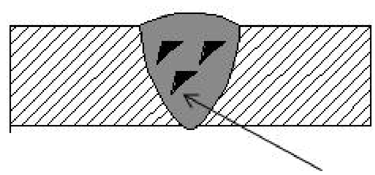
Remedies for crater:

1. Using a proper torch angle may reduce the stress on the metal
2. Using a small electrode may also decrease the crater.
3. Use a proper technique.

Internal Welding Defects

The various types of internal welding defects with their causes and remedies are listed below:

1. Slag Inclusion



Slag inclusion

If there is any slag in the weld, then it affects the toughness and metal weldability of the given material. This decreases the structural performance of the weld material. Slag is formed on the surface of the weld or between the welding turns.

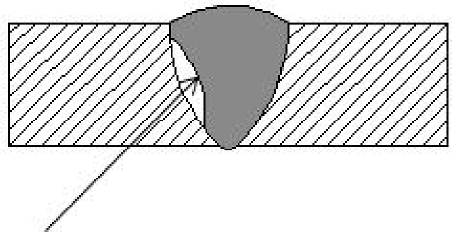
Causes of Slag:

1. Slag is formed if the welding current density is very small, as it does not provide the required amount of heat for melting the metal surface.
2. If the welding speed is too fast then also slag may occur.
3. If the edge of the weld surface is not cleaned properly then also slag may form.
4. Improper welding angle and travel rate of welding rod.

Remedies for Slag Inclusion:

1. Increase the current density
2. Adjust the welding speed so that the slag and weld pool do not mix with each other.
3. Clean the weld edges and remove the slags of previous weld layers
4. Have a proper electrode angle and travel rate.

2. Incomplete Fusion



Incomplete Fusion

Causes of Incomplete fusion:

1. It occurs because of the low heat input.
2. When the weld pool is very large and runs ahead of the arc.
3. When the angle of the joint is too low.
4. Incorrect electrode and torch angle may also lead to incomplete fusion.
5. Unproper bead position.

Remedies for Incomplete Fusion:

1. Increasing the welding current and decreasing the travel speed helps in removing the chances of incomplete fusion.
2. Reducing the deposition rate.
3. Increasing the joint angle.
4. Try to position the electrode and torch angle properly so that the edges of the plate melt away.
5. Positioning the bead properly so that the sharp edges with other beads can be avoided.

3. Necklace Cracking

It occurs in the use of electron beam welding where the weld does not penetrate properly. Therefore, the molten metal does not flow into the cavity and results in a cracking known as "Necklace Cracking".

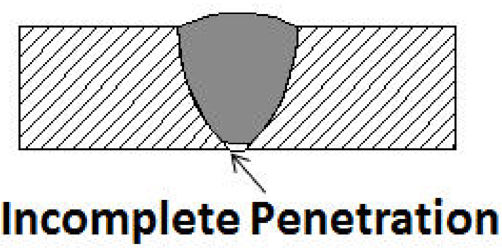
Causes of Necklace Cracking:

1. Improper welding technique.
2. It occurs in materials such as nickel base alloys, stainless steel, carbon steels and Tin alloys.
3. Using high speed of electron beam welding

Remedies for Necklace Cracking:

1. Using a proper welding technique reduce the chances of necklace cracking.
2. Using proper materials for welding.
3. Using a constant speed during the welding process.
4. Improper welding technique

4. Incompletely Filled Groove or Incomplete Penetration



These defects occur only in the butt welds where the groove of the metal is not filled completely. It is also called as incomplete penetration defect.

Causes of an Incomplete filled groove are:

1. Less deposition of the weld metal
2. Use of improper size of the electrode
3. Improper welding technique

Remedies for Incomplete filled groove are:

1. More deposition of the weld metal.
2. Use a proper size of the electrode.
3. By using a proper welding technique.

Testing and Inspection of Welded Joints

Testing and inspection of welded joints is done on the same lines as for castings. The tests fall under two categories: Destructive testing and Non-destructive testing.

Destructive Testing: These tests are done on a sample to improve the design of the weld, welding technique etc. and to know the mechanical properties of the weldment. These mechanical tests included: Tensile test, Bend test, Impact strength test, Hardness test and relative elongation test. The shape and size of the test specimen are selected to comply with state standards.

Non – Destructive Testing (NDT): The tests under this category include:

1. Visual Inspection: Visual Inspection of the weld and checking of its dimensions can reveal: shape of profile, uniformity of surface, undercuts of surface, undercuts, surface cavities and slag inclusions, cracks, porosity, unfilled craters etc.
2. Hydraulic tests (pressure tests) are applied to weldments that are to operate under pressure.
3. Air pressure tests are done to check the air tightness of the work.

The other NDT include:

→ Radiographic inspection of the weld (X-ray and gama-ray testing) will reveal such defects as porosity, blowholes, cracks, poor fusion and slag inclusion.

→ Fluorescent penetrant inspection to reveal fine surface cracks.

→ Magnetic inspection reveals fine cracks and pores in the weld.

→ Ammonia penetrant test: This is a leak test. The welded vessel is filled with compressed air to which 1% ammonia has been added. The welded joint is then covered with paper impregnated with a 5% solution of mercuric nitrate. Black spots appear on the paper in case of leakage.

Comparison among Welding, Brazing and Soldering:

Welding	Soldering	Brazing
1. In welding process fusion is obtained by heat and or pressure.	1. In Soldering the joint is obtained by means of filler material whose melting point is less than 450° C and less than the melting point of base metal.	1. In brazing the joint is obtained by means of filler material whose melting point is above the 450° C and less than the melting temperature of base metal.
2. The strength of the joint is highest comparing to soldering and brazing.	2. The soldering joints are weakest among the soldering, welding and brazing.	2. The brazed joints are stronger than soldered joint but weaker than welded joints.
3. The joint strength at times may be equal to even greater than the strength of the base metals.	3. The joint strength depends upon the adhesive qualities of filler material and can never reach the strength of base metal.	3. The joint strength depends upon the adhesive qualities of filler material and can never reach the strength of base metal.
4. The filler material may or may not be used.	4. The filler material is essentially used because joint is made by filler material only.	4. The filler material is essentially used because joint is made by filler material only.
5. The composition of filler metal is normally same as that of base metal. (the metal to be welded)	5. Essentially filler metals are alloys of lead and tin	5. he filler metals are alloys of copper (e.g. copper zinc alloys and copper silver alloys)
6. Welded joints can withstand high temperature.	6. Soldered joints are not suitable for high temperature service because of lower melting point of the filler metal.	6. Brazed joints are also not suitable for high temperature service because of lower melting point of filler metal.
7. The process cannot joint dissimilar metals which are insoluble in other.	7. The process can join dissimilar metals which are insoluble in each other.	7. The process can join dissimilar metals which are insoluble in each other.
8. The parent metals are heated to the melting temperature, so welding is likely to cause the metallurgical damage and change in the properties.	8. Heating of parent metal is negligible to cause any change in their structure and properties.	8. Heating of parent metal is negligible to cause any change in their structure and properties.
9. Welding has wide applications in construction and maintenance of boilers, pressure vessels, tanks bridges, building constructions, cutting tools dies, and furnaces.	9. Soldering is widely used in joining small assemblies, electric and electronics parts.	9. Brazing is used for joining electrical parts, joining carbide tips to tools, heat exchangers, radiators etc…

Unit -3. Bulk Metal Forming Processes

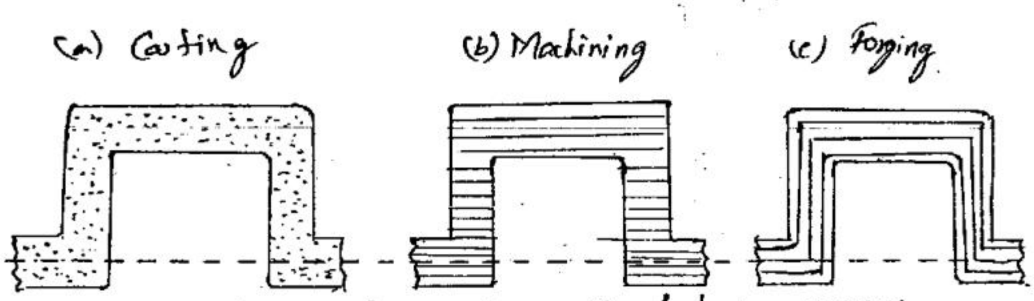
[**Bulk forming**: -Plastic deformation in metals and alloys, Recovery, Re- crystallization and grain growth. Hot working and Cold working; Strain hardening and Annealing. Bulk forming processes: Forging, Types of Forging, Forging defects and remedies. Rolling: Fundamentals, Types of rolling mills and products. Forces in rolling and power requirements. Extrusion and its characteristics. Types of extrusion. Impact extrusion, Hydrostatic extrusion; Wire drawing and Tube drawing.]

Introduction

Metal forming includes a large group of manufacturing processes in which plastic deformation is used to change the shape of metal work pieces. Deformation results from the use of a tool, usually called a die in metal forming, which applies stresses that exceed the yield strength of the metal. The metal therefore deforms to take a shape determined by the geometry of the die. Metal forming dominates the class of shaping operations. Stresses applied to plastically deform the metal are usually compressive. However, some forming processes stretch the metal, while others bend the metal, and still others apply shear stresses to the metal. To be successfully formed, a metal must possess certain properties. Desirable properties include low yield strength and high ductility. These properties are affected by temperature. Ductility is increased and yield strength is reduced when work temperature is raised. The effect of temperature gives rise to distinctions between cold working, warm working, and hot working. Strain rate and friction are additional factors that affect performance in metal forming. We examine all of these issues in this chapter, but first let us provide an overview of the metal forming processes.

Compare three methods of manufacturing a crank shaft. Casting, machining and forging (hot working process):

(i) The crank shaft produced by castings has no grain flow so has the poorest mechanical properties.
(ii) The crank shaft made by machining has interrupted fiber flow of metal so the mechanical properties of this shaft will be proper than those of forging.
(iii) The third figure shows the crank shaft made by forging process. Here the fibre of metal is not interrupted and is continuous along the entire length of the shaft. Hence it will develop superior mechanical properties.



Comparison of grain flow in Various Manufacturing processes.

It is clear from above discussion that components manufactured from metal forming processes will have higher strength and mechanical properties as compared to casting and machining processes. Direction of grain flow lines can be controlled in metal forming process and these components will develop maximum mechanical properties in application where components are subjected to impact or fatigue loading. For static loading direction of grain flow lines is not so important.

Forming

Forming is a mechanical process used in manufacturing industries where in materials undergo plastic deformation and acquire the desired shape and sizes by the application of suitable forces such as compression ,tension and shear.
Forming is the operation which reproduces flat stock into the shape of punch and dies with little or no plastic flow of the metal. An example is a punch and dies designed to form a flat strip of steel into a U – shape.

Forming process can be classified in to Two groups :-
(I) Bulk Forming (II) Sheet Metal Forming.

Bulk Forming: Bulk forming is a method of producing materials in large volumes of products whose surface area to volume ratio is small [less]. In this the desired possible shape using a set of tools such as a punch and die. The following are the various bulk forming processes

- Rolling
- Forging
- Extrusion
- Wire drawing

Sheet metal forming: sheet metal forming involve the application of tensile, compressive and shear forces to fabricate sheets, plates and strips to a desired possible shape using a set of tools such as a punch and die. In this surface area to volume ratio is more [large]. The following are the various sheet metal forming processes

- Bending
- Deep drawing
- Stretching
- Blanking
- Punching
- Flanging
- Hemming
- Curling
- Stretch forming
- Stamping

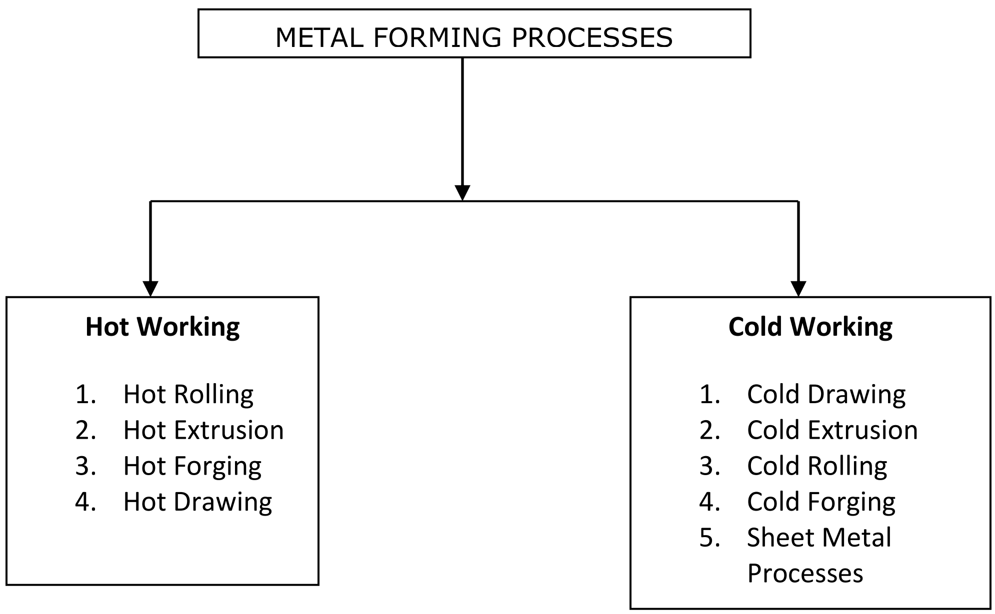
Classification of Bulk Metal Forming Processes:

On the basis of heat applied forming process can be classified into two broad categories:

1. Hot Working Processes.
2. Cold Working Processes.

(1) Hot working is the plastic deformation of metals above recrystallization temperatures.

(2) Cold working is the plastic deformation of metals below recrystallization temperatures.



HOT WORKING:-Mechanical working processes which are done above recrystallization temperature of the metal are known as hot working processes. Some metals, such as lead and tin, have a low recrystallization temperature and can be hot-worked even at room temperature, but most commercial metals require some heating. However, this temperature should not be too high to reach the solidus temperature; otherwise the metal will burn and become unsuitable for use. In hot working, the temperature of completion of metal working is important since any extra heat left after working aid in grain growth. This increase in size of the grains occurs by a process of coalescence of adjoining grains and is a function of time and temperature. Grain growth results in poor mechanical properties. If the hot working is completed just above the recrystallization temperature then the resultant grain size would be fine. Thus for any hot working process the metal should be heated to such a temperature below its solidus temperature, that after completion of the hot working its temperature will remain a little higher than and as close as possible to its recrystallization temperature.

MERITS OF HOT WORKING 1. As the material is above the recrystallization temperature, any amount of working can be imparted since there is no strain hardening taking place. 2. At a high temperature, the material would have higher amount of ductility and therefore there is no limit on the amount of hot working that can be done on a material. Even brittle materials can be hot worked. 3. In hot working process, the grain structure of the metal is refined and thus mechanical properties improved. 4. Porosity of the metal is considerably minimized. 5. If process is properly carried out, hot work does not affect tensile strength, hardness, corrosion resistance, etc. 6. Since the shear stress gets reduced at higher temperatures, this process requires much less force to achieve the necessary deformation. 7. It is possible to continuously reform the grains in metal working and if the temperature and rate of working are properly controlled, a very favorable grain size could be achieved giving rise to better mechanical properties. 8. Larger deformation can be accomplished more rapidly as the metal is in plastic state. 9. No residual stresses are introduced in the metal due to hot working. 10. Concentrated impurities, if any in the metal are disintegrated and distributed throughout the metal. 11. Mechanical properties, especially elongation, reduction of area and izod values are improved, but fiber and directional properties are produced. 12. Hot work promotes uniformity of material by facilitating diffusion of alloy constituents and breaks up brittle films of hard constituents or impurity namely cementite in steel.

DEMERITS OF HOT WORKING:- 1. Due to high temperature in hot working, rapid oxidation or scale formation and surface de- carburization take place on the metal surface leading to poor surface finish and loss of metal. 2. On account of the loss of carbon from the surface of the steel piece being worked the surface layer loses its strength. This is a major disadvantage when the part is put to service. 3. The weakening of the surface layer may give rise to a fatigue crack which may ultimately result in fatigue failure of the component. 4. Some metals cannot be hot worked because of their brittleness at high temperatures. 5. Because of the thermal expansion of metals, the dimensional accuracy in hot working is difficult to achieve. 6. The process involves excessive expenditure on account of high cost of tooling. This however is compensated by the high production rate and better quality of components. 7. Handling and maintaining of hot working setups is difficult and troublesome.

COLD WORKING:-Cold working of a metal is carried out below its recrystallization temperature. Although normal room temperatures are ordinarily used for cold working of various types of steel, temperatures up to the recrystallization range are sometimes used. In cold working, recovery processes are not effective. The common purpose of cold working is given as under 1. Cold working is employed to obtain better surface finish on parts. 2. It is commonly applied to obtain increased mechanical properties. 3. It is widely applied as a forming process of making steel products using pressing and spinning. 4. It is used to obtain thinner material.

ADVANTAGES OF COLD WORKING:- 1. In cold working processes, smooth surface finish can be easily produced. 2. Accurate dimensions of parts can be maintained. 3. Strength and hardness of the metal are increased but ductility decreased. 4. Since the working is done in cold state, no oxide would form on the surface and consequently good surface finish is obtained. 5. Cold working increases the strength and hardness of the material due to the strain hardening which would be beneficial in some situations. 6. There is no possibility of decarburization of the surface 7. Better dimensional accuracy is achieved. 8. It is far easier to handle cold parts and it is also economical for smaller sizes.

DISADVANTAGES OF COLD WORKING:- 1. Some materials, which are brittle, cannot be cold worked easily. 2. Since the material has higher yield strength at lower temperatures, the amount of deformation that can be given to is limited by the capability of the presses or hammers used. 3. A distortion of the grain structure is created. 4. Since the material gets strain hardened, the maximum amount of deformation that can be given is limited. Any further deformation can be given after annealing. 5. Internal stresses are set up which remain in the metal unless they are removed by proper heat-treatment.

Comparison / Differences between Hot Working and Cold Working

Hot Working	Cold Working
1. Hot working is done at a temperature above recrystallization but below melting point. It can be therefore be regarded as a simultaneous process of deformation and recovery. 2. Hardening due to plastic deformation is completely, eliminated by recovery and recrystallization. 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. 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: i) Hot forging ii)Hot rolling iii)Hot spinning iv)Hot extrusion v) Welded pipe and tube manufacturing vi) Roll piercing vii) Hot drawing	1. Cold working is done at temperature below recrystallization temperature. So no appreciable recovery can take place during deformation. 2. Hardening is not eliminated since working is done at a temperature below recrystallization. 3. Cold working decreases elongation, reduction of area. Increases ultimate tensile strength, yield point and hardness. 4. Good surface finish is obtained. 5. Crystallization does not occur. Grains are only elongated. 6. Possibility of crack formation and propagation is great. 7. Internal and residual stresses ate developed in the metal. 8. Cold parts possess less durability. 9. Higher forces are required for deformation. 10. More powerful and heavier equipments 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

STRAIN HARDENING: - Strain hardening (also called work-hardening or cold-working) is the process of making a metal harder and stronger through plastic deformation. When a metal is plastically deformed, dislocations move and additional dislocations are generated. The more dislocations within a material, the more they will interact and become pinned or tangled. This will result in a decrease in the mobility of the dislocations and a strengthening of the material. This type of strengthening is commonly called cold working. It is called cold-working because the plastic deformation must occurs at a temperature low enough that atoms cannot rearrange themselves. When a metal is worked at higher temperatures (hot-working) the dislocations can rearrange and little strengthening is achieved. Strain hardening can be easily demonstrated with piece of wire or a paper clip. Bend a straight section back and forth several times. Notice that it is more difficult to bend the metal at the same place. In the strain hardened area dislocations have formed and become tangled, increasing the strength of the material. Continued bending will eventually cause the wire to break at the bend due to fatigue cracking. (After a large number of bending cycles, dislocations form structures called Persistent Slip Bands (PSB). PSBs are basically tiny areas where the dislocations have piled up and moved the material surface out leave steps in the surface that act as stress risers or crack initiation points.).

Effects of Elevated Temperature on Strain Hardened Materials:-

When strain hardened materials are exposed to elevated: Temperatures, the strengthening that resulted from the plastic deformation can be lost. This can be a bad thing if the strengthening is needed to support a load. However, strengthening due to strain hardening is not always desirable, especially if the material is being heavily formed since ductility will be lowered. Heat treatment can be used to remove the effects of strain hardening. Three things can occur during heat treatment:

1. Recovery 2. Recrystallization 3. Grain growth

RECOVERY:- When a stain hardened material is held at an elevated temperature an increase in atomic diffusion occurs that relieves some of the internal strain energy. Remember that atoms are not fixed in position but can move around when they have enough energy to break their bonds. Diffusion increases rapidly with rising temperature and this allows atoms in severely strained regions to move to unstrained positions. In other words, atoms are freer to move around and recover a normal position in the lattice structure. This is known as the recovery phase and it results in an adjustment of strain on a microscopic scale. Internal residual stresses are lowered due to a reduction in the dislocation density and a movement of dislocation to lower-energy positions. The tangles of dislocations condense into sharp two-dimensional boundaries and the dislocation density within these areas decrease. These areas are called sub grains. There is no appreciable reduction in the strength and hardness of the material but corrosion resistance often improves.

Recrystallization:

At a higher temperature, new, strain-free grains nucleate and grow inside the old distorted grains and at the grain boundaries. These new grains grow to replace the deformed grains produced by the strain hardening. With recrystallization, the mechanical properties return to their original weaker and more ductile states. Recrystallization depends on the temperature, the amount of time at this temperature and also the amount of strain hardening that the material experienced. The more strain hardening, the lower the temperature will be at which recrystallization occurs. Also, a minimum amount (typically 2-20%) of cold work is necessary for any amount of recrystallization to occur. The size the new grains is also partially dependent on the amount of strain hardening. The greater the stain hardening, the more nuclei for the new grains, and the resulting grain size will be smaller (at least initially).

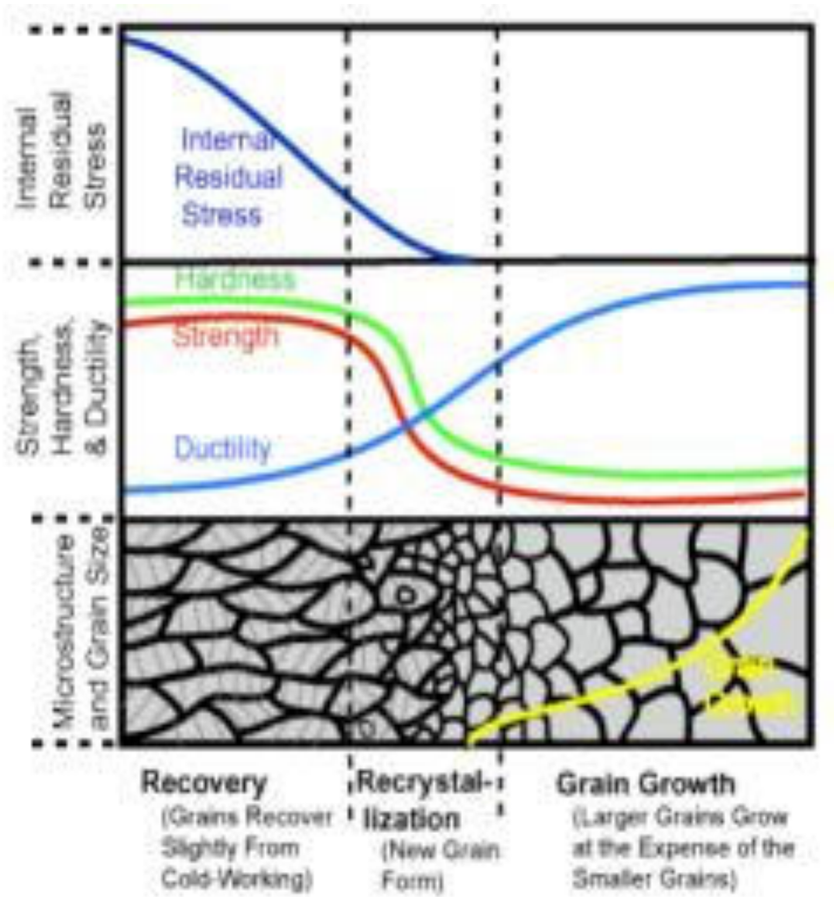
Recrystallization temperature is temperature at which entirely new crystals or grains are formed and old grain structure is destroyed. Recrystallization varies for different materials. The following table shows recrystallization temperature of some of the metals. It is generally one-half to one-third for most of the metals. It also depends upon other variables like if the material is already cold worked and there is large plastic deformation, material would have low recrystallization temperature. This is because after cold working and deformation metal have more stored energy in form of vacancies and dislocation. With this energy available it takes less thermal energy for atoms to rearrange themselves. Therefore, recrystallization can occur at lower temperatures.

Metal	**Temperature in (°C)**
Aluminium	150°C
Copper	200°C
Gold	200°C
Iron	450°C
Silver	200°C
Nickel	590°C
Zinc	At room temperature
Lead	Below room temperature
Tin	Below room temperature

The dividing line between hot working and cold working processes is recrystallization temperature. Hot working does not necessarily mean high absolute temperature. The process may be carried out with or without actual heating. For example, lead and tin have recrystallization temperature below room temperature. So mechanical working of these metals at room temperature is always hot working process. For steels recrystallization temperature is around 1000°C and working below this temperature is still a cold working process.

GRAIN GROWTH:-

If a specimen is left at the high temperature beyond the time needed for complete recrystallization, the grains begin to grow in size. This occurs because diffusion occurs across the grain boundaries and larger grains have less grain boundary surface area per unit of volume. Therefore, the larger grains lose fewer atoms and grow at the expense of the smaller grains. Larger grains will reduce the strength and toughness of the material. Comparison between hot working and cold working processes can be done in aspects like carried out temperature, stress set up, tolerances, hardening, deformation, surface finish, improved properties, and cracks formation.



ANNEALING

Annealing is a general term used to describe the restoration of a cold-worked or heat-treated alloy to its original properties-for instance, to increase ductility (and hence formability) and reduce hardness and strength, or to modify the microstructure of the alloy. The annealing process is also used to relieve residual stresses in a manufactured part, as well as to improve machinability and dimensional stability. The term "annealing" also applies to the thermal treatment of glasses and similar products, castings, and weldments. The annealing process consists of the following steps:

I. Heating the work piece to a specific range of temperature in a furnace;
2. Holding it at that temperature for a period of time (soaking), and
3. Cooling the work piece, in air or in a furnace.

The annealing process may be carried out in an inert or a controlled atmosphere, or it may be per formed at lower temperatures to minimize or prevent surface oxidation. An annealing temperature may be higher than the material's recrystallization temperature, depending on the degree of cold work.

Types of Annealing processes: (i) Full annealing (ii) Process Annealing (iii) Spheroidizing annealing (iv) Stress relief annealing.

Forging:

In forging, metal and alloys are deformed to the specified shapes by application of repeated blows from a hammer**.** The raw material is usually a piece of a round or square cross-section slightly larger in volume than the volume of the finished component. Forging is the oldest metal working process known to mankind. In this process material is squeezed between two or more dies to deform its shape and size in such a way that required final shape is obtained.

Forging is the operation where the metal is heated and then a force (impact type or squeeze type) is applied to manipulate the metal in such a way that the required final shape is obtained.

Forging always considered as hot working unless specified. Forging enhances the mechanical properties of metals and improves the grain flow, which in turn increases the strength and toughness of the forged component.

Forge ability of Metal and Alloys:

It is important to know the deformation behaviour of the metal to be forged with regard to the resistance to deformation and any anticipated adverse effects such as cracking. Hence, forge ability can be defined as the tolerance of a metal or alloy for deformation without failure. It can be evaluated on the basis of the following tests:

(a) Hot twist test
(b) Upset test
(c) Hot-impact tensile test

(a) Hot Twist Test: In this test, hot bar is twisted and count the number of twists until failure. A large number of twists before failure indicate better forge ability.

(b) Upset Test: This test is widely used in the forging industry. In this test, a number of cylindrical billets are upset-forged to various thicknesses. The limit for upset forging without failure or cracking is considered a measure of forge ability.

(c) Hot Impact Tensile Test: A conventional impact testing machine fitted with a tension test attachment is used. The impact tensile strength is taken as measure of forge ability.

Forgeable Materials:

In general, the selection of a forging material is made on the basis of certain desirable mechanical properties inherent in the composition and for those which can be developed by forging such as strength, resistance to fatigue, good machining characteristics, durability etc…

Following is a list indicating the relative forge ability of some alloys in a descending order i.e., alloys with better forge ability are mentioned first;

1. Aluminum alloys
2. Magnesium alloys
3. Copper alloys
4. Plain carbon steels
5. Low – alloy steels
6. Martensitic stainless steels
7. Austenitic stainless steels
8. Nickel alloys
9. Titanium alloys
10. Tantalum alloys
11. Molybdenum alloys
12. Tungsten alloys

Advantages of Forging:

The various advantages of forging are as follows:

1. Forgings have a high strength and offer resistance to impact and fatigue loads.
2. Forging improves the grain structure of metal and hence its mechanical properties.
3. Close tolerances
4. Less machining or no machining in some cases.
5. Smooth surface

Limitations of Forging:

1. High tool cost.
2. High tool maintenance
3. The rapid oxidation of metal surfaces at high temperature results in scaling which wears the dies.

Forging Processes & Classification:

The process of reducing a metal billet between open dies or in a closed impression dies to obtain the required shape are called smith forging or impression die forging respectively. Depending on the equipment used, they are further sub divided as hand forging, press forging, drop hammer forging, mechanical press forging, upset or machine forging.

In general the methods of forging may be classified as follows:

(1) Open Die Forging (Smith Forging)

(a) Hand Forging (b) Power Forging

(c) Hammer Forging

(2) Closed Die Forging (Impression Die Forging)

(a) Drop Forging (b) Press Forging

(c) Machine Forging or Upset Forging

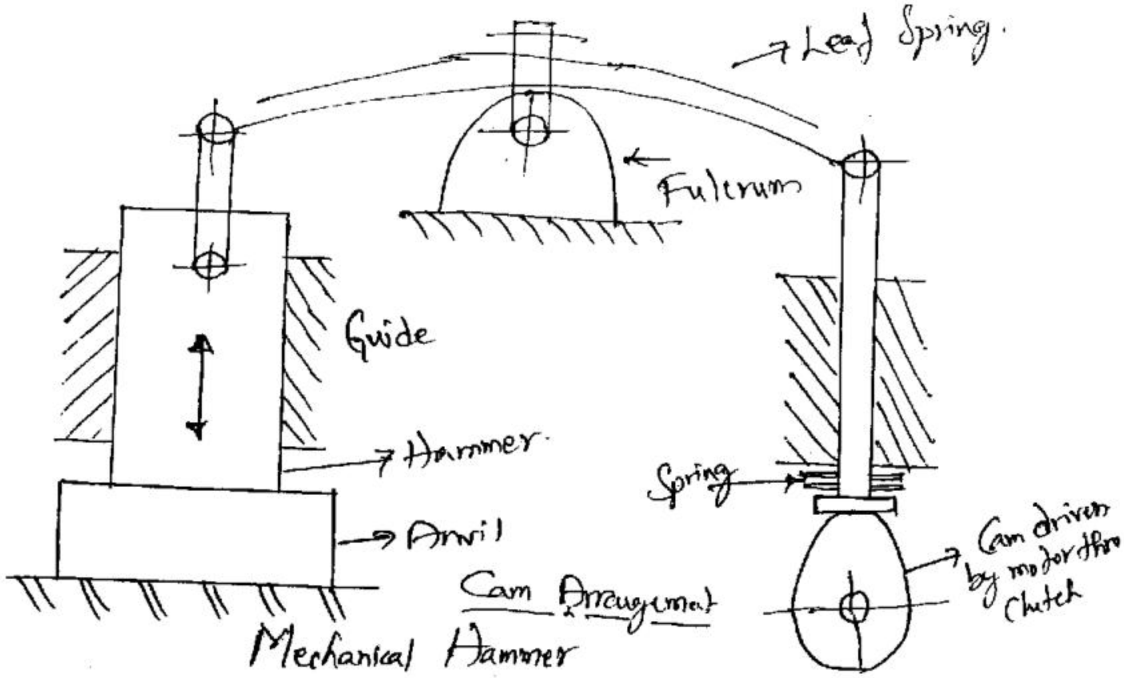
(1) Open Die Forging:

It is also called as Smith forging. In open die forging which is also called 'Hammer forging' or 'Flat die forging', the work piece is struck or pressed between two flat surfaces. Open die forging is used where number of components to be forged is too small to justify the cost of impression dies. The shapes most commonly used by open die forging are, bars, slabs or billets with rectangular, circular, hexagonal or octagonal cross sections, weldless rings and many other components of simple shapes. The accuracy of the component produced by this process is less.

- **(a) Hand Forging:** Smith forging is known as hand forging. It is used to produce a small number of light forgings.
- **(b) Power Forging:** Large components cannot be forged by hand. Moreover hand forging is lengthy process and requires repeated heating of metal. Machines which work on forgings by blow are called hammers, while those working by pressure are called presses.
- **(c) Hammer Forging:** In hammer forging the hammer is lifted up to a certain distance and then it is allowed to fall by gravity. Depending upon the lifting mechanism the hammers may be classified as:

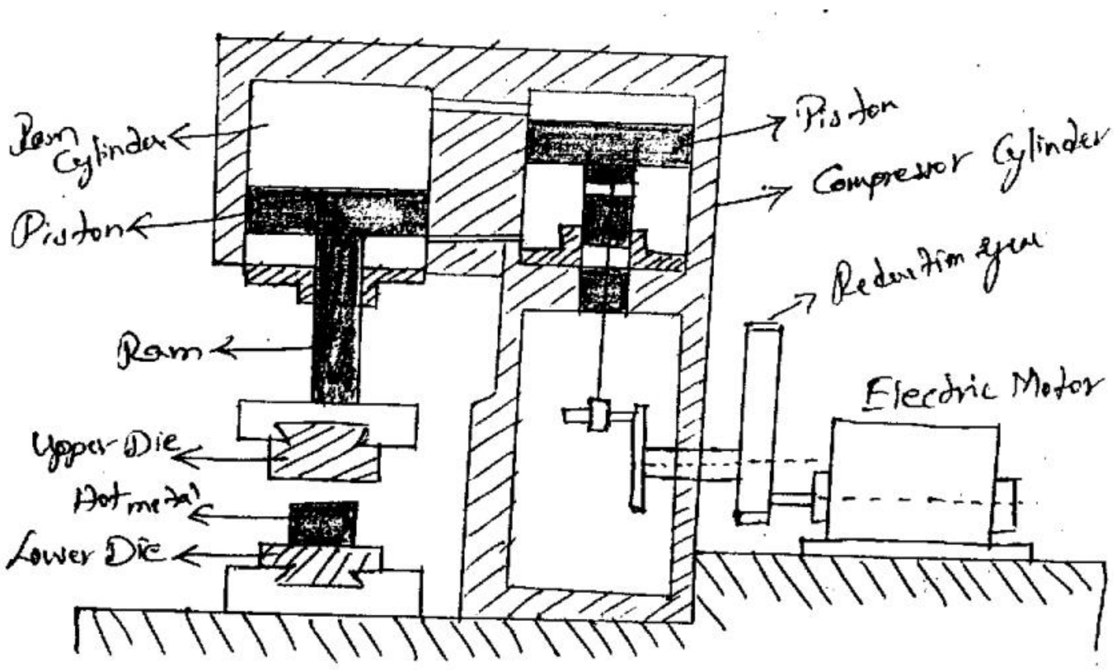
  (i) Mechanical Hammers
  (ii) Pneumatic Hammers
  (iii) Steam or air Hammers

(i) Mechanical Hammers: The mechanical hammers are helve hammers, trip hammers and lever spring hammers. Lever spring hammer has constant lift. The arm is driven from rocking lever acting on an elastic rod. The rocking lever consists of a leaf spring. Mechanism is illustrated in below figure.



(ii) Pneumatic Hammers: Pneumatic hammer is used for smith forging of small parts. A pneumatic hammer has a built in compressor to provide a compressed air to ram cylinder. The upper die is connected to the lower end of the ram. The lower die is supported on the anvil.

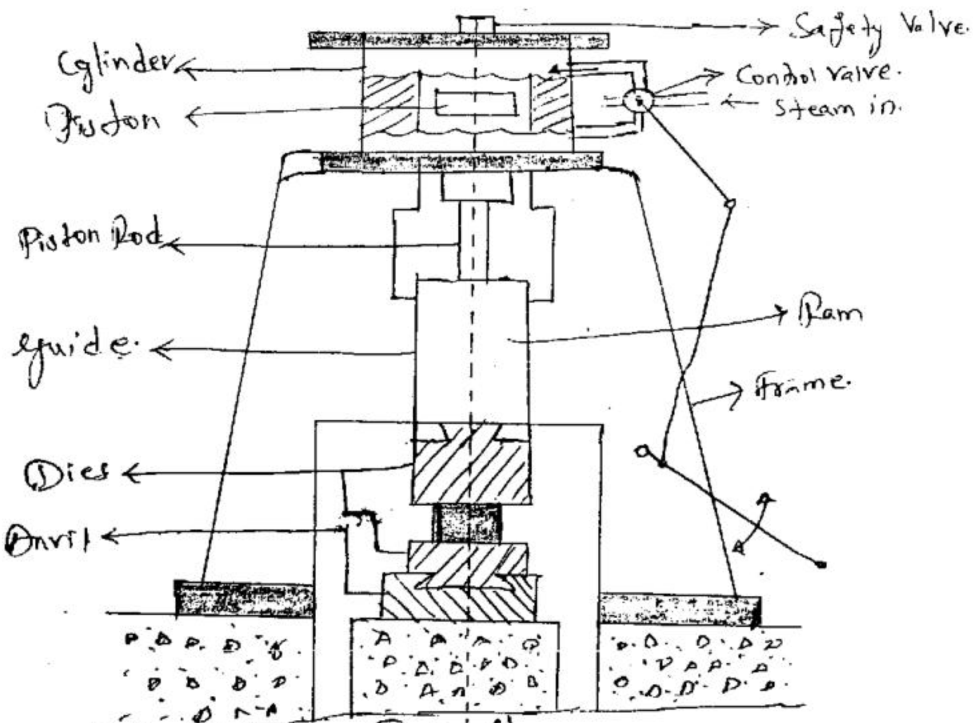
When compressed air enters the ram cylinder from the top of the ram strikes the hot metal placed between the dies. To move the ram up, the compressed air enters from the bottom of the cylinder. Repeated blows are struck until the desired shape is obtained. These are operated at 70 to 190 blows per minute.



Pneumatic Hammer

(iii) Steam or air Hammers: A steam hammer operates with the help of steam and air hammer requires compressed air for its operation. A steam or an air hammer may be (1) single acting (2) double acting. Steam or air pressure is usually between 6 to 8 kgf/cm2.

As shown in below figure steam entering from the top exerts pressure on its piston which moves downwards and upper die applies force on the hot metal to get deformed. The steam then enters from the bottom of the piston so that the piston moves upward. This cycle is repeated till the required shape is obtained.



Steam Forging Hammer

Die: Dies are devices used for shaping metal. The dies used in closed die forging or impression die forging may classified into two groups:

(i) Single Impression Die: This die contains only one cavity or impression which is the finishing impression. The preliminary forging operations are done by hand or on forge hammers, forging rolls etc… and only final finishing operation is done in the die cavity.

(ii) Multi Impression Die: This die contains finishing operation and one or more auxiliary impressions for preliminary forging operations. The final shape of a part is progressively developed over a series of steps from one die impression to the next. Generally multi impression dies are very expensive to make and are employed only when the quantity to be made is sufficiently large.

Advantages of Multi – Impression Die:

1. Complete sequence of forging operations can be carried out on one equipment only avoiding the use of auxiliary forging equipment.
2. Use of multi impression dies is particularly suited for particularly suited for production of small and medium sized forgings in large quantities as this method gives 2 to 3 times the production compared with the method of production using a single die.
3. All the preliminary operations can be performed on these dies with good ease. The use can be prepared to fairly accurate dimensions. Besides this more accurate forgings are prepared.
4. Wastage of forging metal is reduced.
5. Use may not be reheated for the finishing impression.
6. Initial die cost becomes insignificant in case of high output.
7. Finishing impression lasts ling, because much of the load is taken by blocking impression.

(2) Impression Die Forging:

It is also known as closed die forging. In closed – die forging, cavities or impressions are cut in the die block, in which the metal is forced to take its final shape and dimensions. The flow of metal is limited by surfaces of the impressions. Closed die forgings have the following characteristics.

1. Saving the time as compared to open die forging.
2. Makes good utilization of work piece materials.
3. Excellent reproductivity with good dimensional accuracy.
4. Forgings are made with smaller machining allowances, thus reducing considerably the machining time and the consumption of metal required for the forging.
5. Forgings of complicated shaped can be made.
6. The equipment for closed die forging does not require highly skilled workers.
7. The grain flow of metal can be controlled ensuring high mechanical properties.
8. Method is suited for rapid production rate.
9. Cost of tooling is high, therefore suitable for large production runs.

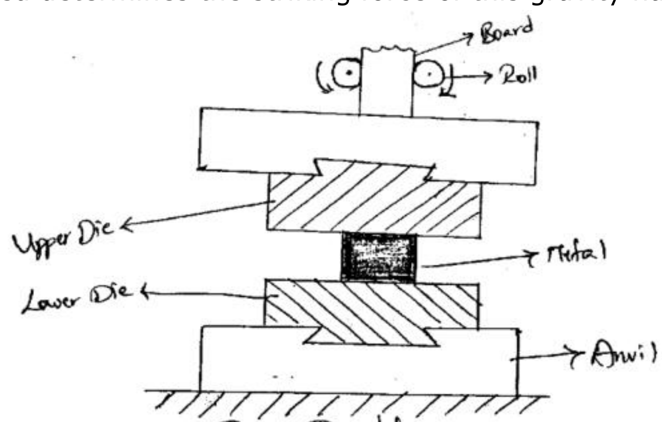
It is used to make more complex shapes of products with greater accuracy. After forging operations, the product should be trimmed to remove flash.

(a) Drop Forging:

The ram is raised to a definite height and then it is allowed to drop or fall freely under its own weight. The commonly used drop hammers are:

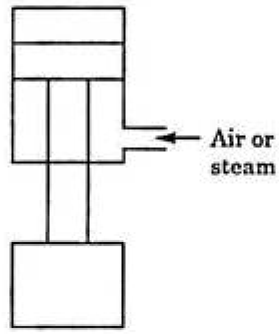
(i) Board hammer or gravity drop hammer
(ii) Air lift hammer(iii) Power drop hammer

(i) Board hammer or gravity drop hammer: In these hammers, tam is fastened to a hard board as shown if below figure. The board is lifted up by two counter revolving rolls. When the rolls are released, the ram falls down producing a working stroke. The height to which the board is lifted determines the striking force of this gravity hammer.



Board Drop Hammer

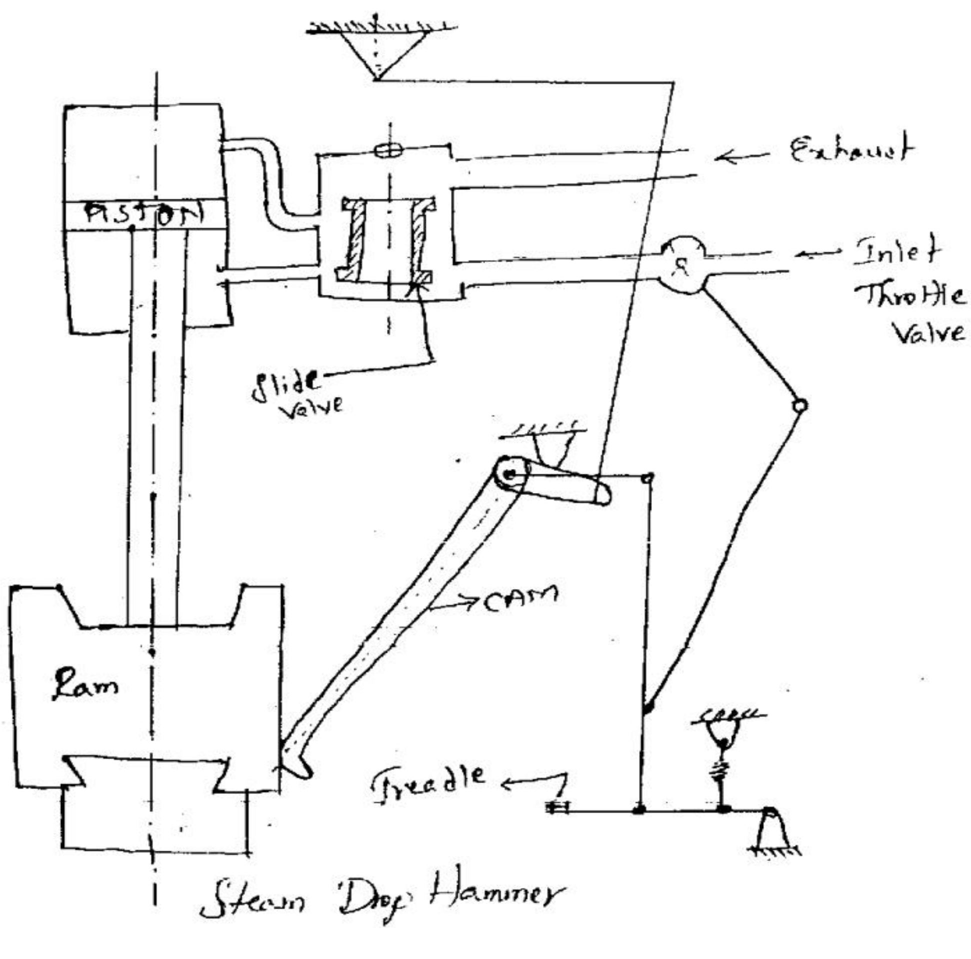
(ii) Air lift hammer: These hammers use compressed air to lift the ram which is then allowed to fall by gravity similar to the board drop hammers.



Air lift
hammer

(iii) Power drop hammer: They use air or steam. They are similar to board drop hammers except that steam or air piston and rod are substituted for board lifting mechanism. They are largest of forging hammers and are made from 450 to 25,000 kgs falling weight hammers.

A variation of the hammer discussed above is the 'gravity drop hammer' or 'air lift hammer'. In this design, the steam or air that is used to lift the ram is suddenly released to allow the ram to fall freely under gravity.



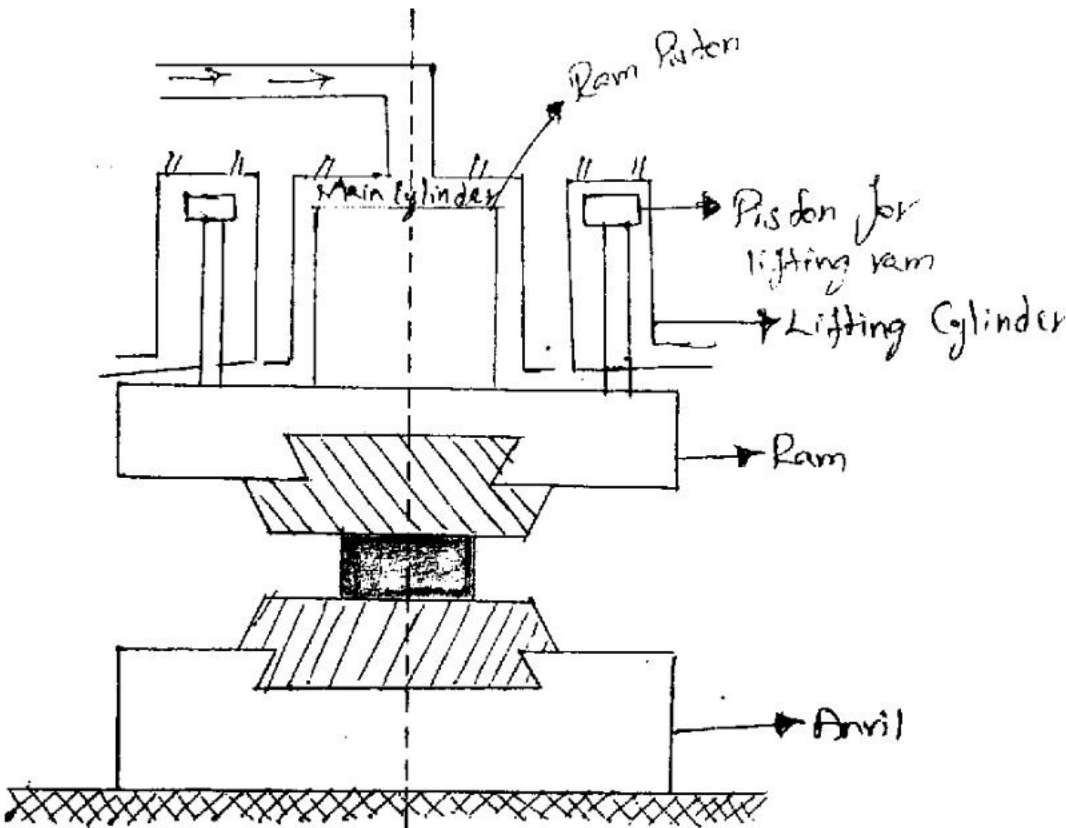
Steam Drop Hammer

(b) Press Forging: The press forging is also done in impression dies. In press forging, the metal is shaped not by means of a series of blows as in drop forging, but by means of continous squeezing action. The manner in which the metal deformation takes place in press forging substantially differs from that of hammer forging. Blow of hammer works only in the surface layer of forging and deformation does not penetrate into the volume of the metal. Squeezing pressure of a press applied to the forging gradually increases and penetrates deep into the metal.

The two types of presses used are:

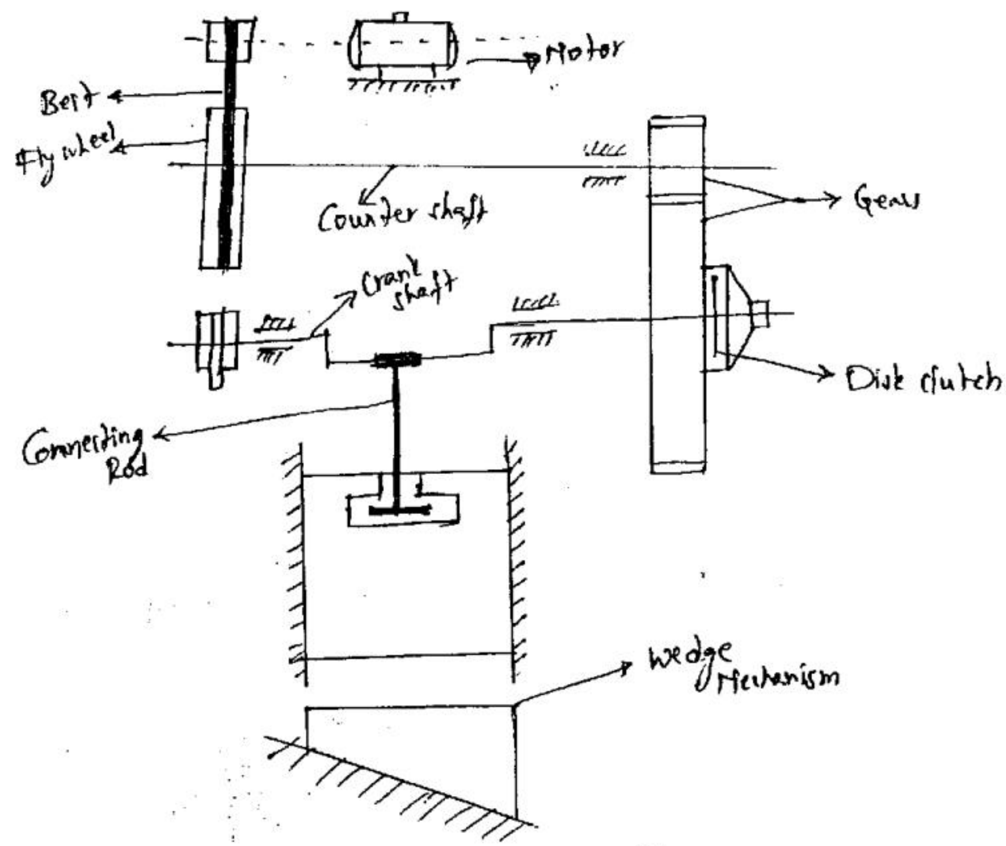
(i) Hydraulic Press (ii) Mechanical Press

(i) Hydraulic Press: The following figure illustrates a hydraulic press. The press is operated by pump which increases the pressure in the oil or water. This pressure is transmitted to main cylinder to move the piston (ram) downward to squeeze the hot metal between the dies. The lifting cylinder raises the ram up. In a hydraulic press, pressure can be changed as desired at any point in the stroke by adjusting the pressure control valve. This will help in controlling the rate of deformation according to the metal being forged. But in hydraulic press, the contact time between the work piece and the dies is more; hence the die life is less.



Hydraulic Press

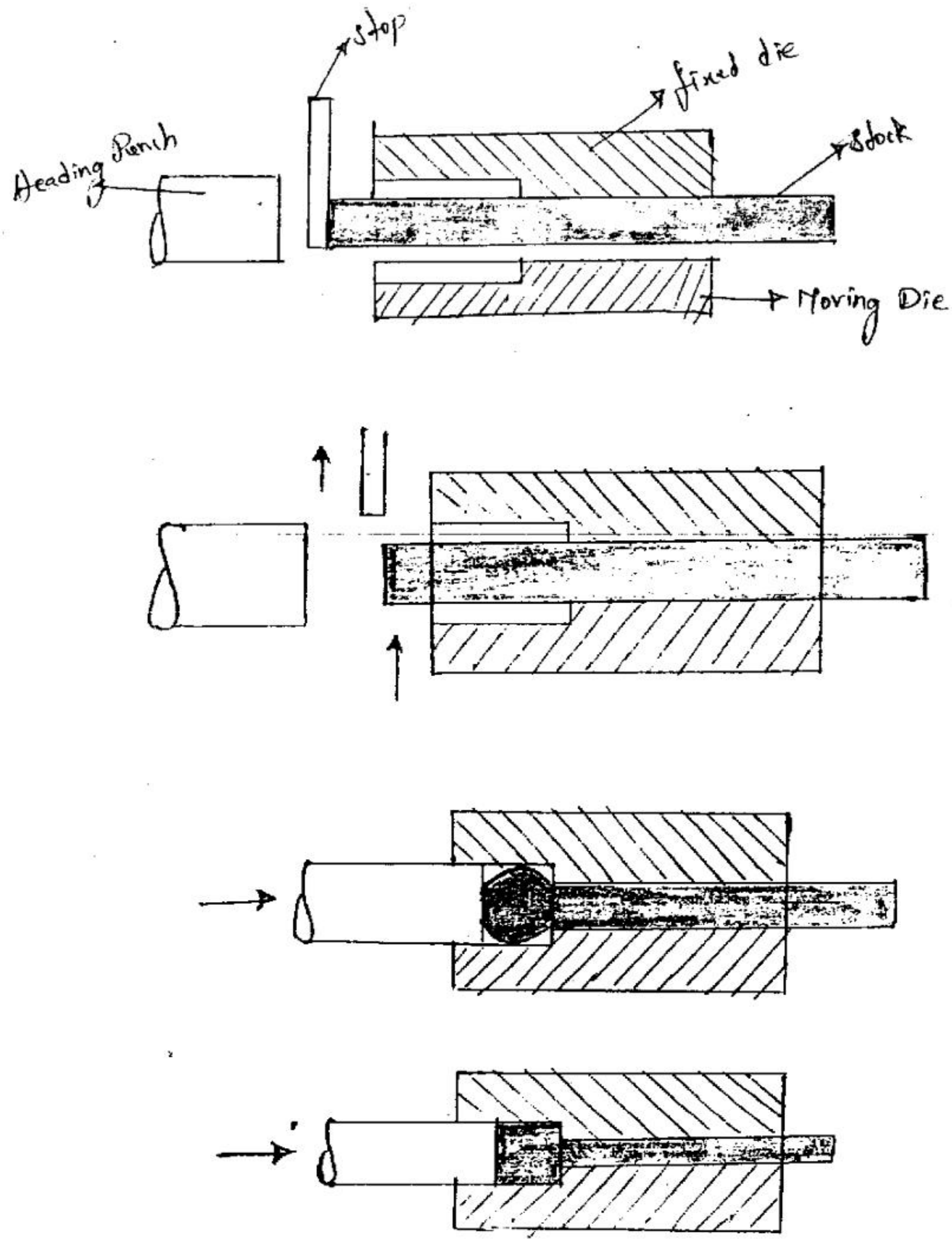
(ii) Mechanical Press: Crank type mechanical press is shown in below figure. An electric motor drives the flywheel mounted on the counter shaft by means of a belt drive. Torque from the counter shaft is transmitted to the crankshaft by gearing. From the crankshaft, the reciprocating motion is given to the ram with the help of connecting rod. The bottom die is locked in position by means of wedge mechanism. Disk clutch is used to start and stop motion of ram, which is brought to a gradual stop by means of a brake. Mechanical press is faster than hydraulic press and operates at about 25 to 100 strokes per minute.



Crank Type Mechanical Press.

(c) Machine Forging or Upset Forging: Unlike press forging, it operates in horizontal direction. As it involves the upsetting operation, it is simply called as upset forging. Upset forging was originally developed for heading operations. But today its scope has been widened to perform a large variety of operations such as punching, bending, cutting and squeezing etc…

The forging machine consists of a heavy cast steel body in which three main components, stationary die, moving die and heading punch are properly secured. The sequence of operation of machine is explained in the below figure. First the bar stock of one end heated is placed between the fixed and movable halved of the set of dies up to stop. Next the moving die grips the bar stock and at the same time, a recess is formed in the closed dies for shaping the projected stock. Stop is then brought to its initial position. Now the heading punch advances to upset the bar end and forms the finished forging.



Up set forging steps.

Defects in Forging Parts:

Various surface and body defects may be observed in forging. The kind of defect depends upon a lot off factors such as forging process, poor quality of stock, improper die design, uneven cooling of stock after forging etc… The most commonly found forging defects are as follows:

1. **Mismatch:** This is due to the misalignment between the top and bottom forging dies. This may be caused due to loose wedges. This results in a lateral displacement between the portions of the forging.
2. **Scale Pits:** These are shallow surface depressions caused by not removing scale from the dies. The scale is worked into a surface of the forging. When this scale is cleaned from the forging, depression remains which are known as scale pits.
3. **Cold Shuts or Laps:** Cold shuts or laps are short cracks, which usually occur at corners and at right angles to the surface. They are caused by metal surface folding against itself during forging. Sharp corners in dies can result in hindered metal flow, which can produce laps.
4. **Unfilled Shapes:** This defect is similar to misrun in casting and occurs when metal does not completely fill the die cavity. It is caused by using insufficient metal or insufficient heating of the metal.
5. **Dents:** Dents are the result of careless work.
6. **Burnt and over Heated Metal:** This defect is due to improper heating conditions and soaking the metal too long time.
7. **Cracks:** Cracks occur on the forging surface may be longitudinal or transverse. These are due to bad quality of ingot, improper heating, and forging at low temperature.
8. **Fins and Rags:** These are small projections or loose metal driven into forging surface.
9. **Dirt, Slag and Sand:** These may be present on the surface of the forging due to their presence in the ingot used for forging.

Internal Cracks: Internal cracks in forging can result from too drastic a change in the shape of the raw stock at too fast a rate

Spring hammer

Spring hammer: It is a light hammer powered by an electric motor and gives repeated blows when it is operated by a foot operated treadle. This type of hammer is now obsolete and was best suited for small forgings. Though various designs of this hammer were in use, a typical spring hammer is shown in Fig.

In this design, an electric motor rotates a pair of pulleys, a loose and another fast pulley. The loose pulley rotates idly on its shaft. The fast pulley is fastened on its shaft by means of a key, so that when fast pulley rotates, it rotates the shaft as well. The shaft carries an eccentric sheave on it with the result that when the electric motor rotates the fast pulley, the eccentric sheave also rotates with it and imparts vertical reciprocatory motion to the connecting rod. This upper end of the connecting rod is connected to one end of a laminated bearing spring. The other end of this spring is connected to a ram which can slide up and down in a vertical guide provided in the machine frame at the front of the machine. To this ram, a tup (and a die, if required) is fitted. Also resting vertically below the ram and tup is an anvil resting on a base. The electric motor is normally connected to the loose pulley, but when the hammer operator depresses the treadle with his foot, the motor gets connected to the fast pulley and when the connecting rod moves up, the front end of the spring moves down, the spring buckle in the centre of the spring being pivoted. When the connecting rod moves down, the ram moves up. Thus rotation of motor causes up and down motion of ram and tup which is used for hammering the work piece kept on the anvil. Usually there is an arrangement for shifting the position of the pivot. If the pivot is shifted towards the connecting rod, the vertical movement of ram and tup increases and so does the severity of the hammering action. When the pressure of foot is removed from the treadle, the motor gets connected to the loose pulley and a brake applies automatically stopping the hammering action instantly. Spring hammers were made in various capacities with tups weighing from 30 to 250 kg and having a capability of running up to 300 blows per minute.

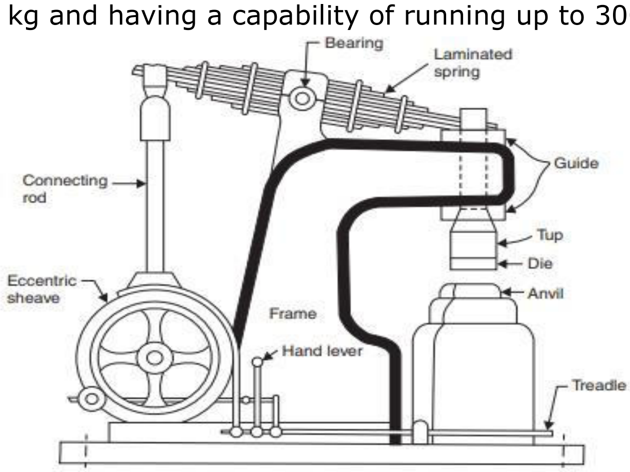


Fig. ⁝ ↓ A spring hammer

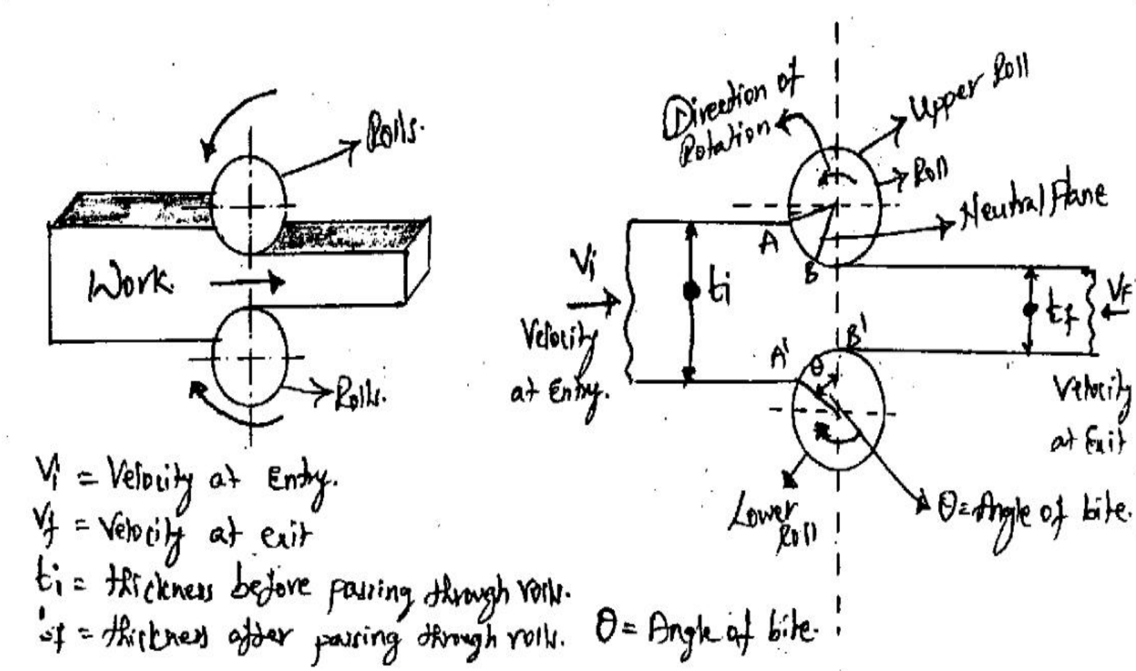
Rolling

Rolling is the process of compressing the metal by passing it between two revolving cylinders called rolls. As the metal is compressed its cross section area is reduced and length is increased.

In this process, metals and alloys are plastically deformed into semi-finished or finished products by being pressed between two rolls which are rotating. The metal is initially pushed into the space between two rolls, thereafter once the roll takes a "bite" into the edge of the material, the material gets pulled in by the friction between the surfaces of the rolls and the material. The material is subjected to high compressive force as it is squeezed (and pulled along) by the rolls. This is a process to deal with material in bulk in which the cross-section of material is reduced and its length increased. The final cross-section is determined by the impression cut in the roll surface through which the material passes and into which it is compressed.

Rolling is normally a hot working process unless specifically mentioned as cold working. The starting material is the molded ingot which is rolled into intermediate shapes like blooms, billets and slabs. These intermediate shapes are rolled further into plates, sheets, bars, structural shapes, I, L, T or channel section.

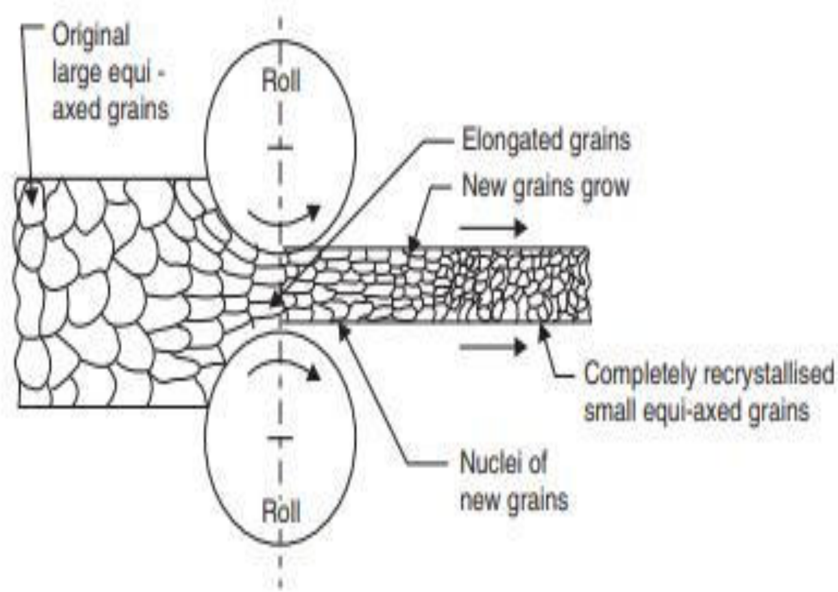
The rolling process is explained in below. Heated metal is passed between two rolls that rotate in opposite direction; the gap between the rolls is somewhat less than the thickness of metal at entrance.



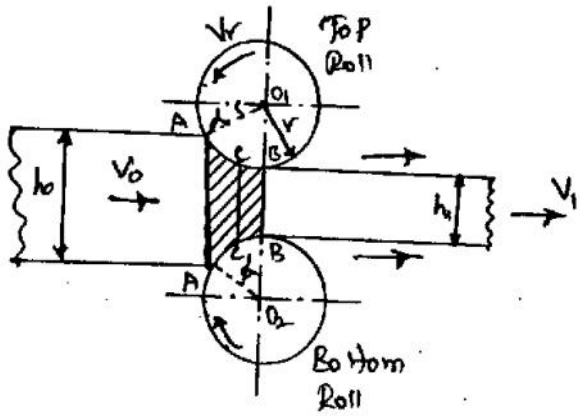
Following are the characteristics of rolling process:

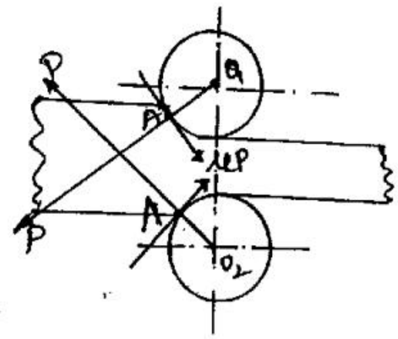
1. The amount of thickness that can be reduced in single pass between a given pair of rolls depends upon the friction between the roll surface and metal. Rougher rolls would be able to achieve greater reduction than smoother rolls, but the roll surface gets embedded into rolled metal and produces rough surface. The reduction that can be achieved with given pair of rolls in single pass is known as angle of bite.
2. In the process of rolling, the speed of metal is continuously changing between the entry and exit of roll whereas roll speed remains constant. Since cross-sectional area is decreasing metal enters the rolls with a speed less than speed of rolls and exits from rolls traveling at a higher speed than it enters. At a point between contacts length A and B as shown in above figure the metal speed is same as the roll speed. This is designated as neutral plane.
3. During the rolling of ingot, the volume of the metal that enters rolling mill is same as that leaving except in initial passes when there might be some loss due to filling of voids and cavities.

The following figure shows, how grain structure is refined during rolling by recrystallization. Original coarse grains are elongated by rolling action. Because of high temperature recrystallization starts and small grains begin to form.



Mechanism of Rolling and Forces during Rolling:





Forces During Rolling.

The above figure shows a schematic diagram of the rolling process. The metal contacts each of the two rolls along the arc AB, which is known as the arc of contact. The arc corresponds to the central angle , called the "angle of contact or bite". The process of metal rolling is made possible by the friction that occurs between the contact surfaces of the rolls and the part being rolled. At the moment of bite, two forces act on the metal from the side of each roll, normal force P and the tangential for μP, where μ is the co-efficient of friction between the metal and the roll surfaces. The part would be dragged in if the resultant of horizontal component of the normal force P and tangential force (frictional force) μP is directed in that direction. Where h_o is the thickness of material, h_1 the gap between the two rollers at the narrowest point and 'r' is the radius of rollers.

In the limiting case,

$$\cos \alpha = \frac{r - \frac{1}{2}(h_0 - h_1)}{r}$$

$$P \sin \alpha = \mu P \cos \alpha$$

$$\mu = \tan \alpha$$

or

$$\alpha = \tan^{-1} \mu$$

If α is greater than $\tan^{-1} \mu$, the metal would not enter the space between the rolls automatically, that is, unaided.

The maximum permissible angle of bite(α) depends upon the valve of 'μ' which in turn depends upon the materials of the rolls and the job being rolled, the roughness of their surfaces, and the rolling temperatures and speed.

In hot rolling, the primary purpose is to reduce the section and hence the maximum possible reduction is desired. So, the value of α and hence of μ should be greater. In hot rolling, lubrication is generally not necessary. On the other hand, on primary reduction rolling mills such as blooming or rough rolling mills for structural elements, the rolls may sometimes "ragged" to increase μ. **Ragging** is the process of making certain fine grooves on the surface of the roll to increase the friction. In cold rolling, the rolling loads are very high; hence μ should not be much. Besides, cold rolling being a finishing operation, rough rolls will impair the surface of the cold rolled product. Due to this, rolls for cold rolling are ground and lubricants are also used to reduce μ.

The usual values of biting angle are:

α = 3° to 4° for cold rolling of steel and other metals with lubrication on well-ground rolls.
= 6° to 8° for cold rolling of steel and other metals with lubrication on rough rolls.
= 18° to 22° for hot rolling steel sheets
= 20° to 22° for hot rolling aluminum at 350°C
= 28° to 30° for hot rolling steel (blooms and billets) in ragged or well roughed rolls.

On one side, therefore, i.e., point 'A' where contact between the rolls and work material starts, the rolls are moving at faster surface speed than the work material. As the material gets squeezed and passes through the rollers, its speed gradually increases and at a certain section CC (Fig.) called neutral or no slip section, the velocity of metal equals the velocity of rolls. As material is squeezed further, its speeds exceeds the speed of the rolls. The angle subtended at the center of the roll at the neutral section is called angle of no slip or critical angle (angle BO_1C). The deformation zone to the left of the neutral section is called lagging zone and the deformation zone to the right of the neutral section is termed leading zone. If V_r is the velocity of roll surface, V_0 the velocity of material at the entrance to the deformation zone and V_1 at the exit of the rolls, we have

Forward slip = { [V_1- V_r] /V_r} × 100 per cent, and Backward slip = { [V_r- V_0] /V_r} × 100 per cent.

The value of forward slip normally is 3–10% and increases with increase in roll dia and coefficient of friction and also with reduction in thickness of material being rolled.

Some other useful terms associated with rolling are explained below:

Absolute draught Δh = (h0 – h1) mm, Relative draught = Δh / h0 × 100 per cent
Absolute elongation, Δl = Final length – Original length of work material
Coefficient of elongation = Final length /Original length
Absolute spread = Final width of work material – Original width of material
(Note: During cold working absolute spread may be taken as nil.)

Roll Force,Torque, and Power Requirements

The rolls apply pressure on the flat strip in order to reduce its thickness, resulting in a roll force, F, as shown in Fig (c).Note that this force appears in the figure as perpendicular to the plane of the strip, rather than at an angle. This is because, in practice, the arc of contact is very small compared with the roll radius, so we can assume that the roll force is perpendicular to the strip without causing significant error in calculations. The roll force in flat rolling can be estimated from the formula

$$F = Lw * Y_{avg}, \quad \text{-----------------} \quad (i)$$

Where:- **L** is the roll-strip contact length, **w** is the width of the strip, and $\mathbf{Y_{avg}}$ is the average true stress of the strip in the roll gap. Equation **(i)** is for a friction less situation; however, an estimate of the actual roll force, including friction, may be made by increasing this calculated force by about20%. The torque on the roll is the product of '**F'** and '**a'**. i.e

$$\text{Torque (T)} = F * a = F * L/2 \quad \text{----- in S.I. units (N-m)}$$

Where;- $a = L/2$

The power required per roll can be estimated by assuming that Facts in the middle of the arc of contact; thus, in Fig(c) , where $a = L/2$.

Therefore, the total power (for **two** rolls), in S.I. units, is

$$\text{Power (P)} = 2\pi FLN/60{,}000 \ \text{(kW)}$$

Where :'F' is in newton, L is in meters, and 'N' is the revolutions per minute of the roll.

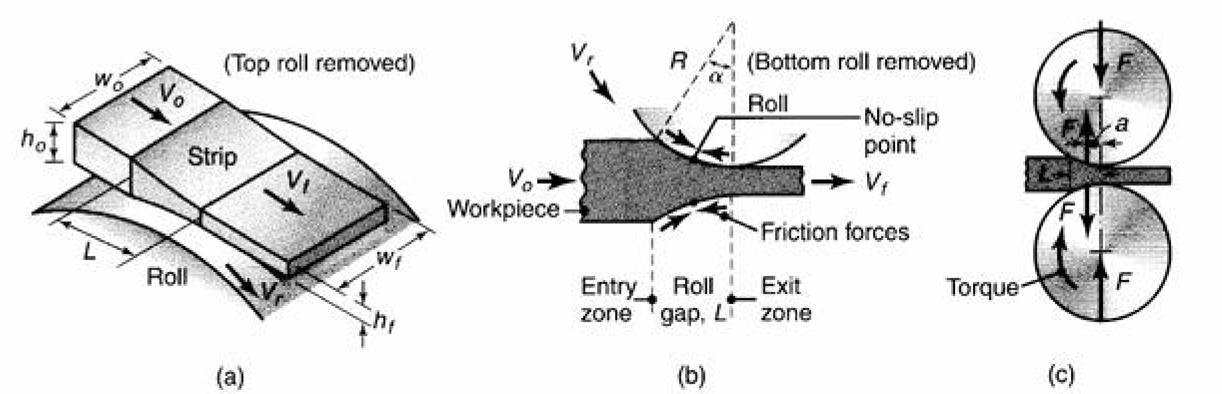
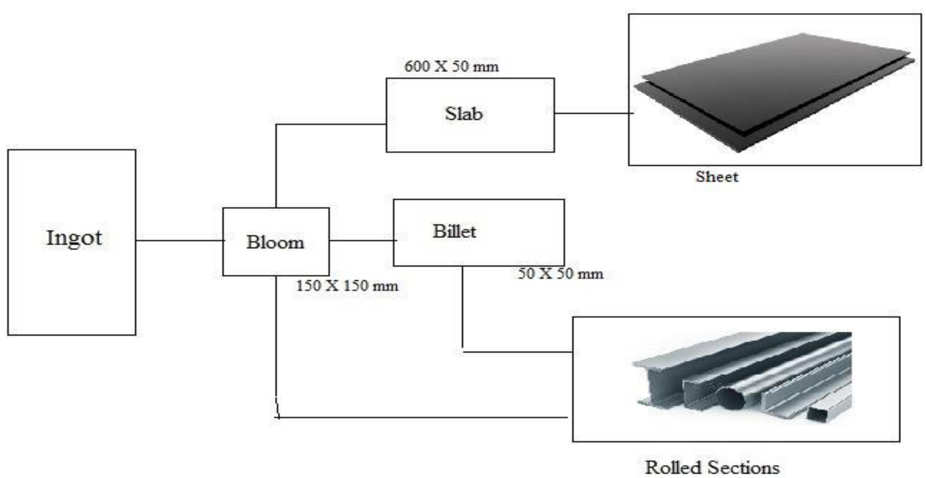


FIGURE : (a) Schematic illustration of the flat-rolling process. (b) Friction forces acting on strip surfaces. (c) Roll force, *F*, and torque, *T*, acting on the rolls. The width of the strip, *w*, usually increases during rolling, as shown later in Fig.

Terminology Associated with Rolled Products:

1. **Ingot:** This is the raw material used in rolling. This is obtained by pouring molten metal into ingot moulds having standard dimension. The ingot is rolled in intermediate shapes like blooms, billets and slabs.
2. **Bloom:** Blooms: It is the first product obtained from the breakdown of Ingots. A bloom has a cross-section ranging in size from 150 mm square to 250 mm square or sometimes 250 × 300 mm rectangle. They are further rolled into shapes such as rounds, rods or bars.
3. **Billet:** A billet is the next product rolled from a bloom. Billets vary from 50 mm square to125 mm square.
4. **Slab:** The standard dimensions of slab are 50 to 150mm thickness and 600 to 1500mm width.
5. **Plate:** A plate is generally 5 mm or thicker and is 1.0 or 1.25 metres in width and 2.5 metres in length**.**
6. **Sheet:** A sheet is up to 4 mm thick and is available in same width and length as a plate.
7. **Flat:** Flats are available in various thickness and widths and are long strips of material of specified cross-section**.**
8. **Foil:** It is a very thin sheet.
9. **Bar:** Bars are usually of circular cross-section and of several metres length. They are common stock (raw material) for capstan and turret lathes.
10. **Wire:** A wire is a length (usually in coil form) of a small round section; the diameter of which specifies the size of the wire.

Production Sequence in Getting Rolled Products:



The ingot is rolled to intermediate shapes – blooms & slabs. These blooms, billets and slabs are further rolled into plate sheets, bar stock and structural shapes as shown in above figure.

Hot and Cold Rolling:

In hot rolling the metal is fed between rolls after being heated above the recrystallisation temperature. This leads to grain refinement, thereby mechanical properties are improved. During hot rolling, the work hardening does not occur and coefficient of friction between the rolls and the metal is higher. Heavy reduction in area of the work piece can be obtained. Hot rolled parts do not have a good surface finish due to scaling.

In cold rolling, the metal is fed to the rolls when it is below its recrystallisation temperature. This results in elongation of grain structure. The metal shows work hardening effect after cold rolling. This increases harness and decreases the ductility of the metal. Heavy reductions are not possible. The coefficient of friction between the rolls and the metal is lower. The cold rolled a surface is smooth and oxide free.

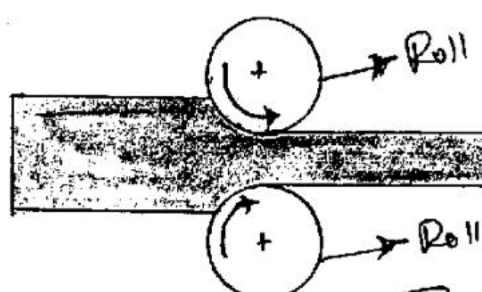
Classification of Rolling Mills:

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

1. Two – high rolling mill } Generally used for Hot Rolling of Metals
2. Three – high rolling mill
3. Four – high rolling mill } Generally used for Cold Rolling of Metals
4. Tandem rolling mill
5. Cluster rolling mill

1. Two – High Rolling Mill:

It consists of two heavy horizontal rolls placed one over the other. It comprises of two heavy rolls placed one over the other. The rolls are supported in bearings housed in sturdy upright frames (called stands) which are grouted to the rolling mill floor. The space between the rolls can be adjusted by raising or lowering the upper roll. The position of the power roll is fixed. The rolls rotate in opposite direction. The work can be rolled by feeding from one direction only. This is called non – reversing mill.

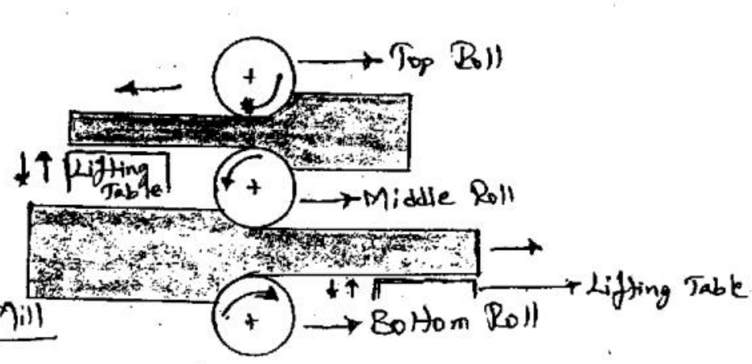


Two – High Rolling Mill

There is another type of two – high mill, which incorporates a drive mechanism that can reverse the direction of rotation of the rolls. This is knows as two – high reversing mill. In this, the rolled metal is passed backward and forth through several times. This type is used in blooming and slabbing mills and for rough work.

2. Three – High Rolling Mill:

It consists of three horizontal rolls placed one over the other. The upper and lower rolls rotate in the same direction; whereas the intermediate roll rotates in direction opposite to the outer roll.

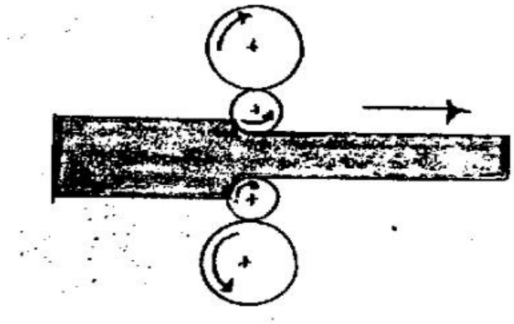


Three – High Rolling Mill

First of all the work piece passes through the bottom and the middle rolls and then returning between the middle and top rolls so that the thickness is reduced at each pass. Mechanically operated lifting tables are used which move vertically on either side of the roll stand. It may be used to make plates or sections.

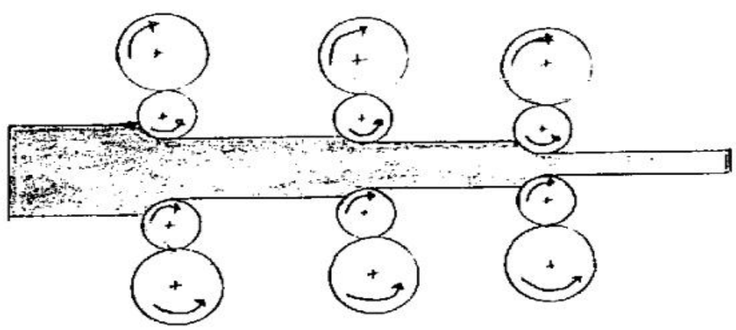
3. Four – High Rolling Mill:

It consist of four horizontal rolls, two of smaller diameter and two of large diameter. The bigger rolls are called back up rolls because they reinforce the smaller rolls to maximize roll deflection there by minimizing the tendency of producing plates and sheets thicker at the center than at the two outer edges. The two smaller rolls are called work rolls. It is used for both hot and cold rolling of plates and sheets.



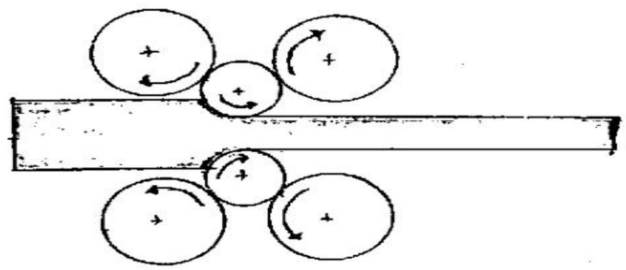
4. Tandem Rolling Mill:

It is set of two or three stands of rolls set in parallel alignment so that a continuous pass may be made through each one successively without change of direction of material. The main advantage of this mill is only one pass is required which saves the time and increase in production. Also greater tensions are possible between the strands and this increases the reduction possible in the strands for the same roll force. The main disadvantage of this mill is high capital cost compared with single stand reversing mill.



5. Cluster Rolling Mill:

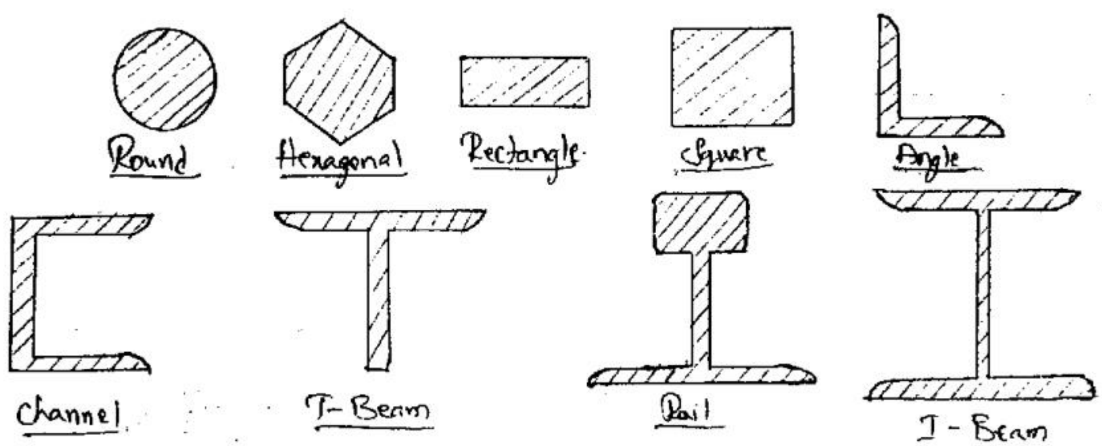
It consists of two working rolls of small diameter and four or more backing rolls. The large number of backup rolls provided becomes necessary as the backup rolls cannot exceed the diameter of working rolls by more than 2–3 times. To accommodate processes requiring high rolling loads (e.g., cold rolling of high strength steels sheets), the size of working rolls becomes small. So does the size of backup rolls and a stage may be reached that backup rolls themselves may offer deflection. So the backup rolls need support or backing up by further rolls. In the world famous SENDZIMIR MILL (also called –Z-Mill), as many as 20 backup rolls are used in the cluster. This mill is used for rolling stainless steel and other high strength steel sheets of thin gauge



Range of Rolled Products:

The whole range of rolled products can be divided into the following:

(a) **Structural Shapes or Sections:** This includes section like round square, hexagonal bars channels, H and I beams and special section like rail sections. The following figure shows some structural shapes.
(b) **Plates and Sheets:** Plates and sheets are produced by rolling.
(c) **Special Purpose Rolled Products:** These include rings, balls, wheels and ribbed tubes.



Lubrication in Rolling Process:

Lubrication in rolling process protects the rolls against wear, reduces friction and allows smooth flow of metal between rolls. It also protects the metal surface from scratching and peeling.

The selection of lubricant depends on
(i) Material
(ii) Roll Pressure

(iii) Speed of rolling.

The most commonly used lubricants are
(i) High penetrating and wetting soluble oils
(ii) Synthetic soluble
(iii) Oils with excellent polarity.

Defects in Rolled Product [ROLLING DEFECTS]

To understand the causes and remedies of rolling defects, we shall divide them in two classes:
1. Surface defects, and
2. Structural defects.

Surface defects include rusting and scaling, surface scratches, surface cracks, pits left on the surface of due to subsequent detachment or removal of scales which may have been pressed into the surface

Structural defects are more important rolling defects some of which are difficult to remedy.

These defects include the following:
(i) Wavy edges
(ii) Zipper cracks
(iii) Edge cracks
(iv) Centre split
(v) Alligatoring
(vi) Folds
(vii) Laminations.

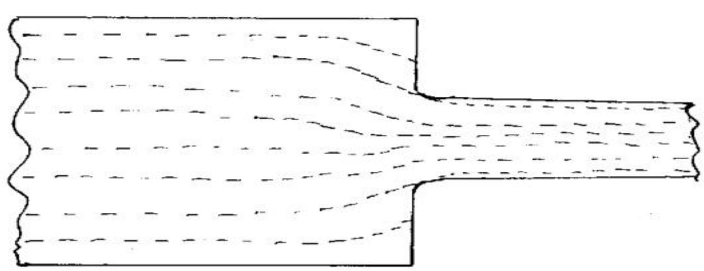
INTRODUCTION

Extrusion is a process in which the metal is subjected to plastic flow by enclosing the metal in a closed chamber in which the only opening provided is through a die. The material is usually treated so that it can undergo plastic deformation at a sufficiently rapid rate and may be squeezed out of the hole in the die. In the process the metal assumes the opening provided in the die and comes out as a long strip with the same cross-section as the die-opening. Incidentally, the metal strip produced will have a longitudinal grain flow. The process of extrusion is most commonly used for the manufacture of solid and hollow sections of nonferrous metals and alloys e.g., aluminum, aluminum-magnesium alloys, magnesium and its alloys, copper, brass and bronze etc. However, some steel products are also made by extrusion.

Pressure required for extrusion depends upon the strength of material and upon the extrusion temperature. It will reduce if the material is hot. It will also depend upon the reduction in cross-section required and the speed of extrusion. There is a limit to the extrusion speed. If extrusion is done at a high speed, the metal may crack. The reduction of cross-sectional area required is also called "extrusion ratio". There is a limit to this also. For steel extruded hot, this ratio should not exceed 40: 1, but for aluminum extruded hot it can be as high as 400: 1.

Extrusion:

Extrusion is the process of confining the metal in closed cavity and then forcing it to flow from one opening (die), so that metal will take the shape of opening. The operation of extrusion is similar to the squeezing of tooth paste out of toothpaste. The paste inside the tooth paste has no shape, when the tooth paste tube is squeezed the paste flows out of the circular opening taking the shape of the opening.



Metal flow in Direct Extrusion.

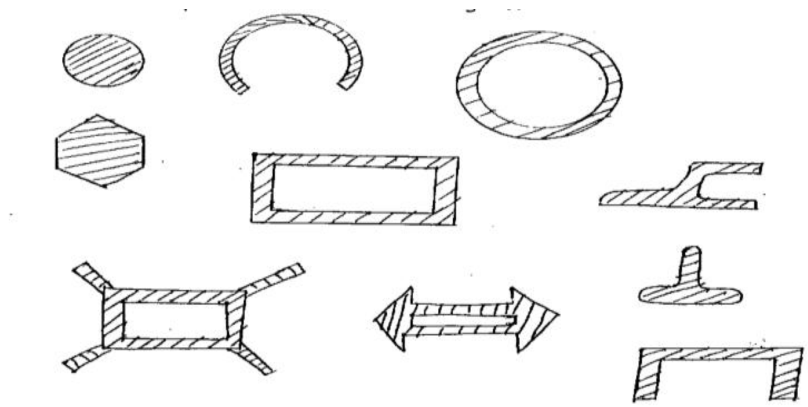
Range of Extrusion Products:

Extrusion process is used to manufacture products like;

(i) Rods
(ii) Tubes
(iii) A variety of circular, square, rectangular, hexagonal and other shapes both in solid or hollow form.

(iv) Channels like I and T and other sections.

Some of the extruded shapes are shown in below figure:



Advantages of the extrusion process are as follows:

2. Extrusion is a single pass process unlike rolling.
3. Dies are easy to manufacture.
4. Variety of shapes of high strength, good accuracy and surface finish can be obtained.
5. High production rate with relatively low die cost.
6. Complicated cross – sectional shapes which are not possible to achieve by rolling can be achieved by extrusion.
7. Larger deformation can be achieved by this process than other processes except casting.
8. Dies can be easily replaced and removed with no loss of time.

Disadvantages:

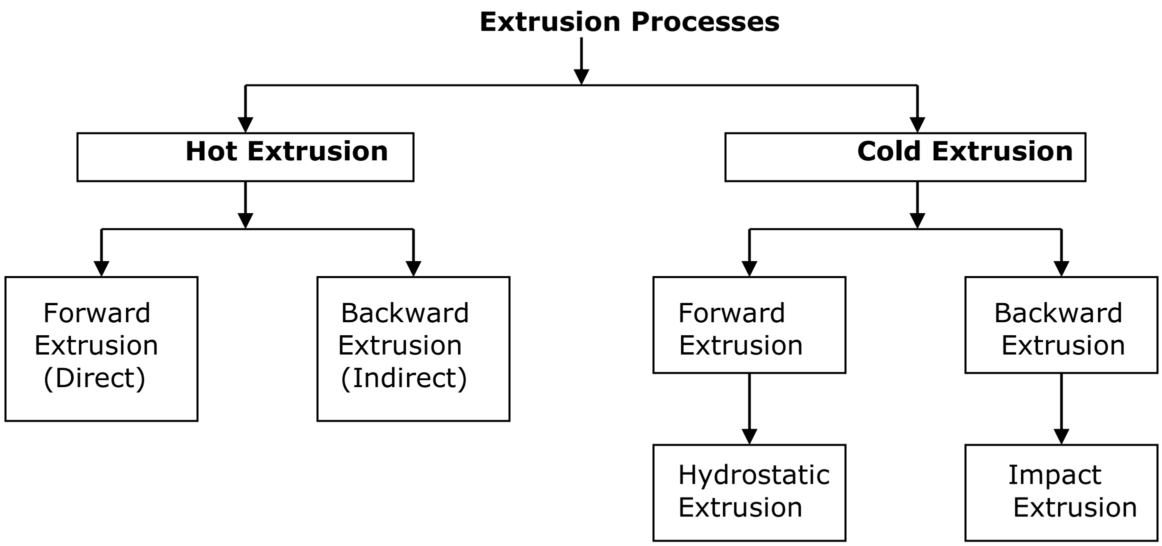
1. Tools are expensive.
2. Metal blank should be free from internal or external defects.

Classification of Extrusion Processes:

The process of extrusion consists of forcing a heated billet inside a chamber through a small opening called die under high pressure. The high pressure is obtained by hydraulic press or mechanical press. In its cross section, the extruded metal acquires the contour and dimensions of the die opening. Extrusion is more widely used in fabricating non-ferrous metals and their alloys.

The Extrusion process can be classified as:

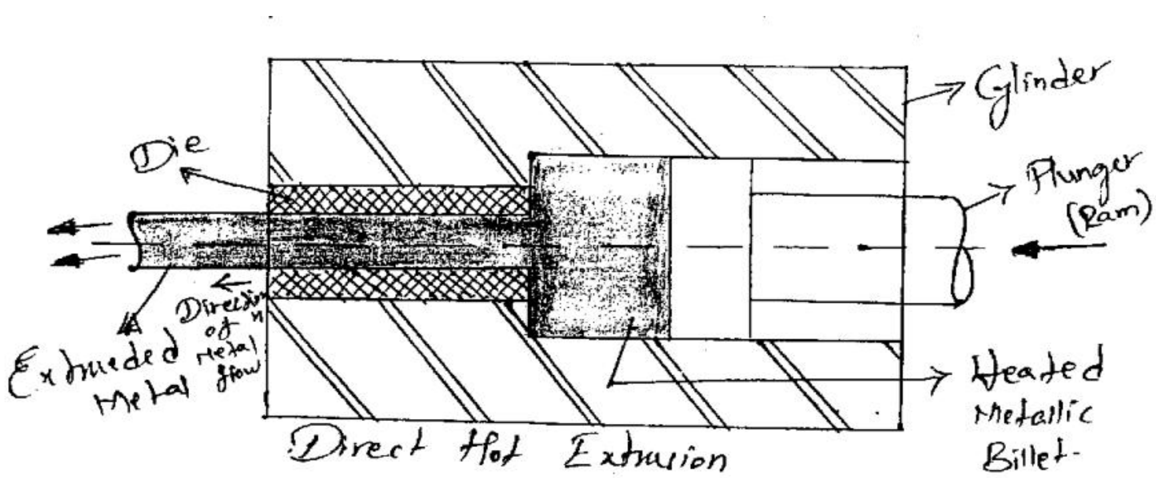
1. Hot extrusion process
2. Cold Extrusion Process



Hot Extrusion Process:

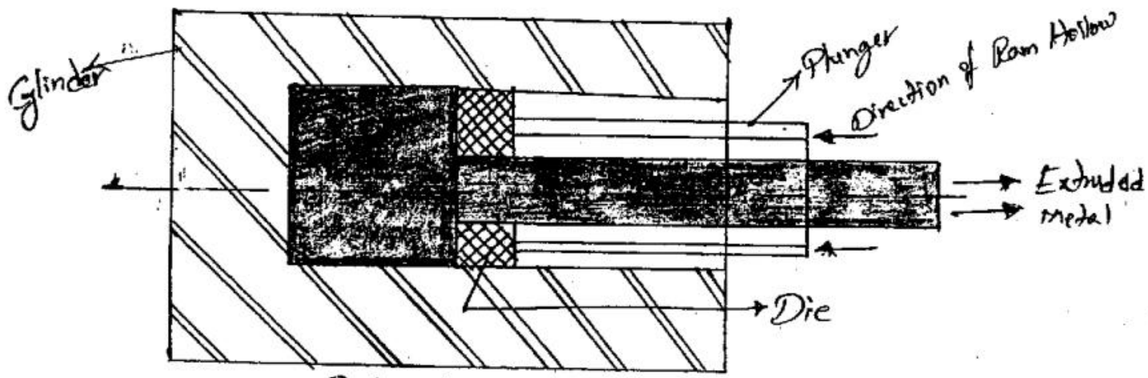
(i) Direct Hot Extrusion (Forward extrusion)

This is the most widely used method. A hot billet is placed in the container and the forced through the die with the help of pressure by a hydraulic driven ram. The extruded metal comes out of the die opening. In this process, the flow of metal through the die is in the same direction as the movement of the ram. The length of the extruded part will depend on the size of the billet and cross section of the die.



(ii) Indirect Hot Extrusion:

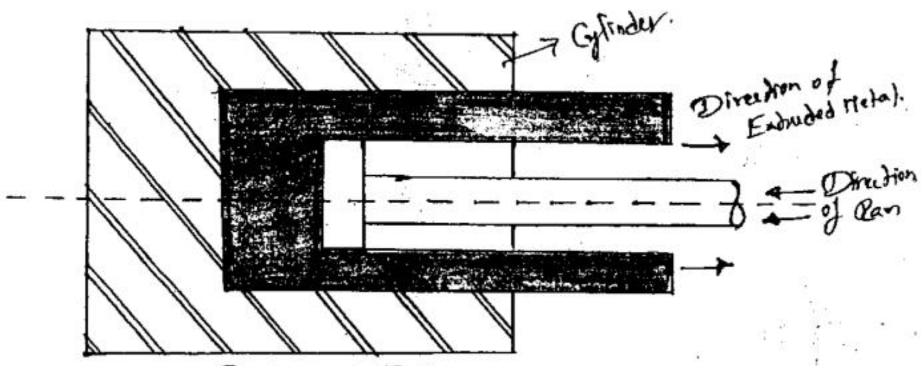
For this type of extrusion, the ram used is hollow and the die is mounted over the bore of the ram. In this process, the billet remains stationary, while the die is pushed into the billet by hollow ram. The metal flows in the direction opposite to the movement of the ram. Indirect extrusion does not require as much force as direct extrusion because no force is required to move the billet inside the chamber.



Indirect Extrusion

(iii) Backward Extrusion:

This is another indirect extrusion method used in manufacturing hollow sections as shown in figure. In direct and indirect extrusion methods the ram is of the same diameter as the bore of the container, where as in backward extrusion the ram is smaller in diameter than the container. In this process, the metal is extruded through the gap between the ram as the container.



Backward Extrusion

Forward or Direct extrusion	Backward or Indirect extrusion
1. Simple, but the material must slide along the chamber wall. 2. High friction forces must be overcome. 3. High extrusion forces required but mechanically simple and uncomplicated. 4. High scrap or material waste—18–20% on an average.	1. In this case, material does not move but die moves. 2. Low friction forces are generated as the mass of material does not move. 3. 25–30% less extruding force required as compared to direct extrusion. But hollow ram required limited application. 4. Low scrap or material waste only 5–6% of billet weight.

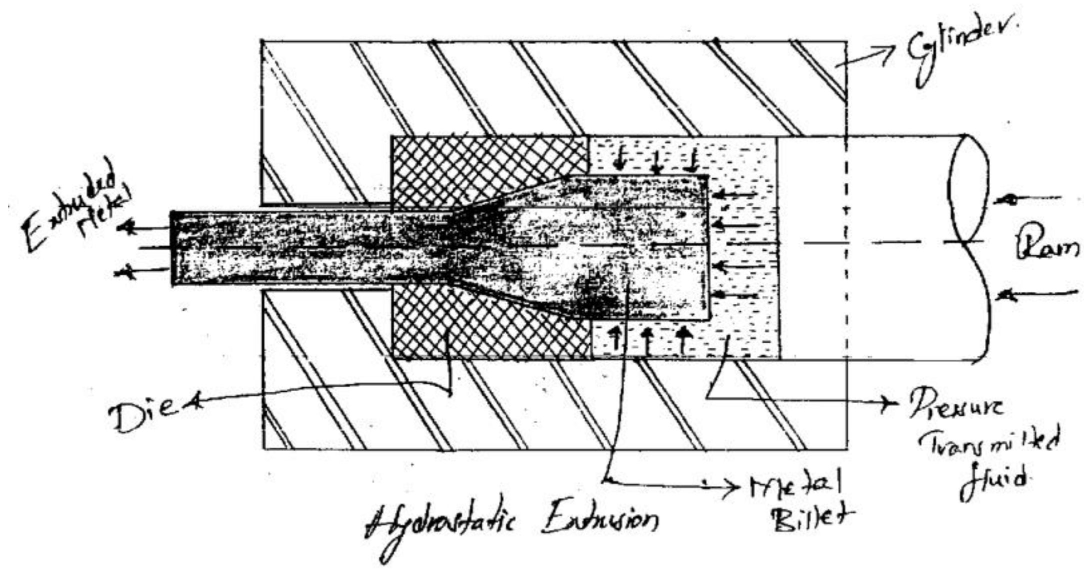
Cold Extrusion Process:

(i) Forward Cold Extrusion:

The forward cold extrusion is similar to forward hot extrusion except that temperature is comparatively lower and extrusion pressures are higher than got extrusion. It is usually used for simple shapes. The cold extruded products have better surface finish and improved mechanical properties. The common applications of cold extrusion are aluminium brackets, tubes, shock-absorber cylinders etc… Now a day's cold extrusion has also been used for forming mild steel parts often in combination with cold forging.

Hydrostatic Extrusion:

It is another extrusion process which makes possible to cold extrude many difficult to form materials such as high strength super alloys, molybdenum etc… Here instead of applying the load directly by ram, a liquid medium is used. The presence of liquid inside the container eliminates the need of lubricant and also force transmitted is uniform from all sides throughout the deformation zone. Because of this highly brittle materials such as grey cast iron can also be extruded. Applications include extrusion of reactor fuel rods, making wire of less ductile materials.



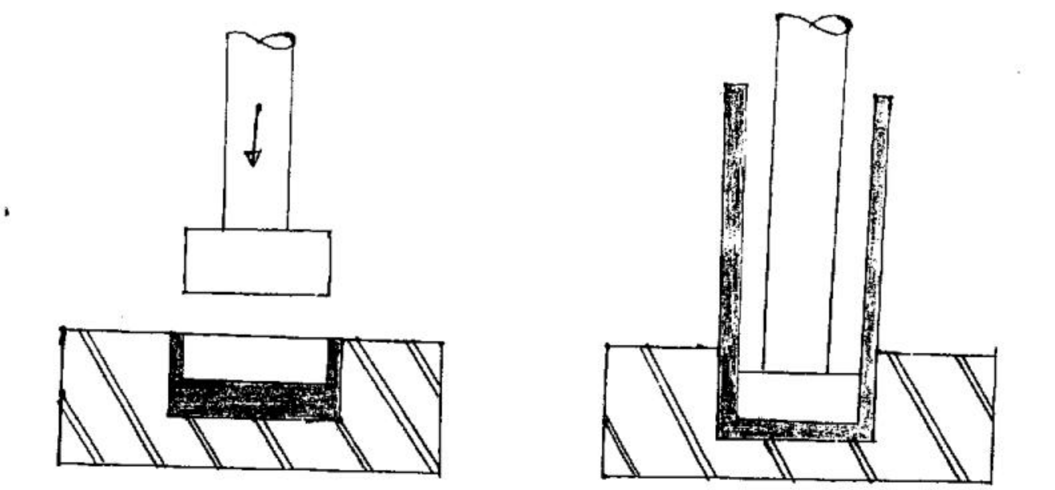
(ii) Backward Cold Extrusion (or) Impact Extrusion:

The backward cold extrusion is called impact extrusion. This process involves striking a cold slug of soft metal (like aluminum) which is held in a shallow die cavity with a moving punch. The metals then extruded through the gap between the punch and die opposite to the punch movement. The height of the sidewalls is controlled by the amount of metal in the slag. Various items of daily use such as tubes for shaving cream, toothpaste and paints are made by impact extrusion.

There are three types of impact extrusion processes:

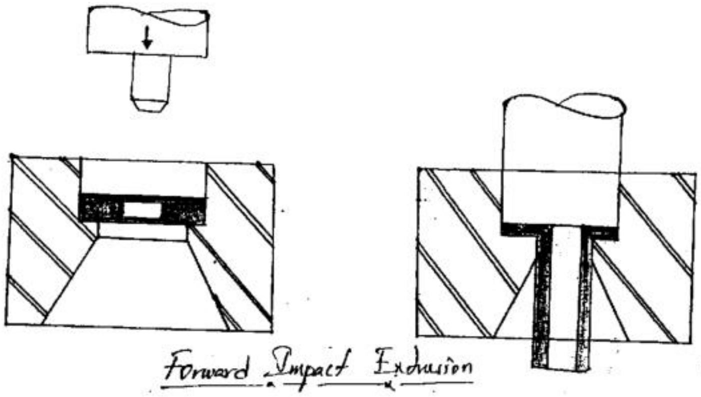
(a) Reverse impact extrusion
(b) Forward impact extrusion
(c) Combination impact extrusion

(a) Reverse Impact Extrusion: The following figure indicates the process of reverse impact extrusion. In this process, the metal flows in reverse direction of the plunger. It is used for making hollow parts with forged bases and extruded walls. The flowing metal is guided only initially, thereafter if goes by its own inertia.



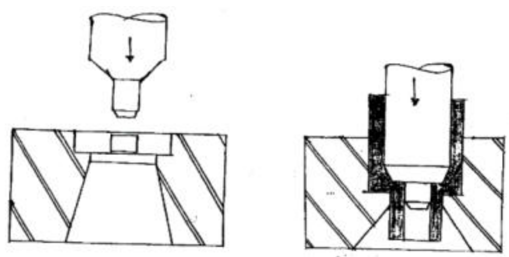
Reverse Impact Extrusion

(b) Forward Impact Extrusion: The process of forward impact extrusion is shown in below figure. It is mainly used for making hollow or semi hollow products with heavy flanges.



Forward Impact Extrusion

(c) Combination Impact Extrusion: Complex shapes can be produced by a combination of the two preceding procedures, which are performed simultaneously in the same single stroke as shown in below figure.



Combination Impact Extrusion

(iii) Hooker extrusion process: This process is also known as extrusion down method. It is used for producing small thin walled seamless tubes of aluminium and copper. This is done in two stages. In the first stage the blank is converted into a cup shaped piece. In the second stage, the walls of the cup one thinned and it is elongated. The process can be understood by referring to Fig. 4.4. This process is a direct extrusion process.

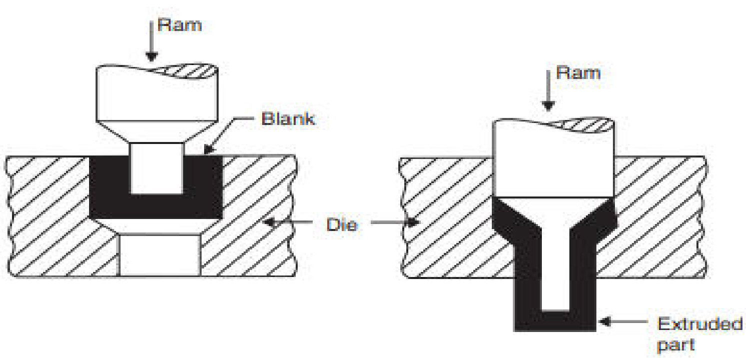


Fig. -.- Hooker extrusion

Cold extrusion	Hot extrusion
1. Better surface finish and lack of oxide layers. 2. Good control of dimensional tolerance—no machining or very little machining required. 3. High production rates at low cost. Fit for individual component production. 4. Improved mechanical properties due to strain hardening. 5. Tooling subjected to high stresses. 6. Lubrication is crucial.	1. Surface is coated with oxide layers. Surface finish not comparable with cold extrusion. 2. Dimensional control not comparable with cold extrusion products. 3. High production rates but process fit for bulk material, not individual components. 4. Since processing is done hot, recrystallization takes place. 5. Tooling subjected to high stresses as well as to high temperature. Tooling stresses are however lower than for cold extrusion. 6. Lubrication is crucial.

Drawing: Drawing is a sheet-metal-forming operation used to make cup-shaped, box-shaped, or other complex-curved and concave parts. It is performed by placing a piece of sheet metal over a die cavity and then pushing the metal into the opening with a punch.
Common parts made by drawing include beverage cans, ammunition shells, sinks,cooking pots, and automobile body panels.
It is also known as cold drawing refers to two different operations.

(a) If the starting material is sheet metal than the operation is sheet metal drawing.
(b) If the starting material is wire, rod or tube then the operation is wire drawing rod drawing or tube drawing respectively.

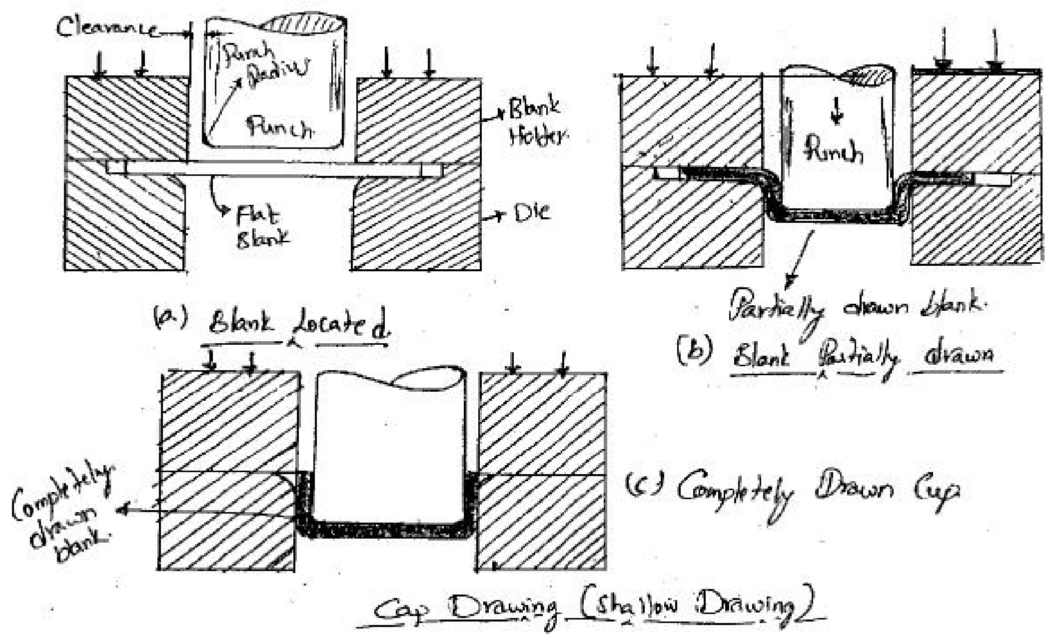
(a) Sheet Metal Drawing:

Sheet metal drawing is defined as process for making cup shaped articles from flat sheet metal blanks. Common examples of such components are dishes, trays, brake drums, cylindrical container etc… Sheet metal drawing operation is shown in below figure.

The setup is similar to that used in blanking except that punch and die are provided with necessary rounding at the corner. The rounding is provided to allow the smooth flow of metal during drawing. The blank is first placed and located above the die. The blank holder comes down properly holds the edges of the blank. After this punch moves downwards to force, the blank to take the shape of cup formed by the end of the punch. The punch and blank holder then returns upward to complete the cycle.

- The punch and die radius should be equal and sufficient large (about 5 times thickness of metal). Large punch radius prevents fracture of metal near the end of punch where tensile forces are maximum. Large die radius prevents tearing of metal as it flows over the edge of the die. The radius should not be too large otherwise wrinkle may form.

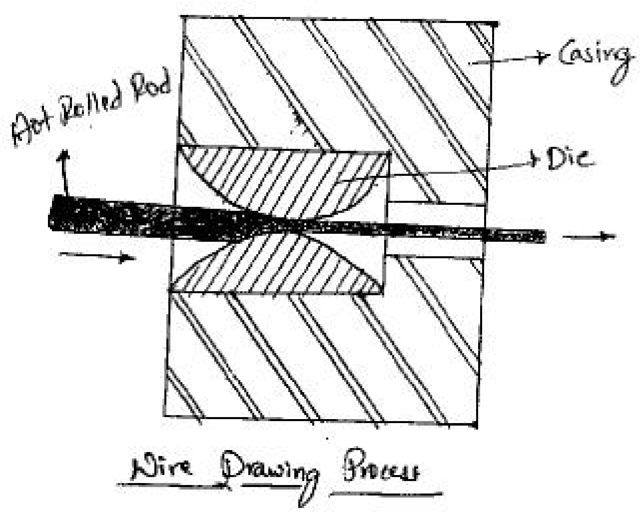
- The depth of draw in sheet metal drawing may be shallow, moderate or deep. If the depth of formed cup is less than half its diameter the process is called shallow drawing. If the depth of formed cup exceeds the diameter, it is known as deep drawing. Bottle caps and automobile panes are the examples of drawing process.

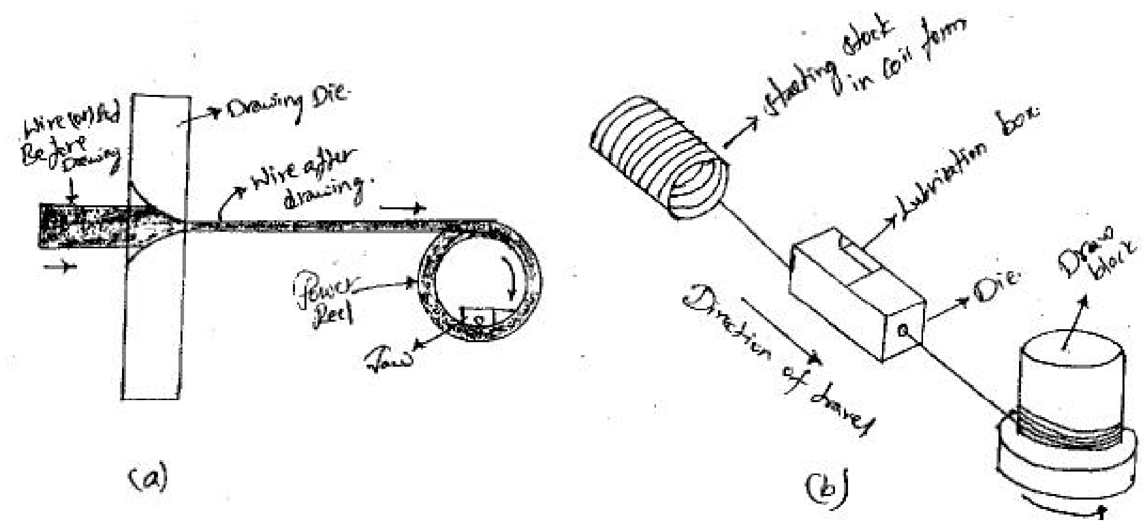


(b) (i)Wire Drawing:

Wire may be defined as metal in form of thread or slender rod which is flexible. Wire drawing process is to obtain wires from rods of bigger diameter through die. Rods are the bars with circular cross section. Wire drawing is always a cold working process.

The below first figure shows wire drawing die and second figure shows wire drawing machine. The opening in the die is generally conical. The end of the wire to be drawn is made in to a point shape and inserted through the die opening. This end is then gripped properly and pulled sufficiently by suitable means so that this end can be attached to power reel. From there on, power reel rotates at proper speed and pulls the entire piece through die.





Before the wire is drawn stock needs to be prepared for wire drawing. The four major aspects of stock preparation for wire drawing are as follows:

1. **Annealing:** The wire should be annealed properly as the material loses its ductility during wire drawing process and when it is to be repeatedly drawn to bring it to the final size, intermediate annealing is required to restore the ductility.

2. **Preparation of conical end:** As the wire is to go through conical portion of die and then pulled out through the exit by gripper. In this process there is no force applied for pushing the wire into die from entrance side. To make an easy entry of wire into die the end of the stock is made pointed by means of simple hammering or by rotary swaging.

3. **Cleaning:** The wire should be cleaned properly as it flows through the die. Cleaning is essentially done to remove any scale and rust present on the surface which may severely affect the die. Cleaning is normally done by acid pickling.

4. **Lubrication:** The pressure acting at the interface of metal and die is quite high and, therefore lubrication of die is a serious problem. Two methods of lubrication are widely employed. In one method wire surface is cleaned, coated with lime and thoroughly dried. Before entering the die lubricant such as grease or soap is applied to surface of wire or rod. Second method is used for very thin wires. In this case electrolytic coating of copper is used to reduce friction.

The material of wire drawing die are generally chilled cast iron, hardened alloy steel, tungsten carbide of diamond. Tungsten carbide die are preferred because of their long life.

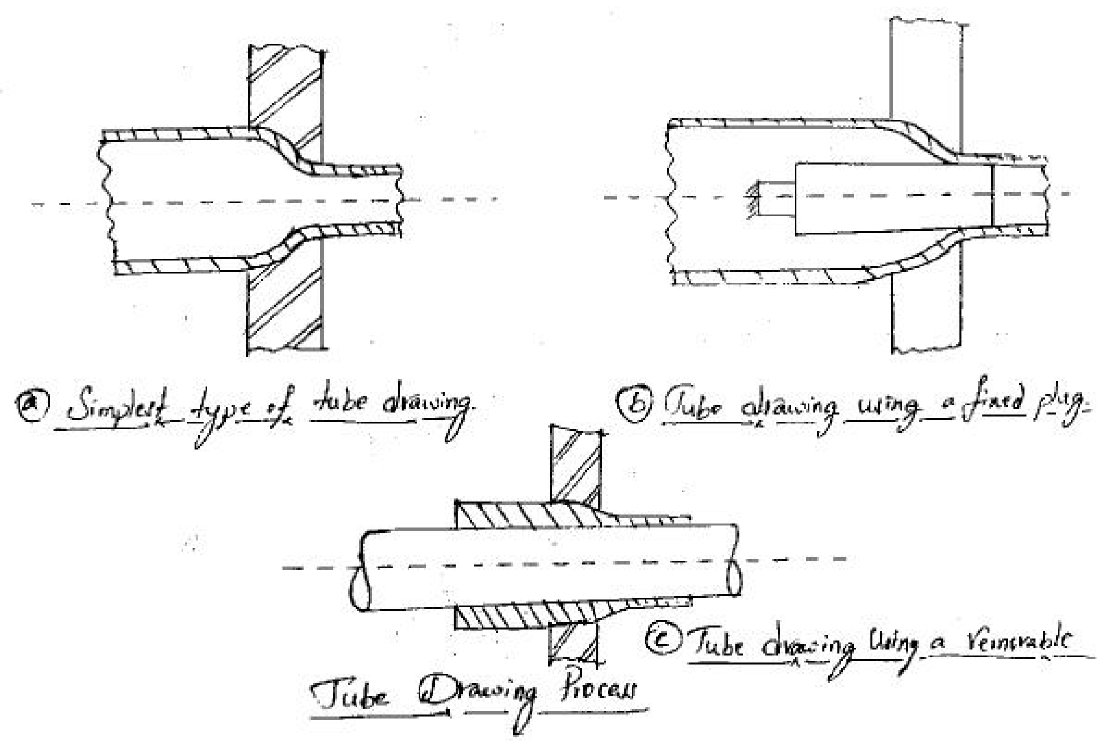
(ii)Tube Drawing:

Tube drawing is also similar to the other drawing processes. In this process the large diameter tube is shrink in to small diameter by drawing the tube through the die. The following are the basic types of tube drawing processes as shown in below figures.

I) Simple tube drawing process [Tube Sinking process]

II) Mandrel drawing process: it is further in three types as (i) Stationary Mandrel process (ii)Moving Mandrel Process (iii) Floating Mandel Process

The first figure indicates the simplest form of tube drawing process. In this process, no internal mandrel is used hence if is called sinking process. The technique shown in second figure reduces the tube diameter and controls its thickness. However, the imitation is length of the tube by length of the mandrel. To overcome this problem, moving mandrel as shown in third figure is used. The tubes are also first pointed and then entered through the die and on the other side of the die; this end is gripped in tongs, which is connected to the draw bench. There may be more than one pass required to get the final size. The reduction in one pass is about 40 percent. The metal is annealed after every pass in order to remove the effect of strain hardening. Hot drawn tubes are also cold drawn to provide good surface finish, better dimensional accuracy and improved physical properties.



Unit -4. Sheet Metal Forming Processes

[**Sheet metal forming**: - Blanking and piercing, Forces and power required in this operations. Deep drawing, Stretch forming, bending, spring back and its remedies, coining and Spinning. High Energy rate forming processes: Principles of explosive forming, electromagnetic forming, electro hydraulic forming, rubber pad forming, advantages and limitations.]

Introduction

Forming is a mechanical process used in manufacturing industries where in materials undergo plastic deformation and acquire the desired shape and sizes by the application of suitable forces such as compression ,tension and shear.

Forming is the operation which reproduces flat stock into the shape of punch and dies with little or no plastic flow of the metal. An example is a punch and dies designed to form a flat strip of steel into a U – shape.

Forming process can be classified in to Two groups :- (I) Bulk Forming (II) Sheet Metal Forming.

Bulk Forming: Bulk forming is a method of producing materials in large volumes of products whose surface area is less than the volume ratio. The following are the various bulk forming processes Examples are:-Rolling ,Forging, Extrusion,Wire drawing .

Sheet metal forming: It is also known as cold drawing process. If the starting material is sheet metal than the operation is sheet metal drawing.Sheet metal forming involve the application of tensile, compressive and shear forces to fabricate sheets, plates and strips to a desired possible shape using s set of tools such as a punch and die. Sheet metal forming process used for making cup shaped articles from flat sheet metal blanks. Common examples of such components are dishes, trays, brake drums, cylindrical container etc The following are the various sheet metal forming processes:Bending,Deep drawing,Stretching,Blanking,Punching,Flanging,Hemming,Curling,Stretch forming, Stamping. Press work is an industrial manufacturing process where sheet metal is manipulated and shaped by press machinery. Sheet metal is cut by a punch/die manually or automatically and it is created in to a particular component during this process.

TOOLS

A set of dies is the required tooling for working with the presses. A die set consists essentially of three parts: (i) a punch (male tool), (ii) a die (a female tool) and (iii) stripper plate.

The punch is fixed or bolted to the ram and the die is fixed on the machine bed in such a manner that the two are in perfect alignment. When the punch along with the ram of the press moves downwards, the punch passes centrally through the die.

When the punch descends, it shears the metal-sheet. The hole punched through has the same profile as the punch. If the remaining portion of the sheet metal is the useful part, the punched out portion is thrown away as scrap. In this case, the operation is called "punching". However, if the punch out portion is the useful part, the operation is termed "blanking" and the punched out piece is referred to as blank. The size of blank is determined by the size of hole in the die.

The function of the stripper plate is to keep the sheet held down during the subsequent upward movement of the punch; otherwise, the sheet may get entangled with the punch during the upward movement of the ram and the punch.

Stamping (metalworking)

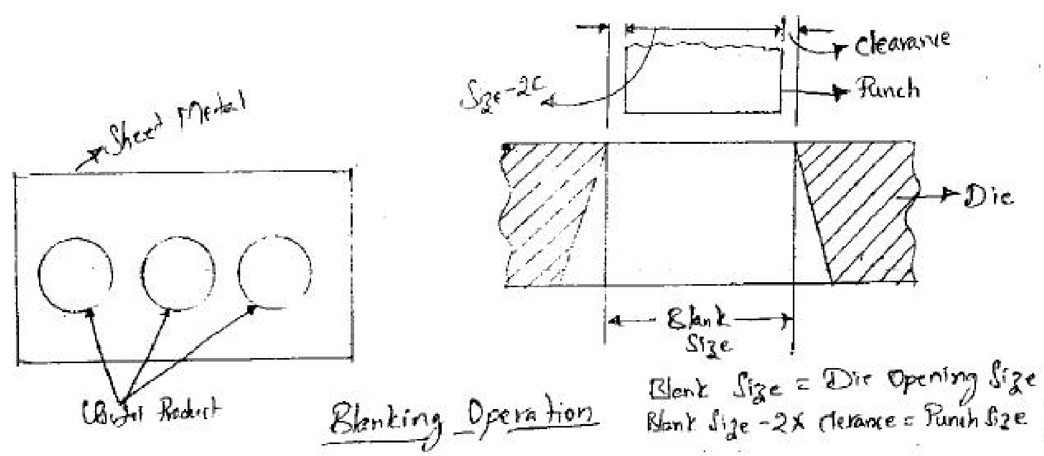
Stamping includes a variety of sheet-metal forming manufacturing processes, such as punching using a machine press or stamping press, blanking, embossing, bending, flanging, and coining. This could be a single stage operation where every stroke of the press produce the desired form on the sheet metal part, or could occur through a series of stages. The process is usually carried out on sheet metal, but can also be used on other materials, such as polystyrene.

Operations

- Bending
- Blanking
- Coining
- Drawing
- Piercing

Blanking:

Blanking is the operation of cutting out flat shapes from sheet metal strip. The removed portion is called blank which is required product of the operation and metal with hole left behind discarded as waste. Blanking is usually first operation and blank is further processed to produce desired part. Blanking is identical to the punching except that in blanking removed portion is desired product where as in punching sheet with the hole is desired product.

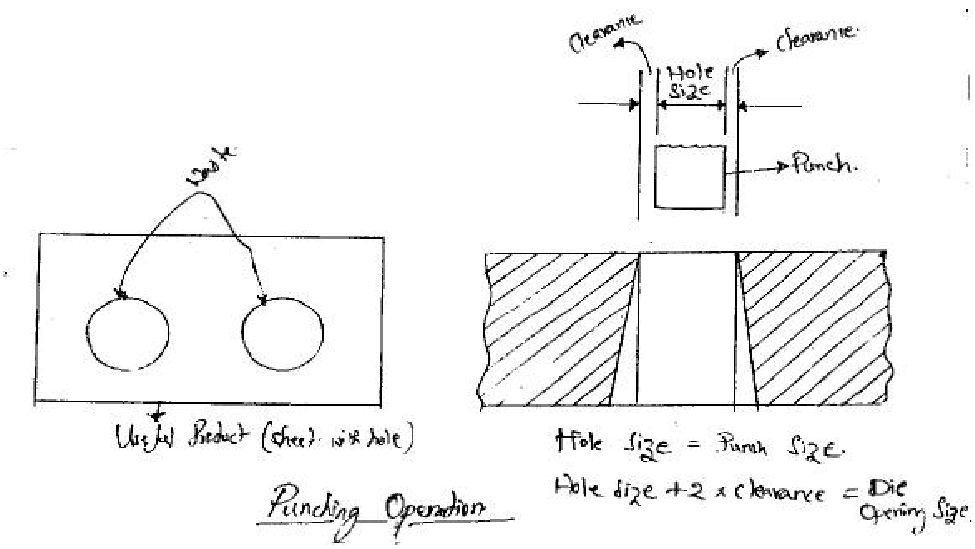


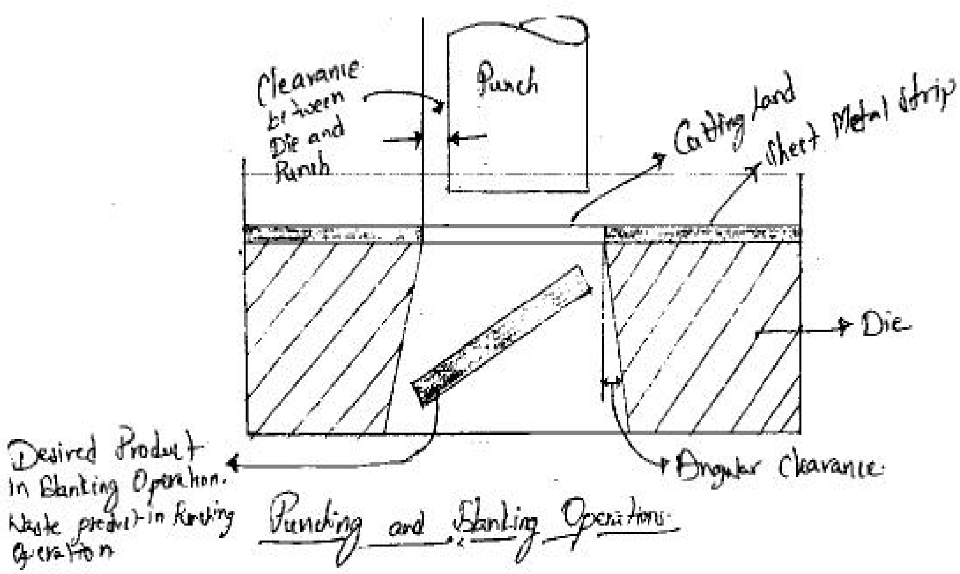
- ➢ The punch and die are made of suitable hard and strong material such as hardened high carbon steel, high chromium oil hardening steel, or tungsten carbide.
- ➢ In blanking operation die opening size equals the blank size and punch size is obtained by subtracting clearance form die opening size.

Punching:

The punching is cutting operation by which various shaped holes are made in sheet metal strip. In punching operations sheet with the hole is desired product and material punched out is scrap. Normally punching operation is performed after blanking.

- The punch and die are made of a suitable hard and strong material, such as hardened high carbon steel, high chromium oil hardening steel or tungsten carbide.
- In punching operation the punch size equals the size of hole and die opening size is obtained by adding the clearance to punch size.





Forces and Power requirement in Punching and Blanking Operations

Punching and blanking are essential sheet metal operations used to cut shapes out of a sheet. Punching creates a hole by removing material (the slug is waste), while blanking creates a part (the blank is the desired product) by cutting it from the surrounding material. In both processes, a punch and die are used to apply force to shear the metal.

The punching force is the force needed to shear material by multiplying the material's shear strength by the shear area (perimeter time’s thickness). The power required depends on this force and the punching speed, often involving pneumatic or hydraulic systems to generate the necessary force. Factors like material type, thickness, hole size, and tool design, including the punch tip shape and stripper, all influence the required forces and power.

Forces in Punching Operation

Shear Force Calculation: The primary force is the shear force, calculated as:

$$\mathbf{F = \tau_u \times Shear\ Area}$$

Where: **F** is the punching force.

τ_u is the shear strength of the material.

Shear Area is the perimeter of the hole multiplied by the material thickness.

For a circular hole, $\mathbf{F = \tau_u \times (\pi d \times t)}$.

For a square hole, $\mathbf{F = \tau_u \times (4a \times t)}$, where '**a**' is the side length.

Factors Influencing Force:

- **Material Properties**: Higher shear strength materials, like steel, require greater force.
- **Material Thickness**: Thicker materials require more force.
- **Hole Size**: Larger holes increase the shear area, demanding higher force.
- **Punch and Die Clearance**: This also impacts the required force.
- **Punch Tip Design**: Concave punch tips can reduce the force needed compared to flat tips.

Power Requirement:

1. **Energy and Work**: Power is the rate at which work is done. To determine power, you must also consider the speed at which the punch moves through the material.
2. **System Power:** Punching operations are powered by systems that generate the necessary force.
    - Pneumatic Power: Uses compressed air to drive the punching action.
    - Hydraulic Power: Utilizes hydraulic fluid pressure to achieve high forces.

Calculation/Formula for Power Requirement:-

Work Done (W): The total work done is equal to the punching force multiplied by the distance the punch travels to shear the material.

Time (T): The time it takes to complete the punch stroke.

Power (P): Therefore, Power = Work / Time = (Force × Distance) / Time.

Following are the terminologies associated with punch and die setup in shearing:

1. Angular clearance: The angular clearance is shown in above figure.

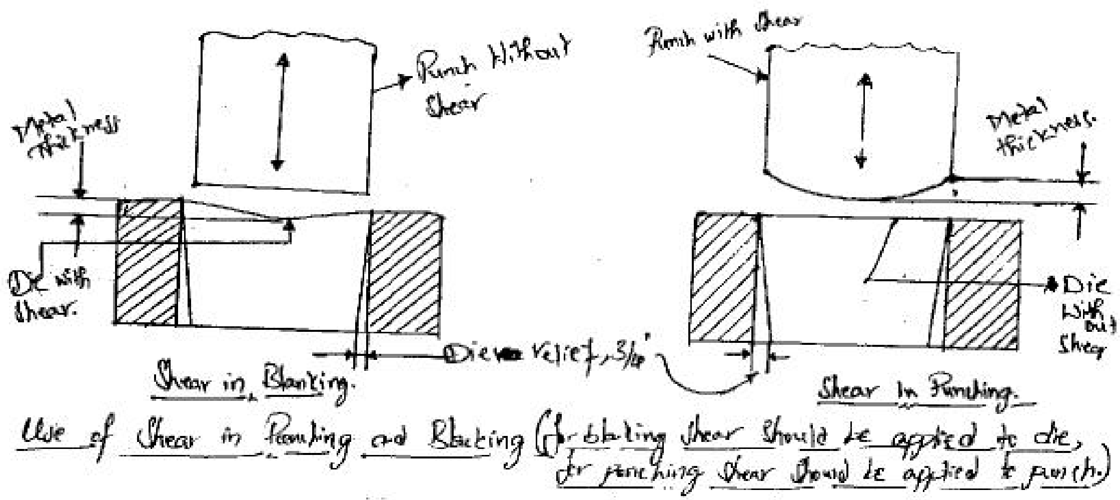
In blanking and punching operation first the material is elastically deformed and then plastically and finally removed from the sheet metal strip. After the final breaking, the size of blank will slightly increase because of spring back and this will make the blank to jam in die. It is usual practice to provide angular clearance on dies to avoid sticking of blank to die face. The angular clearance or draft provided depends on the material, thickness and shape of stock used. For thicker and softer materials generally higher angular clearances are provided. The normal value is from 0.25° to 0.75° per side but occasionally a value as high as 2° may be used.

2. Cutting land: The diameter of die at the top keeps on increasing after every sharpening because of the provision of angular clearance. In order to maintain the die size as per design it is a usual practice to provide straight portion along with angular clearance. This is called die land or cutting land. The length of cutting land is about 3 mm for sheets which are less than 3 mm thick. For greater thicknesses die land same as the material thickness has been found to be a good practice.

3. Stripper: During shearing operation after the final breaking, the hole size of metal strip will slightly decrease because of spring back and strip will cling tightly to the punch. A stripper therefore is provided to remove the metal strip from sides of punch as punch returns upward.

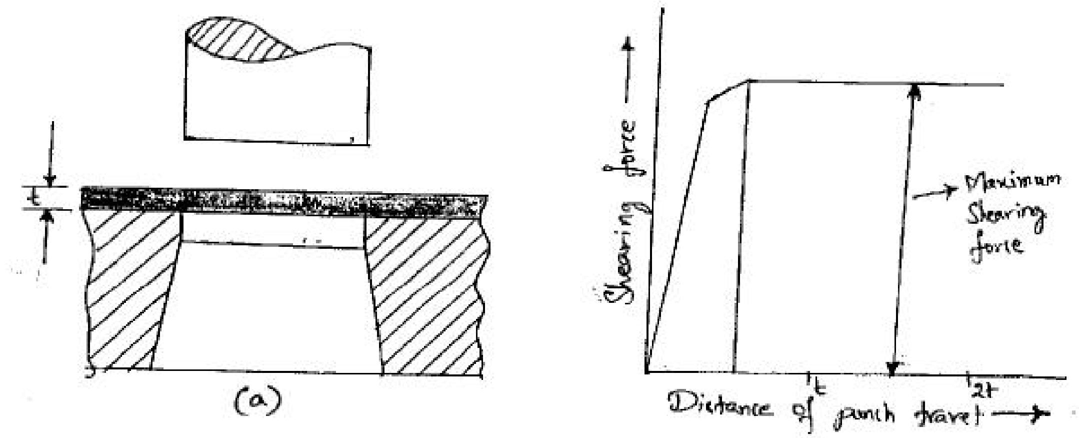
Application of shear in Blanking and Punching and its use:

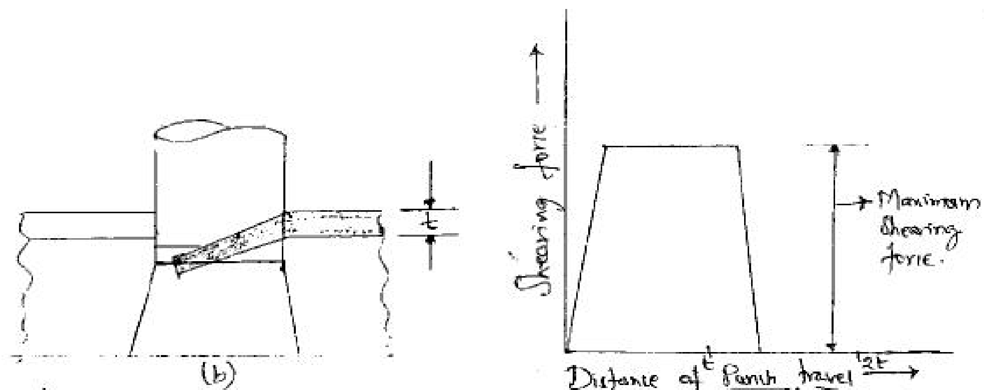
While discussing the shearing processes it was assumed that bottom of punch and top of die block are flat and lie in parallel planes. This process requires very high shearing force exerted over a very short time. It is usual practice to reduce cutting forces and to smooth out the shock of heavy loads by providing shear on either die or punch. The effect of providing shear is to distribute the cutting action over a period of time depending on the amount of shear provided. The following figure shows punching and blanking operations where shear is provided on punch and die respectively.



It may be noted that providing the shear only reduces the maximum force to be applied but not the total energy required in shearing the component. Shearing energy is equal to shearing force multiplied by penetration or distance necessary to effect the completer shearing. By providing shear on die or punch, maximum shearing force decreases and distance necessary to affect complete shearing increases. Thus we can say total energy required to shear provided on die and punch.

Effect of shear on shearing force is shown in below figure.



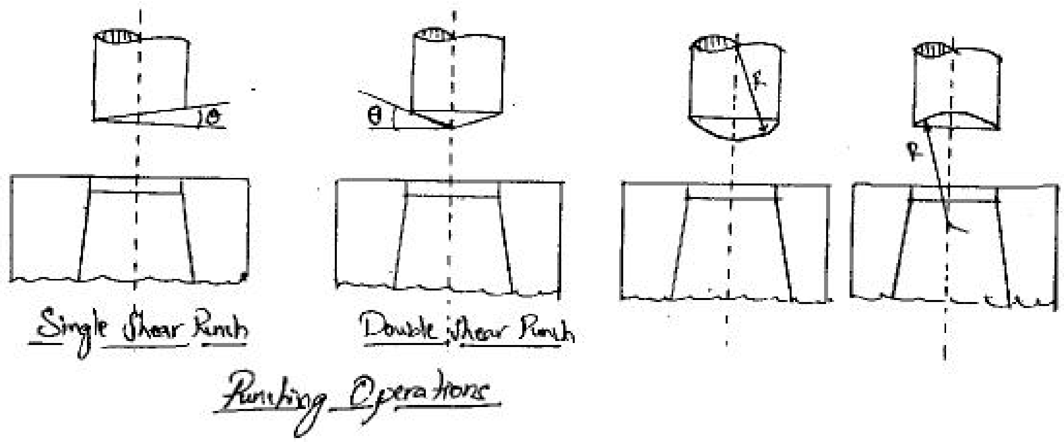


In figure (a) shear is not provided so maximum shearing force is much higher than as shown in fig (b). In fig (b) shear is applied so maximum shearing force is less than as shown in fig (a).

The provision of shear on the punch distorts the shape of blank and provision of shear on die would bend the stock with hole. So, in blanking operation to obtain the flat blank shear is provided on the die and for punching operation shear provided on the punch to obtain sheet with hole as flat.

Piercing:

Piercing is a shearing process where a punch and die are used to create a hole in sheet metal or a plate. The process and machinery are usually the same as that used in blanking, except that the piece being punched out is scrap in the piercing process. There are many specialized types of piercing: lancing, perforating, notching, nibbling, shaving, cutoff, and dinking.



The amount of clearance between a punch and die for piercing is governed by the thickness and strength of the work-piece material being pierced. The punch-die clearance determines the load or pressure experienced at the cutting edge of the tool, commonly known as point pressure. Excessive point pressure can lead to accelerated wear and ultimately failure.

Burr height is typically used as an index to measure tool wear, because it is easy to measure during production.

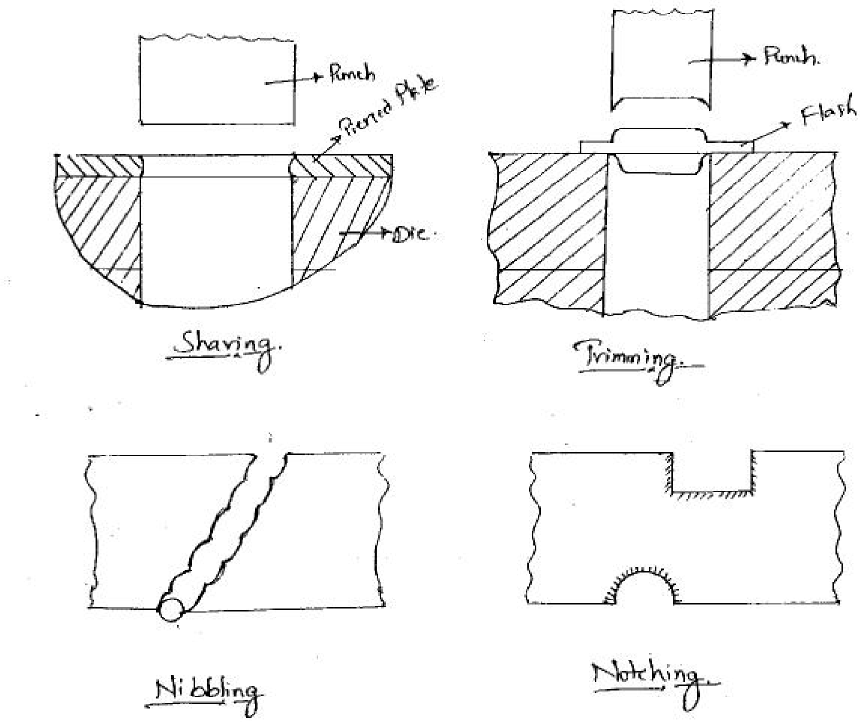
For simple piercing operations a pan cake die is used.

Specialized types of piercing are,

- Lancing
- Perforating
- Notching
- Nibbling
- Shaving
- Cutoff

Shaving:

In blanking or piercing, the edge of blank or the hole is not perfectly clean because of burr generated in the shearing process. It is basically a finishing operation in which the small amount of material is sheared away from the edge of an already blanked or pierced part. Its primary use is to obtain greater dimensional accuracy. It is also used to produce a smoother edge. Because of only small amount of metal is removed the punches and dies must be made with very little clearance. Blanked parts such as small gears can be shared to produce dimensional accuracy within 0.025 mm.



Trimming:

In operations such as forging, die casting and drawing of sheet metals the small amount of excess metal gets spread out neat the parting line. This extra metal is called flash. The flash is to be trimmed before forging or casting is to be used. The dies used for this purpose are similar to blanking dies. The main difference is the type of presses used for trimming, which should normally have a large table. The figure shows trimming operation.

Nibbling:

In nibbling operation a specific contour is cut by producing a series of over lapping holes or notches as shown in figure. In this manner simple punches can be used to cut a complex shape from sheet metals. Nibbling is used when contour is long and separate punch is impractical and uneconomical. The punches used may be square, round or triangular depending upon the applications.

Notching:

Notching is essentially same as the piercing except that it removes small portion of metal along the edge of the stock.

Sheet Metal Forming:

Sheet metal forming is defined as process for making cup shaped articles from flat sheet metal blanks. Common examples of such components are dishes, trays, brake drums, cylindrical container etc… Sheet metal drawing operation is shown in below figure.

It is also known as cold drawing refers to two different operations.

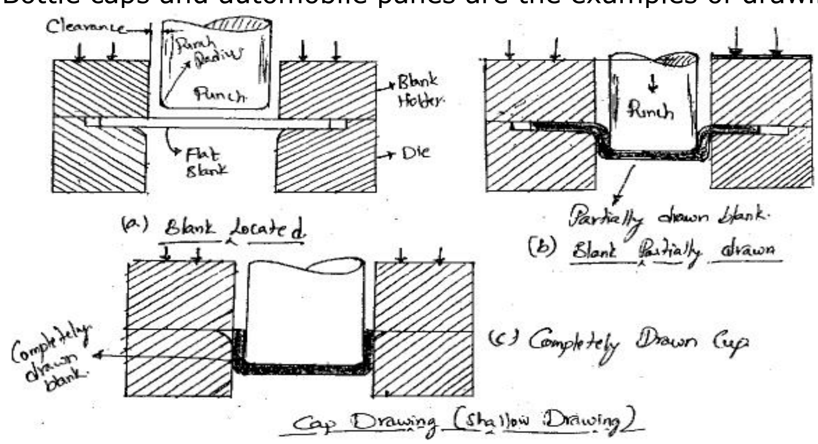
If the starting material is sheet metal than the operation is sheet metal drawing

The set up is similar to that used in blanking except that punch and die are provided with necessary rounding at the corner. The rounding is provided to allow the smooth flow of metal during drawing. The blank is first placed and located above the die. The blank holder comes down properly holds the edges of the blank. After this punch moves downwards to force, the blank to take the shape of cup formed by the end of the punch. The punch and blank holder then returns upward to complete the cycle.

- The punch and die radius should be equal and sufficient large (about 5 times thickness of metal). Large punch radius prevents fracture of metal near the end of punch where tensile forces are maximum. Large die radius prevents tearings of metal as it flows over the edge of the die. The radius should not be too large otherwise wrinkle may form.

The depth of draw in sheet metal drawing may be shallow, moderate or deep. If the depth of formed cup is less than half its diameter the process is called shallow drawing. If the depth of formed cup exceeds the diameter, it is known as deep drawing. Bottle caps and automobile panes are the examples of drawing process

- The punch and die radius should be equal and sufficient large (about 5 times thickness of metal). Large punch radius prevents fracture of metal near the end of punch where tensile forces are maximum. Large die radius prevents tearings of metal as it flows over the edge of the die. The radius should not be too large otherwise wrinkle may form.
- The depth of draw in sheet metal drawing may be shallow, moderate or deep. If the depth of formed cup is less than half its diameter the process is called shallow drawing. If the depth of formed cup exceeds the diameter, it is known as deep drawing. Bottle caps and automobile panes are the examples of drawing process.



DEEP DRAWING:

In deep drawing process, we start with a flat metal plate or sheet and convert it into cupshape by pressing the sheet in the centre with a circular punch fitting into a cup shaped die. In household kitchen, we use many vessels like deep saucepans (or BHAGONA), which are made by deep drawing process. If the depth of cup is more than half its diameter, the process is termed as deep drawing and with a lesser depth to diameter ratio, it is called shallow drawing. Parts of various geometries and shape are made by drawing process. The deep drawing process is illustrated in Fig.

During the drawing process, the sheet metal part is subjected to a complicated pattern of stress. The portion of the blank between the die wall and punch surface is subjected to pure tension, whereas the portion lower down near the bottom is subject both to tension and bending. The portion of metal blank, which forms the flange at the top of the cup is subjected to circumferential compressive stress and buckling and becomes thicker as a result thereof. The flange has therefore to be held down by a pressure pad, otherwise, its surface will become buckled and uneven like an orange peel. Deep drawing is a difficult operation and the material used should be specially malleable and ductile, otherwise it will crack under the induced stresses. The wall thickness of a deep drawn compo nent does not remain uniform. The vertical walls become thinner due to tensile stresses. But the thinnest portion is around the bottom corner of the cup all around. This thinning of sheet at these locations is called “necking”. After deep drawing, the component may be subjected to certain finishing operations like “irowing”, the object of which is to obtain more uniform wall thickness.

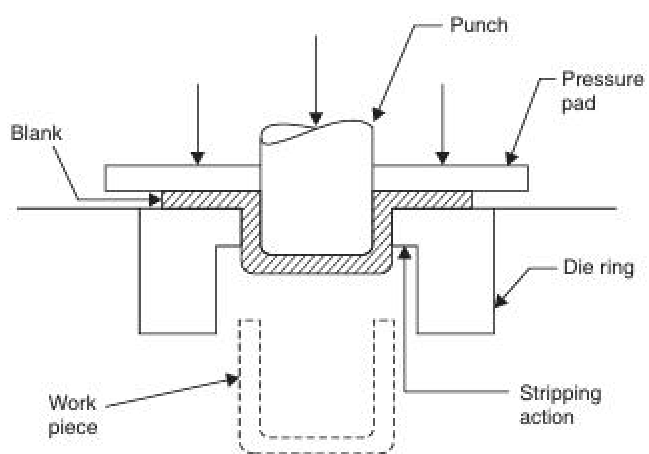


Fig. Deep drawing operation

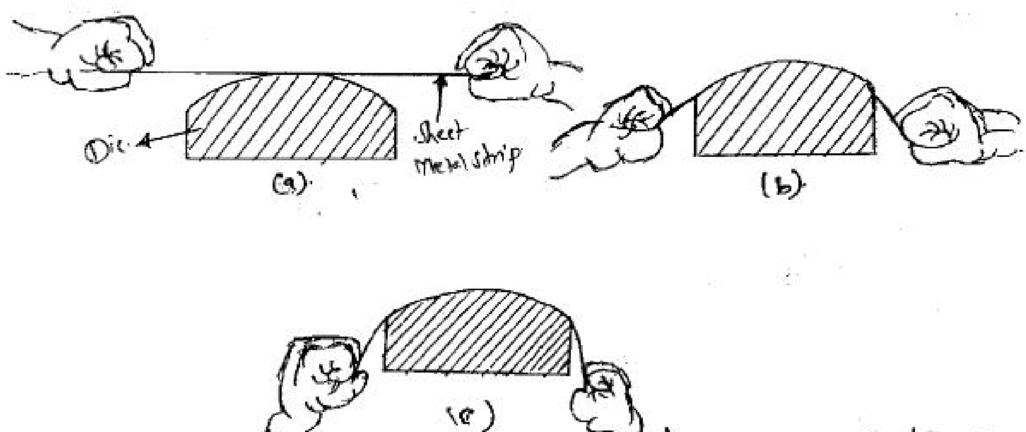
Forming:

Forming is the operation which reproduces flat stock into the shape of punch and dies with little or no plastic flow of the metal. An example is a punch and dies designed to form a flat strip of steel into a U – shape.

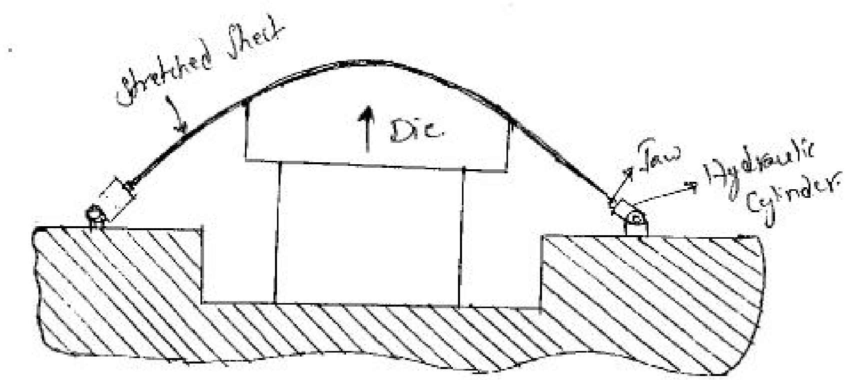
Stretch Forming

Stretch forming is an attractive way of producing the large sheet metal parts in limited or low quantities. In this process the sheet of metal is gripped by two or more sets of jaws that stretch it and wrap it around a single form die block. This process of simultaneously stretching and bending is called stretch bending.

In stretch forming most of the deformation is induced by the tensile stretching, therefore forces on the die are far less than those normally present in bending or forming because forces are so low that the dies can often be made of wood, low melting point metal or even plastic.



Various steps to illustrate the process of stretch forming. It is also shown the how metal is subjected to stretching and bending in stretch forming.



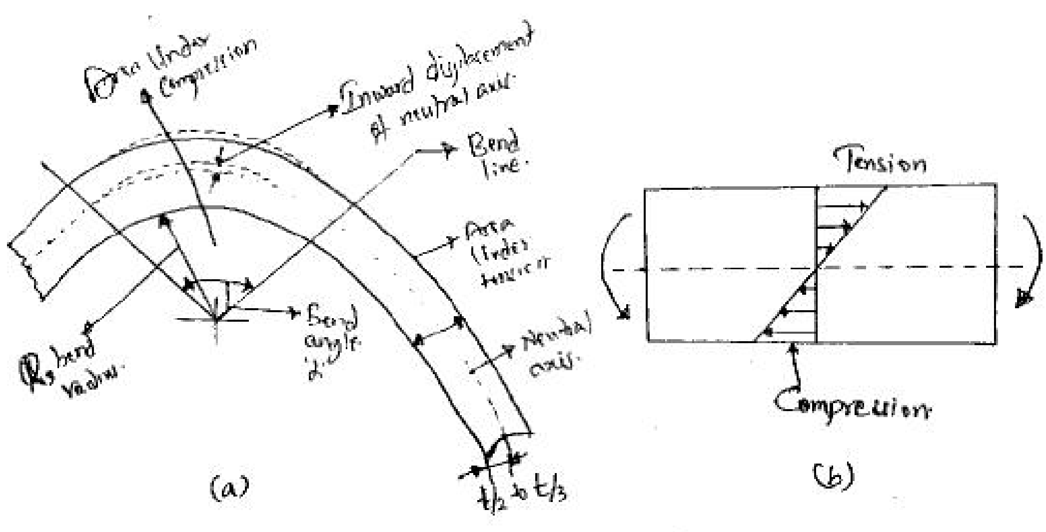
Stretch Forming.

- As in the process deformation is carried out in plastic region there is very little spring back and work piece closely conforms to the shape of tool.
- In stretch forming we can have component either single or double curved surfaces. The sheet should have uniform thickness other wise the thinner portions are likely to be over stretched. Also if the sheer is having any holes before the stretch forming they are likely to be enlarged.
- Stretch forming is quite popular in the air craft industry and frequently used to form aluminium and stainless steel into wing tips, scoops and other large panels.
- Sometimes mating male and female dies are used to shape the metal while it is being stretched. This process is known as stretch draw forming.

Bending:

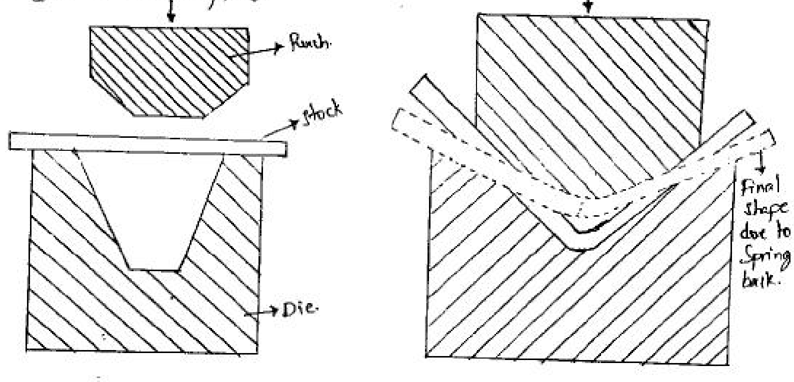
Bending is the plastic deformation of metals about a linear axis with little or no change in surface area. The bending of flat sheet is shown in below figure. Here due to applied forces, metal on the outside is stretched while that on the inside is compressed. There is a plane in between which is neither stretched nor compressed. This plane is known as neutral plane. Neutral plane should be at the center when the material is elastically deformed. When the material is plastically deformed the neutral axis move downward towards compressed layer. Since materials oppose compression much better than tension. The thickness is slightly decreased.

In bending operations there is some elastic recovery after the punch is removed. This is known as **spring back**. Thus is metal is to bent at specific angel the metal must be slightly over bent to compensate for the unbending action of spring back. Bending operation is performed while manufacturing many components such as trays, boxes, brackets, clips etc…



Bending Operation

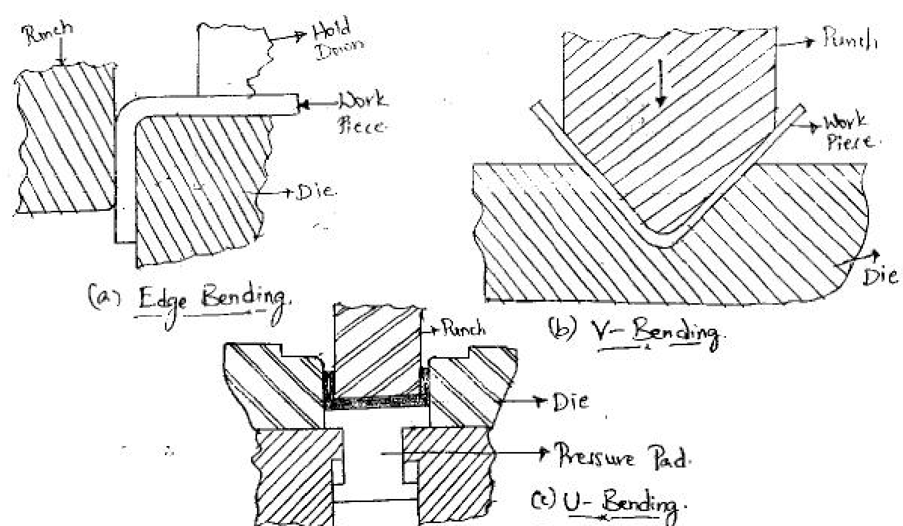
The figure (a) shows a simple case of bending and inward displacement of neutral axis in bending. Figure (b) illustrates that stresses on the outer most sides are maximum and zero at neutral plane.



Spring Back in Bending Operation.

Different types of bending methods are shown in below figure. The first one is edge bending which is used for simple 90° bend only. Here the work piece is held firmly to the die with hold down and punch bends the extended portion of metallic blank. Here the work piece behaves a cantilever beam. V-bending and U-bending is shown is second figure. The punch and die often form a 90° internal angle between the faces of the metal.

Bending operation is closely related to forming operation. Bending is sometimes called forming operation, when multiple bends are made with single die. If the axes of deformation are not linear or are independent, the process becomes drawing and or stretching.

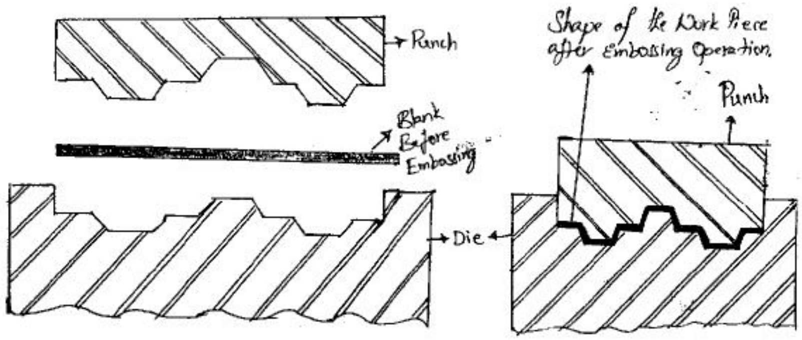


Various Types of Bending Operations.

Embossing:

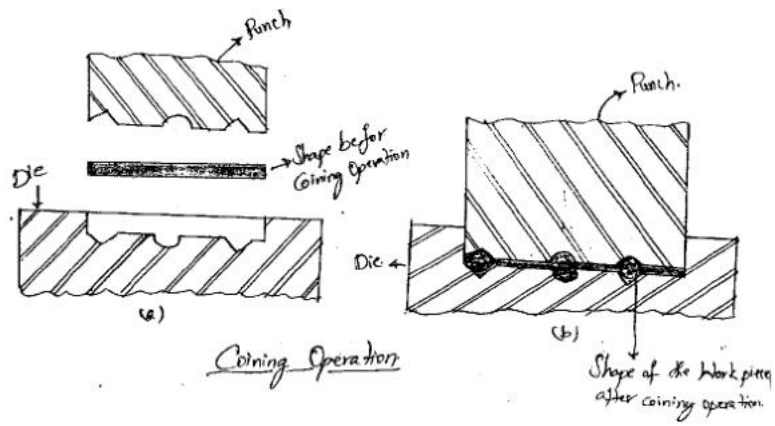
Embossing is the operation in which projected or raised figures are made on sheet metals with corresponding relief on the other side. It basically involves drawing and bending operation. There may be the negligible change in the thickness of the metal.

- The die set consists of punch and die with required contours which are desired on the final product. The clearance between punch and die at meeting is same as the thickness of required product.
- Embossing is used for providing rigidity to sheet metals and for decorative sheet work used in houses and religious places.



Coining:

Coining is basically a cold forging operation. The only difference is that here the flow of metal occurs only at top layers and not at the entire volume as in case of cold forming.



The process is used to produce coins, meals and similar products where exact size and fine details are required. The coining die consists of punch and dies which are engraved with necessary details required on the both sides of final product. A blank is kept on the die and squeezed by it. The pressure required in coining is quite high as very fine details are required in coining. For example, a pressure of 240,00 psi may be required to make a nickel coin of 50 paise.

Spinning:

Spinning is the process used for making cup shaped parts having symmetrical shapes. In this process a blank is rotated, fixed against the forms block and then gradually force is applied on blank so that, blank takes the shape of form block.

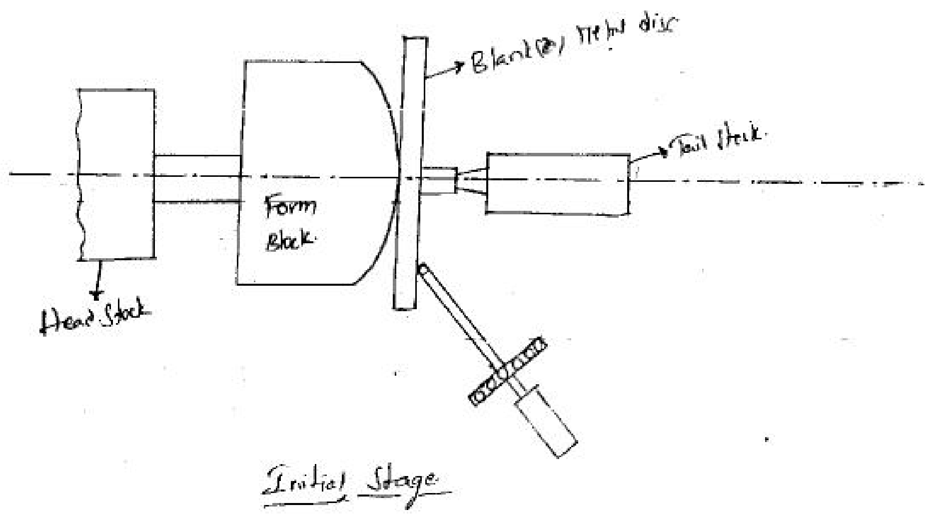
The spinning process may be carried out on machine similar to a lathe machine. A circular blank properly centered with lathe axis is held against the chuck by the pressure of follower attached to tails stock. The form block, which has the shape of desired part, is fixed to the head stock of lathe machine. The tool used in spinning is simple round ended wooden or metal tool or small roller. As the blank and form block are made to rotate, the tool is pressed and moved gradually on the blank so that blank take the shape of form block.

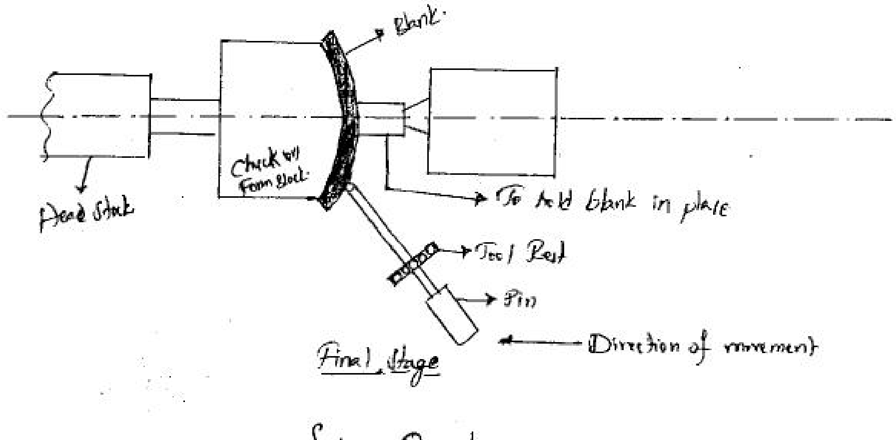
Spinning Lathe

The spinning lathe consists of,

1. Bed
2. Head Stock
3. Form
4. Tail Stock

The bed supports head stock, tail stock and other accessories. The form block is fixed in the lathe spindle and turns with it. The work piece is bent over the form block to take its shape by applying pressure by means of tool. The follower supports the work piece. Steps in spinning are shown in below figure.





Spinning Operation

Types of Spinning Processes:

The Spinning process is classified in two types i.e., hot-spinning and cold-spinning, depending upon whether the blank or work piece has been heated before spinning or not.

(i) Hot Spinning:

In hot spinning, the metal blank is heated to forging temperature and then forming it into the desired shape.

A blunt pressing tool is used which contacts the surface of the rotating part and causes the flow of metal over the form mandrel. This method is generally used for thicker plates and sheets, which do not plastically de-formed at room temperature by pressing tool.

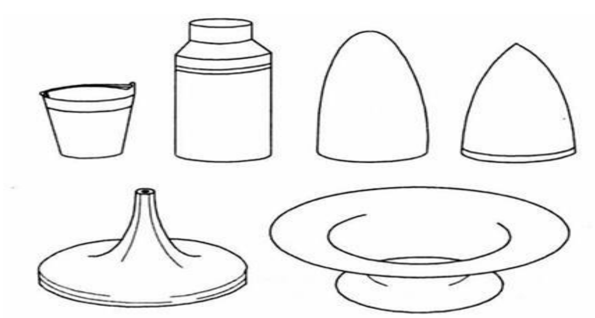
In order to avoid wrinkling at the outer edge a back-up support (hard wood bar) opposite to the tool is used, when working with relatively thin sheets. Hot spinning produces parts such as heads for pressure vessels, refinery equipment's and large tanks.

(ii) Cold Spinning:

Cold spinning process is similar to hot spinning except that the metal blank is worked at room temperature. This method is generally best suited for thin plates and sheets of aluminum and other soft metals.

Cold spinning produces parts such as light reflectors, cooking utensils, liquid containers, radial engine cowling, domestic use hollow parts etc.

Products of Spinning:



High energy rate forming Processes:

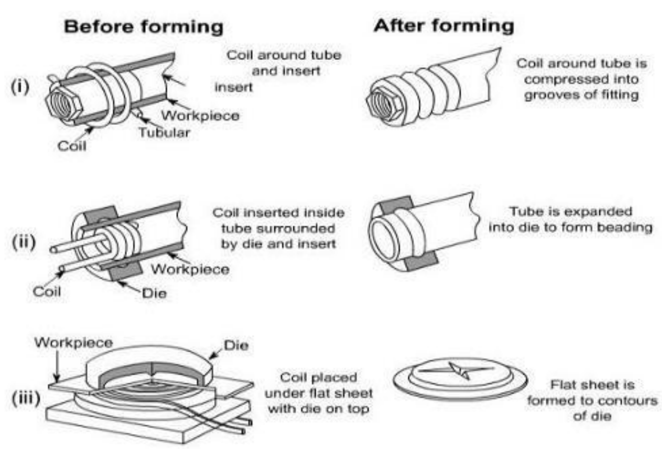
High energy rate forming: In high energy forming process large amount of energy is applied for a very short interval of time. Parts are formed at a rapid rate, and thus these processes are also called high – velocity forming processes.

There are **three** main high energy rate forming processes:

Explosive Forming, Electro Magnetic Forming, Electro Hydraulic Forming.

Electro Magnetic Forming

Electro Magnetic Forming -The process is also called magnetic pulse forming and is mainly used for swaging type operations, such as fastening fittings on the ends of tubes and crimping terminal ends of cables. Other applications are blanking, forming, embossing, and drawing. The work coils needed for different applications vary although the same power source may be used. To illustrate the principle of electromagnetic forming, consider a tubular work piece. This work piece is placed in or near a coil, in the figure below, 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. (i) Swaging, (ii) Expanding, and (iii) Embossing or Blanking

Either permanent or expandable coils may be used. Since the repelling force acts on the coil as well the work, the coil itself and the insulation on it must be capable of withstanding the force, or else they will be destroyed. The expandable coils are less costly and are also preferred when high energy level is needed. Magnetic forming can be accomplished in any of the following three ways, depending upon the requirements. Coil surrounding work piece. When a tube – like part x is to fit over another part y (shown as insert in In Figure above (i), coil is designed to surround x so that when energized, would force the material of x tightly around y to obtain necessary fit. Coil inside work piece. Consider fixing of a collar on a tube – like part, as shown in above figure

(ii). 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, as shown in above figure

(iii).These coils are used in conjunction with a die to form, emboss, blank, or dimple the work piece. In electromagnetic forming, the initial gap between the work piece and the die surface, called the fly distance, must be sufficient to permit the material to deform plastically.

From energy considerations, the ideal pressure pulse should be of just enough magnitude that accelerates the part material to some maximum velocity and then let the part come to zero velocity by the time it covers the full fly distance. All forming coils fail, expendable coils fail sooner than durable coils, and because extremely high voltages and currents are involved, it is essential that proper safety precautions are observed by the production and maintenance personnel.

Electro Hydraulic Forming

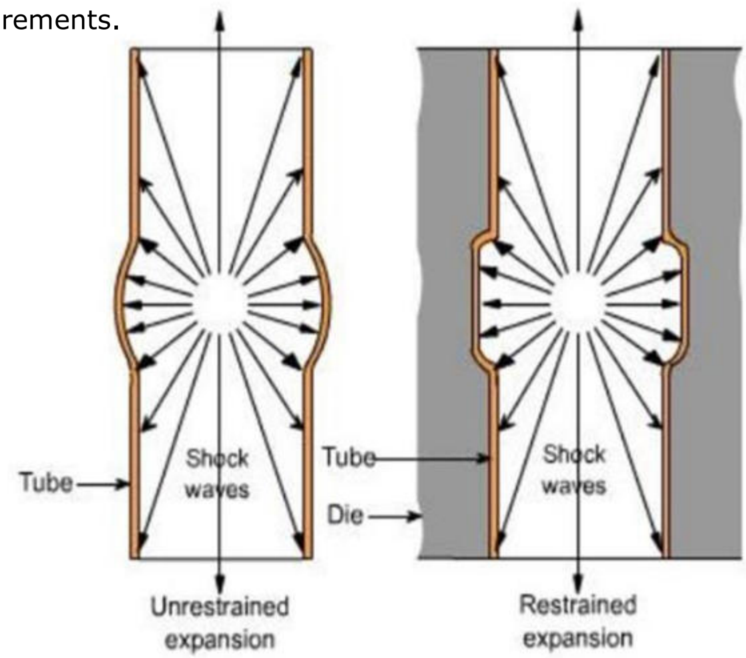
Electro hydraulic forming (EHF), also known as electro spark forming, is a process in which electrical energy is converted into mechanical energy for the forming of metallic parts. A bank of capacitors is first charged to a high voltage and then discharged across a gap between two electrodes, causing 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,

Advantages :-

1. EHF can form hollow shapes with much ease and at less cost compared to other forming techniques.

2. EHF is more adaptable to automatic production compared to other high energy rate forming techniques.

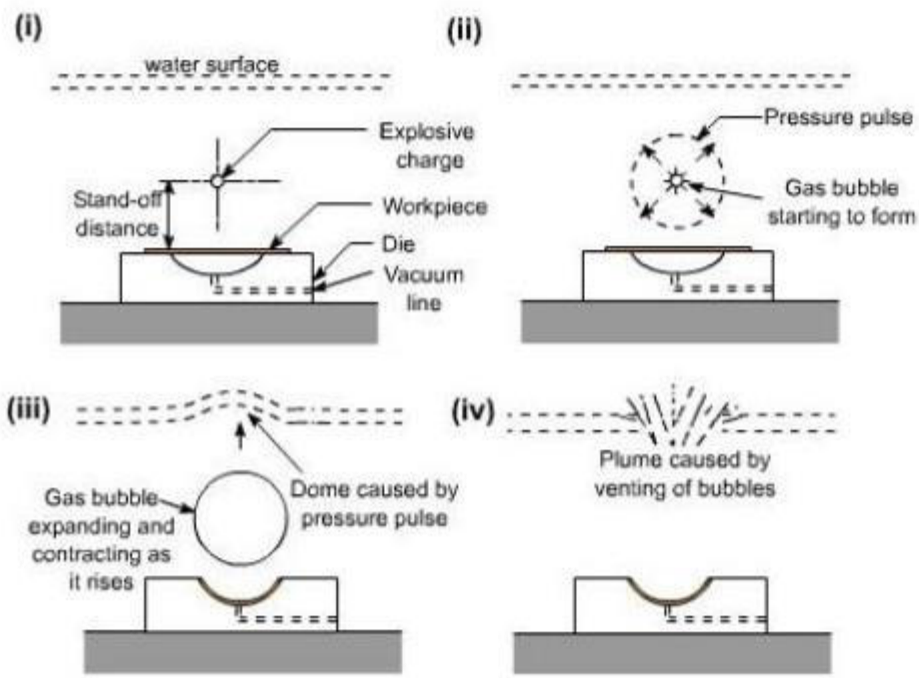
3. EHF can produce small – to intermediate sized parts that don't have excessive energy requirements.



Unrestrained and Restrained Electro-hydraulic forming

Explosive forming

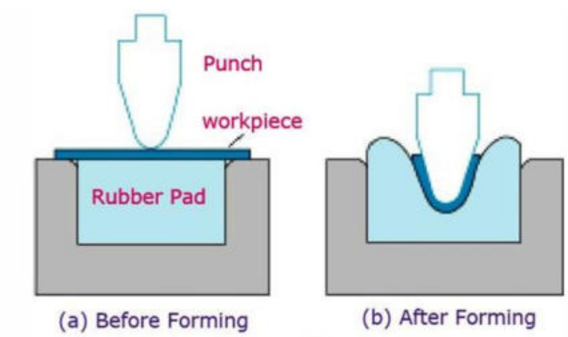
Explosive forming is distinguished from conventional forming in that the punch or diaphragm is replaced by an explosive charge. The explosives used are generally high – explosive chemicals, gaseous mixtures, or propellants. There are two techniques of high – explosive forming: stand – off technique and the contact technique. Standoff Technique The sheet metal work piece blank is clamped over a die and the assembly is lowered into a tank filled with water. The air in the die is pumped out. The 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. A gas bubble is also produced which expands spherically and then collapses. When the pressure pulse impinges against the work piece, the metal is deformed into the die with as high velocity as 120 m/s.



Explosive Forming

Rubber pad forming (RPF)

Rubber pad forming (RPF) is a metalworking process where sheet metal is pressed between a die and a rubber block, made of polyurethane. Under pressure, the rubber and sheet metal are driven into the die and conform to its shape, forming the part. The rubber pads can have a general purpose shape, like a membrane. A form of deep drawing, rubber pad forming is a technique used in the manufacturing industry to manipulate sheet metal by pressing it between a series of rubber pads and a die. It’s not designed to cut sheet metal. Rather, rubber pad forming is designed to bend sheet metal using compressive forces.In bending and embossing of sheet metal, the female die is replaced with rubber pad .Rubber pad forming (RPF) is a metalworking process where sheet metal is pressed between a die and a rubber block, made of polyurethane. Under pressure, the rubber and sheet metal are driven into the die and conform to its shape, forming the part. Rubber pads can have a general purpose shape, like a membrane. Alternatively, they can be machined in the shape of die or punch.



Solid Rubber Pad Forming

Pros and Cons of Rubber Pad Forming:-

With rubber pad forming, manufacturing companies can safely manipulate the shape of finished or polished sheet metal. After finishing or polishing a piece of sheet metal, a manufacturing company may use rubber pad forming to change its shape. While other metalworking processes may damage the finished or polishing sheet metal, rubber pad forming will not. The rubber pads offer a soft and forgiving surface that won’t damage the sheet metal.

Rubber pad forming supports most types of sheet metal. Whether a piece of sheet metal consists of stainless steel, high-carbon steel or aluminum, it can be manipulated using rubber pad forming. This metalworking process even supports sheet metal measuring up to 4 millimeters thick, making it ideal for a variety of manufacturing-related applications.

On the other hand, rubber pad forming is a somewhat costly metalworking process. Manufacturing companies must build both the rubber pads as well as the dies used in this process. And while dies in rubber pad forming tend to last for a long time, the rubber pads do not. The high cost associated with this process makes rubber pad forming somewhat restrictive, especially for smaller manufacturing companies.

Unit V –Additive Manufacturing &Polymer Processing Techniques

[Additive Manufacturing: Steps in Additive manufacturing (AM); Advantages of AM and types of materials for AM, VAT Photo polymerization AM process. Extrusion- based AM process. Powder bed Fusion AM process, Direct energy Deposition AM process. Post processing of AM parts, Applications. Plastics: Classification – Properties – Plastics as engineering materials-Method of processing plastics; Injection moulding –Blow moulding -Extrusion-compression and transfer moulding]

INTRODUCTION to PLASTICS:

Plastics belong to the family of organic materials. Organic materials are those materials are derived directly from carbon. They consist of carbon chemically combined with hydrogen, oxygen and other non-metallic substances, and their structures, in most cases, are fairly complex. The large and diverse organic group includes the natural materials: wood, coal, petroleum, natural rubber, animal fibers and food, which have biological origins. Synthesis include the large group of solvents, adhesives, synthetic fibers, rubbers, plastics, explosives, lubricants, dyes, soaps and cutting oils etc. which have no biological origins. Of them plastics and synthetic tubers termed as "Polymers".

Polymers:

The term "polymer" is derived from the two Greek words: poly, meaning "many", and meros meaning "parts" or "units". Thus polymers are composed of a large number of repeating units (small molecules) called monomers. The monomers are joined together end-to-end in a polymerization reaction.

The most common polymers are those made from compounds of carbon, but polymers can also make from inorganic chemicals such as silicates and silicones. The naturally occurring polymers include: protein, cellulose, resins, starch, shellac and lignin. They are commonly found in leather, fur, wool, cotton, silk, rubber, wood and many others. There are also synthetic polymers such as polyethylene, polystyrene, nylon, Terylene, Dacron etc… termed under plastics, fibers and elastomers. Their properties are superior to those of the naturally occurring counterparts. Our concern here is therefore with synthetic polymers,also called plastics or resins.

Polymerization: The process of linking together of monomers, that is, of obtaining macromolecules is called "polymerization". It can be achieved by one of the two processing techniques i.e., Addition Polymerization and condensation Polymerization.

Polymers can be divided into three broad divisions: plastics, fibers and elastomers. Plastic derive their name from the fact that in a certain phase of their manufacture, they are present in a plastic stage that is acquire plasticity, which makes it possible to impart any desired shape to the product. Plastics fall into a category of known chemically as high polymers.

Plastics:

The "Plastics" is a term applied to compositions consisting of a mixture of high molecular compounds and fillers, plasticizers, stains, and pigments, lubricating and other substances, some of the plastics can contain nothing but resin.

The word plastics is from the Greek word Plastikos, means which are moulded and shaped. Plastics can be easily machined, formed and joined into required shapes. Hence, plastics find place in engineering materials and domestic applications. Plastics are available in rods, sheets, films and tubes.

Types of Plastics:

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

Plastics are classified as,

(a) Thermo setting plastics
(b) Thermoplastics

(a) Thermosetting Plastics: These are formed to shape with heat, with or without pressure, resulting in a product that is permanently hard. The heat first softens the material, but as additional heat or special chemicals are added, the plastic is hardened by chemical change known as "polymerization" and cannot be resoftened. Thermosetting plastics are phenol-formaldehyde. Urea formaldehyde, epoxy resins etc. Products made by thermosetting plastics are T.V cabinets, telephone receivers, camera bodies and automobile parts.

(b) Thermoplastics: Thermoplastics undergo no chemical change in moulding. They remain soft at elevated temperatures until they are hardened by cooling. These plastics can be reused or recycled by melting and remoulding. Most commonly used thermoplastics are polystyrene, polythyne, P.V.C. (polyvinyl chloride) Nylon, Teflon etc… Products made by thermoplastics are photographic films, insulating tapes, hose pipes etc…

Properties of Plastics:

Their great variety of physico chemical and mechanical properties and the ease with which they can be made into various articles have found plastics their wide application in the engineering and the other industries.

1. Their comparatively low density, substantial mechanical strength higher strength – to – weight ratio and high anti friction properties have enabled plastics to be efficiently used as substitute for metals.
2. With certain special properties, plastics can sometimes replace ferrous metals.
3. From the productions point of view, their main advantage is their relatively low melting points and their ability to flow into a mould.
4. Simple processing to obtain machine parts. Generally there is only one production operation required to convert the chemically manufactured plastic in to a finished article.
5. Good damping capacity and good surface finish of the product.

6. The high heat and electric insulation of plastics permits them to be applied in the radio and electrical engineering industries as dielectrics and as substitutes for porcelain, ebonite, shellac, mica, natural rubber etc…
7. Their good chemical stability when subjected to the action of solvents and certain oxidizing agents, water resistance, gas and steam proof properties enable plastics to be used as valuable engineering materials in the automobile and tractor, ship building and other industries.

Comparison between Thermosetting plastics and Thermoplastics:

Thermosetting plastics

1. Once hardened and set, they do not soften with the application of heat.
2. These are stronger and harder.
3. Objects made by these plastics can be used at comparatively high temperatures.
4. These are supplied in monomeric or partially polymerized form in which these are either liquids or semi solids.
5. T.V. Cabinets, Automobile parts are made by these plastics.

Thermoplastics

1. They can be repeatedly softened by heat and hardened by cooling.
2. They are comparatively softer and less strong.
3. Objects made by thermoplastics cannot be used at higher temperatures as these lend to soften under heat.
4. These are usually supplied as granular material.
5. Insulating tapes, photographic films are made by these plastics.

Advantages of Plastics:

1. Light in weight compared to metals.
2. Excellent surface finish.
3. Close dimensional tolerances.
4. Moisture and corrosion resistance.
5. Easy to shape and mould.

Disadvantages of Plastics:

1. Low strength.
2. Low heat resistance.
3. Deteriorate in sunlight.

Applications of Plastics:

Plastics find applications in manufacturing of:

1. Photo films in film industry.
2. Insulating tapes
3. Electrical parts like plugs, switches etc…
4. Radio, T.V. cabinets
5. Furniture like chairs, tubs
6. Telephone receivers
7. Camera bodies
8. Gears and Bearings
9. Toys, bottles, bucket etc…
10. Hose pipes
11. Automobile parts

Methods of Processing:

(a) Moulding of thermoplastics

1. Injection Moulding
2. Blow Moulding
3. Extrusion
4. Thermoforming
5. Calendering

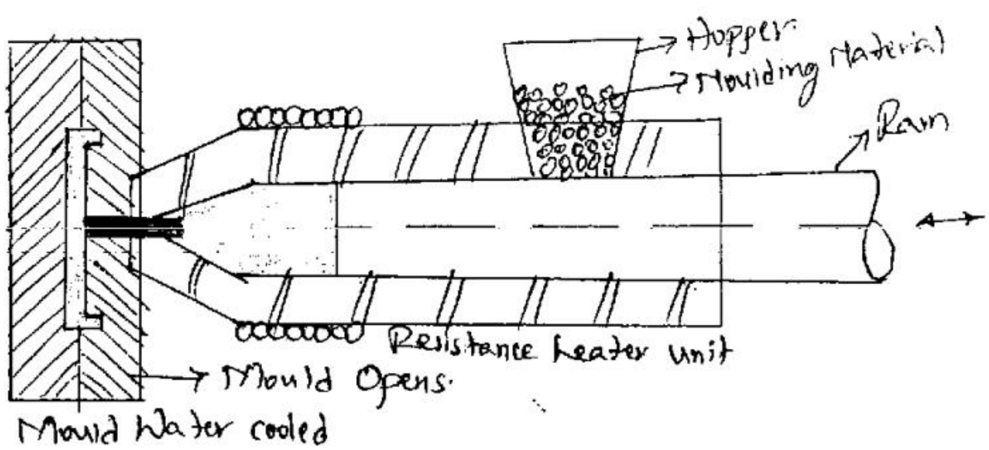
(b) Moulding of thermosetting plastics

1. Compression moulding
2. Transfer moulding

(a)1. Injection Moulding:

Injection moulding machines are somewhat similar to those used for die casting. In this method, the moulding material in the form of granules or pellets is fed through the hopper into the cold end of the injection cylinder. Then the injection ram forces the powder into the heating section of the cylinder where its temperature is raised to 300°C. Then the ram is moved forward by applying hydraulic pressure to inject the soften material through die into water cooled mould. After the mould is filled, it is allowed to cool and harden. Then the ram is retracted, the mould is opened and the product is ejected.

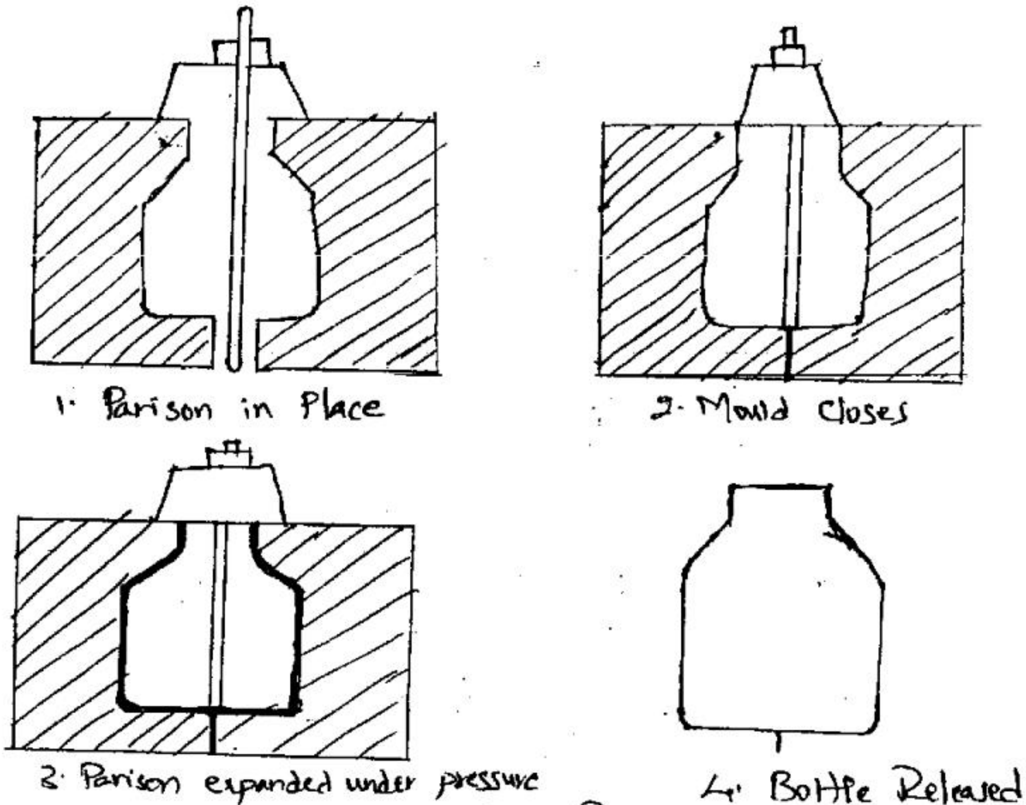
Injection moulding machines have a high production capacity; some can produce from 12 to 16 thousand parts per shift. This method is suitable for making parts with complex threads and intricate shapes. Typical parts include: Cups, containers, housings, tool handles, toys, knobs, plumbing fittings, electrical and communication components such as telephone receivers etc…



Injection Moulding.

The limitations of the process are: Equipment of cylinder and die should be non-corrosive. Also reliable temperature controls are essential.

(a)2. Blow Moulding:

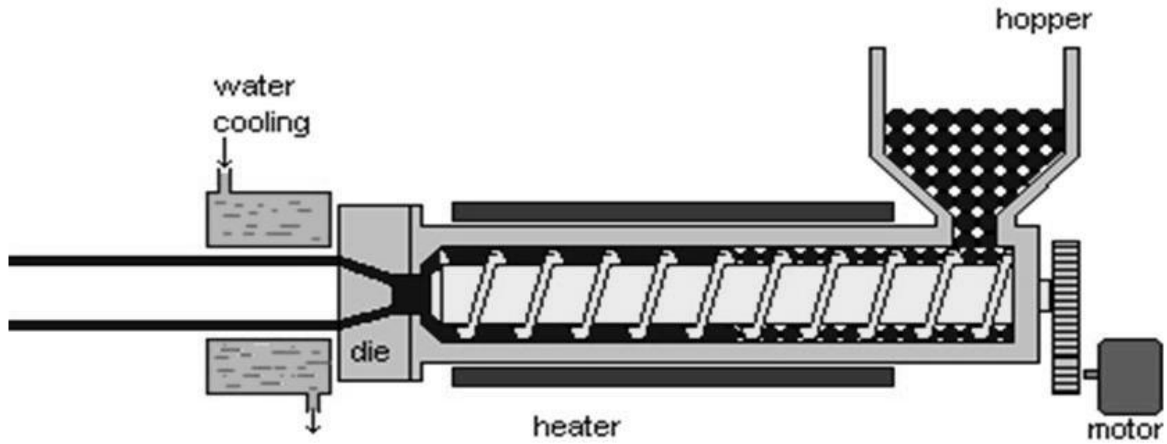


Blow Moulding Process.

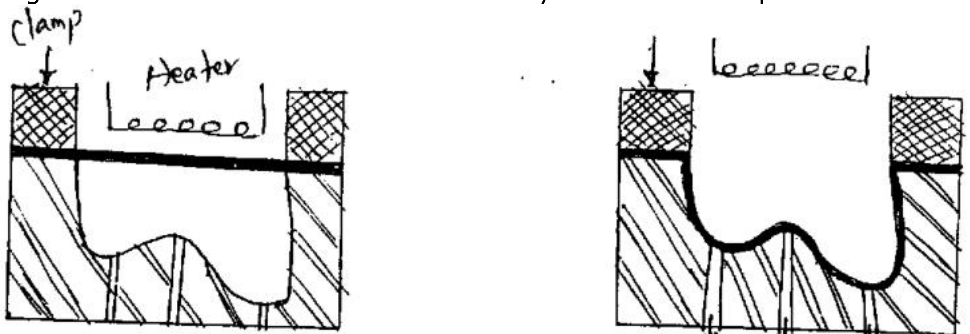
The blow moulding commences with the extrusion of heated tubular piece of plastic known as parison which is transferred to the two piece mould. The parison is gripped in the two-piece mould and its bottom end is sealed. Compressed air is blown into the parison to force the plastic against the walls of water cooled mould. Air pressure ranges from 0.7 to 10 kg/cm^2. The mould is allowed to cool and then opened to remove the article.

Blow moulding is used for making plastic bottles, toys, doll bodies and many other items.

(a)3. Extrusion Moulding: Polymer sheets and films can be produced using a flat extrusion die. These are advantages of extrusion process. The tooling cost is low compared to injection moulding. Material thickness can be controlled. In addition production rates are high and intricate profiles can be produced.



(a)4. Thermoforming: It consists of heating a thermoplastic sheet until it softens and then forcing it to confirm to some mould either by vacuum or air pressure.

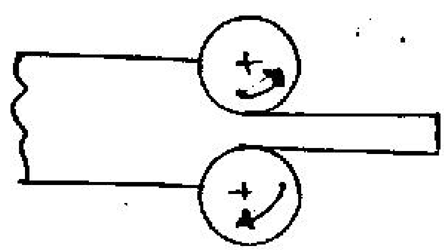


(a) Heating of thermoplastic sheet (b) Vacuum is applied to the mould

Thermoforming Process

The products made by thermoforming are jelly containers used in restaurants, refrigerator inner panels, packing containers etc…

(a)5. Calendering: This is an intermediate process in which extruded thermoplastic sections are reduced to sheets of films.



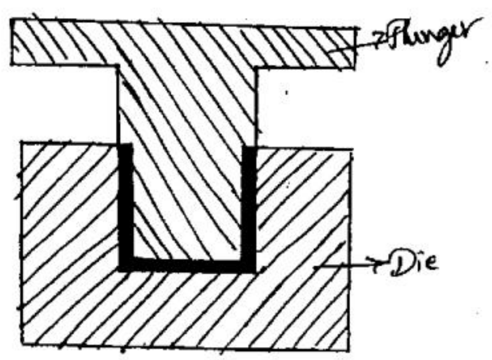
Calendering of Thermoplastic

(b)1. Compression Molding: This is usually for thermosetting plastics. In compression moulding thermosetting material is placed in heated mould (female die). The upper part of the mould is brought down to compress the material into the required shape and density. When the mould is closed, the material undergoes a chemical change or polymerization that hardens it.

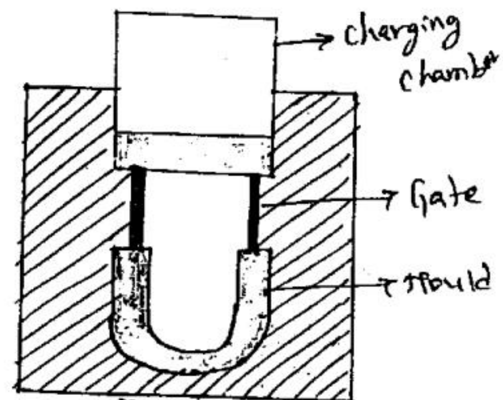
The moulding temperature ranges from 150 – 180°C. The moulding pressure ranges from 150 – 500 kg/cm2. The time required to harden the product ranges from 1 to 1.5 minutes. It also depends on the thickness of the product.

The products made by this process include dishes, container caps etc…

(b)2. Transfer Moulding: Transfer moulding is variation of compression moulding in which heat and pressure is applied to the moulding materials outside the mould until they become fluid. The fluid material is then forced through a series of channels from external chamber to the mould cavity where final cure takes place.



Compression Moulding



Transfer Moulding