METAL FORMING & POWDER METALLURGY

METAL CASTING

WELDING

Lecture 1

FUNDAMENTALS OF METAL FORMING

There are four basic production processes for producing desired shape of a product. These are casting, machining, joining (welding, mechanical fastners, epoxy, etc.), and deformation processes. Casting process exploit the fluidity of a metal in liquid state as it takes shape and solidifies in a mold. Machining processes provide desired shape with good accuracy and precision but tend to waste material in the generation of removed portions. Joining processes permit complex shapes to be constructed from simpler components and have a wide domain of applications.

Deformation processes exploit a remarkable property of metals, which is their ability to flow plastically in the solid state without deterioration of their properties. With the application of suitable pressures, the material is moved to obtain the desired shape with almost no wastage. The required pressures are generally high and the tools and equipment needed are quite expensive. Large production quantities are often necessary to justify the process.

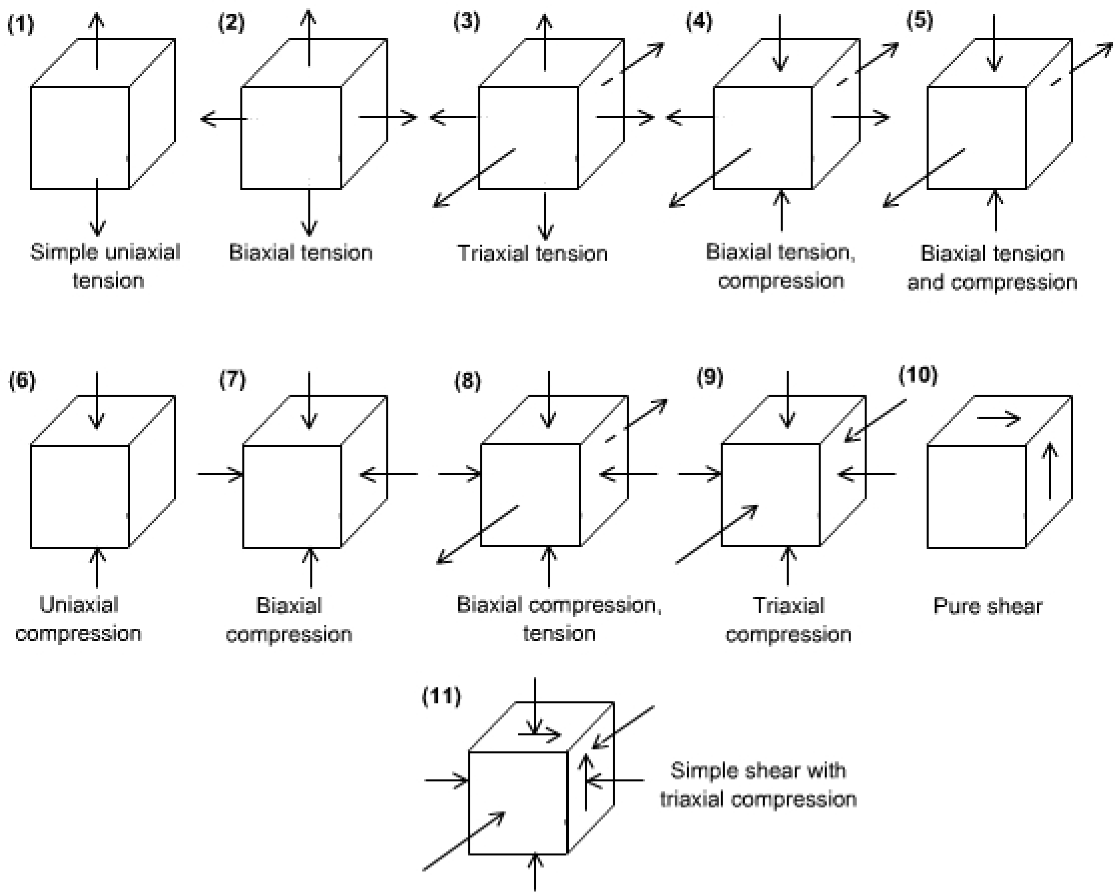
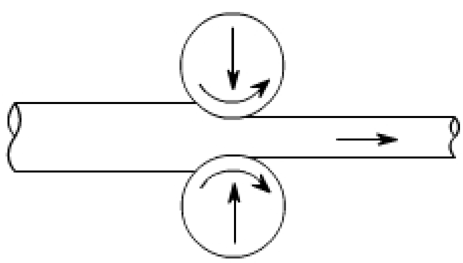
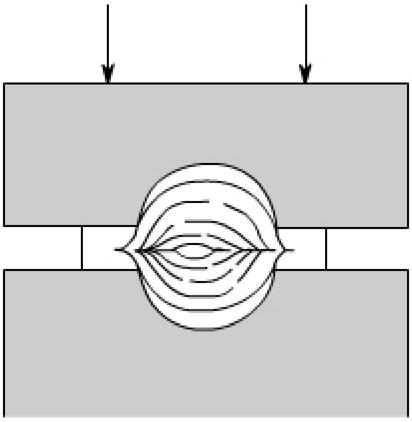
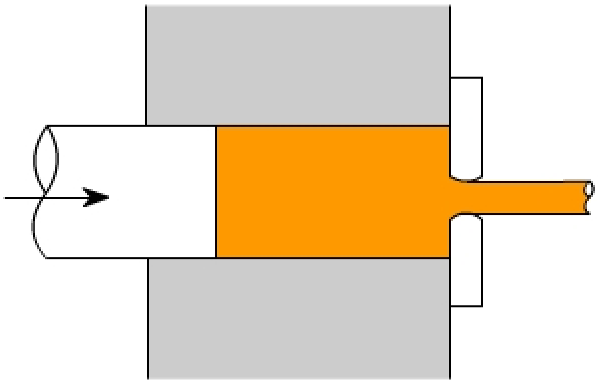
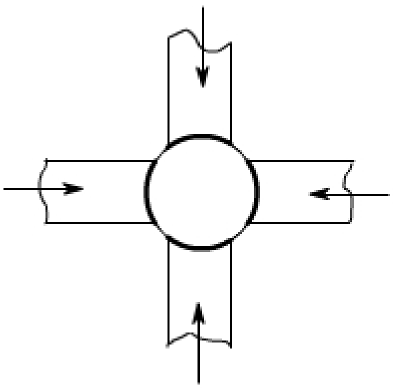
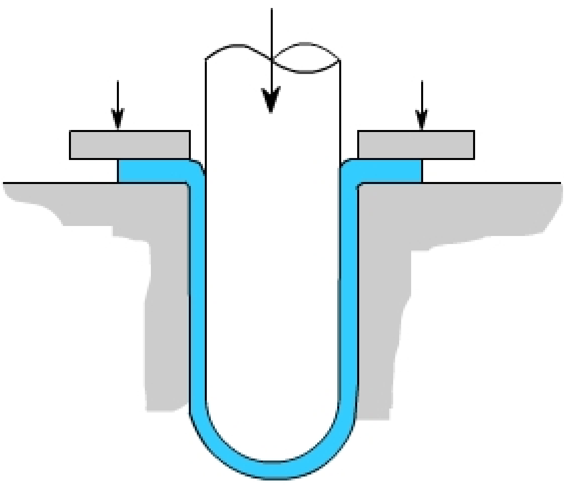


Fig 1.1 State of the stresses metal undergo during deformation.

As a metal is deformed (or formed, as often called) into useful shape, it experiences stresses such as tension, compression, shear, or various combinations there of Fig 1.1 illustrates these states of stresses. Some common metal forming processes are schematically given in Fig 1.2 along with the state of stress(es) experienced by the metal during the process.

Number	Process	State of Stress in Main Part During Forming
1	Rolling 	Bi-axial compression
2	Forging	Tri-axial compression

		
3	 Extrusion	Tri-axial compression
4	swaging 	Bi-axial compression
5	Deep drawing 	In flange of blank, bi-axial tension and compression. In wall of cup, simple uni-axial tension.
6	Wire and tube drawing	Bi-axial compression, tension.

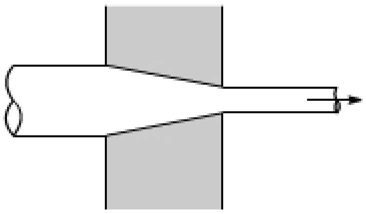
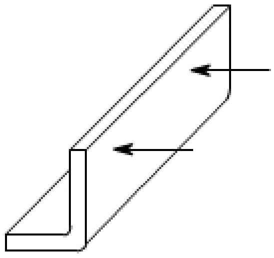
		
7	Straight bending 	At bend, bi-axial compression and bi-axial tension

Fig 1.2 Common metal forming processes. State of stress experienced by metal is also given

To understand the forming of metal, it is important to know the structure of metals. Metals are crystalline in nature and consist of irregularly shaped grains of various sizes. Each grain is made up of atoms in an orderly arrangement, known as a lattice. The orientation of the atoms in a grain is uniform but differs in adjacent grains. When a force is applied to deform it or change its shape, a lot of changes occur in the grain structure. These include grain fragmentation, movement of atoms, and lattice distortion. Slip planes develop through the lattice structure at points where the atom bonds of attraction are the weakest and whole blocks of atoms are displaced. The orientation of atoms, however, does not change when slip occurs.

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

When metal is formed in cold state, there is no recrystallization of grains and thus recovery from grain distortion or fragmentation does not take place. As grain deformation proceeds, greater resistance to this action results in increased hardness and strength. The metal is said to be strain hardened. There are several theories to explain this occurrence. In general, these refer to resistance build up in the grains by atomic dislocation, fragmentation, or lattice distortion, or a combination of the three phenomena.

The amount of deformation that a metal can undergo at room temperature depends on its ductility. The higher the ductility of a metal, the more the deformation it can undergo. Pure metals can withstand greater amount of deformation than metals having alloying elements, since alloying increases the tendency and rapidity of strain hardening. Metals having large grains are more ductile than those having smaller grains.

When metal is deformed in cold state, severe stresses known as *residual stresses* are set up in the material. These stresses are often undesirable, and to remove them the metal is heated to some temperature below the recrystalline range temperature. In this temperature range, the stresses are rendered ineffective without appreciable change in physical properties or grain structure.

COLD AND HOT WORKING OF METALS

Cold Working:

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

In comparison with hot working, the advantages of cold working are

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

Some disadvantages associated with cold-working processes are:

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

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

Warm Working:

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

- Lesser loads on tooling and equipment
- Greater metal ductility
- Fewer number of annealing operation (because of less strain hardening)

Compared to hot forming, warm forming offers the following advantages.

- Lesser amount of heat energy requirement
- Better precision of components
- Lesser scaling on parts
- Lesser decarburization of parts
- Better dimensional control
- Better surface finish
- Lesser thermal shock on tooling
- Lesser thermal fatigue to tooling, and so greater life of tooling.

Hot Working:

Plastic deformation of metal carried out at temperature above the recrystallization temperature, is called hot working. Under the action of heat and force, when the atoms of metal reach a certain higher energy level, the new crystals start forming. This is called recrystallization. When this happens, the old grain structure deformed by previously carried out mechanical working no longer exist, instead new crystals which are strain-free are formed.

In hot working, the temperature at which the working is completed is critical since any extra heat left in the material after working will promote grain growth, leading to poor mechanical properties of material.

In comparison with cold working, the advantages of hot working are

1. No strain hardening
2. Lesser forces are required for deformation
3. Greater ductility of material is available, and therefore more deformation is possible.
4. Favorable grain size is obtained leading to better mechanical properties of material
5. Equipment of lesser power is needed
6. No residual stresses in the material.

Some disadvantages associated in the hot-working of metals are:

1. Heat energy is needed
2. Poor surface finish of material due to scaling of surface
3. Poor accuracy and dimensional control of parts

4. Poor reproducibility and interchangeability of parts

5. Handling and maintaining of hot metal is difficult and troublesome

6. Lower life of tooling and equipment.

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Lecture 2

FORGING

Forging is a process in which material is shaped by the application of localized compressive forces exerted manually or with power hammers, presses or special forging machines. The process may be carried out on materials in either hot or cold state. When forging is done cold, processes are given special names. Therefore, the term forging usually implies hot forging carried out at temperatures which are above the recrystallization temperature of the material.

Forging is an effective method of producing many useful shapes. The process is generally used to produce discrete parts. Typical forged parts include rivets, bolts, crane hooks, connecting rods, gears, turbine shafts, hand tools, railroads, and a variety of structural components used to manufacture machinery. The forged parts have good strength and toughness; they can be used reliably for highly stressed and critical applications.

A variety of forging processes have been developed that can be used for either producing a single piece or mass – produce hundreds of identical parts. Some common forging processes are:

1. Open – die hammer forging
2. Impression – die drop forging
3. Press Forging
4. Upset Forging
5. Swaging
6. Rotary Forging
7. Roll forging

Open – Die Hummer Forging.

It is the simplest forging process which is quite flexible but not suitable for large scale production. It is a slow process. The resulting size and shape of the forging are dependent on the skill of the operator.

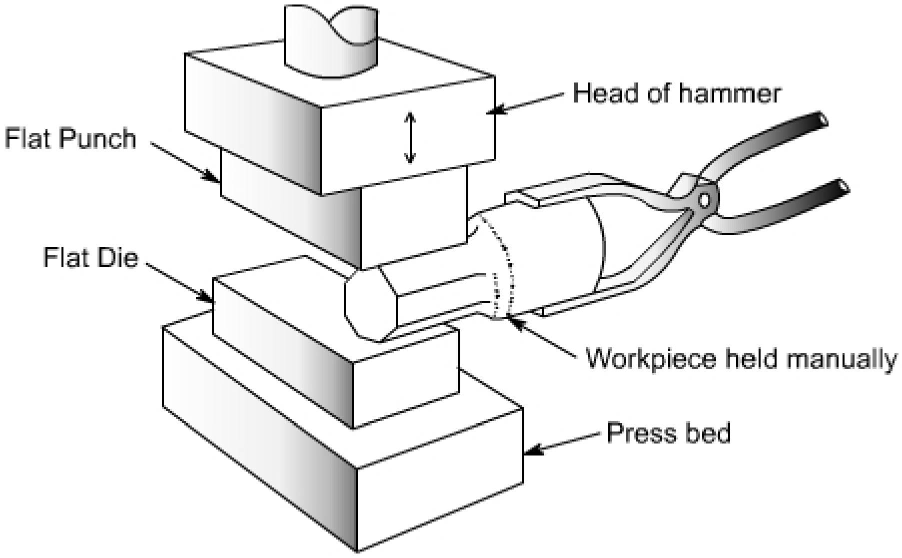

Fig 2.1

Open die forging does not confine the flow of metal, Fig 2.1. The operator obtains the desired shape of forging by manipulating the work material between blows. Use may be made of some specially shaped tools or a simple shaped die between the work piece and the hammer or anvil to assist in shaping the required sections (round, concave, or convex), making holes, or performing cut – off operations. This process is most often used to make near – final shape of the part so that some further operation done on the job produces the final shape.

Forging Force. In open die forging operation, the forging force F, to be applied on a solid cylindrical component can be determined from the relation.

$$F = \sigma_f . \frac{\pi}{4} d^2 \left(1 + \frac{\mu d}{3h}\right)$$

Where s f is the flow stress of the material, μ is the coefficient of friction, and d and h are the diameter and height of the work piece, respectively.

Example. Using open-die forging operation, a solid cylindrical piece of 304 stainless steel having 100 mm dia x 72 mm height is reduced in the height to 60 mm at room temperature. Assuming the coefficient of friction as 0.22 and the flow stress for this material at the required true strain as 1000 MPa, calculate the forging force at the end of stroke.

Solution . Initial diameter = 100 mm

Initial height = 72 mm

Final height = 60 mm

If final diameter is d, $(100)^2 \times 72 = d^2 \times 60$

i.e. d =110 mm

$$F = (1000).\frac{\pi}{4}(110)^2\left(1+\frac{0.22(110)}{3\times 60}\right)$$

$$= 1078 \text{ MN}$$

Impression – Die Drop Forging (Closed – Die Forging)

The process uses shaped dies to control the flow of metal. The heated metal is positioned in the lower cavity and on it one or more blows are struck by the upper die. This hammering makes the metal to flow and fill the die cavity completely. Excess metal is squeezed out around the periphery of the cavity to form flash. On completion of forging, the flash is trimmed off with the help of a trimming die.

Most impression – die sets contain several cavities. The work material is given final desired shape in stages as it is deformed in successive cavities in the die set. The shape of the cavities cause the metal to flow in desired direction, thereby imparting desired fibre structure to the component.

Auto – Forging:

This is a modified form of impression – die forging, used mainly for non – ferrous metals.

In this a cast preform, as removed from the mold while hot, is finish – forged in a die. The flash formed during die forging is trimmed later in the usual manner. As the four steps of the process – casting, transfer from mold to the forging die, forging, and trimming are in most applications completely mechanized, the process has acquired the name Auto – forging.

Coining:

It is a closed – die forging process used mainly for minting coins and making of jewelry. In order to produce fine details on the work material the pressures required are as large as five or six times the strength of the material. Lubricants are not employed in this process because they can get entrapped in the die cavities and, being incompressible, prevent the full reproduction of fine details of the die.

Net - shape Forging (Precession Forging)

Modern trend in forging operation is toward economy and greater precision. The metal is deformed in cavity so that no flash is formed and the final dimensions are very close to the desired component dimensions. There is minimum wastage of material and need for subsequent machining operation is almost eliminated.

The process uses special dies having greater accuracies than those in impression – die gorging, and the equipment used is also of higher capacity. The forces required for forging are high. Aluminum and magnesium alloys are more suitable although steel can also be precision – forged. Typical precision – forged components are gears, turbine blades, fuel injection nozzles, and bearing casings.

Because of very high cost of toolings and machines, precision forging is preferred over conventional forging only where volume of production is extremely large.

Forging Force Requirement:

The forging force, F, required to forge material by impression – die forging operation can be determined by the relation

F = k . s f . A

where k is a constant (whose value can be taken from Table 2.1 s f is the flow stress of material at the forging temperature, and A is the projected area of the forging including the flash.

In hot forging of most non – ferrous metals and alloys, the forging pressure is generally in the range of 500 MPa to 1000 MPa.

Table 2.1 Range of value of k	
Simple shape of part, no flash produced	3 to 5
Simple shape of part, flash produced	5 to 6
Intricate shape of part, flash produced	8 to 12

Press Forging

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

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

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

Upset Forging

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

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

Upsetting machines, called upsetters, are generally horizontal acting.

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

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

Roll Forging

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

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

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Lecture 3

SWAGING

In this process, the diameter of a rod or a tube is reduced by forcing it into a confining die. A set of reciprocation dies provides radial blows to cause the metal to flow inward and acquire the form of the die cavity. The die movements may be of in – and – out type or rotary. The latter type is obtained with the help of a set of rollers in a cage, in a similar action as in a roller bearing. The workpiece is held stationary and the dies rotate, the dies strike the workpiece at a rate as high as 10 - 20 strokes per second.

Screwdriver blades and soldering iron tips are typical examples of swaged products. Fig 3.1 shows these and other products made by swaging.

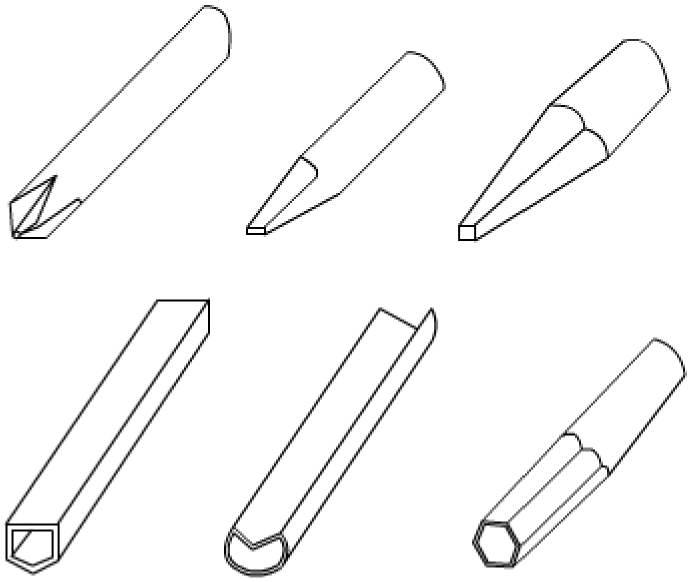

Fig 3.1 Typical parts made by swaging.

In tube swaging, the tube thickness and / or internal dia of tube can be controlled with the use of internal mandrels. For small – diameter tubing, a thin rod can be used as a mandrel; even internally shaped tubes can be swaged by using shaped mandrels. Fig 3.2 shows the process.

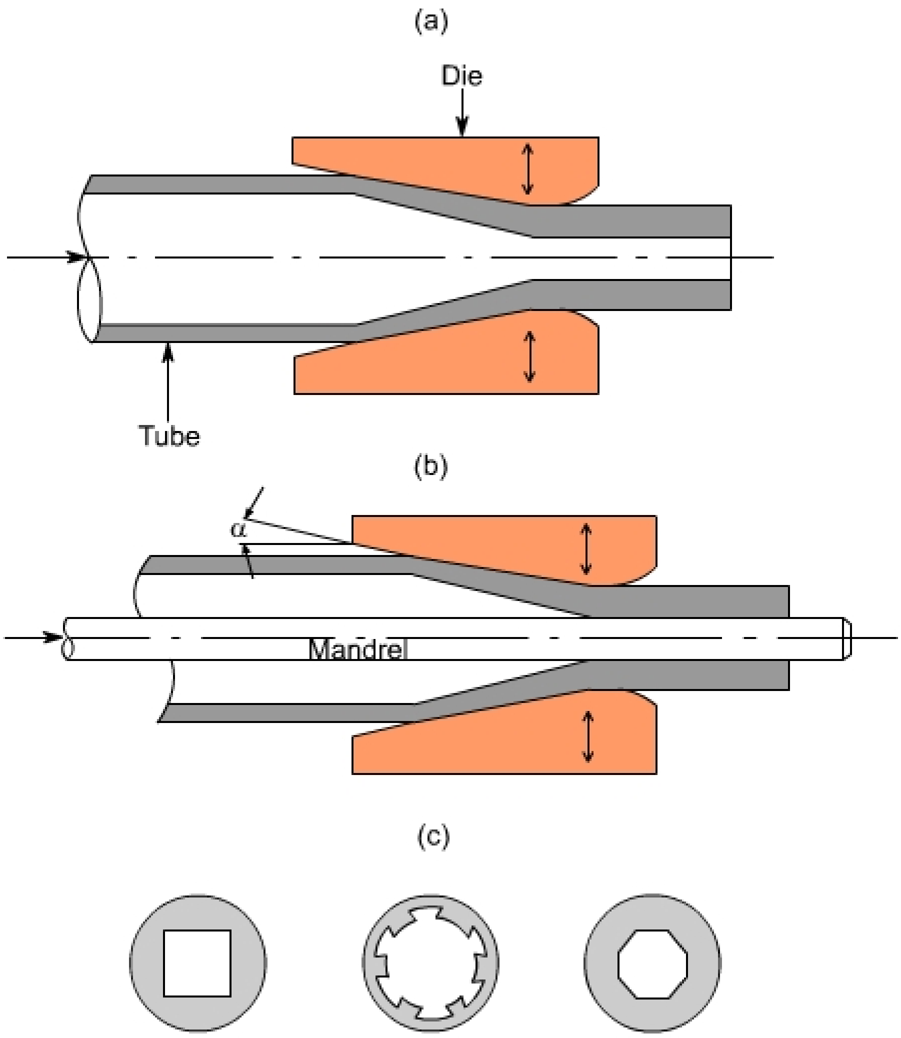

Fig 3.2 (a) Swaging of tubes without a mandrel. Wall thickness is more in the die gap.
(b) Swaging with a mandrel. The final wall thickness of the tube depends on the mandrel diameter.
(c) Examples of cross-sections of tubes produced by swaging on shaped mandrels.

The process is quite versatile. The maximum diameter of work piece that can be swaged is limited to about 150 mm; work pieces as small as 0.5 mm diameter have been swaged. The production rate can be as high as 30 parts per minute depending upon the complexity of the part shape and the part handling means adopted.

The parts produced by swaging have tolerance in the range ± 0.05 mm to ± 0.5 mm and improved mechanical properties. Use of lubricants helps in obtaining better work surface finish and longer die life. Materials, such as tungsten and molybdenum are generally swaged at elevated temperatures as they have low ductility at room temperature. Hot swaging is also used to form long or steep tapers, and for large reductions.

Swaging is a noisy operation. The level of noise can be, however, reduced by proper mounting of the machine or by the use of enclosure.

WIRE DRAWING

Wire drawing is primarily the same as bar drawing except that it involves smaller – diameter material that can be coiled. It is generally performed as a continuous operation on draw bench like the one shown in Fig 3.3

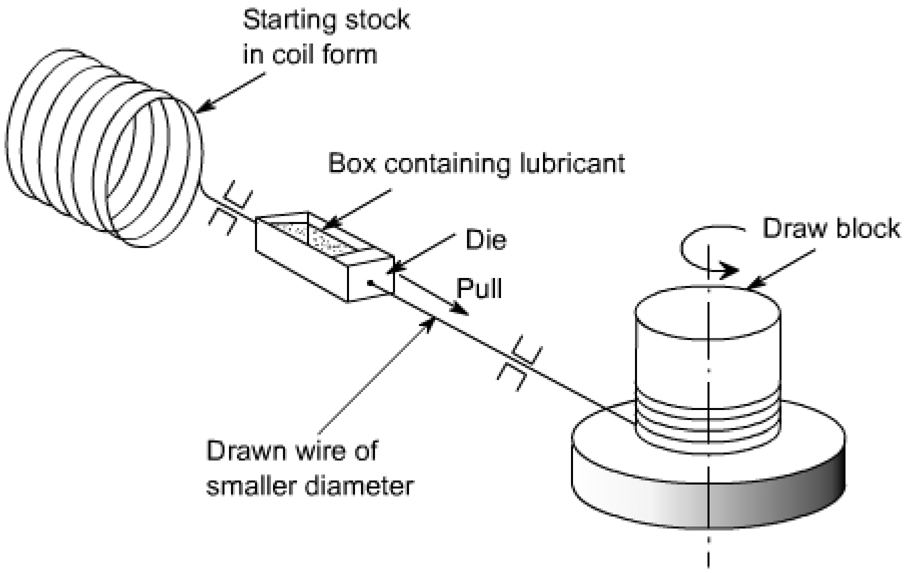

Fig 3.3 Wire drawing on a continuous draw block. The rotating draw block provides a continuous pull on the incoming wire.

Large coil of hot rolled material of nearly 10 mm diameter is taken and subjected to preparation treatment before the actual drawing process. The preparation treatment for steel wire consists of :

- Cleaning. This may be done by acid pickling, rinsing, and drying. Or, it may be done by mechanical flexing.
- Neutralization. Any remaining acid on the raw material is neutralized by immersing it in a lime bath. The corrosion protected material is also given a thin layer of lubricant.

To begin the drawing process, one end of coil is reduced in cross section upto some length and fed through the drawing die, and gripped. A wire drawing die is generally made of tungsten carbide and has the configuration shown in Fig 3.4 for drawing very fine wire, diamond die is preferred.

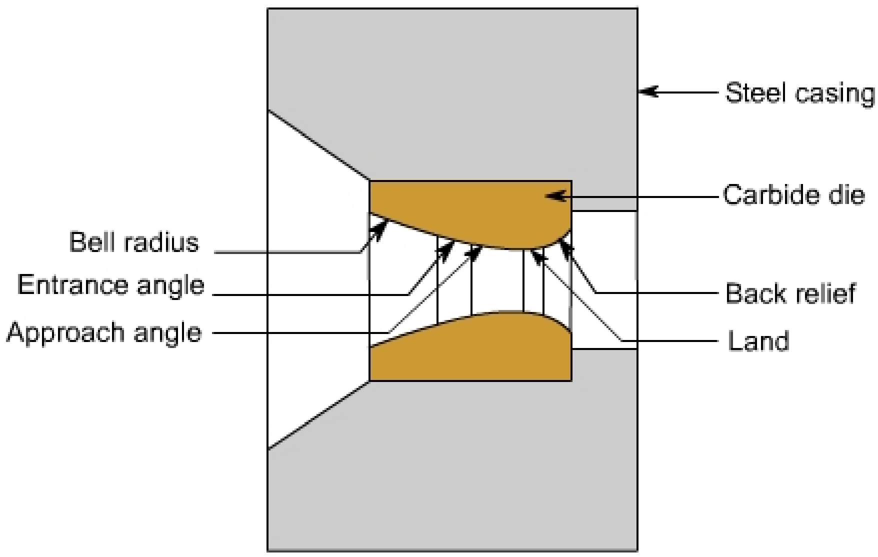

Fig 3.4 Cross section through a typical carbide wire drawing die.

Small diameter wire is generally drawn on tandom machines which consists of a series of dies, each held in a water – cooled die block. Each die reduces the cross section by a small amount so as to avoid excessive strain in the wire. Intermediate annealing of material between different states of wire may also be done, if required.

Wire drawing terms :

$$\text{Draft} = D_o - D_f$$

$$\%\ \text{reduction in area} = \frac{A_o - A_f}{A_f} \times 100 = \frac{D_o^2 - D_f^2}{D_f^2} \times 100$$

$$\%\ \text{elongation} = \frac{L_f - L_o}{L_o}$$

Where D_o , D_f , L_o and L_f are the original and final diameter and length. A_o and A_f are original and final cross sectional area.

For a single cold – drawing pass, the percent area reduction that can be done depends upon many factors. These include the type of material, its size, initial metallurgical condition, the final size and mechanical properties desired, die design and lubrication efficiency. The percent of area reduction per pass can range from near zero to 50%.

Die pull

The force required to pull the stock through the die (under frictionless conditions) can be computed as follows.

$$F = Y_{avg} \cdot A_f \cdot \ln\left(\frac{A_o}{A_f}\right)$$

Where F = die pull, i.e. the force required to pull the stock through the die

Y_{avg} = average true stress of the material in the die gap

A_o , A_f = original and final areas of cross section of material.

Alternatively, the following expression can be used

$F = c\, \sigma_t (A_o - A_f)$

where c is a constant whose value is in the range 1.5 to 3.0 depending upon the % area reduction, (lower value for higher % reduction), and σ_t is tensile strength of material before drawing.

The pull force determines the machine capacity needed.

TUBE DRAWING

The diameter and wall thickness of tubes that have been produced by extrusion or other processes can be reduced by tube drawing process. The process of tube drawing (Fig 3.5) is similar to wire or rod drawing except that it usually requires a mandrel of the requisite diameter to form the internal hole.

Tubes as large as 0.3 m in diameter can be drawn.

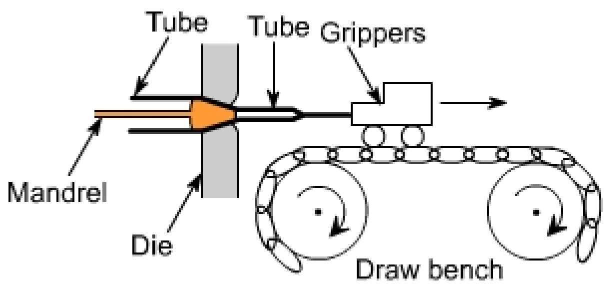

Fig 3.5

Drawing Equipment

Drawing equipment can be of several designs. These designs can be classified into two basic types; Draw bench, and Bull block. A draw bench (Fig 3.5) uses a single die and the pulling force is supplied by a chain drive or by hydraulic means. Draw bench is used for single length drawing of rod or tube with diameter greater than 20mm. Length can be as much as 30 m. The drawing speed attainable on a draw bench ranges from 5 m/min to 50 m/min. Draw benches are available having capacities to provide pull force of upto 1 MN.

Bull block or rotating drum (Fig 3.3) is used for drawing rods or wires of very long length.

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FORMABILITY OF SHEET METAL

Formability may be defined as the ease with which material may be forced into a permanent change of shape.

The formability of a material depends on several factors. The important one concerns the properties of material like yield strength, strain hardening rate, and ductility. These are greatly temperature - dependent. As the temperature of material is increased, the yield strength and rate of strain hardening progressively reduce and ductility increases. The hot working of metal, therefore, permits relatively very large amount of deformation before cracking.

There are several methods of predicting formability. A brief description of some important methods follows.

Cup or Radial Drawing:

Cup drawing test uses a circular blank from the metal to be tested. It is inserted in a die, and the severity of the draw it is able to withstand without tearing called the drawing ratio, is noted. The drawing ratio is the ratio of the cup diameter to the blank diameter.

$$R_d = \frac{D - d}{D}$$

Where R_d = drawing ratio

D = blank diameter

d = punch diameter

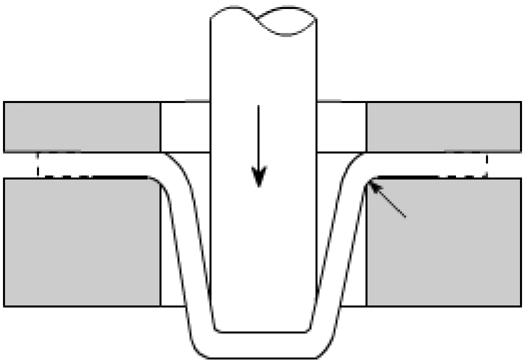

Fig .4.1 (a)

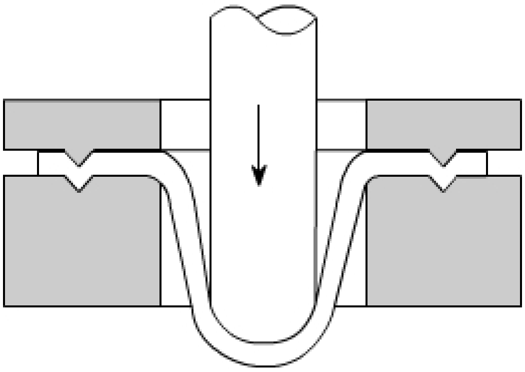

Fig .4.1 (b)

A drawing ratio of 50 % is considered excellent. As shown in Fig 4.1(a), either a flat bottom punch with lubricated blank may be used to draw the cup, or as shown in Fig 4.1(b) a blank may be drawn by a lubricated hemi – spherical punch. In the first case, the action is principally that of drawing in which cylindrical stretching of material takes place. In the second case, there will be bi – axial stretching of the material. For drawing, the clamping force is just sufficient to prevent buckling of the material at the draw radius as it enters the die. The deformation takes place in the flange and over the draw radius.

Fukui Conical – Cup Test:

It utilizes a hemispherical, smoothly polished punch. No blank holder is required. In each test, a drawing ratio which will result in a broken cup is determined. Formation of wrinkles is avoided by using a fixed ratio between the thickness of the sheet, the size of the blank, and the punch and die diameters. Under these conditions, the test produces a known amount of stretching, drawing, and bending under tension.

Normal Anisotropy Coefficient:

The material is subjected to uni-axial tensile test. The anisotropy coefficient is derived from the ratio of the plastic width strain ε_W to the thickness strain ε_t . A material with a high plastic anisotropy also has a greater “thinning resistance.” In general, the higher the anisotropy coefficient the better the material deforms in drawing operations.

Strain-Hardening Coefficient:

Strain hardening refers to the fact that as a metal deforms in some area, dislocations occur in the microstructure. As these dislocations pile up, they tend to strengthen the metal against further deformation in that area. Thus the strain is spread throughout the sheet. However, at some point in the deformations, the strain suddenly localizes and necking, or localized thinning, develops. When this occurs, little further overall deformation of the sheet can be obtained without it fracturing in the necked region.

The strain – hardening coefficient therefore reflects how well the metal distributes the strain throughout the sheet, avoiding or delaying localized necking. The higher the strain – hardening coefficient, the move the material will harden as it is being stretched and the greater will be the resistance to localized necking. Necks in the metal harm surface appearance and affect structural integrity.

For many stamping operations, stretching of the metal is the critical factor and is dependent on the strain – hardening coefficient. Therefore, stampings that need much drawing should be made from metal having high average strain – hardening coefficients. Yield strength should be low to avoid wrinkles or buckling.

Forming Limit Curve:

The forming – limit curve is a good index of determining the formability of sheet metal. Essentially, it requires to draw a curve that shows a boundary line between acceptable strain levels in forming and those that may cause failure, Fig 4.2.

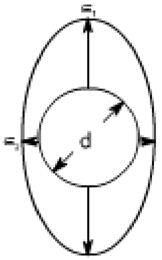

Fig 4.2 The relationship of major, ε_1 , and minor, ε_2 , strains is established by measurement after forming.

The curve indicates the relation between major and minor strains that are perpendicular to the plane of the sheet. To determine these strains, a grid of circles is marked on the sheet metal, say by an electrolytic stencil – etching process. After the metal is deformed, the circles are measured to obtain the major strain ε_1 and the minor strain ε_2 , as shown in Fig 4.2 Typically, ten to fifteen data points are obtained from a test specimen in the region of fracture. Ellipses lying both in the failed region and just outside of it are measured. The forming – limit curve is then drawn to fall below the strains in the necked and fractured zones, and above the strains found just outside these zones (Fig 4.3)

With controlled variation in specimen size it is possible to plot an entire forming – limit curve from one test setup. A reasonably accurate forming limit curve may be obtained with four specimens while a precision curve may be obtained with eight specimens.

In may be noted that “local” ductility varies for different metals, so no universal forming – limit curve can be developed. For example, two metals may have peak local ductilities of 20% and 50% at a given minor strain. The metal with the 20 % local ductility (high strain – hardening coefficient) may turn out to be the best choice because the strain will then have a better distribution throughout, allowing the entire sheet to be stretched 20%. If the other sheet showed little strain hardening, it might stretch by 50% in local area, but leave the rest of the sheet relatively unstrained.

Through the use of formability – prediction techniques. Designers and fabricators are able to make a wiser choice of metals and obtain date quickly on newer metals. The essential data can be obtained before the die is designed. Also metal suppliers will be able to establish whether a material possesses required formability before it is shipped from the plant.

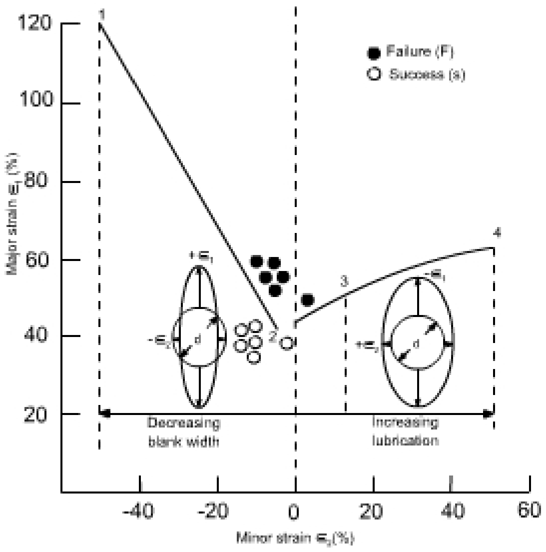

Fig. 4.3

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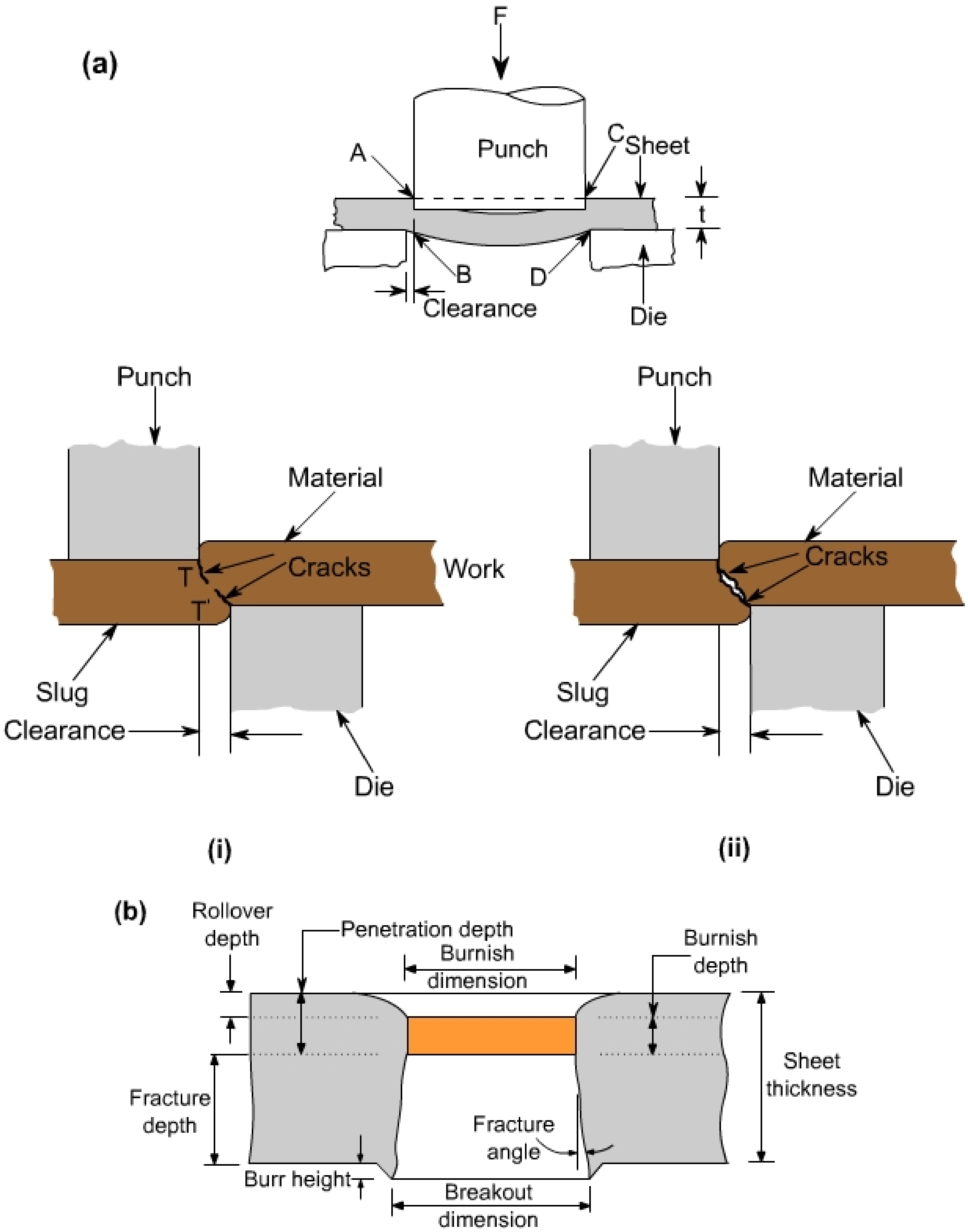
SHEARING

Shearing is a cutting operation used to remove a blank of required dimensions from a large sheet. To understand the shearing mechanism, consider a metal being sheared between a punch and a die, Fig 5.1 Typical features of the sheet and the slug are also shown in this figure. As can be seen that cut edges are neither smooth nor perpendicular to the plane of the sheet.



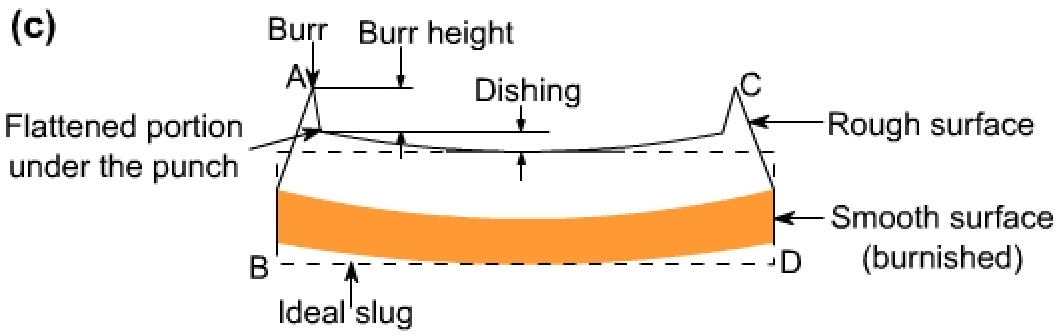


Fig 5.1 (a) Shearing with a punch and die (b) features of a punched hole and (c) features of the slug.

Shearing starts as the punch presses against the sheet metal. At first, cracks form in the sheet on both the top and bottom edges (marked T and T', in the figure). As the punch descends further, these cracks grow and eventually meet each other and the slug separates from the sheet. A close look at the fractured surfaces will revel that these are quite rough and shiny; rough because of the cracks formed earlier, and shiny because of the contact and rubbing of the sheared edge against the walls of the die.

The clearance between the punch and the die plays an important role in the determination of the shape and quality of the sheared ege. There is an optimum range for the clearance, which is 2 to 10% of the sheet thickness, for the best results. If the clearance increases beyond this, the material tends to be pulled into the die and the edges of the sheared zone become rougher. The ratio of the shining (burnished) area to the rough area on the sheared edge decreases with increasing clearance and sheet thickness. The quality of sheared edge is also affected by punch speed; greater the punch speed better the edge quality.

Shearing Operations

For general purpose shearing work, straight line shears are used. as shown in Fig 5.2, small pieces (A, B, C, D……….) may be cut from a large sheet.

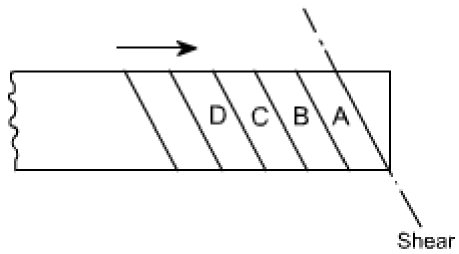


Fig 5.2

Shearing may also be done between a punch and die, as shown in Fig 5.1. The shearing operations make which use of a die, include punching, blanking, piercing, notching, trimming, and nibbling.

Punching/Blanking

Punching or blanking is a process in which the punch removes a portion of material from the larger piece or a strip of sheet metal. If the small removed piece is discarded, the operation is called punching, whereas if the small removed piece is the useful part and the rest is scrap, the operation is called blanking, see Fig 5.3.

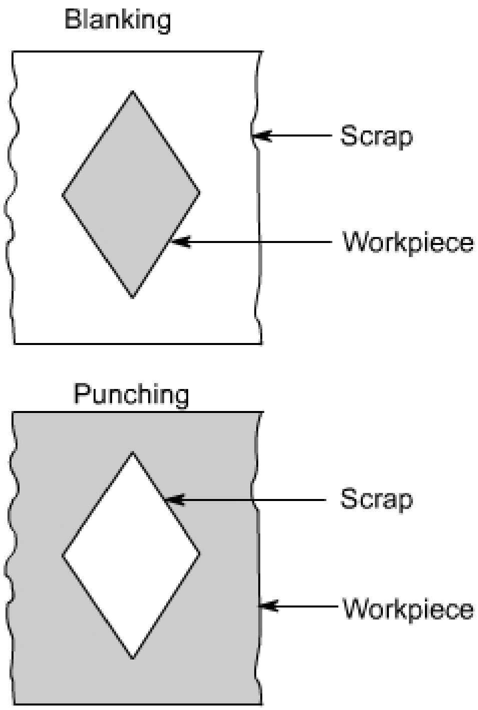


Fig 5.3 Comparison of basic stamping operations.
In punching, the metal inside the part is removed; in blanking, the metal around the part is removed.

A typical setup used for blanking is shown in Fig 5.4.

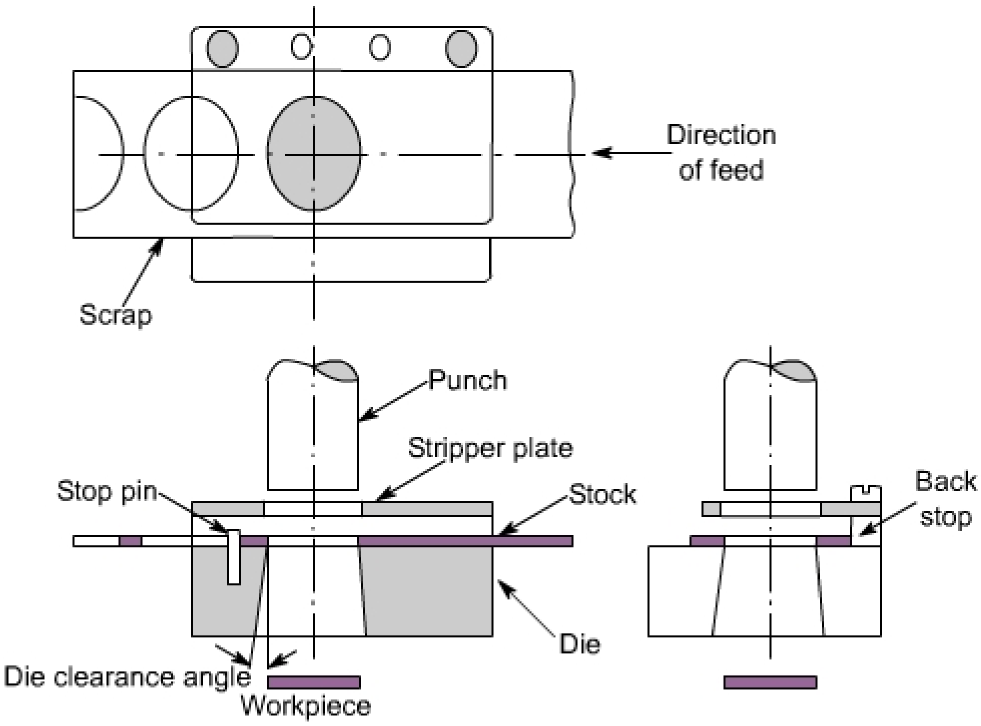


Fig 5.4 Blanking punch and die.

The clearance between the die and punch can be determined as c = 0.003 τ. τ where t is the sheet thickness and τ is the shear strength of sheet material. For blanking operation, die size = blank size, and the punch is made smaller, by considering the clearance.

The maximum force, P required to be exerted by the punch to shear out a blank from the sheet can be estimated as

$$P = t. L. \tau$$

where t is the sheet thickness, L is the total length sheared (such as the perimeter of hole), and t is the shear strength of the sheet material.

Stripping force. Two actions take place in the punching process – punching and stripping. Stripping means extracting the punch. A stripping force develops due to the spring back (or resiliency) of the punched material that grips the punch. This force is generally expressed as a percentage of the force required to punch the hole, although it varies with the type of material being punched and the amount of clearance between the cutting edges. The following simple empirical relation can be used to find this force

SF = 0.02 L.t

where SF = stripping force, kN

L = length of cut, mm

t = thickness of material, mm

Example: A circular blank of 30 mm diameter is to be cut from 2 mm thick 0.1 C steel sheet. Determine the die and punch sizes. Also estimate the punch force and the stripping force needed. You may assume the following for the steel : Tensile strength: 410 MPa ; shear strength : 310 MPa

Solution:- For cutting a blank, die size = blank size

$\therefore$ Die size = 30mm

Clearance = 0.003 x t x τ = 0.003 x 2 x 310

= 1.86 mm

Punch size = blank size – 2 clearance

= 30 – 2 x 1.86 = 26.28 mm

Punch force needed = L. t. π = π x 30 x 2 x 310

= 58.5 kN

Stripping force needed = 0.02 L.t

= 0.02 x π x 30 x 2

= 3.77 kN

Piercing:

It is a process by which a hole is cut (or torn) in metal. It is different from punching in that piercing does not generate a slug. Instead, the metal is pushed back to form a jagged flange on the back side of the hole.

A pierced hole looks somewhat like a bullet hole in a sheet of metal.

Trimming:

When parts are produced by die casting or drop forging, a small amount of extra metal gets spread out at the parting plane. This extra metal, called flash, is cut – off before the part is used, by an operation called trimming. The operation is very similar to blanking and the dies used are also similar to blanking dies. The presses used for trimming have, however, relatively larger table.

Notching:

It is an operation in which a specified small amount of metal is cut from a blank. It is different from punching in the sense that in notching cutting line of the slug formed must touch one edge of the blank or strip. A notch can be made in any shape. The purpose of notching is generally to release metal for fitting up.

Nibbling:

Nibbling is variation of notching, with overlapping notches being cut into the metal. The operation may be resorted to produce any desired shape, for example flanges, collars, etc.

Perforating:

Perforating is an operation is which a number of uniformly spaced holes are punched in a sheet of metal. The holes may be of any size or shape. They usually cover the entire sheet of metal.

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Lecture 6

SHEET METAL PROCESSES

BENDING

Bending is one very common sheet metal forming operation used not only to form shapes like seams, corrugations, and flanges but also to provide stiffness to the part (by increasing its moment of inertia).

As a sheet metal is bent (Fig 6.1), its fibres experience a distortion such that those nearer its outside, convex surface are forced to stretch and come in tension, while the inner fibres come in compression. Somewhere, in the cross section, there is a plane which separates the tension and compression zones. This plane is parallel to the surface around which the sheet is bending, and is called neutral axis. The position of neutral axis depends on the radius and angle of bend. Further, because of the Poisson's ratio, the width of the part L in the outer region is smaller, and in the inner region it is larger, than the initial original width.

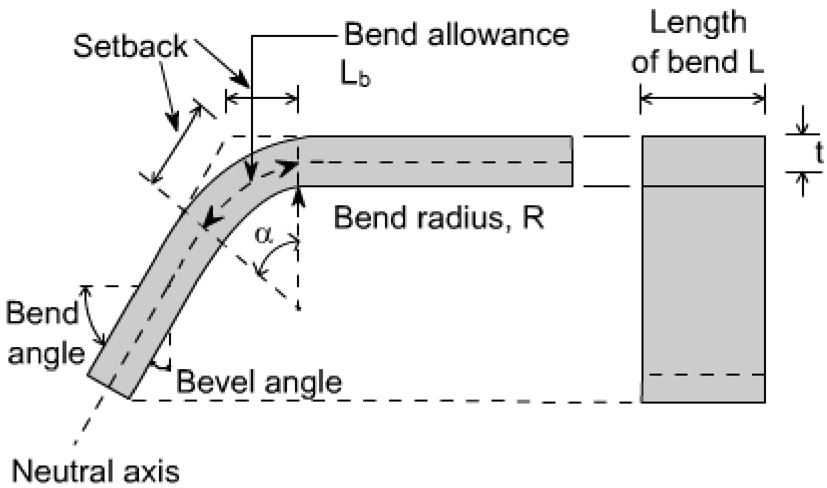


Fig 6.1 Sheet metal bending. It may be noted that the bend radius is measured to the inner surface of the bent part.

BEND ALLOWANCE

It is the length of the neutral axis in the bend, Fig 6.1. This determines the blank length needed for a bent part. It can be approximately estimated from the relation

$$L_b = \alpha (R + kt)$$

where, L_b = bend allowance (mm)

α = bend angle (radian)

R = bend radius (mm)

t = thickness of sheet (mm), and

k = constant, whose value may be taken as 1/3 when $R < 2t$, and as 1/2 when $R \geq 2t$.

Example

A 20 mm wide and 4 mm thick C 20 steel sheet is required to be bent at 60^0 at bend radius 10 mm. Determine the bend allowance.

Solution.

Here, bend radius R = 10 mm

Sheet thickness t = 4 mm

$$\alpha = 2\pi x \frac{60}{360} \text{radian}$$

Since $R > 2t$, k = 0.5

Bend allowance

$$= \left(2\pi x \frac{60}{360} \right) (10 + 0.5x4)$$
$$= 12.56 \text{mm}$$

MINIMUM BEND RADIUS

As the ratio of the bend radius to the thickness of sheet (R / t) decreases, the tensile strain on the outer fibres of sheet increases. If R / t decreases beyond a certain limit, cracks start appearing on the surface of material. This limit is called *Minimum Bend Radius* for the material.

Minimum bend radius is generally expressed in terms of the thickness of material, such as 2t, 3t, 4t, etc. Table 6.1 gives the minimum bend radius allowed for different materials.

Table 6.1 Minimum Bend radius for Various Materials at Room Temperature

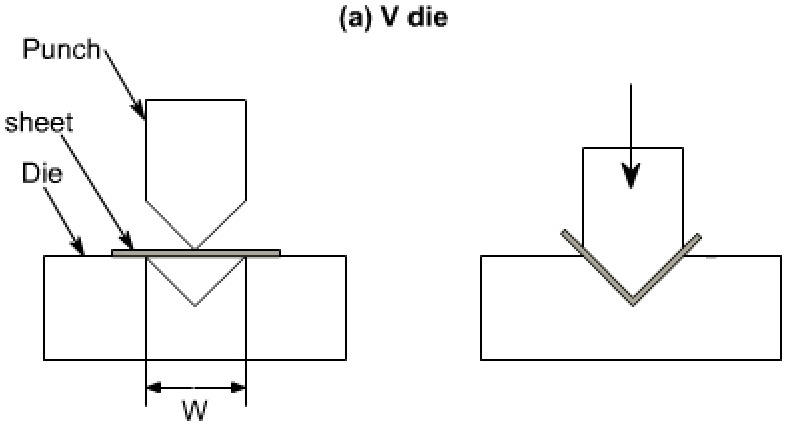
Material	**Condition**	
	Soft	**Hard**
Aluminum alloys	0	6t
Beryllium copper	0	4t
Brass,low-leaded	0	2t
Magnesium	5t	13t
Steels		
Austenitic stainless	0.5t	6t
Low-carbon,low-alloy	0.5t	4t
Titanium	0.7t	3t
Titanium alloys	2.5t	4t

Bending Force :

There are two general types of die bending : V – die bending and wiping die bending. V – die bending is used expensively in brake die operations and stamping die operations. The bending force can be estimated from the following simple relation.

$$P = k.Y.L.t^2 / D$$

where P is bending force, γ is the yield stress of the material, L is the bend length (bend allowance), t is the sheet thickness, D is the die opening and k is a constant whose value can be taken as 1.3 for a V-die and 0.3 for a wiping die. Fig 6.2 shows various types of bending dies.



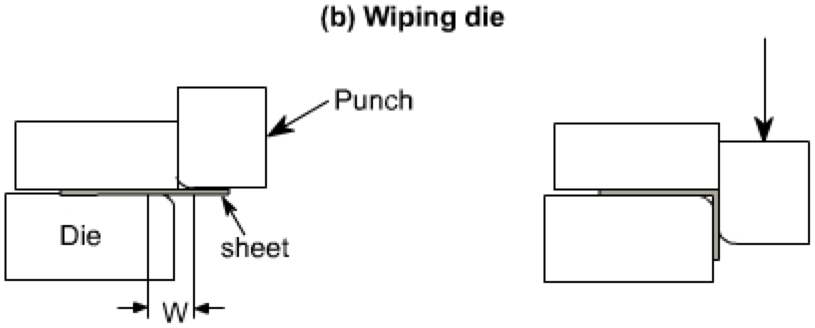


Fig 6.2 Die-bending operations.

Bending force varies as the punch progresses through the bending operation. The force is zero in the beginning. It rises and reaches the maximum value as the punch progresses and reaches the bottom of the stroke.

Example:

A 400 mm long and 2.5 mm thick piece of carbon steel sheet is required to be bent at 90^0 using a V – die. You may assume the yield stress of the material as 500 MPa and the die opening as 10 times the material thickness. Estimate the force required for the operation.

Solution : Here, Y = 500 MPa

L = 400 mm

t = 2.5 mm

k = 1.3 (for V – die)

D = 25 mm

Bending force $P = k.Y.L.t^2 / D$

$= 1.3 \times 500 \times 400 \times (2.5)^2 / 25$

= 65 KN

Example :

If the material as mentioned in the above example is to be bent at 90^0 using wiping die with radius = 3.75 mm, what is the force requirement?

Solution : Here,Y = 500 MPa

L = 400 mm

t = 2.5 mm

k = 0.3

D = 2.5 + 3.75 + 3.75 = 10mm (see Fig 6.3)

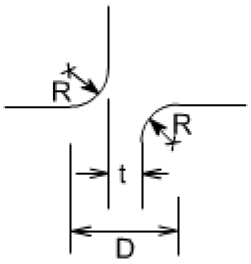


Fig 6.3

Bending force P = k.Y.L.t^2 / D

= 0.3 x 500 x 400 x $(2.5)^2$ / 10

= 37.5 KN

DRAWING

It is a process of cold forming a flat blank of sheet metal into a hollow vessel without much wrinkling, trimming, or fracturing. The process involves forcing the sheet metal blank into a die cavity with a punch. The punch exerts sufficient force and the metal is drawn over the edge of the die opening and into the die, Fig 6.4. In forming a cup, however, the metal goes completely into the die, Fig 6.5.

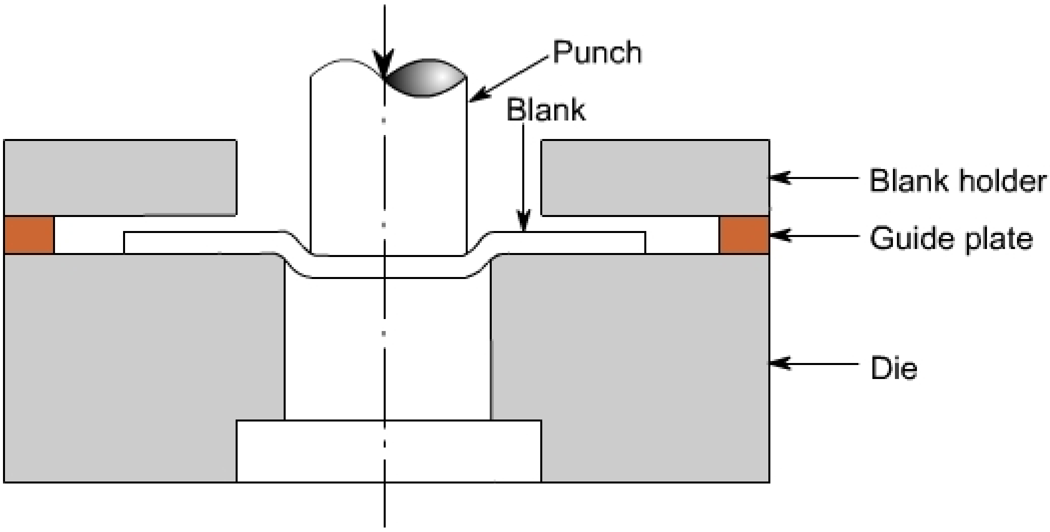


Fig 6.4 Drawing operation.

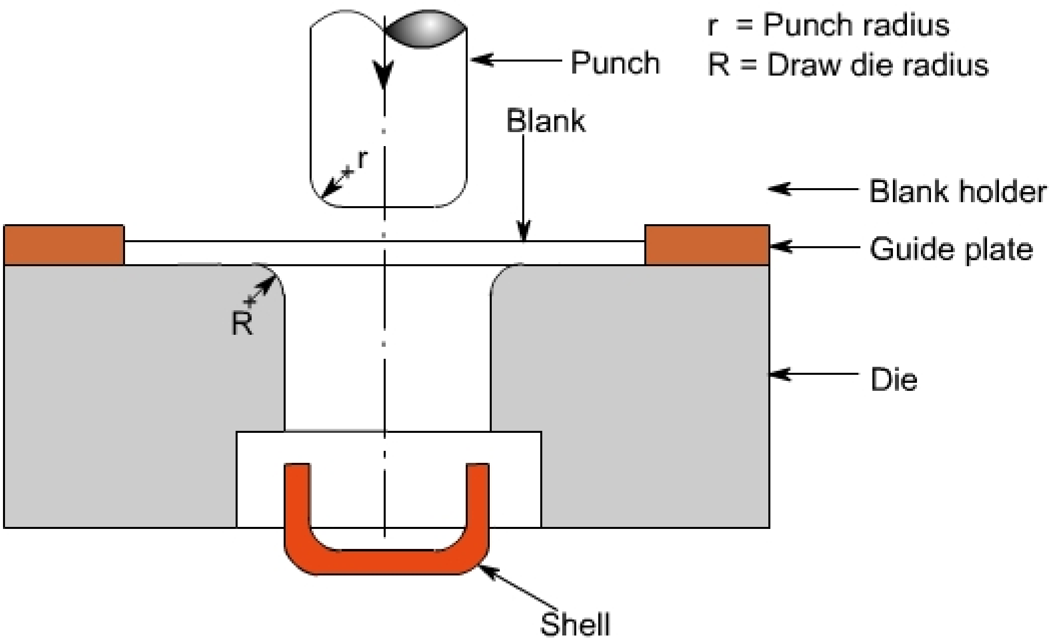


Fig 6.5 Drawing operation.

The metal being drawn must possess a combination of ductility and strength so that it does not rupture in the critical area (where the metal blends from the punch face to the vertical portion of the punch). The metal in this area is subjected to stress that occurs when the metal is pulled from the flat blank into the die.

OPERATION **.** A setup similar to that used for blanking is used for drawing with the difference that the punch and die are given necessary rounding at the corners to permit smooth flow of metal during drawing. The blank of appropriate dimensions is place within the guides on the die plate. The punch descends slowly on the blank and metal is drawn into the die and the blank is formed into the shape of cup as punch reaches the bottom of the die. When the cup reaches the counter – bored portion of the die, the top edge of the cup formed around the punch expands a bit due to the *spring back* . On the return stroke of the punch, the cup is stripped off the punch by this counter – bored portion.

The term *shallow drawing* is used when the height of cup formed is less than half its diameter. When drawing deeper cup (height greater that ½ diameter) the chances of excessive wrinkle formation at the edges of blank increases. To prevent this, a blank holder is normally provided, see Fig 6.4. As the drawing process proceeds the blank holder stops the blank from increasing in thickness beyond a limit and allows the metal to flow radially. The limiting thickness is controlled by the gap between the die and the blank holder, or by the spring pressure in the case of a spring loaded blank holder.

Some lubricant is generally used over the face of the blank to reduce friction and hence drawing load.

Blank Size

It is generally difficult to find the exact size of the blank needed for drawing a given cup, because of thinning and thickening of the metal sheet during the drawing operation. The following simple relations can be used for determine the blank diameter D:

$$D = \sqrt{d^2 + 4dh - 0.5r} \quad \text{when } d \geq 20r$$

$$= \sqrt{d^2 + 4dh - 0.5r} \quad \text{when } d \text{ is between } 15r \text{ and } 20r$$

$$= \sqrt{d^2 + 4dh - 5r} \quad \text{when } d \text{ is between } 10r \text{ and } 15r$$

where d = outside diameter of cup

h = height of cup

r = corner radius on punch.

Drawing Force.

For drawing cylindrical shells having circular cross section, the maximum drawing force P can be determined from the relation

P = k.t.d.t.Y

where d = outside diameter of cup

t = thickness of material

Y = yield strength of material

k = factor whose value is approx. equal to [D/d – 0.6]

D = blank diameter

EMBOSSING

Embossing is an operation in which sheet metal is drawn to shallow depths with male and female matching dies, Fig 6.6. The operation is carried out mostly for the purpose of stiffening flat panels.The operation is also sometimes used for making decoration items like number plates or name plates, jewelry, etc.

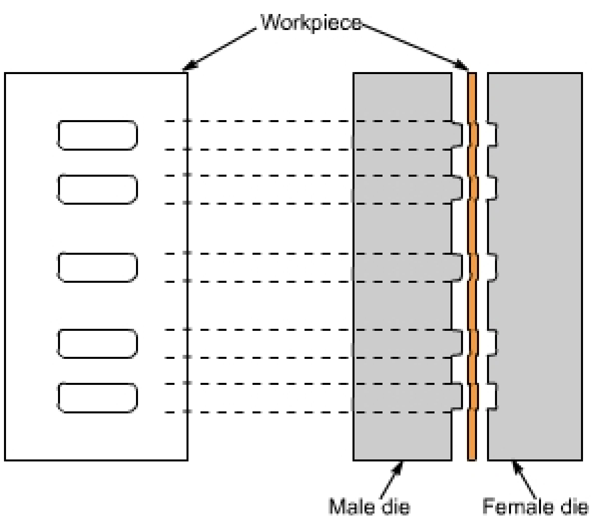


Fig 6.6 Embossing operation with two dies. Letters, numbers and designs on sheet-metal parts can be produced by this operation.

COINING

Coining is a severe metal squeezing operation in which the flow of metal occurs only at the top layers of the material and not throughout the values. The operation is carried out in closed dies mainly for the purpose of producing fine details such as needed in minting coins, and medal or jewelry making. The blank is kept in the die cavity and pressures as high as five to six times the strength of material are applied. Depending upon the details required to be coined on the part, more than one coining operations may be used.

The difference between coining and embossing is that the same design is created on both sides of the work piece in embossing (one side depressed and the other raised), whereas in coining operation, a different design is created on each side of work piece.

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Lecture 7

PRESSES FOR SHEET METAL WORKING

Classification of presses.

Types of presses for sheet metal working can be classified by one or a combination of characteristics, such as source of power, number of slides, type of frame and construction, type of drive, and intended applications.

Classification on the basis of source of power.

- Manual Presses. These are either hand or foot operated through levers, screws or gears. A common press of this type is the arbor press used for assembly operations.
- Mechanical presses.These presses utilize flywheel energy which is transferred to the work piece by gears, cranks, eccentrics, or levers.
- Hydraulic Presses. These presses provide working force through the application of fluid pressure on a piston by means of pumps, valves, intensifiers, and accumulators. These presses have better performance and reliability than mechanical presses.
- Pneumatic Presses. These presses utilize air cylinders to exert the required force. These are generally smaller in size and capacity than hydraulic or mechanical presses, and therefore find use for light duty operations only.

Classification on the basis of number of slides.

- Single Action Presses. A single action press has one reciprocation slide that carries the tool for the metal forming operation. The press has a fixed bed. It is the most widely used press for operations like blanking, coining, embossing, and drawing.
- Double Action Presses. A double action press has two slides moving in the same direction against a fixed bed. It is more suitable for drawing operations, especially deep drawing, than single action press. For this reason, its two slides are generally referred to as outer blank holder slide and the inner draw slide. The blank holder slide is a hollow rectangle, while the inner slide is a solid rectangle that reciprocates within the blank holder. The blank holder slide has a shorter stroke and dwells at the bottom end of its stroke, before the punch mounted on the inner slide touches the workpiece. In this way, practically the complete capacity of the press is available for drawing operation.

  Another advantage of double action press is that the four corners of the blank holder are individually adjustable. This permits the application of non uniform forces on the work if needed.

  A double action press is widely used for deep drawing operations and irregular shaped stampings.
- Triple Action Presses. A triple action press has three moving slides. Two slides (the blank holder and the inner slide) move in the same direction as in a double – action press and the third or lower slide moves upward through the fixed bed in a direction opposite to that of the other two slides. This action allows reverse – drawing, forming or bending operations against the inner slide while both upper actions are dwelling.

  Cycle time for a triple – action press is longer than for a double – action press because of the time required for the third action.

Classification on the basis of frame and construction.

- Arch – Frame Presses. These presses have their frame in the shape of an arch. These are not common.
- Gap Frame Presses. These presses have a C-shaped frame. These are most versatile and common in use, as they provide un – obstructed access to the dies from three sides and their backs are usually open for the ejection of stampings and / or scrap.
- Straight Side Presses. These presses are stronger since the heavy loads can be taken in a vertical direction by the massive side frame and there is little tendency for the punch and die alignment to be affected by the strain. The capacity of these presses is usually greater than 10 MN.
- Horn Presses. These presses generally have a heavy shaft projecting from the machine frame instead of the usual bed. This press is used mainly on cylindrical parts involving punching, riveting, embossing, and flanging edges.

Fig 7.1 shows typical frame designs.

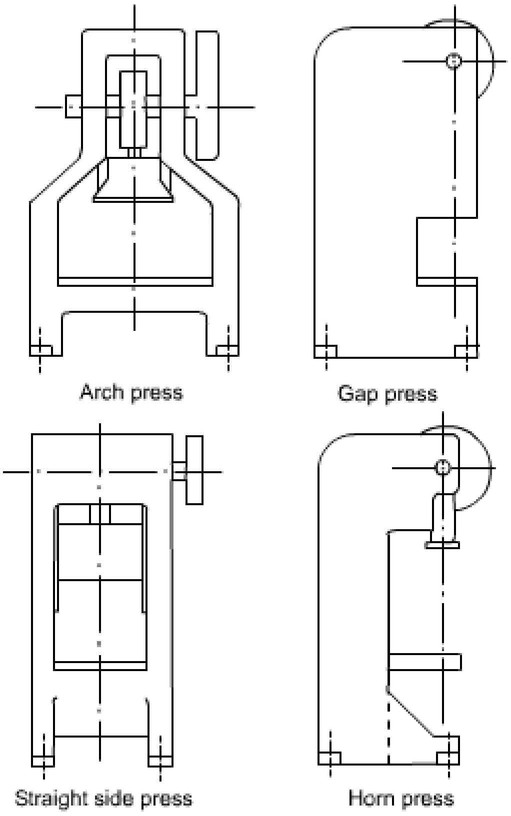

Fig 7.1 Typical frame designs used for power presses.

Press Selection:

Proper selection of a press is necessary for successful and economical operation. Press is a costly machine, and the return on investment depends upon how well it performs the job. There is no press that can provide maximum productively and economy for all application so, when a press is required to be used for several widely varying jobs, compromise is generally made between economy and productivity.

Important factors affecting the selection of a press are size, force, energy and speed requirements.

Size. Bed and slide areas of the press should be of enough size so as to accommodate the dies to be used and to make available adequate space for die changing and maintenance. Stroke requirements are related to the height of the parts to be produced. Press with short stroke should be preferred because it would permit faster operation, thus increasing productivity. Size and type of press to be selected also depends upon the method and nature of part feeding, the type of operation, and the material being formed.

Force and Energy. Press selected should have the capacity to provide the force and energy necessary for carrying out the operation. The major source of energy in mechanical presses is the flywheel, and the energy available is a function of mass of flywheel and square of its speed.

Press Speed. Fast speeds are generally desirable, but they are limited by the operations performed. High speed may not, however, be most productive or efficient. Size, shape and material of workpiece, die life, maintenance costs, and other factors should be considered while attemping to achicve the highest production rate at the lowest cost per piece.

Mechanical versus Hydraulic Presses:

Mechanical presses are very widely used for blanking, forming and drawing operations required to be done on sheet metal. For certain operations which require very high force, for example, hydraulic presses are more advantageous. Table 7.1 gives a comparison of characteristics and preferred application of the two types of press.

Table 7.1 Comparison of Mechanical and Hydraulic Presses

Characteristic	Mechanical Presses	Hydraulic Presses
Force	Depends upon slide position.	Dose not depend upon slide position. Relatively constant.
Stroke length	Short strokes	Long strokes,even as much as 3 m.
Slide speed	High. Highest at mid-stroke. Can be variable	Slow. Rapid advance and retraction. Variable speeds uniform throughout stroke.
Capacity	About 50 MN (maximum)	About 500 MN, or even more.
Control	Full stroke generally required before reversel.	Adjustable, slide reversal possible from any position.
Application	Operations requiring maximum pressure near bottom of stroke. Cutting operations(blanking, shearing, piercing, Forming and drawing to depths of about 100 mm.	Operations requiring steady pressure through-out stoke. Deep drawing. Drawing irregular shaped parts. Straightening. Operations requiring variable forces and /or strokes.

Press Feeding Devices:

Safety is an important consideration in press operation and every precaution must be taken to protect the operator. Material must be tried to be fed to the press that eliminates any chance of the operator having his or her hands near the dies. The use of feeding device allows faster and uniform press feeding in addition to the safety features.

- **Blank and Stamping Feeds.**

Feeding of blanks or previously formed stampings to presses can be done in several ways. Selection of a specific method depends upon factors like production rate needed, cost, and safety considerations.

Manual feeding . Feeding of blanks or stampings by hand is generally limited to low production rate requirements which do not warrant the cost of automatic or semi- automatic feeding devices. Manual feeding, however, is accomplished with the use of a guard or, if a guard is not possible, hand feeding tools and a point – of – operation safety device. Some commonly used hand feeding tools are special pliers, tongs, tweezes, vacuum lifters and magnetic pick – ups.

Chute feeds . For feeding small blanks or stampings, simple chutes are often used. The blank slides by gravity along rails in the bottom of the chute. Slide chutes are designed for a specific die and blank and are generally attached permanently to the die so as to reduce setup time. Slide angle of 20^0 - 30^0 is sufficient in most cases. Chute feeds need barrier guard enclosure for operation protection, with just enough opening in the enclosure for the blanks to slide through to the die.

Push feeds . These feeds are used when blanks need orientation in specific relation to the die. Work piece is manually placed in a nest in a slide, one at a time, and the slide pushed until the piece falls into the die nest. An interlock is provided so that the press cannot be operation until the slide has correctly located the part in the die. To increase production rate, push feeds can be automated by actuating the feed slide through mechanical attachment to the press slide.

Lift and transfer devices . In some automatic installations vacuum or suction cups are used for lifting of blanks one at a time from stacks and then moved to the die by transfer units. Separation of the top blank from a stack is achieved by devices which are operated magnetically, pneumatically or mechanically.

- **Dial Feeds.**

Dial feeds consist of rotary indexing tables (or turntables) having fixtures for holding workpiecs as they are taken to the press tooling. Parts are placed in the fixtures at the loading station (which are located away from the place of press operation) manually or by other means like chutes, hoppers, vibratory feeders, robots etc. Such feeds are being increasingly used because of higher safety and productivity associated with them.

- **Coil Stock Feed.**

Two main classifications of automatic press feeds for coil stock are slide (or gripper) and roll feeds. Both of these may be press or independently driven.

Mechanical slide feeds. Press – driven slide feeds have a gripper arrangement which clamps and feeds the stock during its forward movement and releases it on the return stroke. Material is prevented from backing up during the return stroke of the gripper by a drag unit like a frictional brake. Grippers reciprocate on rods or slides between adjustable positive stops to ensure accuracy. Slide feeds are available in a variety of sizes and designs. These are generally best for narrow coil stock and short feed lengths.

Hitch – type feed. This feed differs from press – driven mechanical slide feed in that actuation is by a simple flat cam attached to the ram or punch holder instead of by the press. On the downward stroke of the ram, one or more springs are compressed by the cam action, then on the upstroke, the springs provide the force to feed stock into the die.

These feeds are best suited for coil stock of small to medium thickness and for relatively short feed progression. These are one of the oldest and least expensive feeding devices still used very widely. Due to their low cost, they are generally left permanently attached to the dies, thus reducing setup time.

Pneumatic slide feeds. These feeds are similar to mechanical slide feeds in that they have grippers or clamps that reciprocate on guide rails or slides between adjustable positive stops to push and / or pull stock into a die. However, these differ in that they are powered by an air cylinder, with actuation and timing of valves by cam – operated limit switches.

These feeds are best for short progression, and find wide applications in job shops because of their low cost and versatility.

Roll feeds. In these feeds, coil stock is advanced by pressure exerted between intermittently driven, opposed rolls which allow the stock to dwell during the working part of the press cycle. Intermittent rotation (or indexing) of the feed rolls, with the rolls rotating in only one direction, is accomplished in many ways. In one common design, the rolls are indexed through a one – way clutch by a rack – and – pinion mechanism that is actuated by an adjustable eccentric on the press – crankshaft.

These feeds are available in several types and sizes to suit almost any width and thickness of stock. Though their initial cost is slightly higher, their greater durability and lower maintenance cost account for their extensive use.

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DIE AND PUNCH

A typical die and punch set used for blanking operation is shown in Fig 8.1. The sheet metal used is called strip or stock. The punch which is held in the punch holder is bolted to the press ram while die is bolted on the press table. During the working stroke, the punch penetrates the strip, and on the return stroke of the press ram the strip is lifted with the punch, but it is removed from the punch by the stripper plate. The stop pin is a gage and it sets the advance of the strip stock within the punch and die. The strip stock is butted against the back stop acting as a datum location for the centre of the blank.

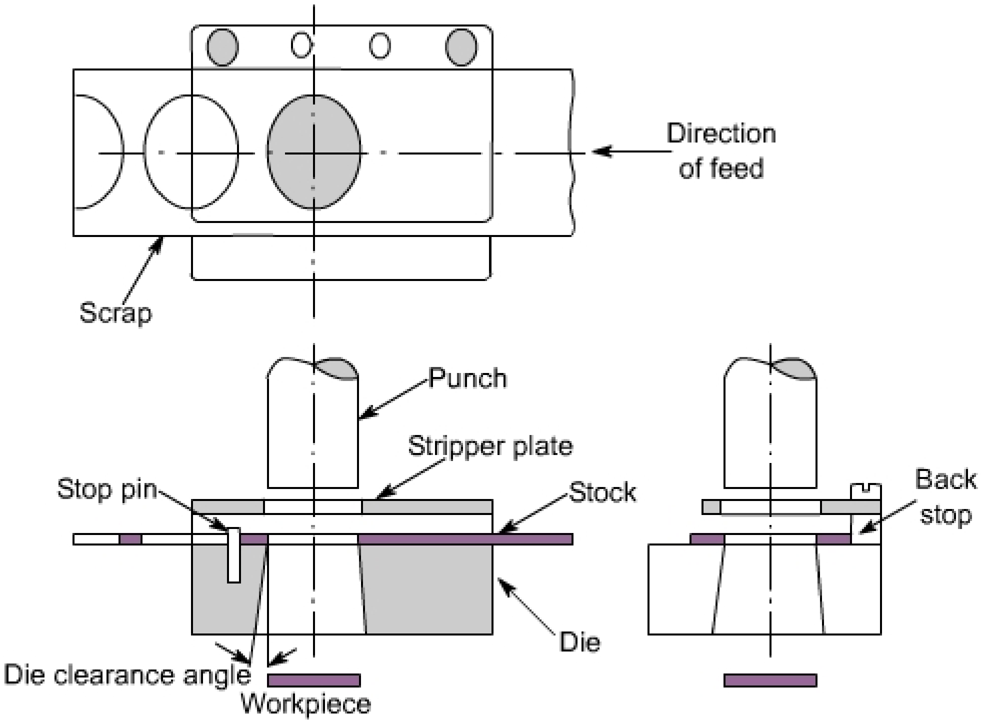

Fig 8.1.

The die opening is given angular clearance to permit escape of good part (blank). The waste skelton of stock strip, from which blanks have been cut, is recovered as salvaged material.

The clearance angle provided on the die (Fig 8.1) depends on the material of stock, as well as its thickness. For thicker and softer materials generally higher angular clearance is given. In most cases, 2 degree of angular clearance is sufficient. The height of cutting land of about 3 mm is generally sufficient.

Clearance

In *blanking operation* , the die size is taken as the blank size and the punch is made smaller giving the necessary clearance between the die and the punch.

Die size = blank size

Punch size = blank size – 2 x clearance

Clearance = k . t . τ

where τ is the shear strength of material, t is the thickness of sheet metal stock, and k is a constant whose value may be taken as 0.003.

In a *piercing operation* , the following equations hold.

Punch size = blank size

Die size = blank size + 2 x clearance

Clearance = k . t . τ

TYPES OF DIES

The components generally incorporated in a piercing or blanking die are shown in Fig 8.3. This Figure shown the die in the conventional closed position. The die set is made up of the punch holder which is fastened to the ram of the punch press and the die shoe which is fastened to the bolster plate of the punch press.

Generally, the punch is fastened to the punch holder and aligned with the opening in the die block. Fig 8.2 shows one type of stripper plate and push – off pins. The stripper holds the scrap strip so that the punch may pull out of the hole. The push – off pins are needed to free the blank in instances where the material strip clings to the bottom of the punch. This may be necessary for thin material, or where lubricants are used on the material.

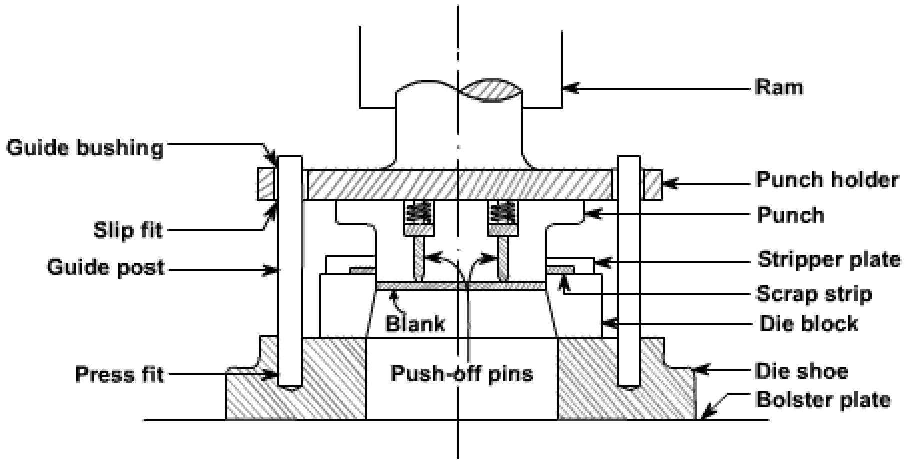

Fig 8.2

Sometimes the die and the punch positions may be interchanged. This may become necessary when the opening in the bolster plate is too small to permit the finished product to pass through the bolster opening. Fig 8.3 shows such a die.

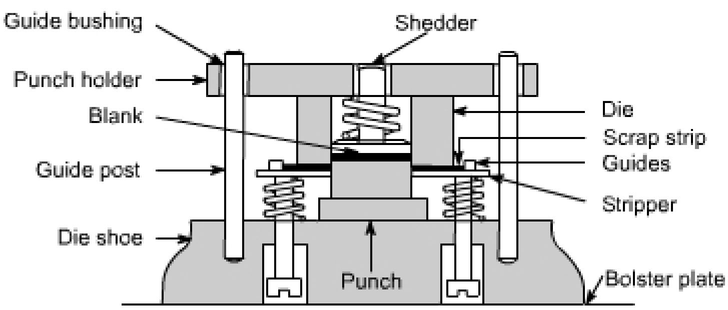

Fig 8.3

Inverted die (Fig 8.3) is designed with the die block fastened to the punch holder and the punch fastened to the die shoe. During the downward stroke of ram, the blank is sheared from the strip. The blank and shedder are forced back into the die opening, which loads a compression spring in the die opening . At the same time the punch is forced through the scrap strip and a spring attached to the stripper is compressed and loaded. On the upstroke of the ram, the shedder pushes the blank out of the die opening and the stripper forces the scrap strip off the punch. The finished part (blank) falls, or is blown, out the rear of the press.

Compound die (Fig 8.4) combines the principles of the conventional and inverted dies in one station. This type of die may produce a workpiece which is pierced and blanked at one station and in one operation. The piercing punch is fastened in the conventional position to the punch holder. Its matching die opening for piercing is machined into the blanking punch. The blanking punch and blanking die opening are mounted in an inverted position. The blanking punch is fastened to the die shoe and the blanking die opening is fastened to the punch holder.

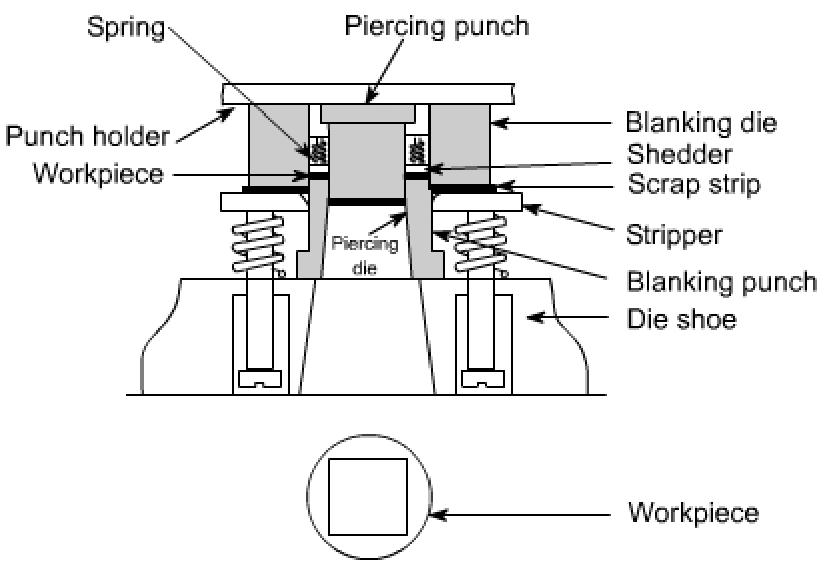

Fig 8.4

Progressive dies are made with two or more stations arranged in a sequence. Each station performs an operation on the workpiece, or provides an idler station, so that the workpiece is completed when the last operation has been accomplished. Thereafter each stroke of the ram produces a finished part. Thus after the fourth stroke of a four – station die, each successive stroke will produce a finished part. Operations which may be carried out in a progressive die are piercing, blanking, forming, drawing, cut – off, etc. The list of possible operations is long. The number and types of operations which may be performed in a progressive die depends upon the ingenuity of the designer.

Fig 8.5 shows a four – station progressive die. The die block is made up of four pieces and fastened to the die shoe. This permits easy replacement of broken or worn die blocks. The stock is fed from the right and registers against a finger strop (not shown). The first stroke of the press Fig 8.5(a) produces a square hole and two notches. These notches form the left end of the first piece.

During the upstroke of ram, the stock is moved to the next station against a finger stop (not shown). The stock is positioned for the second stroke. The second station is an idler, Fig 8.5(b). The right end of the first piece, the left end of the second piece, and a second square hole are pierced.

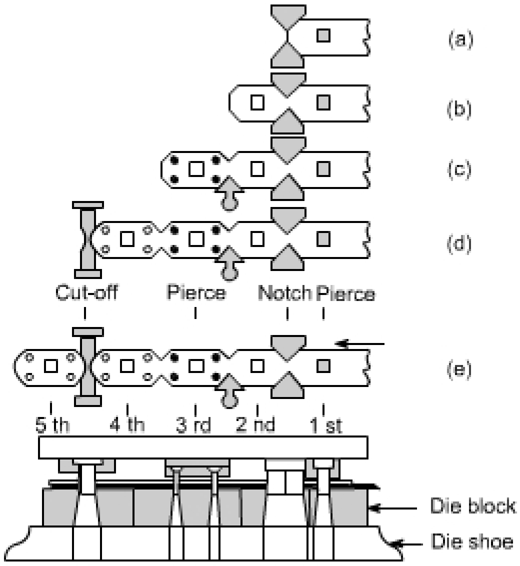

Fig 8.5

The ram retracts and the scrap strip is moved to the third station against an automatic stop, Fig 8.5(c). This stop picks up the notched V and positions the scrap strip. The third stroke of the ram pierces the four holes as shown in Fig 8.5(c). The fourth stroke, Fig 8.5(d), cuts off and forms the radii at the ends of the finished piece. Thereafter every stroke produces a finished part, Fig 8.5(e).

Progressive dies generally have the cut – off or blanking operation as the last operation. It is preferred to have piercing operation as the first operation so that the pierced hole can be advantageously used as a pilot hole. Alternatively, special pilot holes are pierced in the scrapped part of the stock. In certain special cases, blanking is done at the first station, and the blank returned to the die by using spring plates and then moved to the subsequent station by mechanical means or manually.

Progressive dies are used where higher production rates are desired and the material is neither too thick nor too thin. Their use helps in cutting down the material handling costs.

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Lecture 9

HIGH ENERGY RATE FORMING PROCESSES

In these forming processes large amount of energy is applied for a very short interval of time. Many metals tend to deform more readily under extra – fast application of load which make these processes useful to form large size parts out of most metals including those which are otherwise difficult – to – form.

The parts are formed at a rapid rate, and thus these processes are also called high – velocity forming processes. There are several advantages of using these forming processes, like die costs are low, easy maintenance of tolerances, possibility of forming most metals, and material does not show spring-back effect. The production cost of components by such processes is low. The limitation of these processes is the need for skilled personnel.

There are three main high energy rate forming processes: explosive forming, magnetic forming, and electro hydraulic forming. We shall discuss these processes.

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, see Fig 9.1. 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.

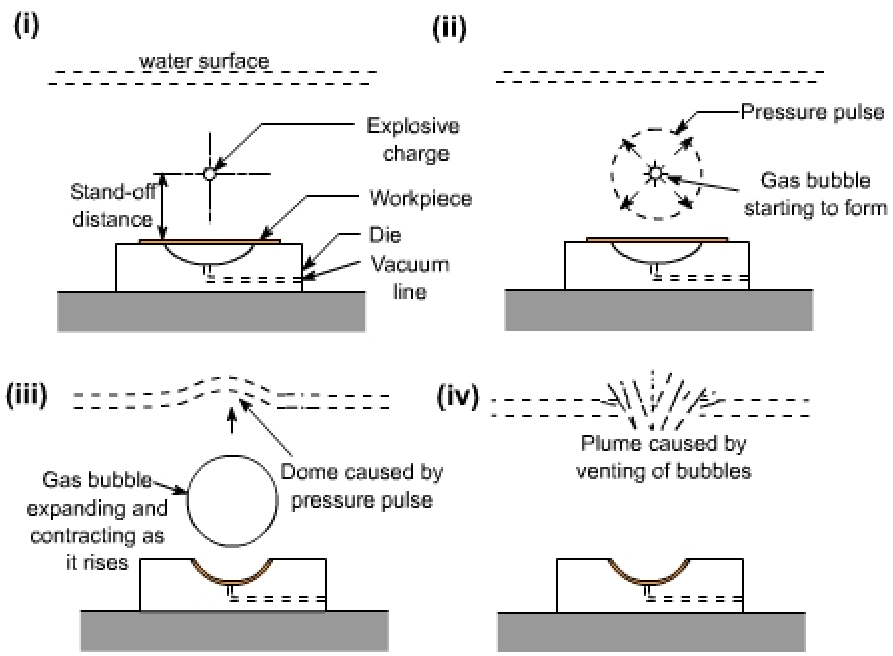

Fig 9.1 Sequeuce of underwater explosive forming operations.(i) explosive charge is set in position (ii) pressure pulse and gas bubble are formed as the detonation of charge occurs, (iii) workpiece is deformed, and (iv) gas bubbles vent at the surface of water.

The use of water as the energy transfer medium ensures a uniform transmission of energy and muffles the sound of the explosive blast. The process is versatile – a large variety of shapes can be formed, there is virtually no limit to the size of the work piece, and it is suitable for low – quantity production as well.

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

Contact Technique. The explosive charge in the form of cartridge is held in direct contact with the work piece while the detonation is initiated. The detonation builds up extremely high pressures (upto 30,000MPa) on the surface of the work piece resulting in metal deformation, and possible fracture. The process is used often for bulging tubes, as shown in Fig 9.2.

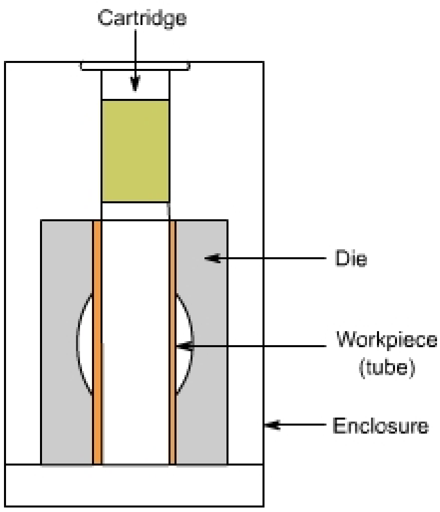

Fig 9.2 Schematic illustration of contact technique of explosive forming.
The process is generally used for bulging of tubes.

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

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, Fig 9.3. 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.

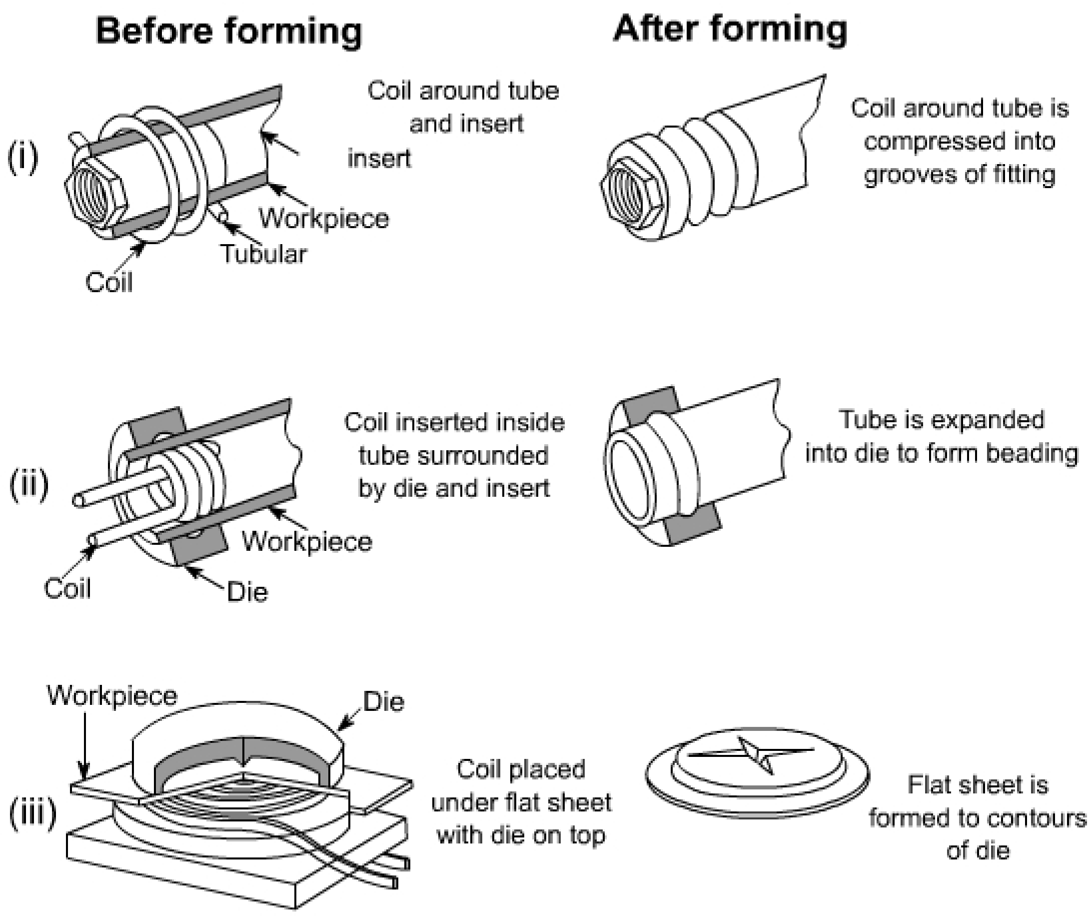

Fig 9.3 Various applications of magnetic forming process. (i) Swaging, (ii) Expanding, and (iii) Embossing or blanking.

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 Fig 9.3(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 Fig 9.3(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, see Fig 9.3(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.

Applications

Electromagnetic forming process is capable of a wide variety of forming and assembly operations. It has found extensive applications in the fabrication of hollow, non – circular, or asymmetrical shapes from tubular stock. The compression applications involve swaging to produce compression, tensile, and torque joints or sealed pressure joints, and swaging to apply compression bands or shrink rings for fastening components together. Flat coils have been used on flat sheets to produce stretch (internal) and shrink (external) flanges on ring and disc – shaped work pieces.

Electromagnetic forming has also been used to perform shearing, piercing, and rivettting.

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, Fig 9.4.

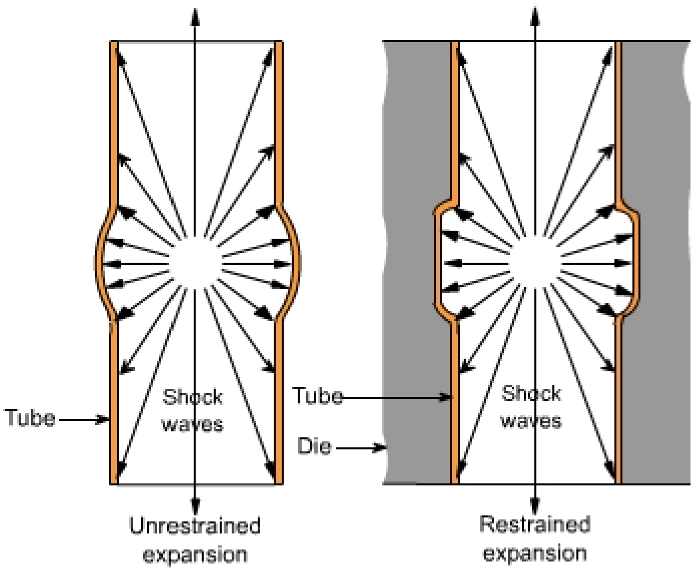

Fig 9.4 Unrestrained and restrained electro-hydraulic forming process.

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.

Accuracy of parts produced

Accuracy of electro hydraulically formed parts depends on the control of both the magnitude and location of energy discharges and on the dimensional accuracy of the dies used. With the modern equipment, it is now possible to precisely control the energy within specified limits, therefore the primary factor is the dimensional accuracy of the die. External dimensions on tubular parts are possible to achieve within ± 0.05 mm with the current state of technology.

Materials formed

Materials having low ductility or having critical impact velocity less than 30 m/s are generally not considered to be good candidate for EHF. All materials that can be formed by conventional forming processes can be formed by EHF also. These materials are aluminum alloys, nickel alloys, stainless steels, titanium, and Inconel 718.

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Lecture 10

POWDER METALLURGY

Powder metallurgy (PM) is a metal working process for forming precision metal components from metal powders. The metal powder is first pressed into product shape at room temperature. This is followed by heating (sintering) that causes the powder particles to fuse together without melting.

The parts produced by PM have adequate physical and mechanical properties while completely meeting the functional performance characteristics. The cost of producing a component of given shape and the required dimensional tolerances by PM is generally lower than the cost of casting or making it as a wrought product, because of extremely low scrap and the fewer processing steps. The cost advantage is the main reason for selecting PM as a process of production for high – volume component which needs to be produced exactly to, or close to, final dimensions. Parts can be produced which are impregnated with oil or plastic, or infiltrated with lower melting point metal. They can be electroplated, heat treated, and machined if necessary.

The rate of production of parts is quite high, a few hundreds to several thousands per hour.

Industrial applications of PM parts are several. These include self – lubricating bearings, porous metal filters and a wide range of engineered shapes, such as gears, cams, brackets, sprockets, etc.

Process Details:

In the PM process the following three steps are followed in sequence: mixing (or blending), compacting, and sintering.

Mixing: A homogeneous mixture of elemental metal powders or alloy powders is prepared. Depending upon the need, powders of other alloys or lubricants may be added.

Compacting: A controlled amount of the mixed powder is introduced into a precision die and then it is pressed or compacted at a pressure in the range 100 MPa to 1000 MPa. The compacting pressure required depends on the characteristics and shape of the particles, the method of mixing, and on the lubricant used. This is generally done at room temperature. In doing so, the loose powder is consolidated and densified into a shaped model. The model is generally called "green compact." As is comes out of the die, the compact has the size and shape of the finished product. The strength of the compact is just sufficient for in – process handling and transportation to the sintering furnace.

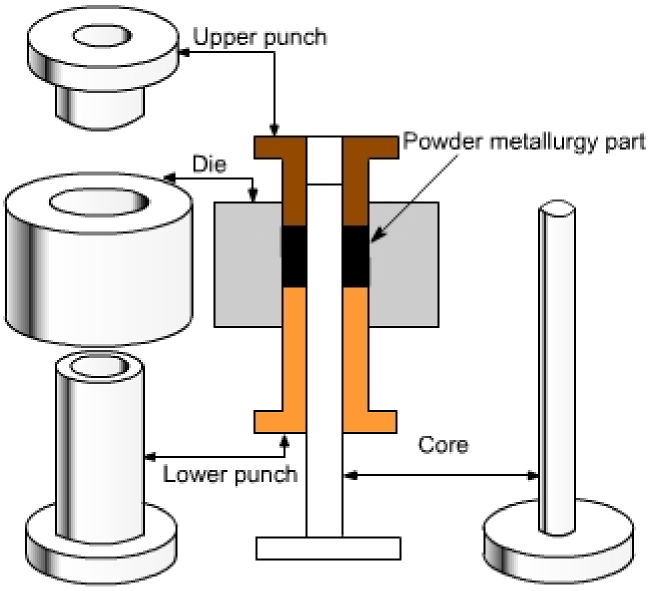

Fig 10.1 Typical set of powder metallurgy tools.

To illustrate the process, let us take a straight cylindrical part such as a sleeve bearing. Fig 10.1 shows a typical set of tools used for producing this part. The compacting cycle for this part (Fig 10.2) follows the following steps.

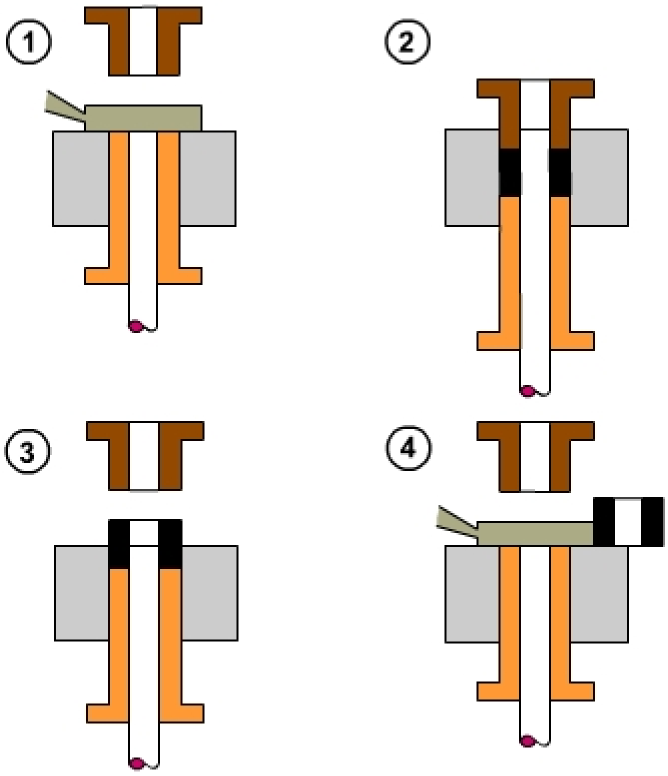

Fig 10.2 Powder metallurgy compacting cycle.

1. With the upper punch in the withdrawn position, the empty die cavity is filled with mixed powder.
2. The metal powder in the die is pressed by simultaneous movement of upper and lower punches.
3. The upper punch is withdrawn, and the green compact is ejected from the die by the lower punch.
4. The green compact is pushed out of the pressing area so that the next operating cycle can start.

This compacting cycle is almost the same for all parts.

Sintering: During this step, the green compact is heated in a protective atmosphere furnace to a suitable temperature, which is below the melting point of the metal. Typical sintering atmospheres are endothermic gas, exothermic gas, dissociated ammonia, hydrogen, and nitrogen. Sintering temperature varies from metal to metal; typically these are within 70 to 90% of the melting point of the metal or alloy. Table 10.1 gives the sintering temperatures used for various metals. Sintering time varies with size and metal of part. Table 10.1 also gives typical range of sintering time needed for various metals.

Table 10.1 Sintering temperature and time for various metal powders

Material	Temperature (^{0}C)	Time
Copper, brass, bronze	760-900	10-40
Nickel	1000-1150	30-40
Stainless steels	1100-1290	30-60
Ferrites	1200-1500	10-600
Tungsten carbide	1430-1500	20-30
Molybdenum	2050	120
Tungsten	2350	480
Tantalum	2400	480

Sintering is a solid state process which is responsible for producing physical and mechanical properties in the PM part by developing metallurgical bond among the powder particles. It also serves to remove the lubricant from the powder, prevents oxidation, and controls carbon content in the part. The structure and porosity obtained in a sintered compact depend on the temperature, time, and processing details. It is not possible to completely eliminate the porosity because voids cannot be completely closed by compaction and because gases evolve during sintering. Porosity is an important characteristic for making PM bearings and filters.

SECONDARY AND FINISHING OPERATIONS

Sometimes additional operations are carried out on sintered PM parts in order to further improve their properties or to impart special characteristics. Some important operations are as under.

1. Coining and sizing. These are high pressure compacting operations. Their main function is to impart (a) greater dimensional accuracy to the sintered part, and (b) greater strength and better surface finish by further densification.

2. Forging. The sintered PM parts may be hot or cold forged to obtain exact shape, good surface finish, good dimensional tolerances, and a uniform and fine grain size. Forged PM parts are being increasingly used for such applications as highly stressed automotive, jet – engine and turbine components.

3. Impregnation. The inherent porosity of PM parts is utilized by impregnating them with a fluid like oil or grease. A typical application of this operation is for sintered bearings and bushings that are internally lubricated with upto 30% oil by volume by simply immersing them in heated oil. Such components have a continuous supply of lubricant by capillary action, during their use. Universal joint is a typical grease – impregnated PM part.

4. Infiltration. The pores of sintered part are filled with some low melting point metal with the result that part's hardness and tensile strength are improved. A slug of metal to be impregnated is kept in close contact with the sintered component and together they are heated to the melting point of the slug. The molten metal infiltrates the pores by capillary action. When the process is complete, the component has greater density, hardness, and strength. Copper is often used for the infiltration of iron – base PM components. Lead has also been used for infiltration of components like bushes for which lower frictional characteristics are needed.

5. Heat Treatment. Sintered PM components may be heat treated for obtaining greater hardness or strength in them.

6. Machining. The sintered component may be machined by turning, milling, drilling, threading, grinding, etc. to obtain various geometric features.

7. Finishing. Almost all the commonly used finishing method are applicable to PM parts. Some of such methods are plating, burnishing, coating, and colouring.

   Plating. For improved appearance and resistance to wear and corrosion, the sintered compacts may be plated by electroplating or other plating processes. To avoid penetration and entrapment of plating solution in the pores of the part, an impregnation or infiltration treatment is often necessary before plating. Copper, zinc, nickel, chromium, and cadmium plating can be applied.

   Burnishing. To work harden the surface or to improve the surface finish and dimensional accuracy, burnishing may be done on PM parts. It is relatively easy to displace metal on PM parts than on wrought parts because of surface porosity in PM parts.

   Coating. PM sintered parts are more susceptible to environmental degradation than cast and machined parts. This is because of inter – connected porosity in PM parts. Coatings fill in the pores and seal the entire reactive surface.

   Colouring. Ferrous PM parts can be applied colour for protection against corrosion. Several methods are in use for colouring. One common method to blacken ferrous PM parts is to do it chemically, using a salt bath.

8. Joining. PM parts can be welded by several conventional methods. Electric resistance welding is better suited than oxy-acetylene welding and arc welding because of oxidation of the interior porosity. Argon arc welding is suitable for stainless steel PM parts.

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Lecture 11

METAL POWDERS FOR PM

Metal powders play an extremely important role in powder metallurgy. These are highly engineered materials. The particle size, shape and size distribution of metal powder affect the characteristics and properties of the compacted product. A large number of types and grades of powders available which makes possible the production of a wide variety of components for meeting numerous performance requirements. All metals can be produced in powder form but not all have the desired properties which are necessary for economical production. Some widely used metal powders for manufacturing PM parts are listed in Table 11.1. The characteristic of powders given in this Table are significant from the viewpoint of application feasibility for PM parts

Table 11.1 Widely used Metal Powders

Pure Metals:	Alloys:
Aluminum	Aluminium-iron
Antimony	Brass
Berylium	Copper-zinc-nickel
Bismuth	Nickel-chromium
Cadmium	Nickel-chromium-iron
Chromium	Nickel-copper
Cobalt	Nickel-iron
Copper	Silicon-iron
Iron	Solder
Lead	Stainless steel
Manganese	
Molybdenum	**Compounds:**
Nickel	Borides(chromium, tungsten, etc.)
Precious metals(gold, silver, platinum)	Carbides (molybdenum, tungsten, etc.)
Rhenium	Molybdenum disilicide
Silicon	Nitrides (siliconn titanium, etc.)
Tantalum	Zirconium hydride
Tin	
Titanium	
Tungsten	
Vanadium	
Zinc	

Powder Production

All metal powders, because of their individual physical and chemical characteristics, cannot be produced in the same way.

There are several methods for producing metal powders each giving different size and structure of the particles. Table 11.2 gives important characteristics of powders produced by some commercial methods. Also given in this Table are advantages and disadvantages of these methods. A brief description of some of these methods follows.

Table 11.2 Metal Powder Characteristics

Apparent Density The apparent density or specific gravity of a powder is expressed in kg/m 3 . It should be kept constant. This means that the same amount of powder should be fed into the die each time.

Chemical Properties

These are the properties like the purity of the powder, amount of oxides permitted, and the percentage of other elements allowed.

Compressibility

Compressibility is the ratio of the volume of intial powder to the volume of the compressed piece. It varies considerably and is affected by the particle-size distribution and shape. Compressibility affects the green strength of a compact.

Fineness

Fineness refers to the particle size and is determined by passing the powder through a standard sieve or by microscopic measurement.

Flowablity

Flowablity is the characteristic of a powder that permits it to flow readily and conform to the mold cavity. It can be described as the rate of flow through a fixed orifice.

Particle-Size Distribution

Particle-Size Distribution refers to the amount of each standard particle size in the powder. It influences the flowablity and apparent density as well as porosity of the product.

Sintering Ability

Sintering ability is the suitability of a powder for bonding of particles by the application of heat.

Atomization: It is as excellent and very widely used method of producing metal powders. In case of low melting point metals, the molten metal is kept in a tank. It is raised by the suction produced by hot air, through a pipe to the atomizing nozzle. A fine stream of molten metal is broken into small droplets, which solidify into metal powder particles. The size of particles can be controlled but the shape of particles remains irregular. However, the technique used for high melting point metals is slightly different. A stream of molten metal coming from an orifice at the bottom of a reservoir is broken up by a jet of atomizing fluid (which may be inert gas, air , water or steam) into metal powder particles. It is possible to control the powder characteristics (average particle size, particle shapes, particle size distribution, particle chemistry, and particle structure) by changing the process variables (such as temperature, stream velocity, etc.) in the atomizing process.

Electrolysis: Electrolytic deposition or electrolysis is a widely used method of producing powders of iron, coppers, silver, and several other metals. For producing iron, for example, a tank containing a suitable electrolyte is taken. In it steel plates are placed as anode and stainless steel plates are placed as cathode. The two electrodes are connected to a powerful de source. In about 50 hours, a 2 mm thick deposit of is obtained on the cathode plates. This deposit of electrolytic iron is stripped, washed, screened, and sized. The iron powder may be annealed if its brittleness is to be reduced.

Reduction: In this process, metal oxide is reduced to metal powder through contact with a reducing gas at temperature below the melting point. For example, in case of iron the iron oxide is crushed and passed through a furnace. The hydrogen atmosphere in the furnace reacts with the oxygen of iron oxide at a temperature of nearly 1050 0 C and pure iron with sponge – like structure is obtained. In addition to iron, other commonly produced commercially by this method include nickel, cobalt, molybdenum, and tungsten.

Machining and Grinding. Machining has been used to produce coarse magnesium powder. Milling and grinding processes utilize various types of rotary mills, stamping mills, crushers, and grinders, break down brittle metals into powders of almost any fineness but of irregular shaped particles.

There are several other methods involving precipitation, condensation and other chemical processes, that are employed for producing metal powders.

Powder Mixing

Mixing of powders precedes compacting.

The process of mixing includes mixing of various metal powders with lubricants as a result of which the powders are thoroughly intermingled. This is carried out in batch mixers. The surface friction properties of the powders to be mixed significantly affect the properties of the mixtures. If the powders differ to much in density, segregation of the heavier powder may occur because gravitational forces may be stronger than the frictional forces.

The temperature during mixing affects the friction between powder particles. With increasing temperature, the friction coefficient between most materials increases and the flow of powders is impaired. It is therefore desirable to maintain lower mixing temperature.

When parts are pressed in rigid dies, the use of lubricant becomes essential in order to reduce friction between powder particles and between the compact being pressed and the die wall and core rod. The lubricant also reduces the pressure required to eject compacts from the die. The lubricant, which is generally ½ to 1% by weight, is introduced as a fine powder mixing time and the intensity of mixing powder and lubricant affect flow and apparent density of the powder mixture.

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POWDER METALLURGY

Advantages: Metal in powder form is costlier than in solid form. Further, expensive dies and equipment needed to adapt this process implies that the process is justified by the unusual properties obtained in the products. Powder metallurgy offers the following specific advantages.

i. Parts can be produced from high melting point refractory metals with respectively less difficulty and at less cost.

ii. Production rates are high even for complex parts. This is primarily because of the use of automated equipment in the process.

iii. Near net shape components are produced. The dimensional tolerances on components are mostly such that no further machining is needed. Scrap is almost negligible.

iv. Parts can be made from a great variety of compositions. It is therefore much easy to have parts of desired mechanical and physical properties like density, hardness toughness, stiffness, damping, and specific electrical or magnetic properties.

v. Parts can be produced with impregnation and infiltration of other materials to obtain special characteristics needed for specific applications.

vi. Skilled machinists are not needed, so labour cost is low

vii. Parts with controlled porosity can be produced

viii. Bi-metallic products, sintered carbides and porous bearings can be produced only by this process.

Limitations: Powder metallurgy has the following limitations.

i. High cost of metal powders compared to the cost of raw material used for casting or forging a component. A few powders are even difficult to store without some deterioration.

ii. High cost of tooling and equipment. This is particularly a limitation when production volumes are small.

iii. Large or complex shaped parts are difficult to produce by PM process.

iv. Parts have lower ductility and strength than those produced by forging.

v. Uniformly high – density products are difficult to produce.

vi. Some powders (such as aluminum, magnesium, titanium and zirconium) in a finally divided state present fire hazard and risk of explosion.

vii. Low melting point metal powders (such as of zinc, tin, cadmium) give thermal difficulties during sintering operation, as most oxides of these metals cannot be reduced at temperatures below the melting point.

Applications of Powder Metallurgy:

There is a great variety of machine components that are produced from metal powders, many of these are put to use without any machining operation carried out on them. Following are some of the prominent PM Products.

Filters: Permanent metal powder filters have greater strength and shock resistance than ceramic filters. Fiber metal filters, having porosity upto 95% and more, are used for filtering air and fluids. Such filters find use in dehydration for filtering air and fluids. Such filters find use in dehydrators for diffusing moisture – laden air around some drying agent such as silica gel, Fig 12.1.

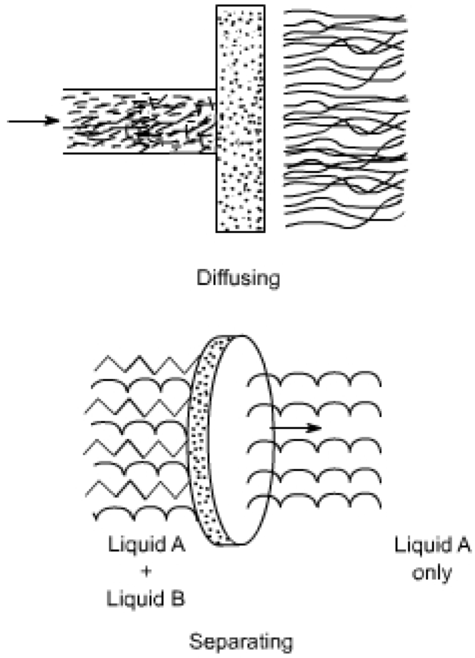

Fig 12.1 Applications of powder metallurgy parts. Filiers can be used for diffusing or for separating.

These filters find wide usage also in petrol / diesel engines for separating dirt and moisture from fuel system. Metal powder filters are also used for arresting flame and attenuating sound.

Cutting Tools and Dies. Cemented carbide cutting tool inserts find extensive applications in machine shops. These are produced by PM from tungsten carbide powder mixed with cobalt binder.

Machinery Parts. Several machinery parts including gears, bushes and bearings, sprockets, rotors are made from metal powders mixed with sufficient graphite to give to product the desired carbon content. The parts have nearly 20 percent porosity. The pores of the parts which are to rub against another surface in their use, are impregnated with oil to promote quiet operation.

Bearing and Bushes. Bearing and bushes to be used with rotating parts are made from copper powder mixed with graphite. In small quantities, lead or tin may also be added for obtaining better wear resistance. After sintering, the bearings are sized and then impregnated with oil by vacuum treatment. Porosity in the bearings may be as high as 40 percent of the volume. Other machinery parts made by PM include clutch plates, brake drums, ball retainers and welding rods.

Magnets. Small magnets produced from different compositions of powders of iron, aluminum, nickel and cobalt have shown excellent performance, far superior to those cast.

Electrical Parts. The possibility of combining several metal powders and maintaining some characteristics of each has promoted PM for production of electric contact parts. These parts are required to have excellent electrical conductively, be wear resistant, and somewhat refractory. Several combinations such as copper – tungsten, cobalt – tungsten, silver – tungsten, copper-nickel, and silver – molybdenum have been used for production of these parts.

Economics of Powder Metallurgy:

Since it is possible to produce near net shape parts by PM, there is usually very little scrap and also no need for secondary manufacturing and assembly operations. PM is therefore becoming increasingly competitive with conventional manufacturing processes like forging, casting, and machining. The high initial cost of dies, punches, and equipment for PM processing, however, requires sufficiently high production volume to make this process cost – effective.

Design Considerations for PM Parts

The following recommendations should be kept in mind while designing parts to be made by PM

1. The shape of the part must permit ejection from the die.
2. The shape of the part must not require the powder to flow into thin walls, narrow passages, or sharp corners.
3. The shape of the part should permit construction of strong and rigid tooling.
4. The shape of the part should make allowance for the length to which thin – walled portion of the part can be compacted.
5. The shape of the part should have the fewest possible change in section.
6. The special capabilities afforded by PM to produce certain part forms, should be utilized.

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Lecture 1

Metal Casting

Introduction

Virtually nothing moves, turns, rolls, or flies without the benefit of cast metal products. The metal casting industry plays a key role in all the major sectors of our economy. There are castings in locomotives, cars trucks, aircraft, office buildings, factories, schools, and homes. Figure some metal cast parts.

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. 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.

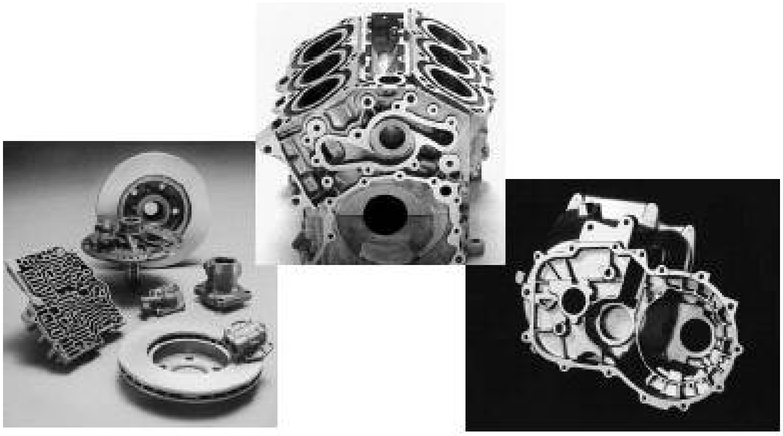

Figure 0: Metal Cast parts

Advantages

The metal casting process is extensively used in manufacturing because of its many advantages.

1. Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized or eliminated.
2. It is possible to cast practically any material that is ferrous or non-ferrous.
3. As the metal can be placed exactly where it is required, large saving in weight can be achieved.
4. The necessary tools required for casting molds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process.
5. There are certain parts made from metals and alloys that can only be processed this way.
6. Size and weight of the product is not a limitation for the casting process.

Limitations

1. Dimensional accuracy and surface finish of the castings made by sand casting processes are a limitation to this technique. Many new casting processes have been developed which can take into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting process, investment casting process, vacuum-sealed molding process, and shell molding process.
2. The metal casting process is a labor intensive process

History

Casting technology, according to biblical records, reaches back almost 5,000 years BC. Gold, pure in nature, most likely caught Prehistoric man's fancy…as he probably hammered gold ornaments out of the gold nuggets he found. Silver would have been treated similarly. Mankind next found copper, because it appeared in the ash of his camp fires from copper-bearing ore that he lined his fire pits with. Man soon found that copper was harder than gold or silver. Copper did not bend up when used. So copper, found a 'nitch' in man's early tools, and then marched it's way into Weaponry. But, long before all this…man found clay. So he made pottery – something to eat from. Then he thought, "now…what else can I do with this mud…" . Early man thought about it, "they used this pottery stuff, (the first patterns), to shape metal into bowls ".

3200 B.C. A copper frog, the oldest known casting in existence, is cast in Mesopotamia.

233 B.C. Cast iron plowshares are poured in China.

500 A.D. Cast crucible steel is first produced in India, but the process is lost until 1750, when Benjamin Huntsman reinvents it in England.

1455 Dillenburg Castle in Germany is the first to use cast iron pipe to transport water.

1480 Birth of Vannoccio Biringuccio (1480-1539), the "father of the foundry industry," in Italy. He is the first man to document the foundry process in writing.

1709 Englishman Abraham Darby creates the first true foundry flask for sand and loam molding.

1750 Benjamin Huntsman reinvents the process of cast crucible steel in England. This process is the first in which the steel is completely melted, producing a uniform composition within the melt. Since the metal is completely molten, it also allows for alloy steel production, as the additional elements in the alloy can be added to the crucible during melting. Prior steel production was accomplished by a combination of forging and tempering, and the metal never reached a molten state.

1809 Centrifugal casting is developed by A. G. Eckhardt of Soho, England.

1896 American Foundrymen's Association (renamed American Foundrymen's Society in 1948 and now called the American Foundry Society) is formed.

1897 Investment casting is rediscovered by B.F. Philbrook of Iowa. He uses it to cast dental inlays.

1947 The Shell process, invented by J. Croning of Germany during WWII, is discovered by U.S. officials and made public.

1953 The Hotbox system of making and curing cores in one operation is developed, eliminating the need for dielectric drying ovens.

1958 H.F. Shroyer is granted a patent for the full mold process, the forerunner of the expendable pattern (lost foam) casting process.

1968 The Coldbox process is introduced by L. Toriello and J. Robins for high production core making.

1971 The Japanese develop V-Process molding. This method uses unbonded sand and a vacuum.

1971 Rheocasting is developed at Massachusetts Institute of Technology.

1996 Cast metal matrix composites are first used in a production model automobile in the brake rotors for the Lotus Elise.

Metal Casting History (India)

3000 BC Earliest castings include the 11 cm high bronze dancing girl found at Mohen-jo-daro.

2000 BC Iron pillars, arrows, hooks, nails, bowls and daggers or earlier have been found in Delhi, Roopar, Nashik and other places.

500 BC Large scale state-owned mints and jewelry units, and processes of metal extraction and alloying have been mentioned in Kautilya's *Arthashastra*

500 A.D. Cast crucible steel is first produced in India, but the process is lost until 1750, when Benjamin Huntsman reinvents it in England

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Lecture 2

Casting Terms (Click on the figure 1 to view)

1. Flask: A metal or wood frame, without fixed top or bottom, in which the mold is formed. Depending upon the position of the flask in the molding structure, it is referred to by various names such as drag – lower molding flask, cope – upper molding flask, cheek – intermediate molding flask used in three piece molding.
2. Pattern: It is the replica of the final object to be made. The mold cavity is made with the help of pattern.
3. Parting line: This is the dividing line between the two molding flasks that makes up the mold.
4. Molding sand: Sand, which binds strongly without losing its permeability to air or gases. It is a mixture of silica sand, clay, and moisture in appropriate proportions.
5. Facing sand: The small amount of carbonaceous material sprinkled on the inner surface of the mold cavity to give a better surface finish to the castings.
6. Core: A separate part of the mold, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.
7. Pouring basin: A small funnel shaped cavity at the top of the mold into which the molten metal is poured.
8. Sprue: The passage through which the molten metal, from the pouring basin, reaches the mold cavity. In many cases it controls the flow of metal into the mold.
9. Runner: The channel through which the molten metal is carried from the sprue to the gate.
10. Gate: A channel through which the molten metal enters the mold cavity.
11. Chaplets: Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force.
12. Riser: A column of molten metal placed in the mold to feed the castings as it shrinks and solidifies. Also known as “feed head”.
13. Vent: Small opening in the mold to facilitate escape of air and gases.

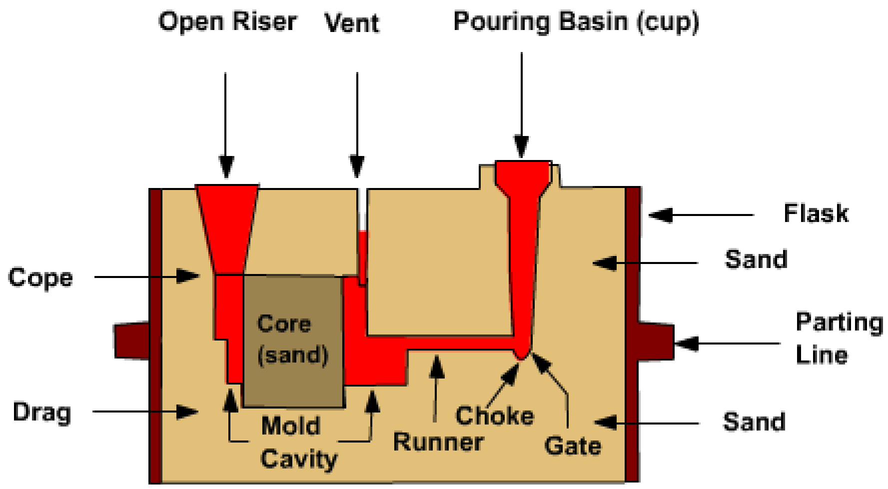

Figure 1 : Mold Section showing some casting terms

Steps in Making Sand Castings

There are six basic steps in making sand castings:

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

Pattern making

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

Core making

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

Molding

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

Melting and Pouring

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

Cleaning

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

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Lecture 3

Pattern (Click on Figure 2 to view a typical 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 pre-requisite for large-scale use of wood as a pattern material.

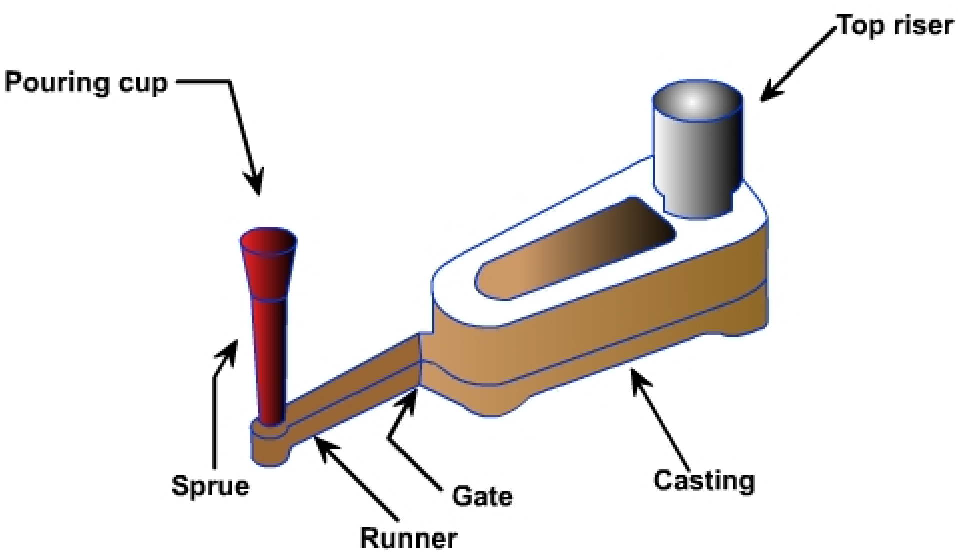


Figure 2: A typical pattern attached with gating and risering system

Pattern Allowances

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

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

Shrinkage or Contraction Allowance (click on Table 1 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:

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

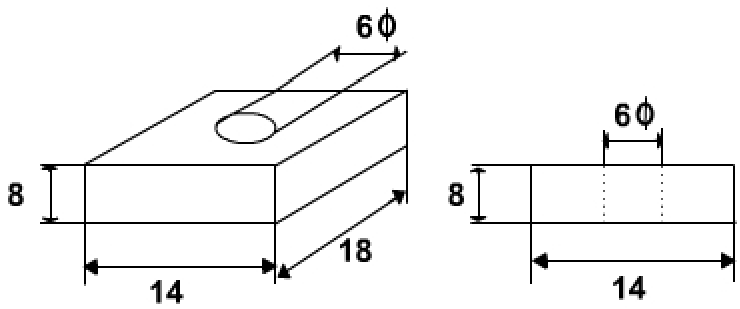
The rate of contraction with temperature is dependent on the material. For example steel contracts to a higher degree compared to aluminum. To compensate the solid shrinkage, a shrink rule must be used in laying out the measurements for the pattern. A shrink rule for cast iron is 1/8 inch longer per foot than a standard rule. If a gear blank of 4 inch in diameter was planned to produce out of cast iron, the shrink rule in measuring it 4 inch would actually measure 4 -1/24 inch, thus compensating for the shrinkage. The various rate of contraction of various materials are given in Table 1.

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

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



Solution 1

The shrinkage allowance for cast iron for size up to 2 feet is o.125 inch per feet (as per Table 1)

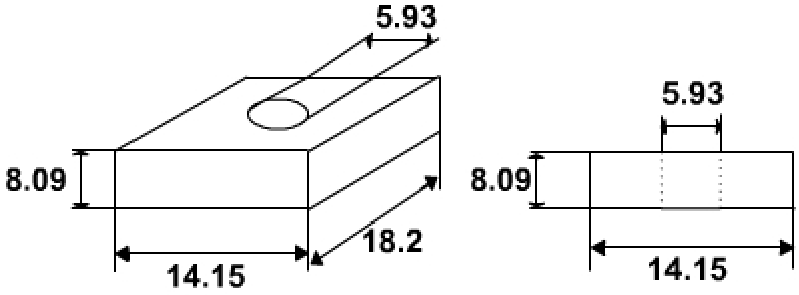
For dimension 18 inch, allowance = 18 *X* 0.125 / 12 = 0.1875 inch » 0.2 inch

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:



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Lecture 4

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 3 (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 3 (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.

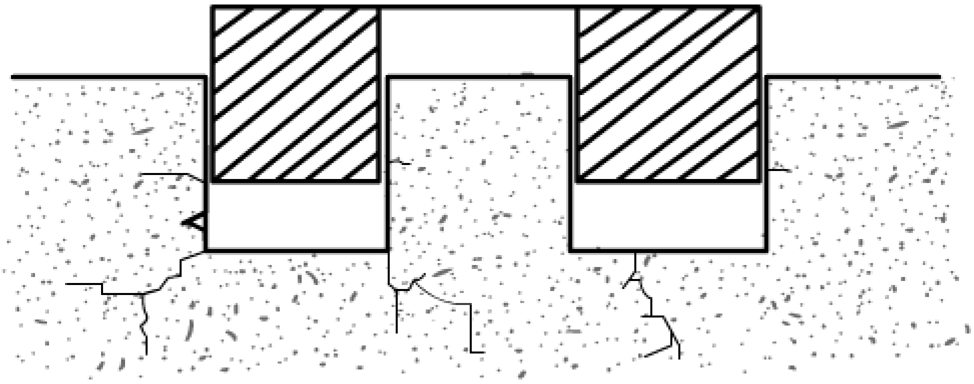


Figure 3 (a) Pattern Having No Draft on Vertical Edges

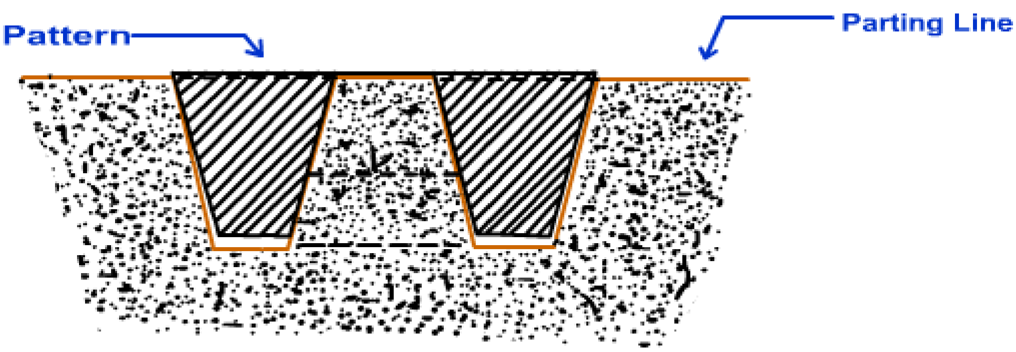


Figure 3 (b) Pattern Having Draft on Vertical Edges

Draft allowance varies with the complexity of the sand job. But in general inner details of the pattern require higher draft than outer surfaces. The amount of draft depends upon the length of the vertical side of the pattern to be extracted; the intricacy of the pattern; the method of molding; and pattern material. Table 2 provides a general guide lines for the draft allowance.

Table 2 : Draft Allowances of Various Metals

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

Machining or Finish Allowance

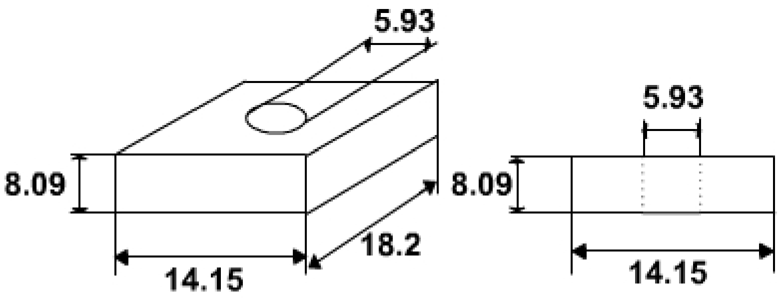
The finish and accuracy achieved in sand casting are generally poor and therefore when the casting is functionally required to be of good surface finish or dimensionally accurate, it is generally achieved by subsequent machining. Machining or finish allowances are therefore added in the pattern dimension. The amount of machining allowance to be provided for is affected by the method of molding and casting used viz. hand molding or machine molding, sand casting or metal mold casting. The amount of machining allowance is also affected by the size and shape of the casting; the casting orientation; the metal; and the degree of accuracy and finish required. The machining allowances recommended for different metal is given in Table 3.

Table 3 : Machining Allowances of Various Metals

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

Exercise 2

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



Solution 2

The machining allowance for cast iron for size, up to 12 inch is o.12 inch and from 12 inch to 20 inch is 0.20 inch ((Table 3)

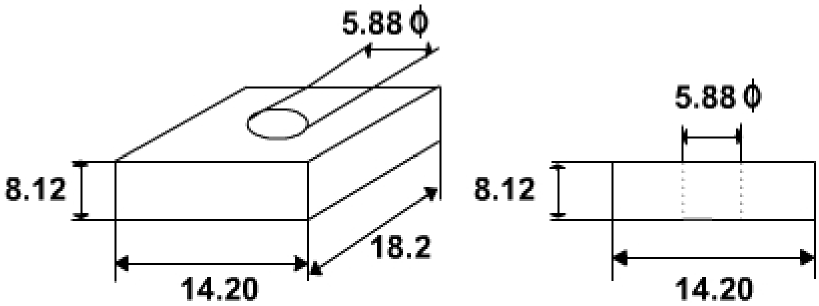
For dimension 18 inch, allowance = 0.20 inch

For dimension 14 inch, allowance = 0.20 inch

For dimension 8 inch, allowance = 0.12 inch

For dimension 6 inch, allowance = 0.12 inch

The pattern drawing with required dimension is shown in Figure below



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)

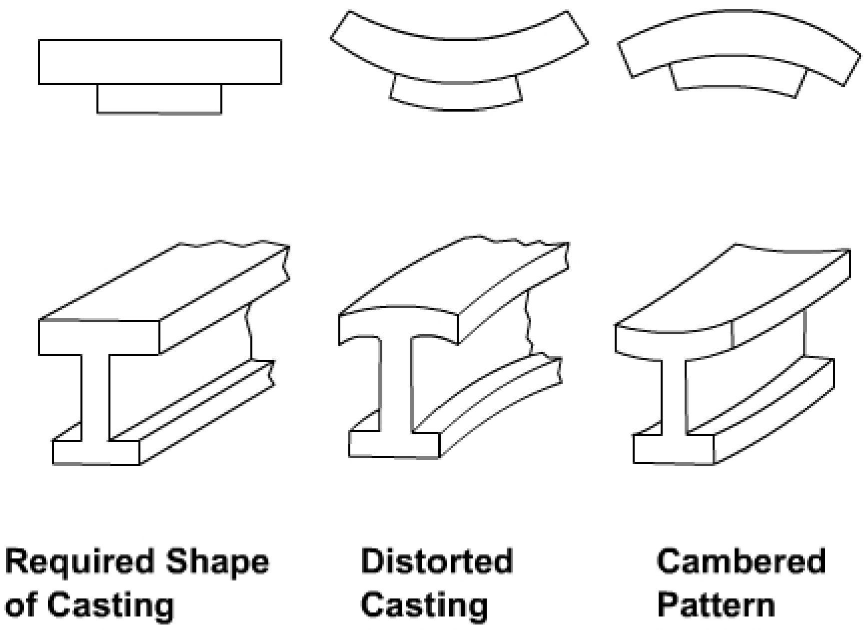


Figure 4: Distortions in Casting

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.

Core and Core Prints

Castings are often required to have holes, recesses, etc. of various sizes and shapes. These impressions can be obtained by using cores. So where coring is required, provision should be made to support the core inside the mold cavity. Core prints are used to serve this purpose. The core print is an added projection on the pattern and it forms a seat in the mold on which the sand core rests during pouring of the mold. The core print must be of adequate size and shape so that it can support the weight of the core during the casting operation. Depending upon the requirement a core can be placed horizontal, vertical and can be hanged inside the mold cavity. A typical job, its pattern and the mold cavity with core and core print is shown in Figure 5.

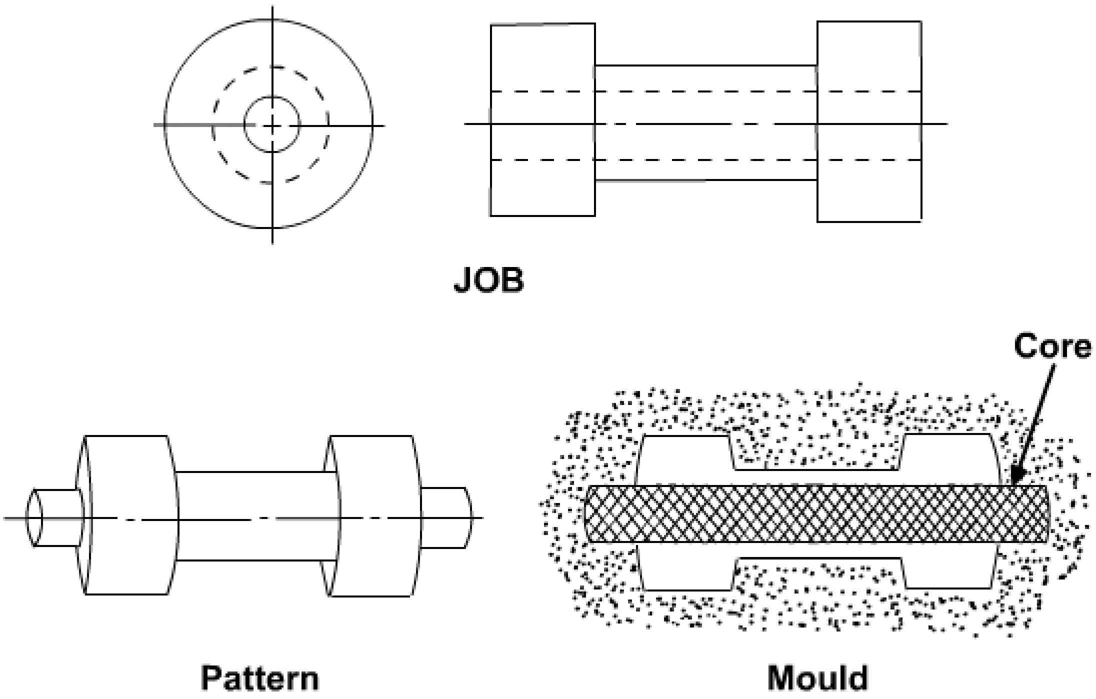


Figure 5: A Typical Job, its Pattern and the Mold Cavity

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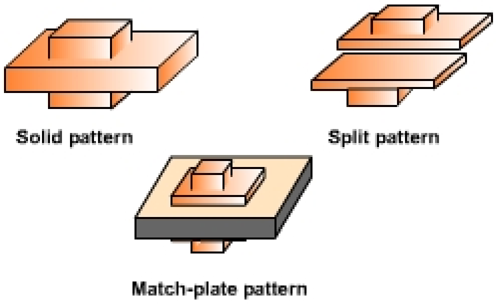
Lecture 5

Types of Pattern

Patterns are of various types, each satisfying certain casting requirements.

1. Single piece pattern
2. Split or two piece pattern
3. Match plate pattern



Single Piece Pattern

The one piece or single pattern is the most inexpensive of all types of patterns. This type of pattern is used only in cases where the job is very simple and does not create any withdrawal problems. It is also used for application in very small-scale production or in prototype development. This type of pattern is expected to be entirely in the drag and one of the surface is is expected to be flat which is used as the parting plane. A gating system is made in the mold by cutting sand with the help of sand tools. If no such flat surface exists, the molding becomes complicated. A typical one-piece pattern is shown in Figure 6.

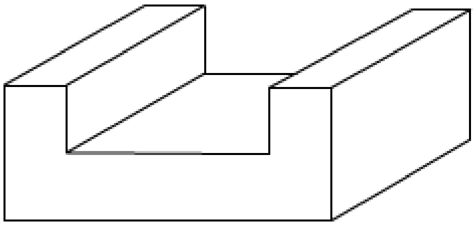


Figure 6: A Typical One Piece Pattern

Split or Two Piece Pattern

Split or two piece pattern is most widely used type of pattern for intricate castings. It is split along the parting surface, the position of which is determined by the shape of the casting. One half of the pattern is molded in drag and the other half in cope. The two halves of the pattern must be aligned properly by making use of the dowel pins, which are fitted, to the cope half of the pattern. These dowel pins match with the precisely made holes in the drag half of the pattern. A typical split pattern of a cast iron wheel Figure 7 (a) is shown in Figure 7 (b).

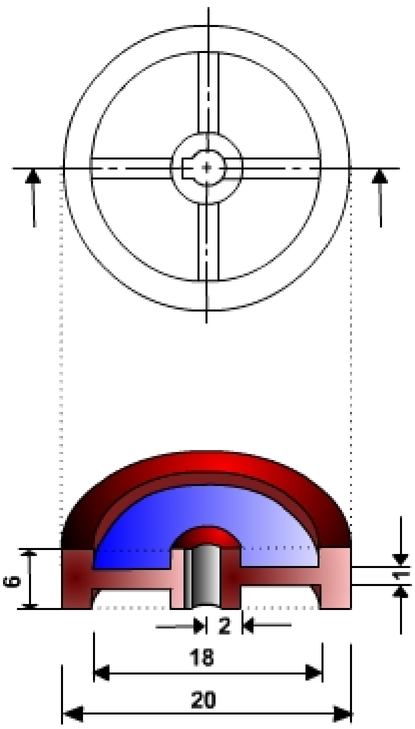


Figure 7 (a): The Details of a Cast Iron Wheel

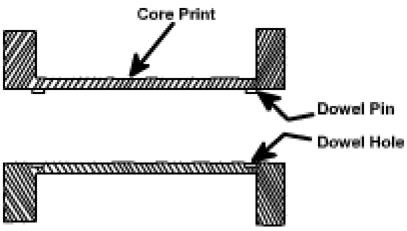


Figure 7 (b): The Split Piece or Two Piece Pattern of a Cast Iron Wheel

Classification of casting Processes

Casting processes can be classified into following FOUR categories:

1. Conventional Molding Processes

    a. Green Sand Molding
    b. Dry Sand Molding
    c. Flask less Molding

2. Chemical Sand Molding Processes

    a. Shell Molding
    b. Sodium Silicate Molding
    c. No-Bake Molding

3. Permanent Mold Processes

    a. Gravity Die casting
    b. Low and High Pressure Die Casting

4. Special Casting Processes

    a. Lost Wax
    b. Ceramics Shell Molding
    c. Evaporative Pattern Casting
    d. Vacuum Sealed Molding
    e. Centrifugal Casting

Green Sand Molding

Green sand is the most diversified molding method used in metal casting operations. The process utilizes a mold made of compressed or compacted moist sand. The term "green" denotes the presence of moisture in the molding sand. The mold material consists of silica sand mixed with a suitable bonding agent (usually clay) and moisture.

Advantages

1. Most metals can be cast by this method.
2. Pattern costs and material costs are relatively low.
3. No Limitation with respect to size of casting and type of metal or alloy used

Disadvantages

Surface Finish of the castings obtained by this process is not good and machining is often required to achieve the finished product.

Sand Mold Making Procedure

The procedure for making mold of a cast iron wheel is shown in (Figure 8(a),(b),(c)).

- The first step in making mold is to place the pattern on the molding board.
- The drag is placed on the board ((Figure 8(a)).
- Dry facing sand is sprinkled over the board and pattern to provide a non sticky layer.
- Molding sand is then riddled in to cover the pattern with the fingers; then the drag is completely filled.
- The sand is then firmly packed in the drag by means of hand rammers. The ramming must be proper i.e. it must neither be too hard or soft.
- After the ramming is over, the excess sand is leveled off with a straight bar known as a strike rod.
- With the help of vent rod, vent holes are made in the drag to the full depth of the flask as well as to the pattern to facilitate the removal of gases during pouring and solidification.
- The finished drag flask is now rolled over to the bottom board exposing the pattern.
- Cope half of the pattern is then placed over the drag pattern with the help of locating pins. The cope flask on the drag is located aligning again with the help of pins ((Figure 8 (b)).
- The dry parting sand is sprinkled all over the drag and on the pattern.

- A sprue pin for making the sprue passage is located at a small distance from the pattern. Also, riser pin, if required, is placed at an appropriate place.
- The operation of filling, ramming and venting of the cope proceed in the same manner as performed in the drag.
- The sprue and riser pins are removed first and a pouring basin is scooped out at the top to pour the liquid metal.
- Then pattern from the cope and drag is removed and facing sand in the form of paste is applied all over the mold cavity and runners which would give the finished casting a good surface finish.
- The mold is now assembled. The mold now is ready for pouring (see ((Figure 8 (c))

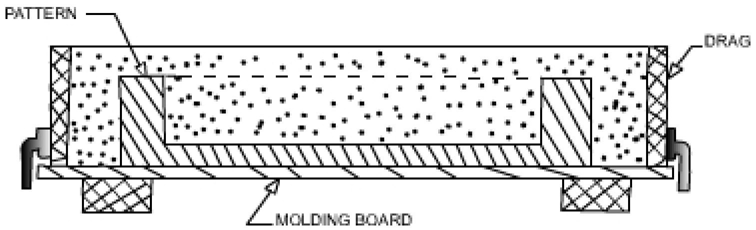


Figure 8 (a)

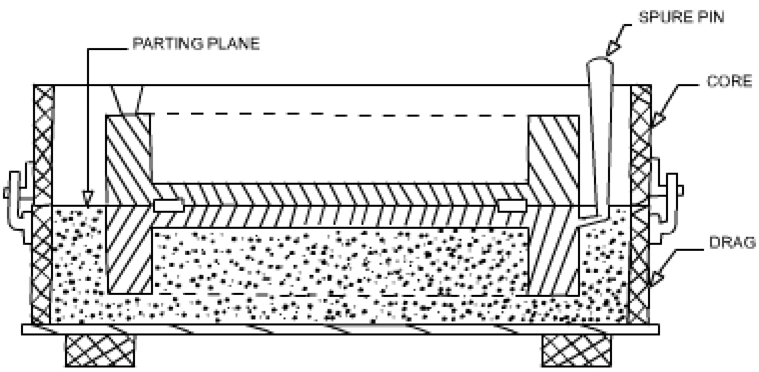


Figure 8 (b)

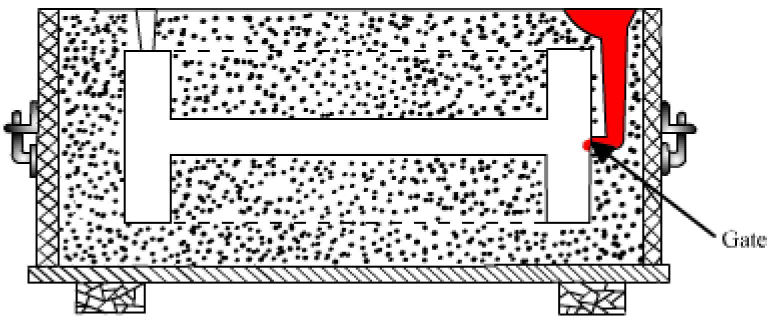


Figure 8 (c)

Figure 8 (a, b, c): Sand Mold Making Procedure

Lecture 6

Molding Material and Properties

A large variety of molding materials is used in foundries for manufacturing molds and cores. They include molding sand, system sand or backing sand, facing sand, parting sand, and core sand. The choice of molding materials is based on their processing properties. The properties that are generally required in molding materials are:

Refractoriness

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

Permeability

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

Green Strength

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

Dry Strength

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

Hot Strength

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

Collapsibility

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

Molding Sand Composition

The main ingredients of any molding sand are:

- Base sand,
- Binder, and
- Moisture

Base Sand

Silica sand is most commonly used base sand. Other base sands that are also used for making mold are zircon sand, Chromite sand, and olivine sand. Silica sand is cheapest among all types of base sand and it is easily available.

Binder

Binders are of many types such as:

1. Clay binders,
2. Organic binders and
3. Inorganic binders

Clay binders are most commonly used binding agents mixed with the molding sands to provide the strength. The most popular clay types are:

Kaolinite or fire clay (Al_2O_3 2 SiO_2 2 H_2O) and Bentonite (Al_2O_3 4 SiO_2 nH_2O)

Of the two the Bentonite can absorb more water which increases its bonding power.

Moisture

Clay acquires its bonding action only in the presence of the required amount of moisture. When water is added to clay, it penetrates the mixture and forms a microfilm, which coats the surface of each flake of the clay. The amount of water used should be properly controlled.

This is because a part of the water, which coats the surface of the clay flakes, helps in bonding, while the remainder helps in improving the plasticity. A typical composition of molding sand is given in (Table 4).

Table 4 : A Typical Composition of Molding Sand

Molding Sand Constituent	Weight Percent
Silica sand	92
Clay (Sodium Bentonite)	8
Water	4

Goto Home

Lecture 7

Dry Sand Molding

When it is desired that the gas forming materials are lowered in the molds, air-dried molds are sometimes preferred to green sand molds. Two types of drying of molds are often required.

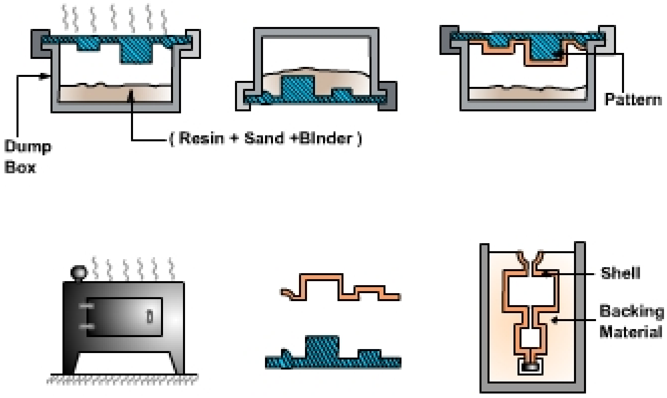
1. Skin drying and
2. Complete mold drying.

In skin drying a firm mold face is produced. Shakeout of the mold is almost as good as that obtained with green sand molding. The most common method of drying the refractory mold coating uses hot air, gas or oil flame. Skin drying of the mold can be accomplished with the aid of torches, directed at the mold surface.

Shell Molding Process

It is a process in which, the sand mixed with a thermosetting resin is allowed to come in contact with a heated pattern plate (200 ^{o}C), this causes a skin (Shell) of about 3.5 mm of sand/plastic mixture to adhere to the pattern.. Then the shell is removed from the pattern. The cope and drag shells are kept in a flask with necessary backup material and the molten metal is poured into the mold.

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 aluminum and copper alloys.



Molding Sand in Shell Molding Process

The molding sand is a mixture of fine grained quartz sand and powdered bakelite. There are two methods of coating the sand grains with bakelite. First method is Cold coating method and another one is the hot method of coating.

In the method of cold coating, quartz sand is poured into the mixer and then the solution of powdered bakelite in acetone and ethyl aldehyde are added. The typical mixture is 92% quartz sand, 5% bakelite, 3% ethyl aldehyde. During mixing of the ingredients, the resin envelops the sand grains and the solvent evaporates, leaving a thin film that uniformly coats the surface of sand grains, thereby imparting fluidity to the sand mixtures.

In the method of hot coating, the mixture is heated to 150-180 o C prior to loading the sand. In the course of sand mixing, the soluble phenol formaldehyde resin is added. The mixer is allowed to cool up to 80 – 90 o C. This method gives better properties to the mixtures than cold method.

Sodium Silicate Molding Process

In this process, the refractory material is coated with a sodium silicate-based binder. For molds, the sand mixture can be compacted manually, jolted or squeezed around the pattern in the flask. After compaction, CO_2 gas is passed through the core or mold. The CO_2 chemically reacts with the sodium silicate to cure, or harden, the binder. This cured binder then holds the refractory in place around the pattern. After curing, the pattern is withdrawn from the mold.

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

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

Permanent Mold Process

In al the above processes, a mold need to be prepared for each of the casting produced. For large-scale production, making a mold, for every casting to be produced, may be difficult and expensive. Therefore, a permanent mold, called the die may be made from which a large number of castings can be produced. , the molds are usually made of cast iron or steel, although graphite, copper and aluminum have been used as mold materials. The process in which we use a die to make the castings is called permanent mold casting or gravity die casting, since the metal enters the mold under gravity. Some time in die-casting we inject the molten metal with a high pressure. When we apply pressure in injecting the metal it is called pressure die casting process.

Advantages

- Permanent Molding produces a sound dense casting with superior mechanical properties.
- The castings produced are quite uniform in shape have a higher degree of dimensional accuracy than castings produced in sand
- The permanent mold process is also capable of producing a consistent quality of finish on castings

Disadvantages

- The cost of tooling is usually higher than for sand castings
- The process is generally limited to the production of small castings of simple exterior design, although complex castings such as aluminum engine blocks and heads are now commonplace.

Centrifugal Casting

In this process, the mold 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 mold can be rotated about a vertical, horizontal or an inclined axis or about its horizontal and vertical axes simultaneously. The length and outside diameter are fixed by the mold cavity dimensions while the inside diameter is determined by the amount of molten metal poured into the mold.Figure 9(Vertical Centrifugal Casting), Figure 10 (Horizontal Centrifugal Casting)

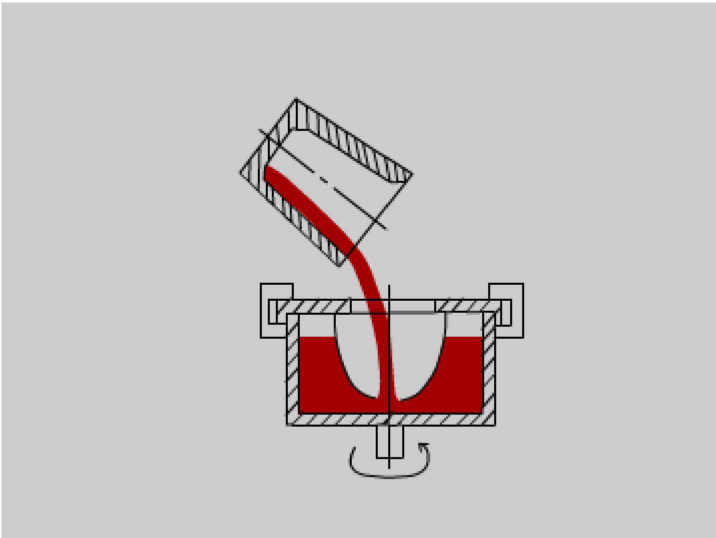


Figure 9: (Vertical Centrifugal Casting)

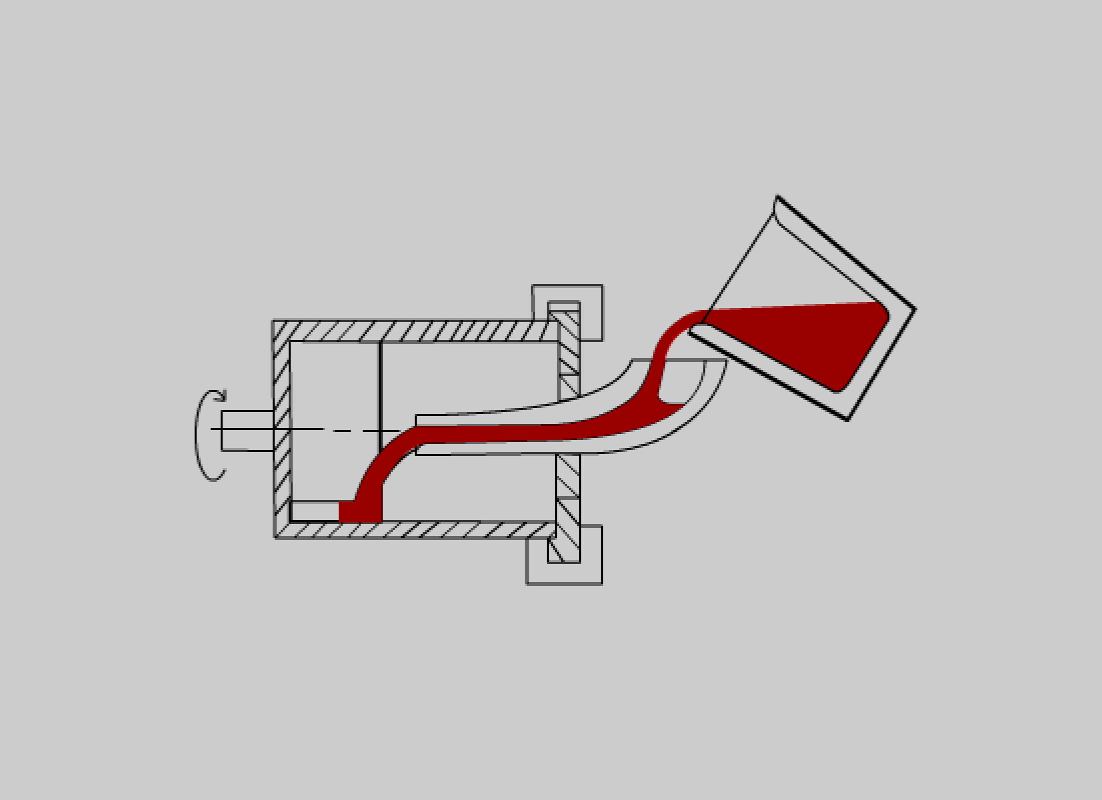


Figure 10: (Horizontal Centrifugal Casting)

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

Goto Home

Lecture 8

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) :

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

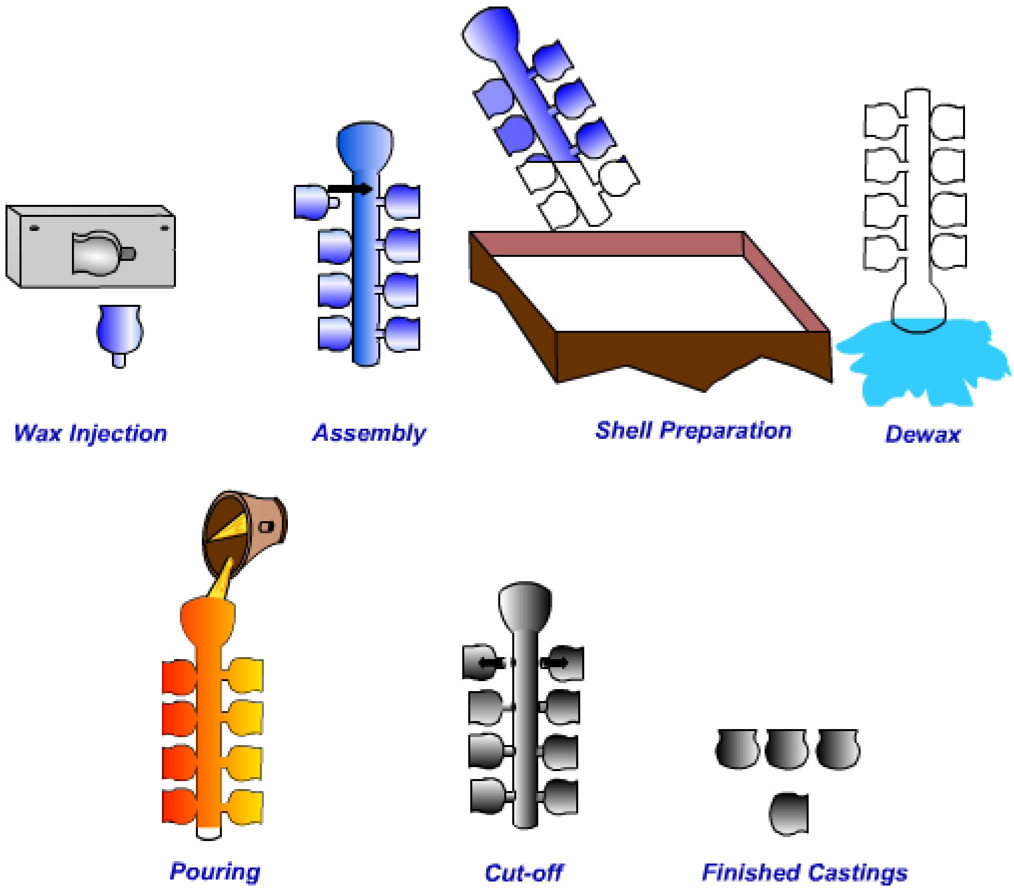


Figure 11: The Basic Steps of the Investment Casting Process

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

Ceramic Shell Investment Casting Process

The basic difference in investment casting is that in the investment casting the wax pattern is immersed in a refractory aggregate before dewaxing whereas, in ceramic shell investment casting a ceramic shell is built around a tree assembly by repeatedly dipping a pattern into a slurry (refractory material such as zircon with binder). After each dipping and stuccoing is completed, the assembly is allowed to thoroughly dry before the next coating is applied. Thus, a shell is built up around the assembly. The thickness of this shell is dependent on the size of the castings and temperature of the metal to be poured.

After the ceramic shell is completed, the entire assembly is placed into an autoclave or flash fire furnace at a high temperature. The shell is heated to about 982 o C to burn out any residual wax and to develop a high-temperature bond in the shell. The shell molds can then be stored for future use or molten metal can be poured into them immediately. If the shell molds are stored, they have to be preheated before molten metal is poured into them.

Advantages

- excellent surface finish
- tight dimensional tolerances
- machining can be reduced or completely eliminated

Goto Home

Lecture 9

Full Mold Process / Lost Foam Process / Evaporative Pattern Casting Process

The use of foam patterns for metal casting was patented by H.F. Shroyer on April 15, 1958. In Shroyer's patent, a pattern was machined from a block of expanded polystyrene (EPS) and supported by bonded sand during pouring. This process is known as the full mold process. With the full mold process, the pattern is usually machined from an EPS block and is used to make primarily large, one-of-a kind castings. The full mold process was originally known as the lost foam process. However, current patents have required that the generic term for the process be full mold.

In 1964, M.C. Flemmings used unbounded sand with the process. This is known today as lost foam casting (LFC). With LFC, the foam pattern is molded from polystyrene beads. LFC is differentiated from full mold by the use of unbounded sand (LFC) as opposed to bonded sand (full mold process).

Foam casting techniques have been referred to by a variety of generic and proprietary names. Among these are lost foam, evaporative pattern casting, cavity less casting, evaporative foam casting, and full mold casting.

In this method, the pattern, complete with gates and risers, is prepared from expanded polystyrene. This pattern is embedded in a no bake type of sand. While the pattern is inside the mold, molten metal is poured through the sprue. The heat of the metal is sufficient to gasify the pattern and progressive displacement of pattern material by the molten metal takes place.

The EPC process is an economical method for producing complex, close-tolerance castings using an expandable polystyrene pattern and unbonded sand. Expandable polystyrene is a thermoplastic material that can be molded into a variety of complex, rigid shapes. The EPC process involves attaching expandable polystyrene patterns to an expandable polystyrene gating system and applying a refractory coating to the entire assembly. After the coating has dried, the foam pattern assembly is positioned on loose dry sand in a vented flask. Additional sand is then added while the flask is vibrated until the pattern assembly is completely embedded in sand. Molten metal is poured into the sprue, vaporizing the foam polystyrene, perfectly reproducing the pattern.

In this process, a pattern refers to the expandable polystyrene or foamed polystyrene part that is vaporized by the molten metal. A pattern is required for each casting.

Process Description ((Figure 12)

1. The EPC procedure starts with the pre-expansion of beads, usually polystyrene. After the pre-expanded beads are stabilized, they are blown into a mold to form pattern sections. When the beads are in the mold, a steam cycle causes them to fully expand and fuse together.
2. The pattern sections are assembled with glue, forming a cluster. The gating system is also attached in a similar manner.
3. The foam cluster is covered with a ceramic coating. The coating forms a barrier so that the molten metal does not penetrate or cause sand erosion during pouring.
4. After the coating dries, the cluster is placed into a flask and backed up with bonded sand.
5. Mold compaction is then achieved by using a vibration table to ensure uniform and proper compaction. Once this procedure is complete, the cluster is packed in the flask and the mold is ready to be poured .

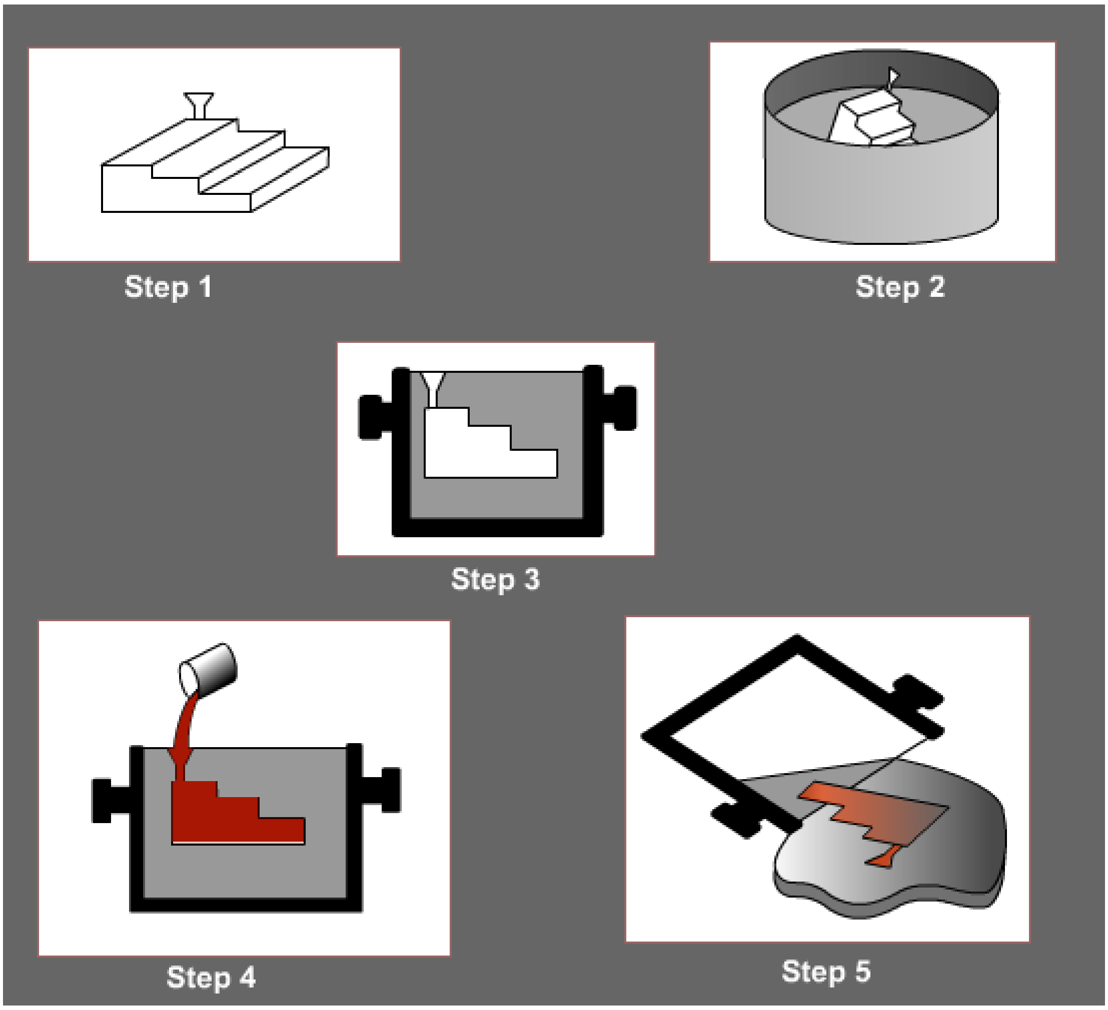


Figure 12: The Basic Steps of the Evaporative Pattern Casting Process

Advantages

The most important advantage of EPC process is that no cores are required. No binders or other additives are required for the sand, which is reusable. Shakeout of the castings in unbonded sand is simplified. There are no parting lines or core fins.

Goto Home

Lecture 10

Vacuum Sealed Molding Process

It is a process of making molds utilizing dry sand, plastic film and a physical means of binding using negative pressure or vacuum. V-process was developed in Japan in 1971. Since then it has gained considerable importance due to its capability to produce dimensionally accurate and smooth castings. The basic difference between the V-process and other sand molding processes is the manner in which sand is bounded to form the mold cavity. In V-process vacuum, of the order of 250 – 450 mm Hg, is imposed to bind the dry free flowing sand encapsulated in between two plastic films. The technique involves the formation of a mold cavity by vacuum forming of a plastic film over the pattern, backed by unbounded sand, which is compacted by vibration and held rigidly in place by applying vacuum. When the metal is poured into the molds, the plastic film first melts and then gets sucked just inside the sand voids due to imposed vacuum where it condenses and forms a shell-like layer. The vacuum must be maintained until the metal solidifies, after which the vacuum is released allowing the sand to drop away leaving a casting with a smooth surface. No shakeout equipment is required and the same sand can be cooled and reused without further treatment.

Sequence of Producing V-Process Molds

- The Pattern is set on the Pattern Plate of Pattern Box. The Pattern as well as the Pattern Plate has Numerous Small Holes. These Holes Help the Plastic Film to Adhere Closely on Pattern When Vacuum is Applied.
- A Heater is used to Soften the Plastic Film
- The Softened Plastic Film Drapes over the Pattern. The Vacuum Suction Acts through the Vents (Pattern and Pattern Plate) to draw it so that it adheres closely to the Pattern.
- The Molding Box is Set on the Film Coated Pattern
- The Molding Box is filled with Dry Sand. Slight Vibration Compacts the Sand
- Level the Mold. Cover the Top of Molding Box with Plastic Film. Vacuum Suction Stiffens the Mold.
- Release the Vacuum on the Pattern Box and Mold Strips Easily.
- Cope and Drag are assembled and Metal is poured. During Pouring the Mold is Kept under Vacuum
- After Cooling, the Vacuum is released. Free Flowing Sand Drops Away, Leaving a Clean Casting

Advantages

- Exceptionally Good Dimensional Accuracy
- Good Surface Finish
- Longer Pattern Life
- Consistent Reproducibility
- Low Cleaning / Finishing Cost

Click to view the sequence of producing V - Process Mode.

Goto Home

Lecture 11

Melting Practices

Melting is an equally important parameter for obtaining a quality castings. A number of furnaces can be used for melting the metal, to be used, to make a metal casting. The choice of furnace depends on the type of metal to be melted. Some of the furnaces used in metal casting are as following:.

- Crucible furnaces
- Cupola
- Induction furnace
- Reverberatory furnace

Crucible Furnace.

Crucible furnaces are small capacity typically used for small melting applications. Crucible furnace is suitable for the batch type foundries where the metal requirement is intermittent. The metal is placed in a crucible which is made of clay and graphite. The energy is applied indirectly to the metal by heating the crucible by coke, oil or gas.The heating of crucible is done by coke, oil or gas. .

Coke-Fired Furnace(Figure 13) .

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

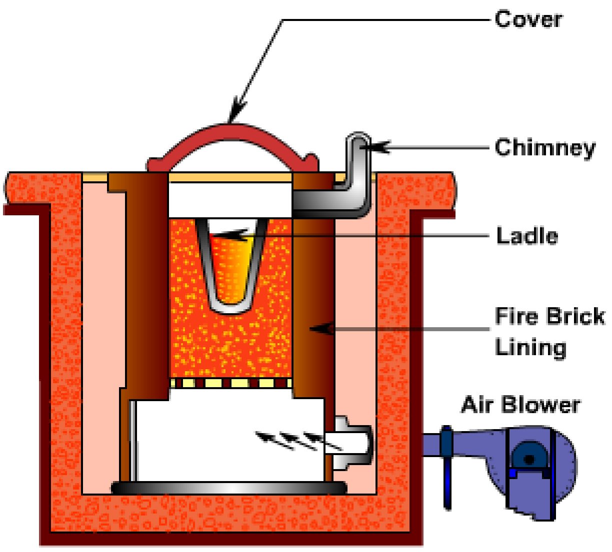


Figure 13: Coke Fired Crucible Furnace

Oil-Fired Furnace.

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

Cupola

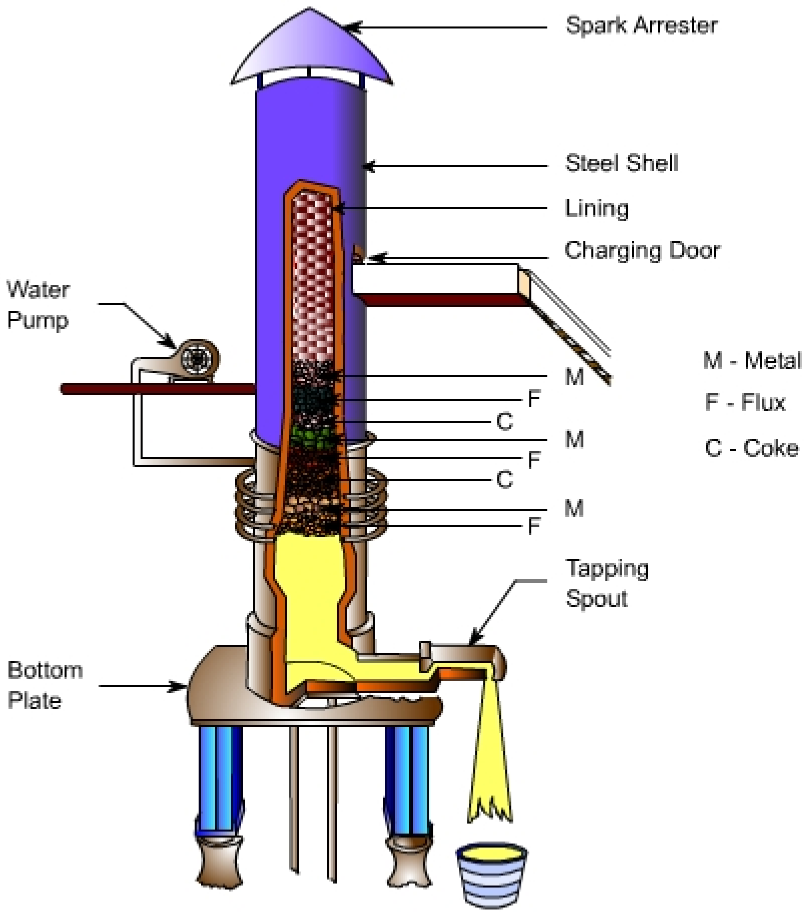
Cupola furnaces are tall, cylindrical furnaces used to melt iron and ferrous alloys in foundry operations. Alternating layers of metal and ferrous alloys, coke, and limestone are fed into the furnace from the top. A schematic diagram of a cupola is shown in Figure14 . This diagram of a cupola illustrates the furnace's cylindrical shaft lined with refractory and the alternating layers of coke and metal scrap. The molten metal flows out of a spout at the bottom of the cupola. .

Description of Cupola

- The cupola consists of a vertical cylindrical steel sheet and lined inside with acid refractory bricks. The lining is generally thicker in the lower portion of the cupola as the temperature are higher than in upper portion
- There is a charging door through which coke, pig iron, steel scrap and flux is charged
- The blast is blown through the tuyeres
- These tuyeres are arranged in one or more row around the periphery of cupola
- Hot gases which ascends from the bottom (combustion zone) preheats the iron in the preheating zone
- Cupolas are provided with a drop bottom door through which debris, consisting of coke, slag etc. can be discharged at the end of the melt
- A slag hole is provided to remove the slag from the melt
- Through the tap hole molten metal is poured into the ladle
- At the top conical cap called the spark arrest is provided to prevent the spark emerging to outside

Operation of Cupola

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



.**Figure 14: Schematic of a Cupola**

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Lecture 12

Reverberatory furnace

A furnace or kiln in which the material under treatment is heated indirectly by means of a flame deflected downward from the roof. Reverberatory furnaces are used in opper, tin, and nickel production, in the production of certain concretes and cements, and in aluminum. Reverberatory furnaces heat the metal to melting temperatures with direct fired wall-mounted burners. The primary mode of heat transfer is through radiation from the refractory brick walls to the metal, but convective heat transfer also provides additional heating from the burner to the metal. The advantages provided by reverberatory melters is the high volume processing rate, and low operating and maintenance costs. The disadvantages of the reverberatory melters are the high metal oxidation rates, low efficiencies, and large floor space requirements. A schematic of Reverberatory furnace is shown in Figure 15

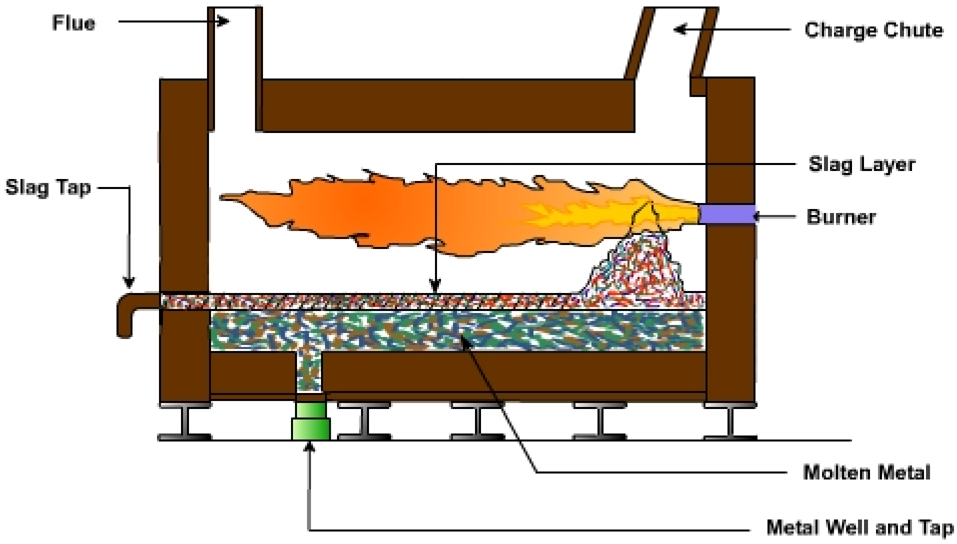

Figure 15: Schematic of a Reverberatory Furnace

Induction furnace

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

The heating system in an induction furnace includes:

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

The induction heating power supply sends alternating current through the induction coil, which generates a magnetic field. Induction furnaces work on the principle of a transformer. An alternative electromagnetic field induces eddy currents in the metal which converts the electric energy to heat without any physical contact between the induction coil and the work piece. A schematic diagram of induction furnace is shown in Figure 16. The furnace contains a crucible surrounded by a water cooled copper coil. The coil is called primary coil to which a high frequency current is supplied. By induction secondary currents, called eddy currents are produced in the crucible. High temperature can be obtained by this method. Induction furnaces are of two types: cored furnace and coreless furnace. Cored furnaces are used almost exclusively as holding furnaces. In cored furnace the electromagnetic field heats the metal between two coils. Coreless furnaces heat the metal via an external primary coil.

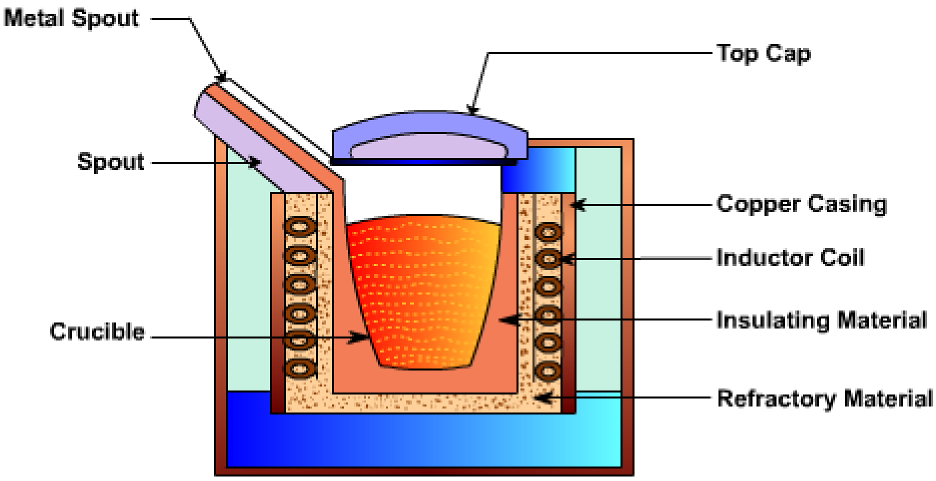

Figure 16: Schematic of a Induction Furnace

Advantages of Induction Furnace

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

Disadvantages of Induction Furnace

- High capital cost of the equipment
- High operating cost

Goto Home

Lecture 13 & 14

Gating System

The assembly of channels which facilitates the molten metal to enter into the mold cavity is called the gating system (Figure17). Alternatively, the gating system refers to all passage ways through which molten metal passes to enter into the mold cavity. The nomenclature of gating system depends upon the function of different channels which they perform.

- Down gates or sprue
- Cross gates or runners
- Ingates or gates

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

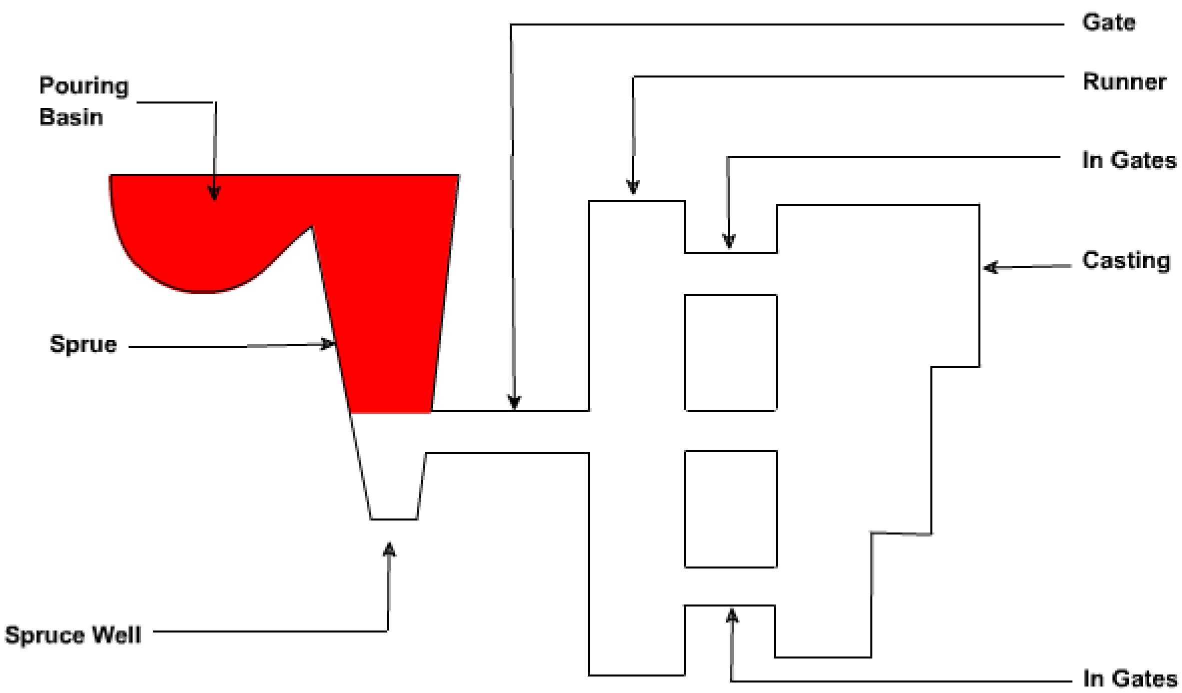

Figure 17: Schematic of Gating System

Goals of Gating System

The goals for the gating system are

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

Hydraulic Principles used in the Gating System

Reynold's Number

Nature of flow in the gating system can be established by calculating Reynold's number

$$R_N = \frac{VD\rho}{\mu}$$

R_N = Reynold's number

V = Mean Velocity of flow

D = diameter of tubular flow

μ = Kinematics Viscosity = Dynamic viscosity / Density

ρ = Fluid density

When the Reynold's number is less than 2000 stream line flow results and when the number is more than 2000 turbulent flow prevails. As far as possible the turbulent flow must be avoided in the sand mold as because of the turbulence sand particles gets dislodged from the mold or the gating system and may enter into the mould cavity leading to the production of defective casting. Excess turbulence causes

- Inclusion of dross or slag
- Air aspiration into the mold
- Erosion of the mold walls

Bernoulli's Equation

$$h + \frac{P}{\rho g} + \frac{v^2}{2g} = \text{const.}$$

h = height of liquid

P = Static Pressure

ν = metal velocity

g = Acceleration due to gravity

ρ = Fluid density

Turbulence can be avoided by incorporating small changes in the design of gating system. The sharp changes in the flow should be avoided to smooth changes. The gating system must be designed in such a way that the system always runs full with the liquid metal. The most important things to remember in designing runners and gates are to avoid sharp corners. Any changes in direction or cross sectional area should make use of rounded corners.

To avoid the aspiration the tapered sprues are designed in the gating systems. A sprue tapered to a smaller size at its bottom will create a choke which will help keep the sprue full of molten metal.

Types of Gating Systems (Figure18a, 18b)

The gating systems are of two types:

- Pressurized gating system
- Un-pressurized gating system

Pressurized Gating System

- The total cross sectional area decreases towards the mold cavity
- Back pressure is maintained by the restrictions in the metal flow
- Flow of liquid (volume) is almost equal from all gates
- Back pressure helps in reducing the aspiration as the sprue always runs full
- Because of the restrictions the metal flows at high velocity leading to more turbulence and chances of mold erosion

Un-Pressurized Gating System

- The total cross sectional area increases towards the mold cavity
- Restriction only at the bottom of sprue
- Flow of liquid (volume) is different from all gates
- aspiration in the gating system as the system never runs full
- Less turbulence

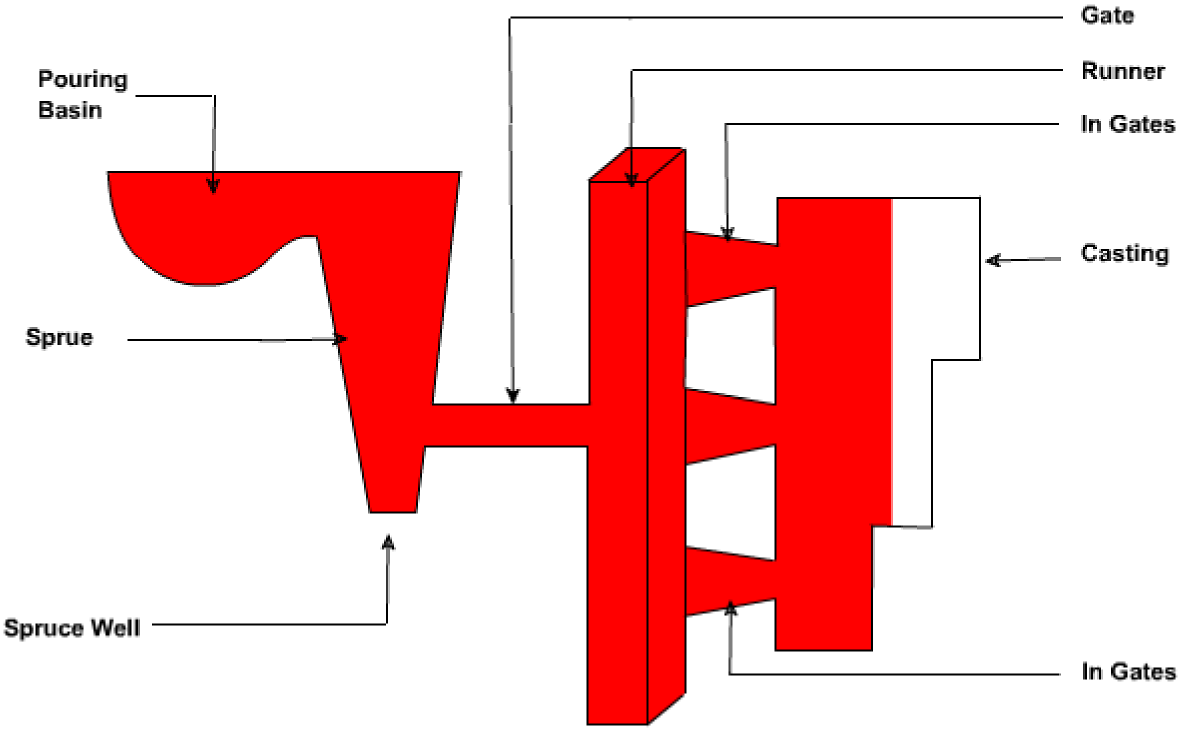

Fig 18a : Pressurized Gating System

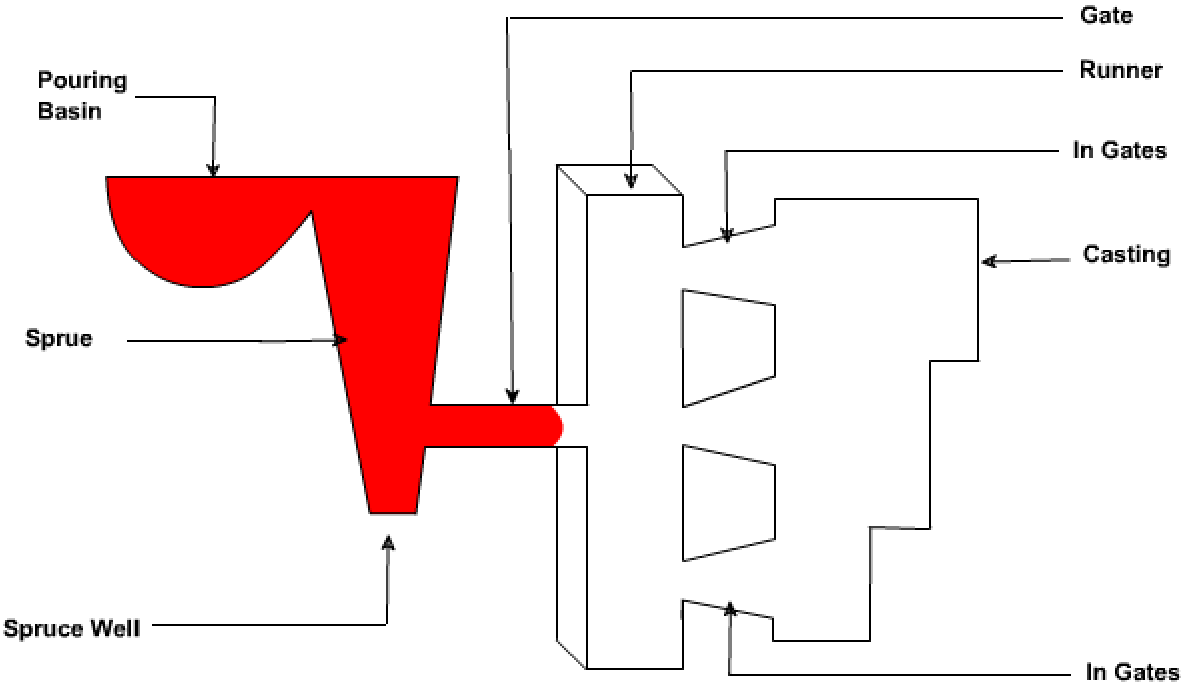

Fig 18b : Un-Pressurized Gating System

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

1. 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.
2. Riser placement: the spacing of risers in the casting must be considered by effectively calculating the feeding distance of the risers.
3. 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.

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Lecture 15

Casting Defects (Figure19)

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

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 superheat 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.

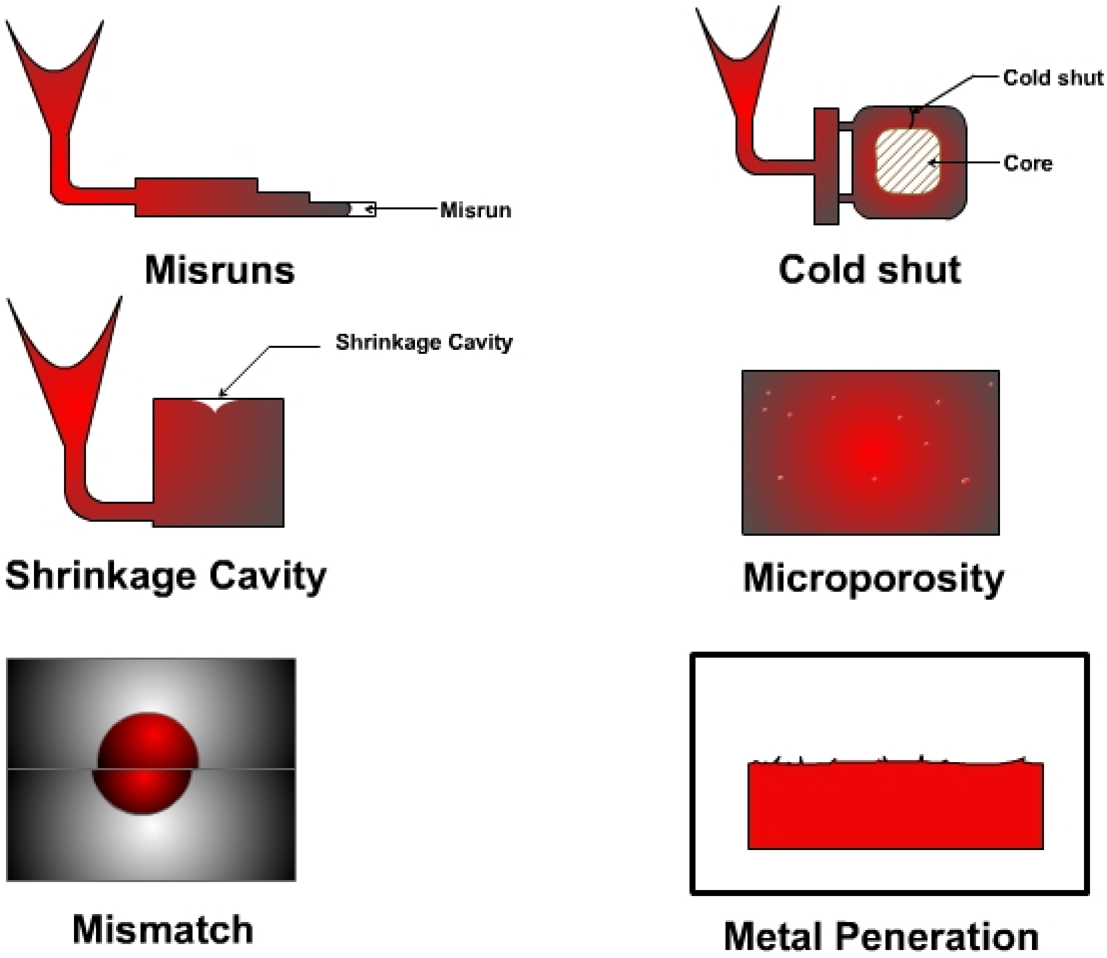

Figure 19 : Casting Defects

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Lecture 1

Introduction:

Welding which is the process of joining two metallic components for the desired purpose, can be defined as the process of joining two similar or dissimilar metallic components with the application of heat, with or without the application of pressure and with or without the use of filler metal. Heat may be obtained by chemical reaction, electric arc, electrical resistance, frictional heat, sound and light energy. If no filter metal is used during welding then it is termed as 'Autogenous Welding Process'.

During 'Bronze Age' parts were joined by forge welding to produce tools, weapons and ornaments etc, however, present day welding processes have been developed within a period of about a century.

First application of welding with carbon electrode was developed in 1885 while metal arc welding with bare electrode was patented in 1890. However, these developments were more of experimental value and applicable only for repair welding but proved to be the important base for present day manual metal arc (MMAW) welding and other arc welding processes.

In the mean time resistance butt welding was invented in USA in the year 1886. Other resistance welding processes such as spot and flash welding with manual application of load were developed around 1905.

With the production of cheap oxygen in 1902, oxy – acetylene welding became feasible in Europe in 1903.

When the coated electrodes were developed in 1907, the manual metal arc welding process become viable for production/fabrication of components and assemblies in the industries on large scale.

Subsequently other developments are as follows:

- Thermit Welding (1903)
- Cellulosic Electrodes (1918)
- Arc Stud Welding (1918)
- Seam Welding of Tubes (1922)
- Mechanical Flash Welder for Joining Rails (1924)
- Extruded Coating for MMAW Electrodes (1926)
- Submerged Arc Welding (1935)
- Air Arc Gouging (1939)
- Inert Gas Tungsten Arc (TIG) Welding (1941)
- Iron Powder Electrodes with High Recovery (1944)
- Inert Gas Metal Arc (MIG) Welding (1948)
- Electro Slag Welding (1951)
- Flux Cored Wire with CO_2 Shielding (1954)
- Electron Beam Welding (1954)
- Constricted Arc (Plasma) for Cutting (1955)
- Friction Welding (1956)
- Plasma Arc Welding (1957)
- Electro Gas Welding (1957)
- Short Circuit Transfer for Low Current, Low Voltage Welding with CO_2 Shielding (1957)
- Vacuum Diffusion Welding (1959)
- Explosive Welding (1960)
- Laser Beam Welding (1961)
- High Power CO_2 Laser Beam Welding (1964)

All welded ' Liberty ' ships failure in 1942, gave a big jolt to application of welding. However, it had drawn attention to fracture problem in welded structures.

Applications:

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. 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.

General Applications:

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

Pressure Vessels:

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

Bridges:

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

Ship Building :

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

Building Structures:

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

Aircraft and Spacecraft:

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

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

Railways:

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

Automobiles:

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

Electrical Industry:

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

Electronic Industry:

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

Nuclear Installations:

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

Defence Industry:

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

Micro-Joining:

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

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

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Lecture 2

Classification of Welding Processes:

Welding processes can be classified based on following criteria;

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

1. Welding can be carried out with or without the application of filler material. Earlier only gas welding was the fusion process in which joining could be achieved with or without filler material. When welding was done without filler material it was called 'autogenous welding'. However, with the development of TIG, electron beam and other welding processes such classification created confusion as many processes shall be falling in both the categories.
2. Various sources of energies are used such as chemical, electrical, light, sound, mechanical energies, but except for chemical energy all other forms of energies are generated from electrical energy for welding. So this criterion does not justify proper classification.
3. Arc and Non-arc welding processes classification embraces all the arc welding processes in one class and all other processes in other class. In such classification it is difficult to assign either of the class to processes such as electroslag welding and flash butt welding, as in electroslag welding the process starts with arcing and with the melting of sufficient flux the arc extinguishes while in flash butt welding tiny arcs i.e. sparks are established during the process and then components are pressed against each other. Therefore, such classification is also not perfect.
4. Fusion welding and pressure welding is most widely used classification as it covers all processes in both the categories irrespective of heat source and welding with or without filler material. In fusion welding all those processes are included where molten metal solidifies freely while in pressure welding molten metal if any is retained in confined space under pressure (as may be in case of resistance spot welding or arc stud welding) solidifies under pressure or semisolid metal cools under pressure. This type of classification poses no problems so it is considered as the best criterion.

Processes falling under the categories of fusion and pressure welding are shown in Figures 2.1 and 2.2.

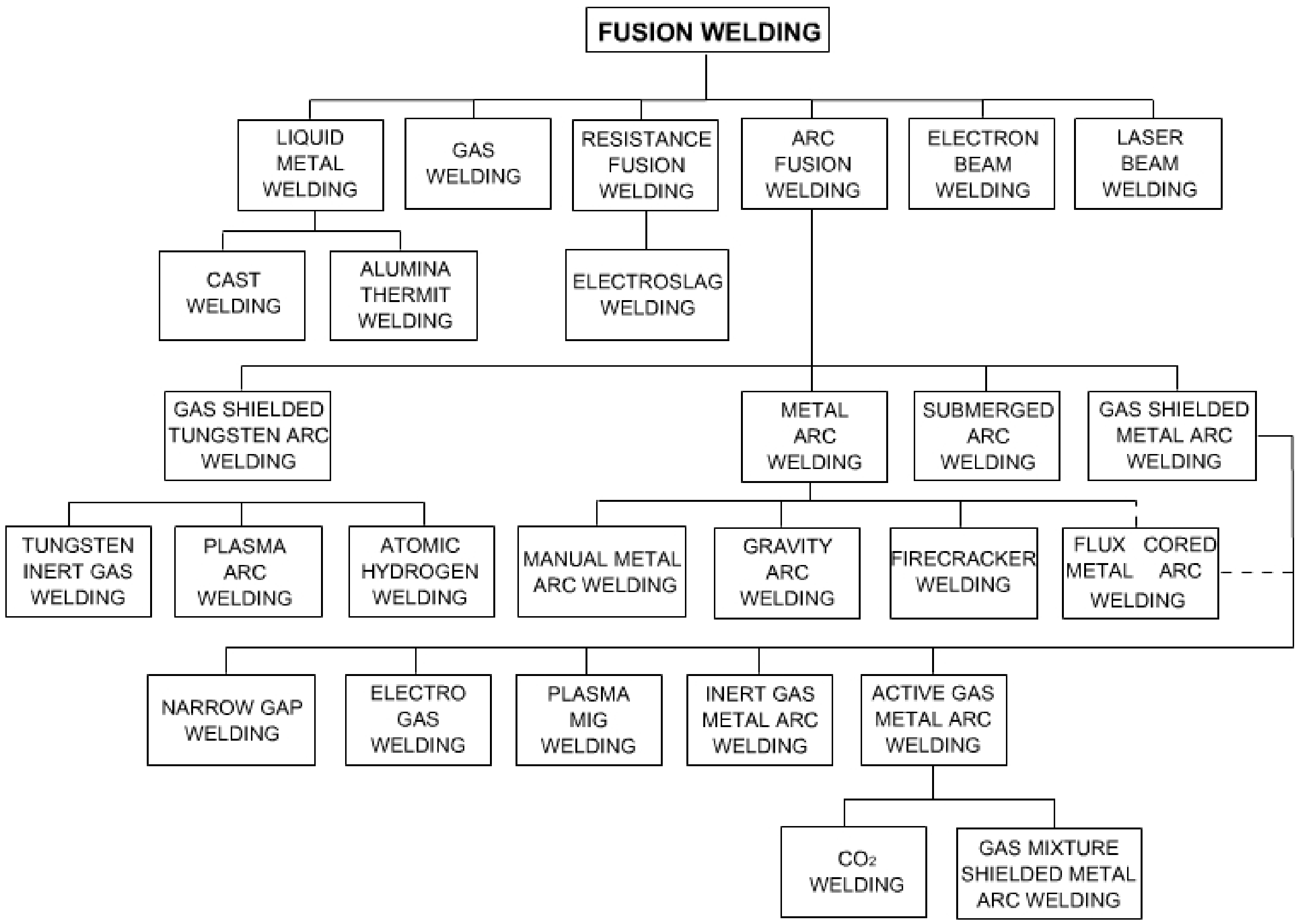

Figure 2.1: Classification of Fusion Welding Processes

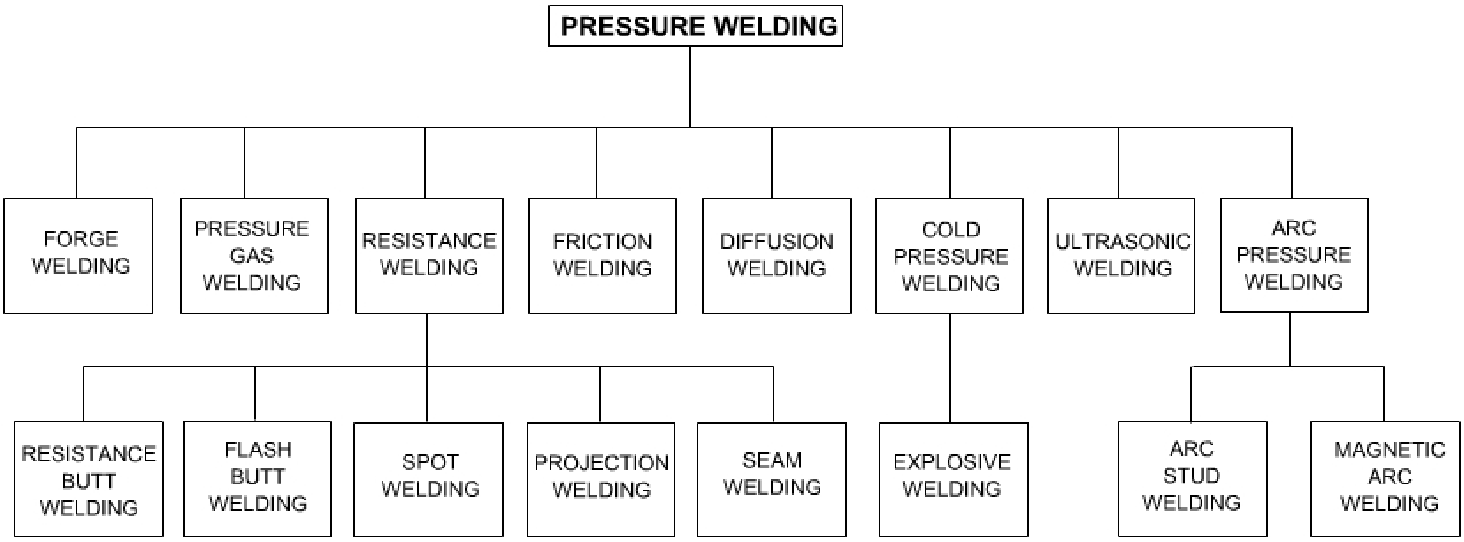

Figure 2.2: Classification of Pressure Welding Processes

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Lecture 3

Brazing and Soldering:

Both brazing and soldering are the metal joining processes in which parent metal does not melt but only filler metal melts filling the joint with capillary action. If the filler metal is having melting temperature more than 450°C but lower than the melting temperature of components then it is termed as process of brazing or hard soldering. However, if the melting temperature of filler metal is lower than 450°C and also lower than the melting point of the material of components then it is know as soldering or soft soldering.

During brazing or soldering flux is also used which performs the following functions:

- Dissolve oxides from the surfaces to be joined.
- Reduce surface tension of molten filler metal i.e. increasing its wetting action or spreadability.
- Protect the surface from oxidation during joining operation.

The strength of brazed joint is higher than soldered joint but lower than welded joint. However, in between welding and brazing there is another process termed as 'braze welding'.

Braze Welding:

Unlike brazing, in braze welding capillary action plays no role but the filler metal which has liquidus above 450 ° C but below the melting point of parent metal, fills the joint like welding without the melting of edges of parent metal. During the operation, the edges of the parent metal are heated by oxy-acetylene flame or some other suitable heat source to that temperature so that parent metal may not melt but melting temperature of filler metal is reached. When filler rod is brought in contact with heated edges of parent metal, the filler rod starts melting, filling the joint. If edges temperature falls down then again heat source is brought for melting filler rod. The molten filler metal and parent metal edges produce adhesion on cooling resulting into strong braze weld.

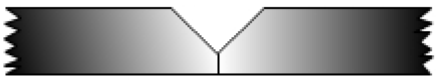

Fig 3.1(a) Two Components to be joined with V Joint

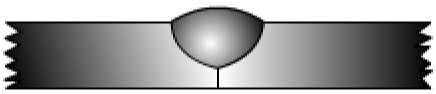

Fig 3.1(b) Welded Joint

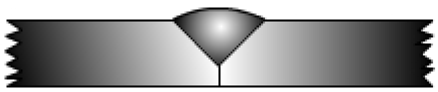

Fig 3.1(c) Braze Welded Joint

The braze welding filler material is normally brass with 60% Cu and remaining Zn with small additions of tin, manganese and silicon. The small additions of elements improve the deoxidizing and fluidity characteristics of filler metal.

Brazing:

The most commonly used filler metal is copper base zinc alloy consisting of normally 50-60% Cu, approximately 40% Zn, 1% Ni, 0.7 % Fe and traces of Si and Mn, which is brass and termed as 'spelter'. In some cases around 10% Ni may also be added to filler alloys. Copper base alloys may be available in the form of rod, strip and wire. Silver brazing filler metal may consists of 30-55% Ag, 15-35% Cu, 15-28% Zn, 18-24% Cd and sometimes 2-3% Ni or 5% Sn. Silver brazing alloys are available in form of wire, strip, rods and powders.

Borax and boric acid are commonly used fluxes for brazing with copper base filler metals. Many other commercial fluxes may be available in the form of paste or liquid solution leading to ease of application and adherence to the surface in any position.

Various commonly used method of brazing are followings:

- Torch Brazing

Torch brazing utilizes the heat of oxy-acetylene flame with neutral or reducing flame. Filler metal may be either preplaced in form of washers, rings, formed strips, powders or may be fed manually in form of rod.

- Dip Brazing

In dip brazing components with filler metal in proper form is preplaced at the joint and assembly is dipped in bath of molten salt which acts as heat source as well as flux for brazing. Preplaced preform melts and fills the joint. Another variant is to dip assembled parts in metallic bath and metal of bath fills the joint.

- Furnace Brazing

Self fixturing assembly with preplaced filler metal is placed inside electrically heated furnace with temperature control for heating and cooling. These furnaces may also be using protective atmosphere with inert gases like argon and helium or vacuum for brazing of reactive metal components.

• Infra-red Brazing

The heat for brazing is obtained from infra-red lamps. Heat rays can be concentrated at desired area or spot with concave reflectors. Such method of brazing requires automation and parts to be joined should be self fixturing. Filler metal is to be preplaced in the joint. The operation can be performed in air or in inert atmosphere or in vacuum.

• Induction Brazing

The heat is generated by induced current into the workpiece from a water cooled coil which surrounds the workpieces to be brazed. High frequencies employed vary from 5 to 400 kHz. Higher the frequency of current, shallow is the heating effect while lower frequencies of current lead to deeper heating and so it can be employed for thicker sections. Fluxes may or may not be used during brazing.

• Resistance Brazing

In resistance brazing the heat is generated at the interfaces to be brazed by resistive heating. The components are connected to high current and low voltage power supply through two electrodes under pressure. Only those fluxes are used which are electrically conductive and filler metal is preplaced.

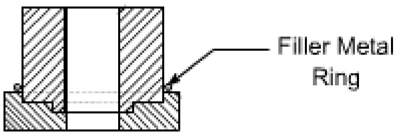

Fig 3.2: Typical Self Fixturing Brazing Assembly

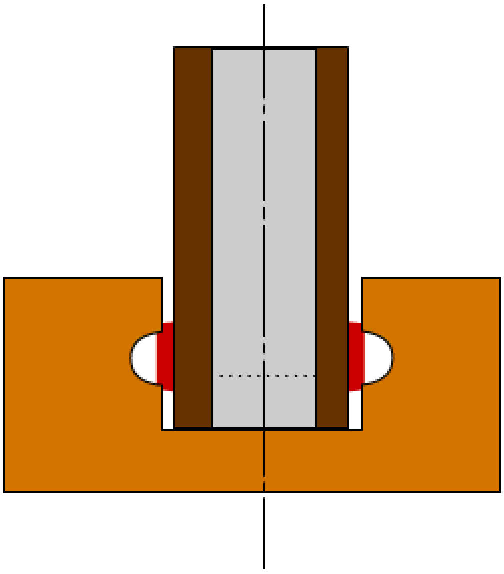

Fig 3.3: Preplaced Brazing Material and filling of joint during Brazing.

Soldering:

The soldering filler metal is called solder. The most commonly used solder is lead and tin alloy containing tin ranging from 5 to 70% and lead 95 to 30%. Higher the contents of tin, lower the melting point of alloy. Other filler metal are tin-antimony solder (95% tin and 5% antimony), tin-silver solder (tin 96% and silver 4%), lead-silver solder (97% lead, 1.5 tin and 1.5 silver), tin-zinc solder (91 to 30% tin and 9 to 70% zinc), cadmium-silver solder (95% cadmium and 5% silver). These are available in the form of bars, solid and flux cored wires, preforms, sheet, foil, ribbon and paste or cream.

Fluxes used in soldering are ammonium chloride, zinc chloride, rosin and rosin dissolved in alcohol.

Various soldering methods are soldering with soldering irons, dip soldering, torch soldering, oven soldering, resistance soldering, induction soldering, infra-red and ultrasonic soldering.

Soldering iron being used for manual soldering, consists of insulated handle and end is fitted with copper tip which may be heated electrically or in coke or oil/gas fired furnace. Solder is brought to molten state by touching it to the tip of the soldering iron so that molten solder can spread to the joint surface.

Ultrasonic soldering uses ultrasonics i.e. high frequency vibrations which break the oxides on the surface of workpieces and heat shall be generated due to rubbing between surfaces. This heat melts the solder and fills the joint by capillary action.

Flux Residue Treatment:

When brazing or soldering is completed then the flux residues are to be removed because without removal the residues may lead to corrosion of assemblies.

Brazing flux residues can be removed by rinsing with hot water followed by drying. If the residue is sticky then it can be removed by thermal shock i.e. heating and quenching. Sometimes steam jet may be applied followed by wire brushing.

Soldering flux residues of rosin flux can be left on the surface of joint, however, activated rosin flux and other flux residues require proper treatment. If rosin residues removal is required then alcohol, acetone or carbon tetrachloride can be used. Organic flux residues are soluble in hot water so double rising in warm water shall remove it. Residue removal of zinc chloride base fluxes can be achieved by washing first in 2% hydrochloric acid mixed in hot water followed by simple hot water rinsing.

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Lecture 4

Arc Welding Power Sources:

The main requirement of a power source is to deliver controllable current at a voltage according to the demands of the welding process being used. Each welding process has distinct differences from one another, both in the form of process controls required to accomplish a given operating condition and the consequent demands on the power source. Therefore, arc welding power sources are playing very important role in welding. The conventional welding power sources are:

Power Source Supply

Power Source	**Supply**
(i) Welding Transformer	AC
(ii) Welding Rectifier	DC
(iii) Welding Generators	AC or DC (Depending on generator)

Welding transformers, rectifiers and DC generators are being used in shop while engine coupled AC generators as well as sometimes DC generators are used at site where line supply is not available. Normally rectifiers and transformers are preferred because of low noise, higher efficiency and lower maintenance as compared to generators. Selection of power source is mainly dependent on welding process and consumable. The open circuit voltage normally ranges between 70-90 V in case of welding transformers while in case of rectifiers it is 50-80 V. However, welding voltages are lower as compared to open circuit voltage of the power source.

Based on the static characteristics power sources can be classified in two categories

- Constant current or drooping or falling characteristic power source.
- Constant potential or constant voltage or flat characteristic power source.

Constant voltage power source does not have true constant voltage output. It has a slightly downward or negative slope because of sufficient internal electrical resistance and inductance in the welding circuit to cause a minor droop in the output volt ampere characteristics.

With constant voltage power supply the arc voltage is established by setting the output voltage on the source. The power source shall supply necessary current to melt the electrode at the rate required to maintain the preset voltage or relative arc length. The speed of electrode drive is used to control the average welding current. The use of such power source in conjunction with a constant electrode wire feed results in a self regulating or self adjusting arc length system. Due to some internal or external fluctuation if the change in welding current occurs, it will automatically increase or decrease the electrode melting rate to regain the desired arc length.

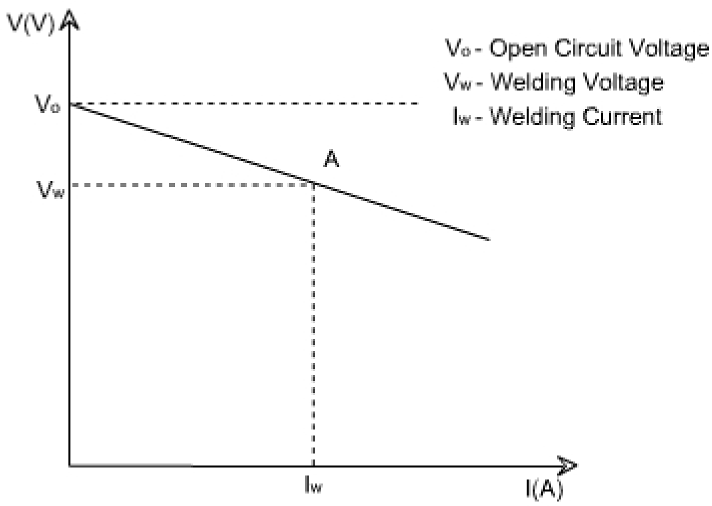

Fig 4.1: Constant Potential or Constant Voltage or Flat Characteristic.

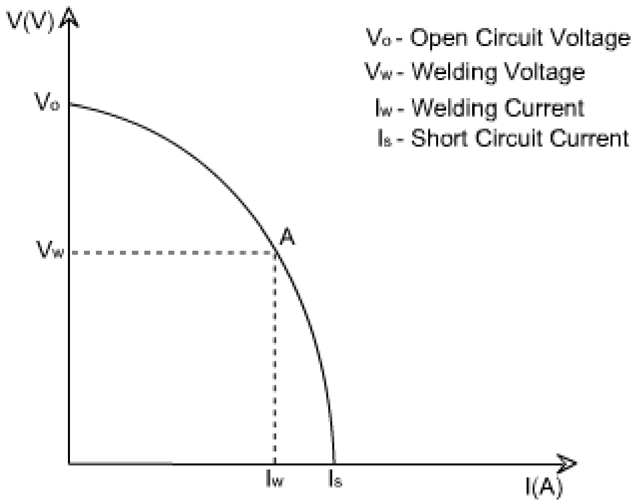

Fig 4.2: Drooping or Constant current or Falling Characteristic.

The volt ampere output curves for constant current power source are called 'drooper' because of substantial downward or negative slope of the curves. The power source may have open circuit voltage adjustment in addition to output current control. A change in either control will change the slope of the volt ampere curve. With a change in arc voltage, the change in current is small and, therefore, with a consumable electrode welding process, electrode melting rate would remain fairly constant with a change in arc length. These power sources are required for processes using relatively thicker consumable electrodes which may sometimes get stubbed to workpiece or with nonconsumable tungsten electrode where during touching of electrode for starting of arc may lead to damage of electrode if current is unlimited. Under these conditions the short circuiting current shall be limited leading to safety of power source and the electrode.

Some power sources need high frequency unit to start the arc, which may be requirement of processes like TIG and plasma arc. High frequency unit is introduced in the welding circuit but in between the control circuit and HF unit, filters are required so that high frequency may not flow through control circuit and damage it. High frequency unit is a device which supplies high voltage of the order of few KV along with high frequency of few KHz with low current. This high voltage ionizes the medium between electrode and workpiece/nozzle starting pilot arc which ultimately leads to the start of main arc. Although high voltage may be fatal for the operator but when it is associated with high frequencies then current does not enter body but it causes only skin effect i.e. current passes through the skin of operator causing no damage to the operator.

Duty Cycle:

Duty cycle is the ratio of arcing time to the weld cycle time multiplied by 100. Welding cycle time is either 5 minutes as per European standards or 10 minutes as per American standard and accordingly power sources are designed. It arcing time is continuously 5 minutes then as per European standard it is 100% duty cycle and 50% as per American standard. At 100% duty cycle minimum current is to be drawn i.e. with the reduction of duty cycle current drawn can be of higher level. The welding current which can be drawn at a duty cycle can be evaluated from the following equation;

$$D_R \times I_R^2 = I^2 \times D_{100}$$

Where I - is current at 100% duty cycle

D_{100} - 100% duty cycle

I_R - Current at required duty cycle

D_R - Required duty cycle

Duty cycle and associated currents are important as it ensures that power source remains safe and its windings are not getting damaged due to increase in temperature beyond specified limit. The maximum current which can be drawn from a power source depends upon its size of winding wire, type of insulation and cooling system of the power source.

Table 4.1: Welding Processes, Type of Current and Static Characteristic

Welding Process	Type of Current	Static Characteristic of The Power Source
Manual Metal Arc Welding	DC AC	Constant Current
Tungsten Inert Gas Welding	DC AC[AI]	Constant Current
Plasma Arc Welding	DC	Constant Current

Submerged Arc Welding	DC AC	Constant Current (if electrode Φ = 2.4 mm)
	DC	Constant Potential (if electrode Φ = 2.4 mm)
Gas Metal Arc Welding / Metal Inert Gas Welding / Metal Active Gas Welding	DC	Constant Potential

Goto Home

Lecture 5 & 6

Manual Metal Arc Welding:

Manual metal arc welding (MMAW) or shielded metal arc welding (SMAW) is the oldest and most widely used process being used for fabrication. The arc is struck between a flux covered stick electrode and the workpieces. The workpieces are made part of an electric circuit, known as welding circuit. It includes welding power source, welding cables, electrode holder, earth clamp and the consumable coated electrode. Figure 5.1 Shows details of welding circuit.

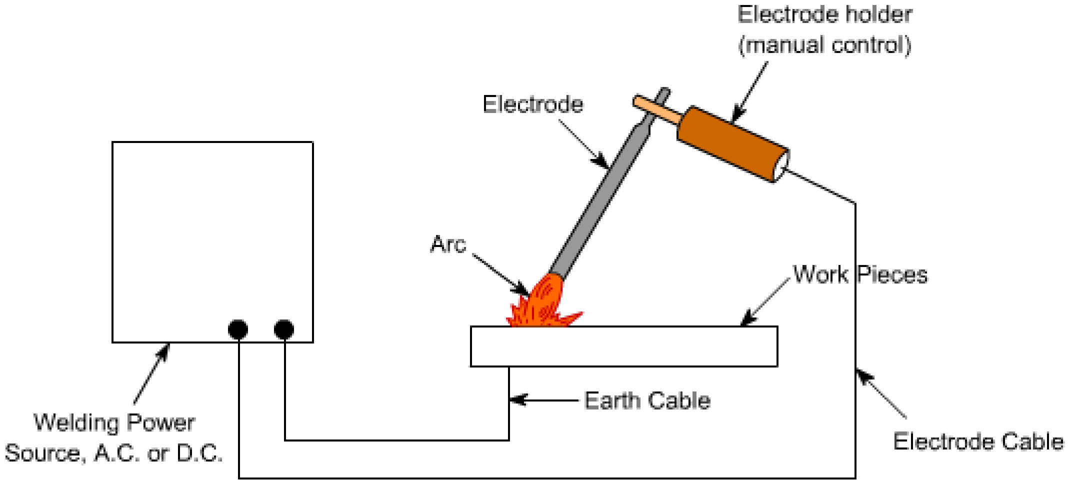

Fig 5.1: Manual Metal Arc Welding Circuit

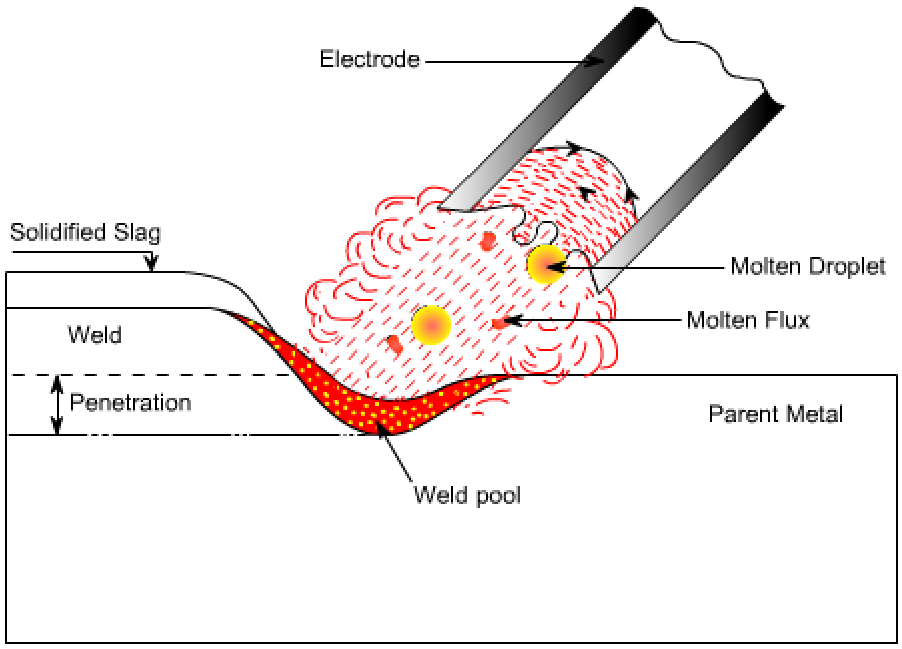

Fig 5.2: Molten Metal and Flux Transfer to Weld Pool

Figure 5.2 shows the fine molten droplets of metal and molten flux coming from the tip of the coated electrode. The flux melts along with the metallic core wire and goes to weld pool where it reacts with molten metal forming slag which floats on the top of molten weld pool and solidifies after solidification of molten metal and can be removed by chipping and brushing.

Welding power sources used may be transformer or rectifier for AC or DC supply. The requirement depends on the type of electrode coating and sometimes on the material to be welded.

The constant-current or drooping type of power source is preferred for manual metal arc welding since it is difficult to hold a constant arc length. The changing arc length causes arc voltage to increase or decrease, which in turn produces a change in welding current. The steeper the slope of the volt-ampere curve within the welding range, the smaller the current change for a given change in arc voltage. This results into stable arc, uniform penetration and better weld seam inspite of fluctuations of arc length.

The welding voltages range from 20 to 30 V depending upon welding current i.e. higher the current, higher the voltage. Welding current depends on the size of the electrode i.e. core diameter. The approximate average welding current for structural steel electrodes is 35.d (where d is electrode diameter in mm) with some variations with the type of coating of electrode. Table 5.1 shows influence of welding parameters on weld characteristics.

Table 5.1: Welding Variables and Their Influence

Welding Condition	Main Effects
Current in excess of optimum	Excess spatter. Flat wide deposit. Deep crater. Deep penetration. Electrode overheats.
Current less than optimum	Slag difficult to control. Metal piles up. Poor dead shape. Poor penetration.
Voltage in excess of optimum	Deposit irregular and flat. Arc wander. Porosity. Spatter.
Voltage less than optimum	Irregular piling of weld metal. Arc extinctions. Little penetration.
Travel speed in excess of optimum	Narrow thin weld bead. Undercut.
Travel speed less than optimum	Wide thick deposit. Difficulty in slag control.
Optimum Welding conditions	Smooth even weld deposit. Stable arc condition. Easily controlled slag. Little spatter produced.

The output voltage of the power source on ‘no load' or ‘open circuit' must be high enough to enable the arc to be started. A value of 80 V is sufficient for most electrodes but certain types may require more or less than this value.

A manual welding power source is never loaded continuously because of operations such as, electrode changing, slag removal etc. Most MMA welding equipment has a duty cycle of around 40% at maximum welding current.

Coated Electrodes are specified based on core wire diameter. Commonly used electrode diameters are 2, 2.5, 3.18, 4, 5 and 6 mm. Length of electrodes may depend on diameter of core wire ranging from 250 to 450 mm i.e. larger the core diameter larger the length. However, special electrodes may be of 8-10 mm diameter. Table 5.2 gives the details of electrode sizes and currents.

Table 5.2: Size and Welding Current for Stick Mild Steel Electrodes

Diameter d mm	**2.0**	**2.5**	**3.18(1/8")**	**4.0**	**5.0**	**6.0**
Length L mm	250/300	350	350/450	450	450	450
Welding I Current A	50-80	70-100	90-130	120-160	160-200	190-240

The electrodes are also specified based on ratio of diameter of coated portion of electrode to core wire diameter. If this ratio is lesser than 1.2 then electrodes are thin coated, if ratio ranges between 1.2 to 1.5 then medium coated and if ratio exceeds 1.5 then electrodes are heavy coated or thick coated. This ratio may vary slightly in different codes.

Thin coated electrodes have very good bridgeability at the joint gap but weld bead has coarse ripples and penetration is also poor. Medium coated electrodes lead to reasonably good bridgeability, medium ripples in weld bead and modest penetration. Thick coated electrodes have poor bridgeability, however, bead appearance is excellent with fine ripples and also excellent penetration.

The ingress of oxygen and nitrogen from the atmosphere to the weld pool and arc environment would cause embrittlement and porosity in the weld metal and this must be prevented. The Actual method of arc shielding from atmospheric nitrogen and oxygen attack varies with different type of electrodes which are in two main categories.

1. Bulk of covering material converts to a gas by the heat of the arc, only a small amount of slag is produced. Protection depends largely upon a gaseous shield to prevent atmospheric contamination as in case of cellulosic electrode.

2. Bulk of covering material converts to a slag, only a small volume of shielding gas produced as in the case of rutile and basic coated electrodes.

Electrode coating performs many functions depending upon coating constituents, during welding to improve weld metal properties. The important functions are as follows:

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

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

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

1. Cellulosic Electrodes

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

2. Rutile Electrodes

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

3. Acidic Electrodes

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

4. Basic Electrodes

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

Table 5.3: Coating Constituents and Their Functions

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

Clay (Aluminum Silicate)	Slag former	Coating strength
Talc (Magnesium Silicate)	Slag former	Arc stabilizer
Rutile (TiO_2)	Arc stabilizer, Slag former, Fluidity	Slag removal and bead appearance
Iron Oxides	Fluidity, Slag former	Arc Stabilizer, improved metal transfer,
Calcium Carbonate	Gas former, Arc stabilizer	Slag basicity, Slag former
Asbestos	Coating strength	Slag former
Quartz (SiO_2)	Slag fluidity, Slag former	Increase in current carrying capacity.
Sodium Silicate / Potassium Silicate	Binder, Arc stabilizer	Slag former
FeMn / FeSi	Deoxidizer	-
Iron Powder	Deposition Rate	-
Powdered Alloys	Alloying	-

Classification of Electrodes as per Indian Standard:

Structural steel electrodes were classified as per IS 814:1974 and this code was revised and the revised code is IS 814:1991.

The corresponding code is given on each packet of electrode.

IS 815:1974

As per IS 815 electrodes are designated with letters and digits.

P X X X X X X S

Prefix (P) is either E or R which indicates solid extruded (E) or reinforced extruded (R) Electrode.

1 st digit – Indicates type of coating.

2 nd digit – Indicates weld positions in which electrode can be used.

3 rd digit – Indicates welding current conditions.

4 th and 5 th digit – Indicate UTS and YS of all weld metal.

6 th digit – Requirement of minimum % elongation and absorbed energy in charpy V- notch impact test of weld metal.

Suffix (s) – P – Deep penetration electrode

H – Hydrogen controlled electrode

J, K and L – Amount of metal recovery in case of iron powder electrode

Suffix (s) are optional and may or may not be given if not applicable.

IS 814:1991

As per IS 814 electrodes are designated with letters and digits as given below:

E L X X X X S

In this code E indicates extruded solid electrode, L is a letter to designate type of coating, first digit indicates UTS and YS of deposited weld metal, second digit gives percentage elongation and impact values of weld metal deposited, third digit gives welding positions in which electrode can be used and fourth digit gives the current conditions for the use of electrode.

Suffix(s) are optional and indicate special characteristics of electrode such as H_1, H_2, and H_3 indicate hydrogen controlled electrodes with different amount of diffusible hydrogen J, K, L indicate different amount of metal recovery in weld pool in case of iron powder electrodes and X means radiographic weld quality.

Note: For details see the above codes published by Bureau of Indian Standards (BIS), Manak Bhawan, Bahadur Shah Jafar Marg, New Delhi .

Weld Bead Geometry

Figure 5.3 shows the important parameters of the weld bead geometry for a butt weld.

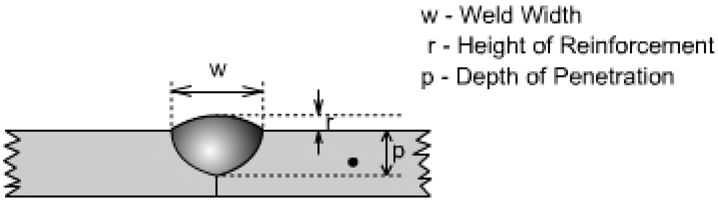

FIg 5.3: Weld Bead Geometry

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Lecture 7 & 8

Submerged Arc Welding:

Submerged arc welding is an arc welding process in which heat is generated by an arc which is produced between bare consumable electrode wire and the workpiece. The arc and the weld zone are completely covered under a blanket of granular, fusible flux which melts and provides protection to the weld pool from the atmospheric gases.

The molten flux surrounds the arc thus protecting arc from the atmospheric gases. The molten flux flows down continuously and fresh flux melts around the arc. The molten flux reacts with the molten metal forming slag and improves its properties and later floats on the molten/solidifying metal to protect it from atmospheric gas contamination and retards cooling rate. Process of submerged arc welding is illustrated in Figure 7.1.

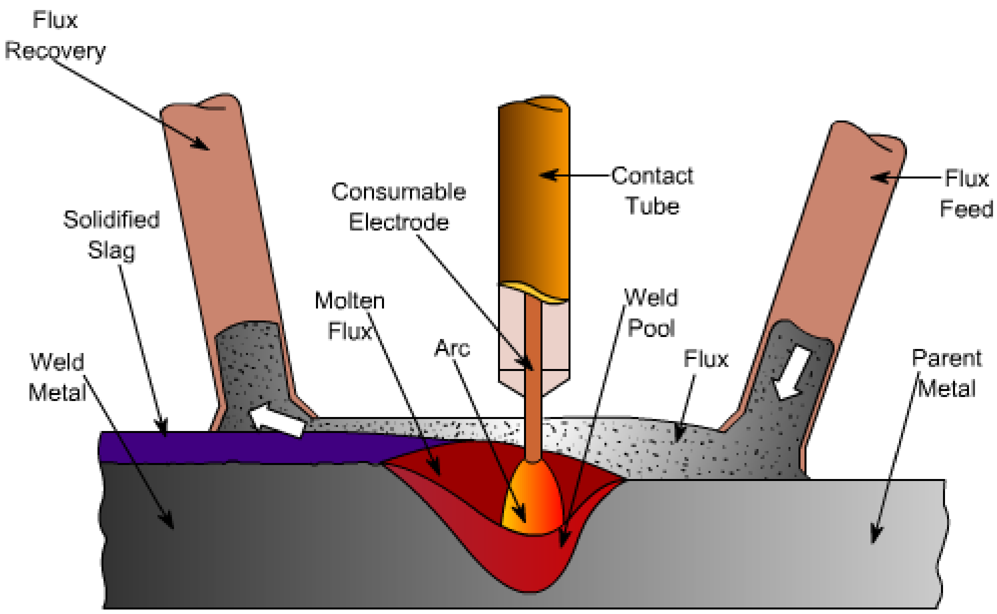


Fig 7.1: Process of Submerged Arc Welding

Extremely high welding currents can be used without the danger of spatter and atmospheric contamination giving deep penetration with high welding speeds. A proper selection of flux-wire combination can produce welds of very high quality. This makes the process very suitable for the welding of high strength steel at welding speeds much higher than conventional manual metal arc welding. It is found that the desired composition of the weld metal can be more economically obtained through adding alloying elements in the flux and using a relatively unalloyed wire as compared with welding with alloyed wire and ordinary flux.

A continuous consumable wire electrode is fed from a coil through contact tube which is connected to one terminal of power source. Wires in the range 1 – 5 mm diameters are usually employed and with wires at the lower end of this range (upto 2.4 mm) constant-potential DC power source can be used allowing arc length control by the self-adjusting effect. For higher diameter electrodes constant current DC source is used.

Submerged arc welding head may be mounted on self-propelled tractors carrying a flux hopper and the coiled electrode. A suction device may also be carried to recover the unused flux for reuse.

Since the end of the electrode and the welding zone are completely covered at all times during the actual welding operation, the weld is made without the sparks, spatter, smoke or flash commonly observed in other arc welding processes.

Power source requirement may be DC or AC. Normally electrode is connected to positive terminal of DC power source. Sometime depending on the nature of flux AC can be used with single electrode wire or with multiple electrodes where one electrode may be connected to DC and other to AC if independent power sources are to be used.

Electrode wires and fluxes are two major consumables. Wires of structural steel are coated with copper to protect it from atmospheric corrosion and increasing its current carrying capacity while stainless steel wires are not coated with copper.

Flux in submerged arc welding performs more or less the similar functions as the electrode coating in the case of MMA welding, except from generation of shielding gas. However, these fluxes perform additional function of pickup or loss of alloying elements through gas metal and slag metal reactions as the molten flux gets sufficient time to react with molten metal and performs above reactions and then forming slag. Some fluxes require baking before use, to remove moisture which might have been absorbed during storage. Such fluxes should be baked as per manufacturer's recommendations or at 250–300 ° C for 1 - 2 hours duration before use.

Fluxes are fused or agglomerated consisting of MnO, SiO_2, CaO, MgO, Al_2O_3, TiO_2, FeO, and CaF_2 and sodium/potassium silicate. Particular flux may consist of some of these constituents and other may not be present. Depending upon the flux constituents the base of flux is decided. Also the basicity index of flux is decided on the flux constituents. The ratio of contents of all basic oxides to all acidic oxides in some proportion is called basicity index of a flux. CaO, MgO, BaO, CaF_2, Na_2O, K_2O, MnO are basic constituents while SiO_2, TiO_2, Al_2O_3 are considered to be acidic constituents.

When welding with low basicity index fluxes, better current carrying capacity, slag detachability and bead appearance are achieved while mechanical properties and crack resistance of the weld metal are poor. High basicity fluxes produce weld metal with excellent mechanical properties and resistance to cracking, however, bead appearance and current carrying capacity are poor.

Electrode wire size, welding voltage, current and speed are four most important welding variables apart from flux. Welding current is the most influential variable as it controls electrode melting rate, depth of penetration and the amount of base metal fused. However, very high current shall lead to too much penetration resulting into burn through in the metal being joined, excessive reinforcement and increased weld shrinkage and, therefore, large amount of distortion. On the other hand low current shall lead to insufficient penetration, lack of fusion and unstable arc.

Welding voltage has nominal effect on the electrode wire melting rate but high voltage leads to flatter and wider bead, increased flux consumption and resistance to porosity caused by rust or scale and helps bridge gap when fitup is poor. Lower voltage produces resistance to arc blow but high narrow bead with poor slag removal. Welding voltages employed vary from 22 to 35 V.

If the welding speed is increased, power or heat input per unit length of weld is decreased, less welding material is applied per unit length of weld, and consequently less weld reinforcement results and penetration decreases. Travel speed is used primarily to control bead size and penetration. It is interdependent with current.

Excessive high travel speed decreases wetting action, increases tendency for undercut, arc blow, porosity and uneven bead shapes while slower travel speed reduces the tendency to porosity and slag inclusion.

The electrode size principally affects the depth of penetration for fixed current. Small wires are generally used in semiautomatic equipment to provide flexibility to the welding gun. The small wires are also used in multiple electrodes, parallel wire setups.

The larger electrodes are generally used to take advantage of higher currents and consequently higher deposition rates. Where poor fitup is countered a larger electrode is capable of bridging gaps better than smaller ones.

Variations in submerged arc welding may be single electrode wire and multiple electrode wires i.e. multiple arcs.

Multiple arcs are used to increase deposition rates and to direct the arc blow in order to provide an increase in welding speed. Multiple arcs may also reduce the solidification rate and porosity in the weld metal. Multiple arcs may be used either with a single power source or with separate power sources for each electrode.

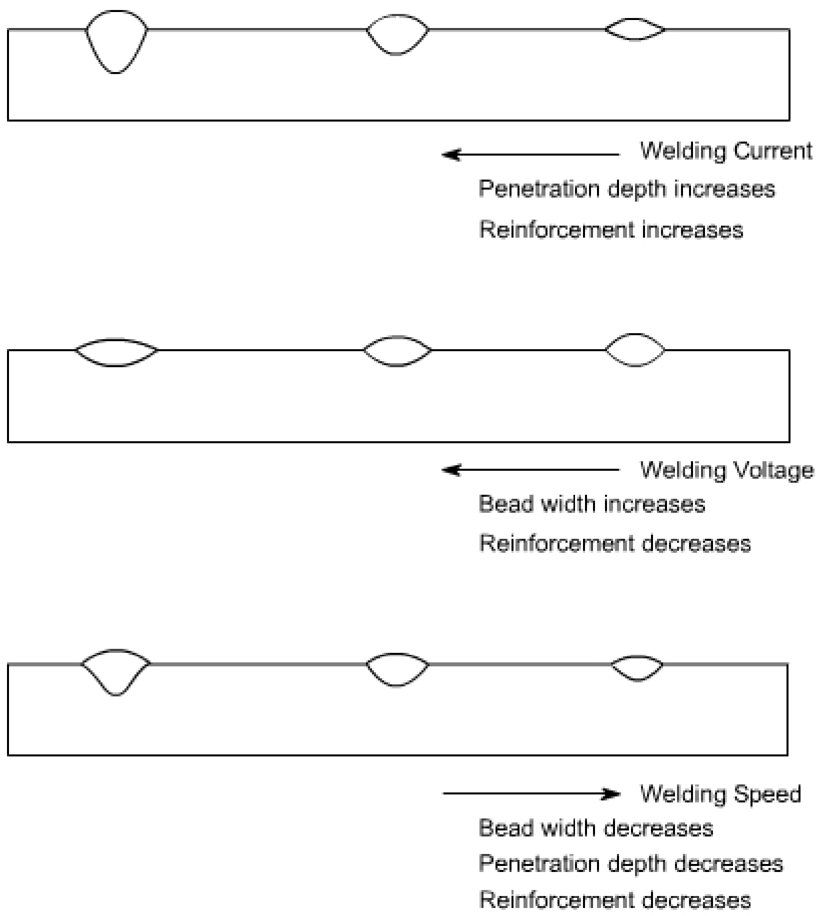


Fig 7.2: Influence of Welding Parameters on Bead Shape.

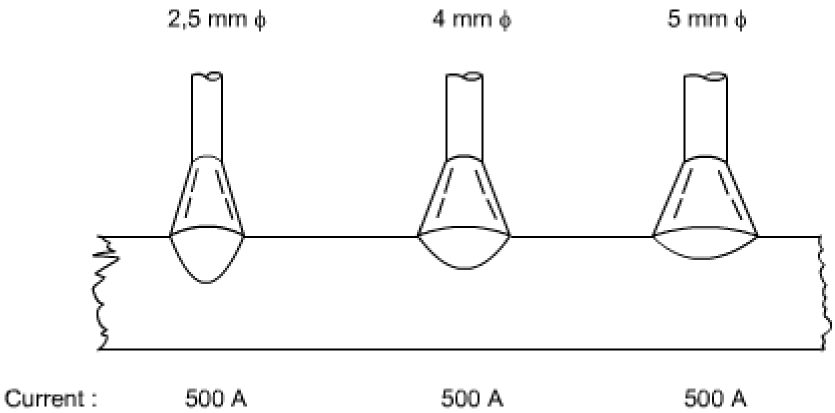
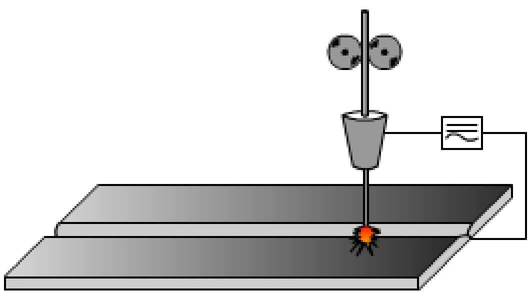


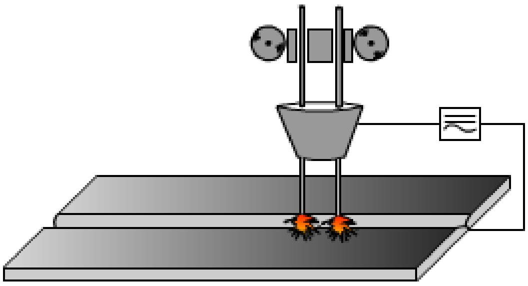
Fig 7.3: Influence of Electrode Size on Weld Bead.



One electrode wire, one power source and one control unit.

High deposition rate compared to other consumable electrode welding processes.

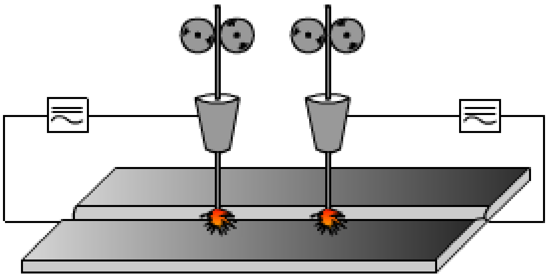
Fig 7.4: Conventional Single Electrode SAW



Two electrode wires, one power source and one control unit.

High deposition rate, good bridgeability for gaps, high welding speed.

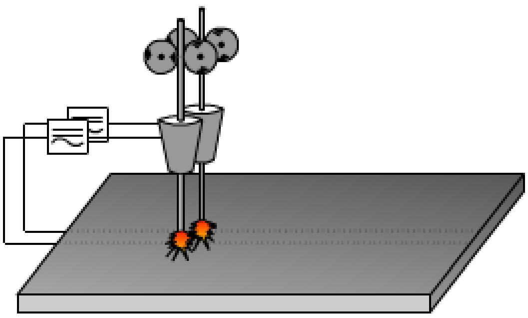
Fig 7.5: Twin Arc SAW



Two electrode wires, two power sources and two control units.

High deposition rate and higher welding speed, improved mechanical properties and bead geometry.

Fig 7.6: Tandem Wire SAW



Two electrode wires, two power sources and two control units.

Normally used for cladding or welding in wide grooves.

Fig 7.7: Parallel Wire SAW

Submerged arc welding process has high deposition rate with high depth of penetration. This is continuous welding process with no interruptions as electrode wire is supplied through coil on a spool. Welding is carried out without sparks, smoke or spatter. Weld bead is very clean and smooth. Welds produced are of high quality with good mechanical and metallurgical characteristics.

As the arc is not visible, being covered with the layer of slag, so it necessitates accurate guidance of the welding head on the weld groove, failing which an improper fusion will result. Further, process can be used only in flat or HV positions. Plates of lesser thickness (less than 5 mm) can not be welded because of danger of burn through which may occur. Circumferential welds cannot be made in small diameter components because the flux falls away.

Submerged arc welding is mainly being used for different grades of steels. It is widely being used in shipbuilding, offshore, structural and pressure vessel industries. General fabrication such as fabrication of pipes, penstocks, LPG cylinders, bridge girders and other structures are produced by SA welding. Surfacing for reclamation of worn out parts or for deposition of wear or corrosion resistant layers or for hardfacing layers also employ submerged arc process.

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Lecture 9

Gas Metal Arc Welding

Gas metal arc welding (GMAW) is the process in which arc is struck between bare wire electrode and workpiece. The arc is shielded by a shielding gas and if this is inert gas such as argon or helium then it is termed as metal inert gas (MIG) and if shielding gas is active gas such as CO_2 or mixture of inert and active gases then process is termed as metal active gas (MAG) welding. Figure 9.1 illustrates the process of GMA welding.

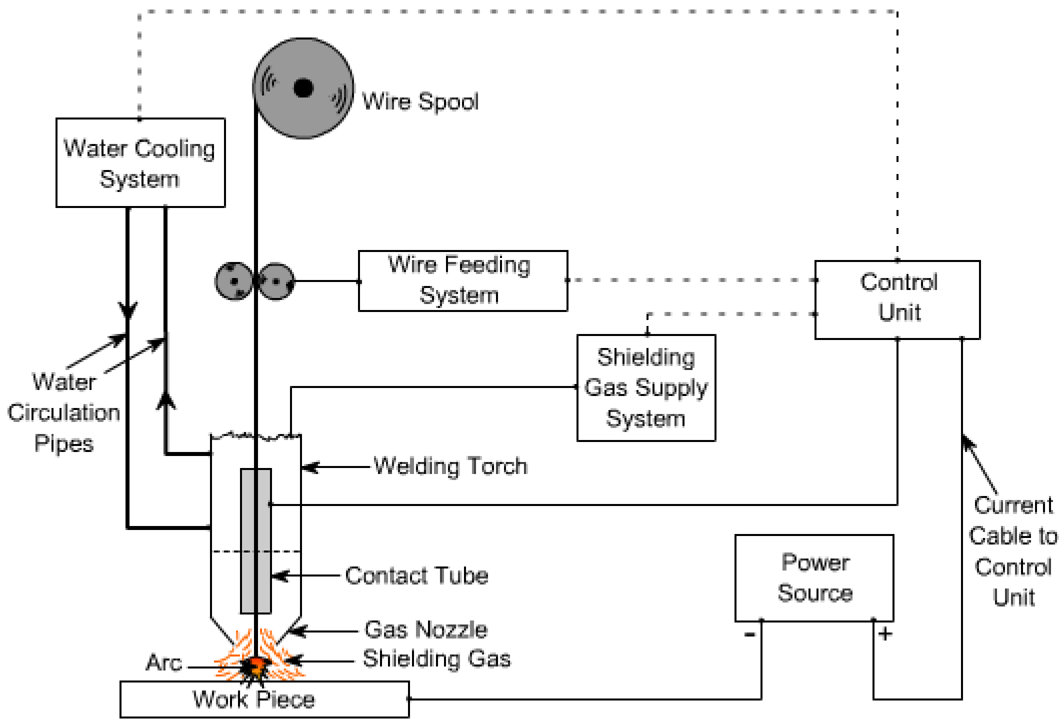

Fig 9.1 Schematic Diagram of GMA Welding

Direct current flat characteristic power source is the requirement of GMAW process. The electrode wire passing through the contact tube is to be connected to positive terminal of power source so that stable arc is achieved. If the electrode wire is connected to negative terminal then it shall result into unstable spattery arc leading to poor weld bead. Flat characteristic leads to self adjusting or self regulating arc leading to constant arc length due to relatively thinner electrode wires.

GMA welding requires consumables such as filler wire electrode and shielding gas. Solid filler electrode wires are normally employed and are available in sizes 0.8, 1.0, 1.2 and 1.6 mm diameter. Similar to submerged arc welding electrode wires of mild steel and low alloyed steel, are coated with copper to avoid atmospheric corrosion, increase current carrying capacity and for smooth movement through contact tube. The electrode wire feeding system is shown in Figure 9.2.

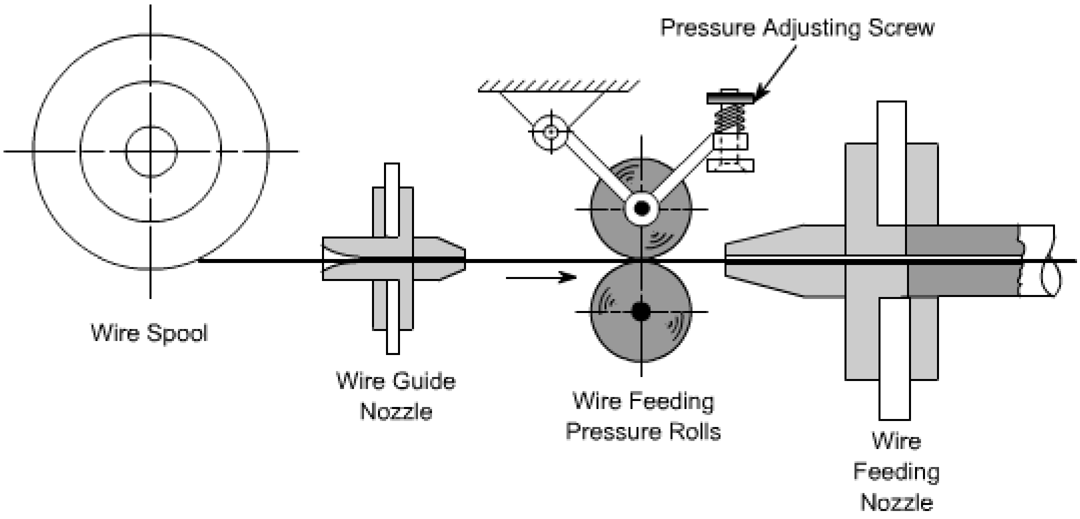

Fig 9.2: Electrode Wire Feeding System

Pressure adjusting screw is used to apply required pressure on the electrode wire during its feeding to avoid any slip. Depending on the size and material of the wire, different pressures are required for the smooth feeding of wire with minimum deformation of the wire. Further, wire feeding rolls have grooves of different sizes and are to be changed for a particular wire size.

The range of welding current and voltage vary and is dependent on material to be welded, electrode size and mode of metal transfer i.e. mode of molten drop formed at the tip of electrode and its transfer to the weld pool. This process exhibits most of the metal transfer modes depending on welding parameters.

The range of current and voltage for a particular size of electrode wire, shall change if material of electrode wire is changed. With lower currents normally lower voltages are employed while higher voltages are associated with higher currents during welding. Thin sheets and plates in all positions or root runs in medium plates are welded with low currents while medium and heavy plates in flat position are welded with high currents and high voltages. Welding of medium thickness plates in horizontal and vertical positions are welded with medium current and voltage levels.

Table 9.1 gives the total range of currents and voltages for different sizes of structural steel i.e. mild steel electrodes of different sizes.

Electrode Wire Diameter (mm)	Current Range (A)	Voltage Range (V)
0.8	50-180	14-24
1.0	70-250	16-26
1.2	120-320	17-30
1.6	150-380	18-34

Table 9.1: Welding Current and Voltage Ranges for Mild Steel Electrodes

Both inert gases like argon and helium and active gases like CO_2 and N_2 are being used for shielding depending upon the metal to be welded. Mixtures of inert and active gases like CO_2 and O_2 are also being used in GMA welding process. For mild steel carbon dioxide is normally used which gives high quality, low current out of position welding i.e. also in welding positions other than flat position. Low alloyed and stainless steels require argon plus oxygen mixtures for better fluidity of molten metal and improved arc stability. The percentage of oxygen varies from 1-5% and remaining is argon in argon and oxygen mixtures. However, low alloy steels are also welded with 80% argon and 20% CO_2 mixture.

Nickel, monel, inconel, aluminum alloys, magnesium, titanium, aluminum bronze and silicon bronze are welded with pure argon. Nickel and nickel alloys may sometimes be welded with mixture of argon and hydrogen (upto 5%). Copper and aluminum are also welded with 75% helium and 25% argon mixture to encounter their thermal conductivity. Nitrogen may be used for welding of copper and some of its alloys, but nitrogen and argon mixtures are preferred over pure nitrogen for relatively improved arc stability.

The process is extremely versatile over a wide range of thicknesses and all welding positions for both ferrous and nonferrous metals, provided suitable welding parameters and shielding gases are selected. High quality welds are produced without the problem of slag removal. The process can be easily mechanized / automated as continuous welding is possible.

However, process is costly and less portable than manual metal arc welding. Further, arc shall be disturbed and poor quality of weld shall be produced if air draught exists in working area.

GMA welding has high deposition rate and is indispensable for welding of ferrous and specially for nonferrous metals like aluminum and copper based alloys in shipbuilding, chemical plants, automobile and electrical industries. It is also used for building structures.

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Lecture 10

TIG Welding

Tungsten Inert Gas (TIG) or Gas Tungsten Arc (GTA) welding is the arc welding process in which arc is generated between non consumable tungsten electrode and workpiece. The tungsten electrode and the weld pool are shielded by an inert gas normally argon and helium. Figures 10.1 & 10.2 show the principle of tungsten inert gas welding process.

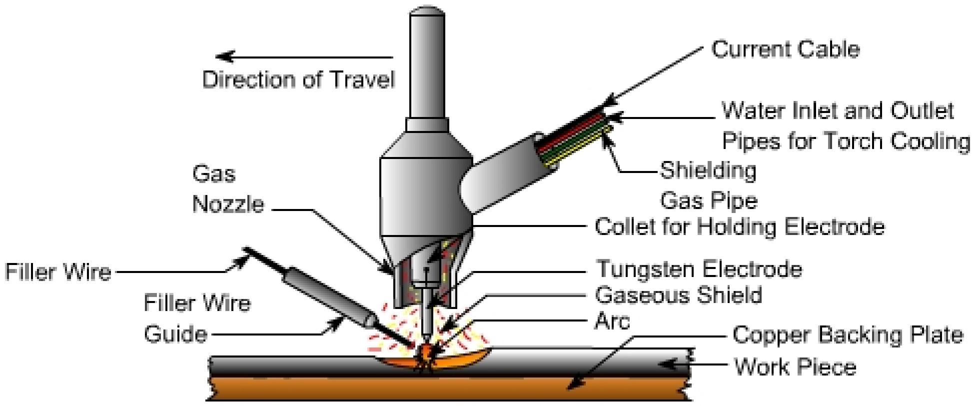

Fig 10.1: Principle of TIG Welding.

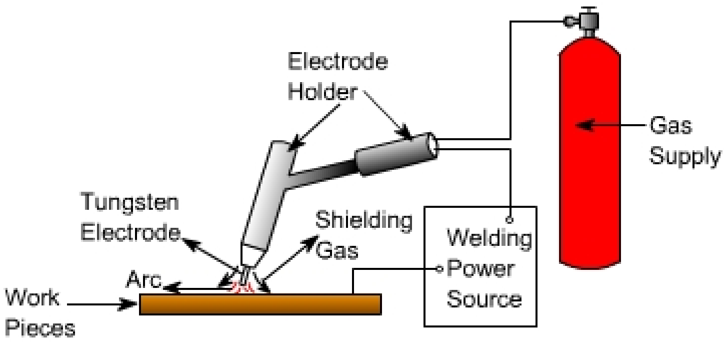

Fig 10.2: Schematic Diagram of TIG Welding System.

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

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

Selection of electrode composition and size is not completely independent and must be considered in relation to the operating mode and the current level. Electrodes for DC welding are pure tungsten or tungsten with 1 or 2% thoria, the thoria being added to improve electron emission which facilitates easy arc ignition. In AC welding, where the electrode must operate at a higher temperature, a pure tungsten or tungsten-zirconia electrode is preferred as the rate of tungsten loss is somewhat lesser than with thoriated electrodes and the zirconia aids retention of the ‘balled' tip.

Table 10.1 gives chemical composition of tungsten electrodes as per American Welding Society (AWS) classification.

AWS Classification	Tungsten, min. percent	Thoria, percent	Zirconia, percent	Total other elements, max. percent
EWP	99.5	-	-	0.5
EWTh-1	98.5	0.8 to 1.2	-	0.5

EWTh-2	97.5	1.7 to 2.2	-	0.5
EWZr	99.2	-	0.15 to 0.40	0.5

Table 10.1: Chemical Composition of TIG Electrodes.

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of each size of electrode depends on whether it is connected to negative or positive terminal of DC power source. AC is used only in case of welding of aluminum and magnesium and their alloys. Table 10.2 gives typical current ranges for TIG electrodes when electrode is connected to negative terminal (DCEN) or to positive terminal (DCEP).

Electrode Dia. (mm)	DCEN	DCEP
	Pure and Thoriated Tungsten	Pure and Thoriated Tungsten
0.5	5-20	-
1.0	15-80	-
1.6	70-150	10-20
2.4	150-250	15-30
3.2	250-400	25-40
4.0	400-500	40-55
4.8	500-750	55-80
6.4	750-1000	80-125

Table 10.2: Typical Current Ranges for TIG Electrodes

The power source required to maintain the TIG arc has a drooping or constant current characteristic which provides an essentially constant current output when the arc length is varied over several millimeters. Hence, the natural variations in the arc length which occur in manual welding have little effect on welding current. The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the workpiece, otherwise excessively high current shall flow, damaging the electrode. Open circuit voltage of power source ranges from 60 to 80 V.

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

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

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

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Lecture 11 & 12

Resistance Welding

Resistance welding processes are pressure welding processes in which heavy current is passed for short time through the area of interface of metals to be joined. These processes differ from other welding processes in the respect that no fluxes are used, and filler metal rarely used. All resistance welding operations are automatic and, therefore, all process variables are preset and maintained constant. Heat is generated in localized area which is enough to heat the metal to sufficient temperature, so that the parts can be joined with the application of pressure. Pressure is applied through the electrodes.

The heat generated during resistance welding is given by following expression:

$$H = I^2 R T$$

Where, **H** is heat generated

I is current in amperes

R is resistance of area being welded

T is time for the flow of current.

The process employs currents of the order of few KA, voltages range from 2 to 12 volts and times vary from few ms to few seconds. Force is normally applied before, during and after the flow of current to avoid arcing between the surfaces and to forge the weld metal during post heating. The necessary pressure shall vary from 30 to 60 N mm^{-2} depending upon material to be welded and other welding conditions. For good quality welds these parameters may be properly selected which shall depend mainly on material of components, their thicknesses, type and size of electrodes.

Apart from proper setting of welding parameters, component should be properly cleaned so that surfaces to be welded are free from rust, dust, oil and grease. For this purpose components may be given pickling treatment i.e. dipping in diluted acid bath and then washing in hot water bath and then in the cold water bath. After that components may be dried through the jet of compressed air. If surfaces are rust free then pickling is not required but surface cleaning can be done through some solvent such as acetone to remove oil and grease.

The current may be obtained from a single phase step down transformer supplying alternating current. However, when high amperage is required then three phase rectifier may be used to obtain DC supply and to balance the load on three phase power lines.

The material of electrode should have higher electrical and thermal conductivities with sufficient strength to sustain high pressure at elevated temperatures. Commonly used electrode materials are pure copper and copper base alloys. Copper base alloys may consist of copper as base and alloying elements such as cadmium or silver or chromium or nickel or beryllium or cobalt or zirconium or tungsten. Pure tungsten or tungsten-silver or tungsten-copper or pure molybdenum may also be used as electrode material. To reduce wear, tear and deformation of electrodes, cooling through water circulation is required. Figure 11.1 shows the water cooling system of electrodes.

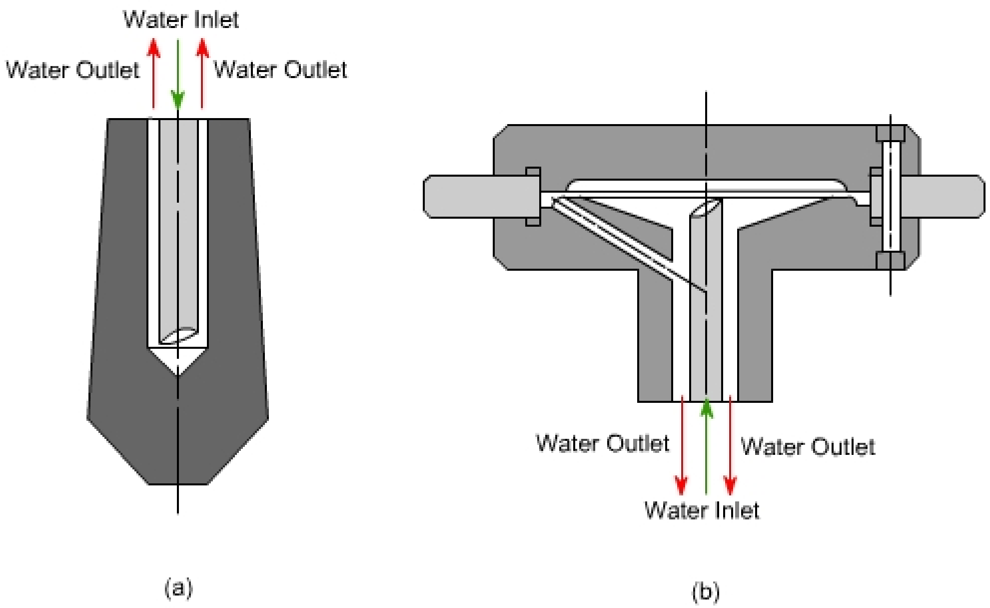

Fig 11.1: Water Cooling of Electrodes (a) Spot Welding (b) Seam Welding.

Commonly used resistance welding processes are spot, seam and projection welding which produce lap joints except in case of production of welded tubes by seam welding where edges are in butting position. In butt and flash welding, components are in butting position and butt joints are produced.

1. Spot Welding

In resistance spot welding, two or more sheets of metal are held between electrodes through which welding current is supplied for a definite time and also force is exerted on work pieces. The principle is illustrated in Figure 11.2.

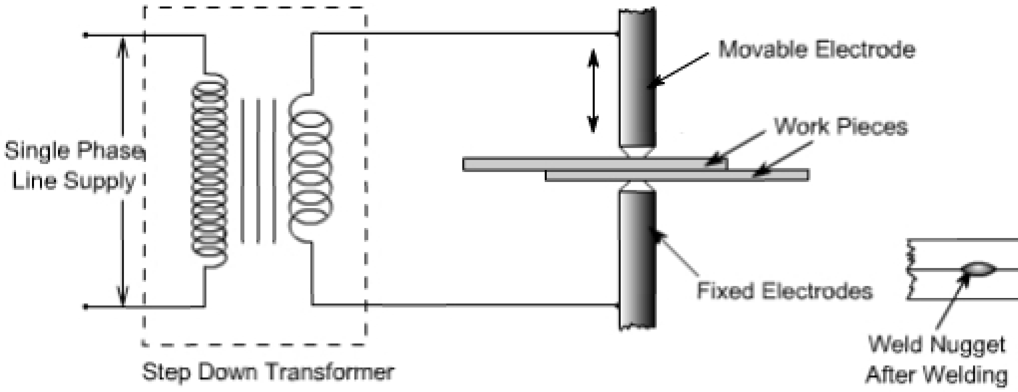

Fig 11.2: Principle of Resistance spot Welding

The welding cycle starts with the upper electrode moving and contacting the work pieces resting on lower electrode which is stationary. The work pieces are held under pressure and only then heavy current is passed between the electrodes for preset time. The area of metals in contact shall be rapidly raised to welding temperature, due to the flow of current through the contacting surfaces of work pieces. The pressure between electrodes, squeezes the hot metal together thus completing the weld. The weld nugget formed is allowed to cool under pressure and then pressure is released. This total cycle is known as resistance spot welding cycle and illustrated in Figure 11.3

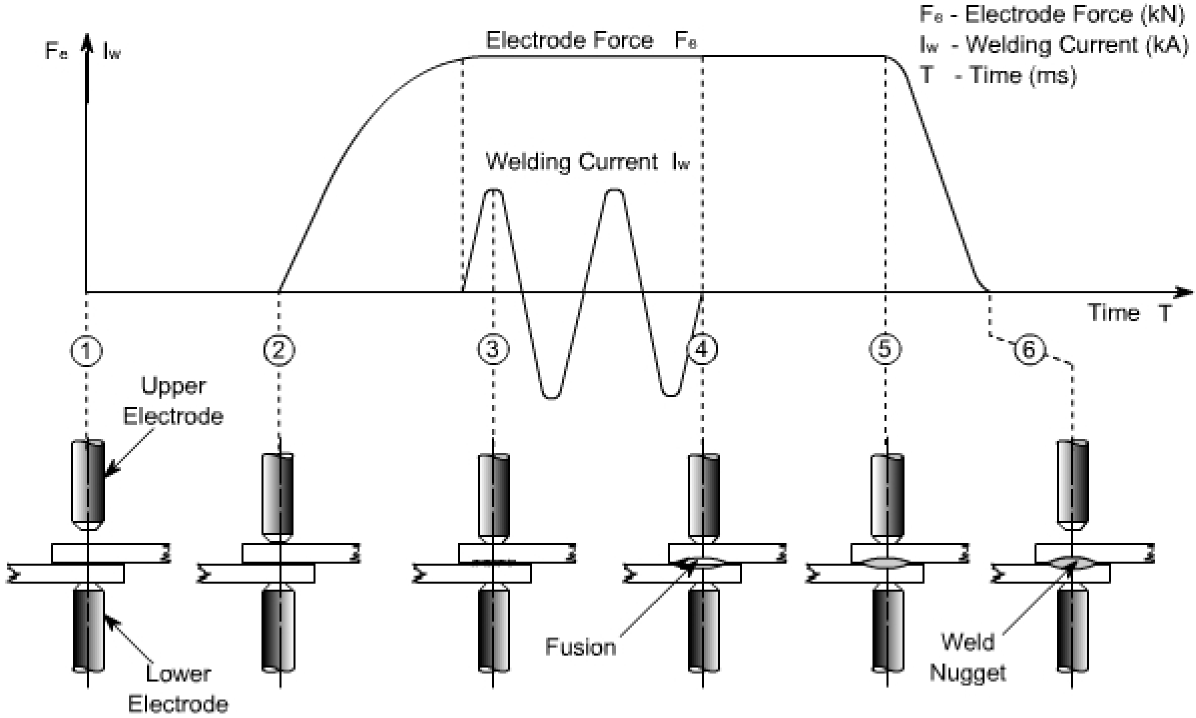

Fig 11.3: Resistance Spot Welding Cycle

Spot welding electrodes of different shapes are used. Pointed tip or truncated cones with an angle of 120° - 140° are used for ferrous metal but with continuous use they may wear at the tip. Domed electrodes are capable of withstanding heavier loads and severe heating without damage and are normally useful for welding of nonferrous metals. The radius of dome generally varies from 50-100 mm. A flat tip electrode is used where minimum indentation or invisible welds are desired.

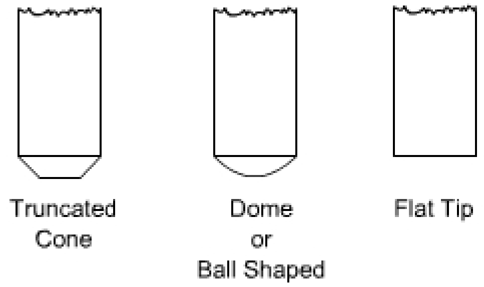

Fig 11.4: Electrode Shapes for Spot Welding

Most of the industrial metal can be welded by spot welding, however, it is applicable only for limited thickness of components. Ease of mechanism, high speed of operation and dissimilar metal combination welding, has made is widely applicable and acceptable process. It is widely being used in electronic, electrical, aircraft, automobile and home appliances industries.

2. Seam Welding:

In seam welding overlapping sheets are gripped between two wheels or roller disc electrodes and current is passed to obtain either the continuous seam i.e. overlapping weld nuggets or intermittent seam i.e. weld nuggets are equally spaced. Welding current may be continuous or in pulses. The process of welding is illustrated in Figure 11.5.

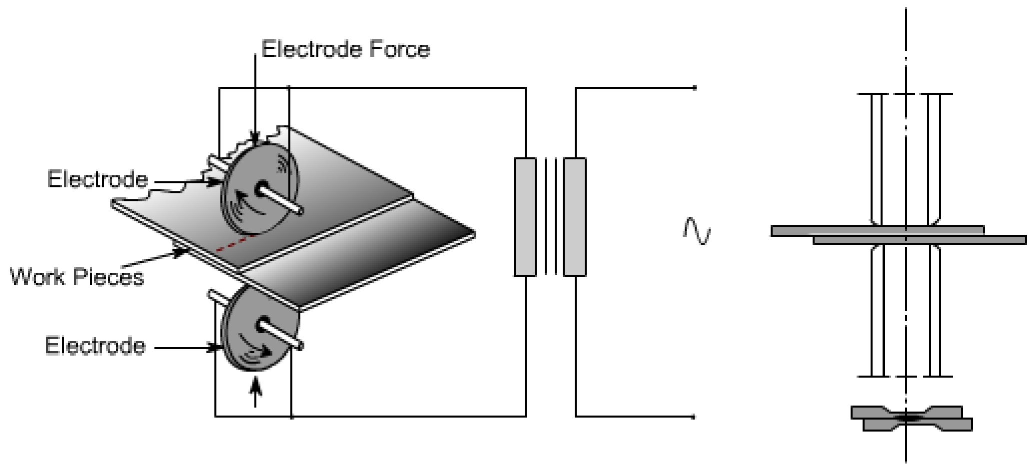

Fig 11.5: Process of Seam welding

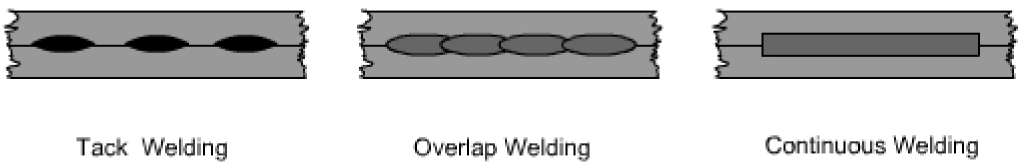

Fig 11.6: Type of Seam Welds

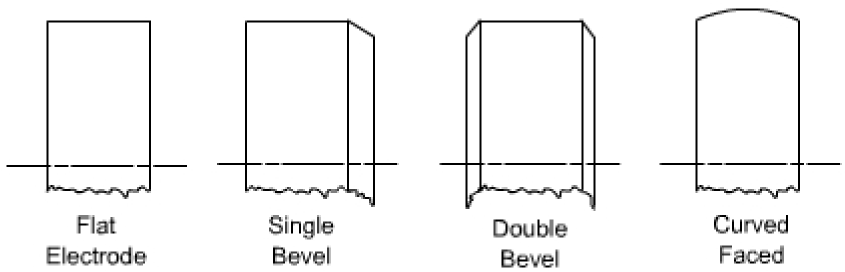

Fig 11.7: Electrode Shapes of Seam Welding

Overlapping of weld nuggets may vary from 10 to 50 %. When it is approaching around 50 % then it is termed as continuous weld. Overlap welds are used for air or water tightness.

It is the method of welding which is completely mechanized and used for making petrol tanks for automobiles, seam welded tubes, drums and other components of domestic applications.

Seam welding is relatively fast method of welding producing quality welds. However, equipment is costly and maintenance is expensive. Further, the process is limited to components of thickness less than 3 mm.

3. Projection Welding:

Projections are little projected raised points which offer resistance during passage of current and thus generating heat at those points. These projections collapse under heated conditions and pressure leading to the welding of two parts on cooling. The operation is performed on a press welding machine and components are put between water cooled copper platens under pressure. Figures 11.8 and 11.9 illustrate the principle of resistance projection welding.

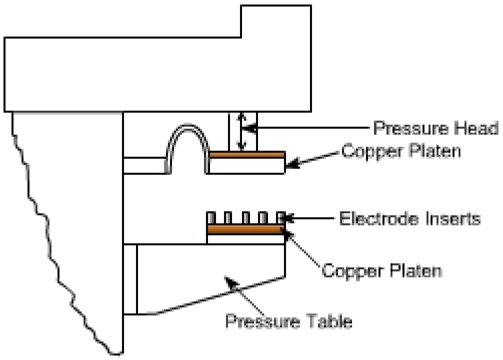

Fig 11.8: Resistance Projection Welding Machine

These projections can be generated by press working or machining on one part or by putting some external member between two parts. Members such as wire, wire ring, washer or nut can be put between two parts to generate natural projection.

Insert electrodes are used on copper platen so that with continuous use only insert electrodes are damaged and copper platen is safe. Relatively cheaper electrode inserts can be easily replaced whenever these are damaged.

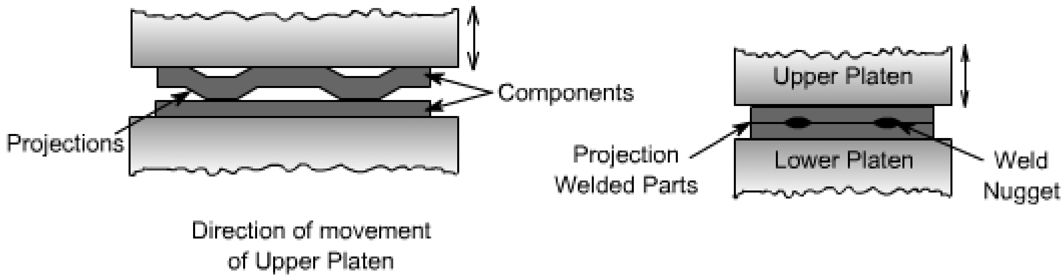

Fig 11.9: Formation of Welds from Projections on Components

Projection welding may be carried out with one projection or more than one projections simultaneously.

No consumables are required in projection welding. It is widely being used for fastening attachments like brackets and nuts etc to sheet metal which may be required in electronic, electrical and domestic equipment.

Production of seam welded Tubes:

Welded tubes are produced by resistance seam welding. Tubes are produced from strips which are wrapped on spool with trimmed edges. The width of strip should be slightly bigger than the periphery of the tube to be produced to take care for the loss of metal in flashout. The strip is fed through set of forming rollers to form first the shape of the tube and then it is passed under the seam welding rolls. Under seam welding rolls the edges are butt welded with some flash out on the joint. This flash out is trimmed and then tubes are cut to required size. The process is shown in Figures 11.10 & 11.11.

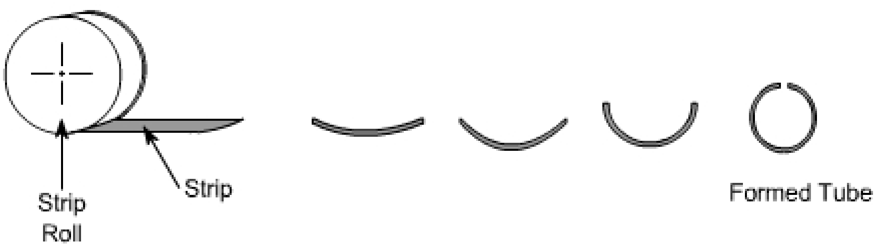

Fig 11.10: Forming of Tube from Strip

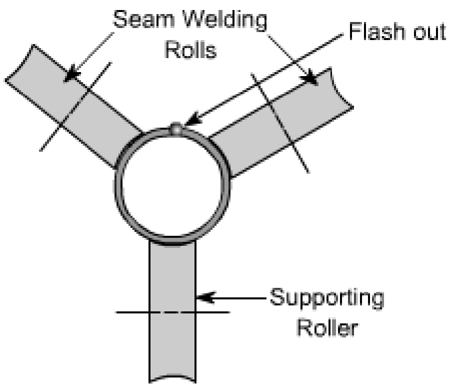

Fig 11.11: Seam Welding of Tube

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Lecture 13

Welding Defects

The defects in the weld can be defined as irregularities in the weld metal produced due to incorrect welding parameters or wrong welding procedures or wrong combination of filler metal and parent metal.

Weld defect may be in the form of variations from the intended weld bead shape, size and desired quality. Defects may be on the surface or inside the weld metal. Certain defects such as cracks are never tolerated but other defects may be acceptable within permissible limits. Welding defects may result into the failure of components under service condition, leading to serious accidents and causing the loss of property and sometimes also life.

Various welding defects can be classified into groups such as cracks, porosity, solid inclusions, lack of fusion and inadequate penetration, imperfect shape and miscellaneous defects.

1. Cracks

Cracks may be of micro or macro size and may appear in the weld metal or base metal or base metal and weld metal boundary. Different categories of cracks are longitudinal cracks, transverse cracks or radiating/star cracks and cracks in the weld crater. Cracks occur when localized stresses exceed the ultimate tensile strength of material. These stresses are developed due to shrinkage during solidification of weld metal.

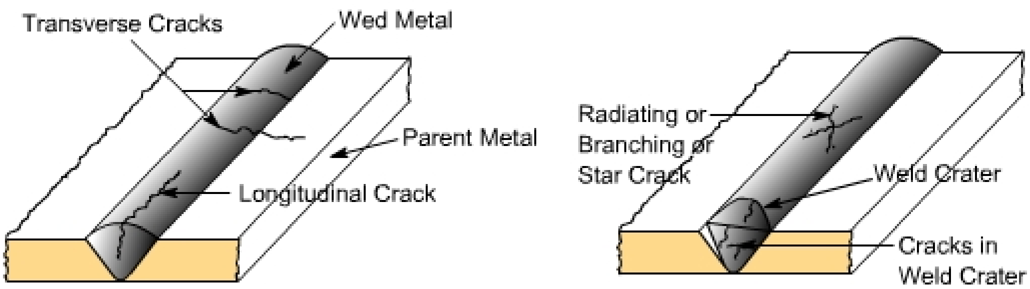


Fig 13.1: Various Types of Cracks in Welds

Cracks may be developed due to poor ductility of base metal, high sulpher and carbon contents, high arc travel speeds i.e. fast cooling rates, too concave or convex weld bead and high hydrogen contents in the weld metal.

2. Porosity

Porosity results when the gases are entrapped in the solidifying weld metal. These gases are generated from the flux or coating constituents of the electrode or shielding gases used during welding or from absorbed moisture in the coating. Rust, dust, oil and grease present on the surface of work pieces or on electrodes are also source of gases during welding. Porosity may be easily prevented if work pieces are properly cleaned from rust, dust, oil and grease.Futher, porosity can also be controlled if excessively high welding currents, faster welding speeds and long arc lengths are avoided flux and coated electrodes are properly baked.

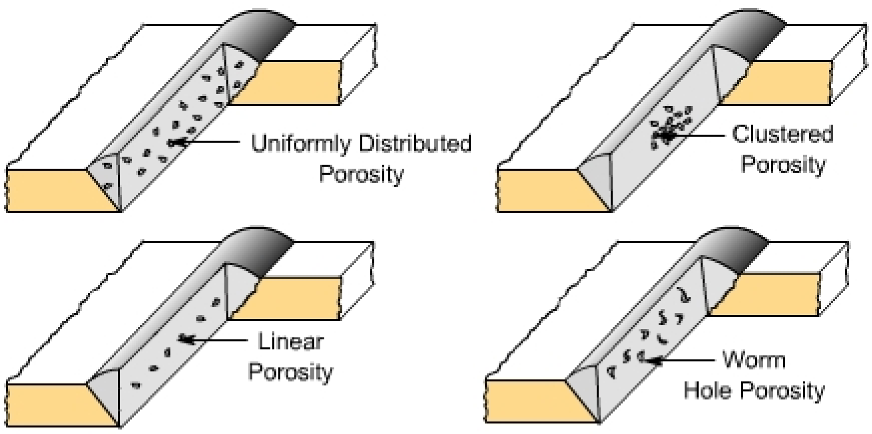


Fig 13.2: Different Forms of Porosities

3. Solid Inclusion

Solid inclusions may be in the form of slag or any other nonmetallic material entrapped in the weld metal as these may not able to float on the surface of the solidifying weld metal. During arc welding flux either in the form of granules or coating after melting, reacts with the molten weld metal removing oxides and other impurities in the form of slag and it floats on the surface of weld metal due to its low density. However, if the molten weld metal has high viscosity or too low temperature or cools rapidly then the slag may not be released from the weld pool and may cause inclusion.

Slag inclusion can be prevented if proper groove is selected, all the slag from the previously deposited bead is removed, too high or too low welding currents and long arcs are avoided.

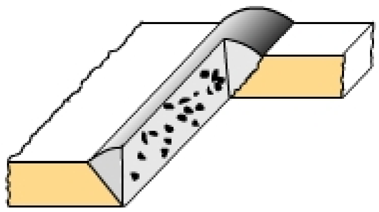


Fig 13.3: Slag Inclusion in Weldments

4. Lack of Fusion and Inadequate or incomplete penetration:

Lack of fusion is the failure to fuse together either the base metal and weld metal or subsequent beads in multipass welding because of failure to raise the temperature of base metal or previously deposited weld layer to melting point during welding. Lack of fusion can be avoided by properly cleaning of surfaces to be welded, selecting proper current, proper welding technique and correct size of electrode.

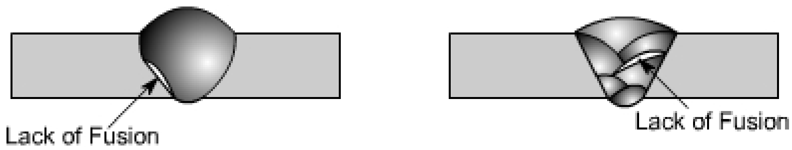


Fig 13.4: Types of Lack of Fusion

Incomplete penetration means that the weld depth is not upto the desired level or root faces have not reached to melting point in a groove joint. If either low currents or larger arc lengths or large root face or small root gap or too narrow groove angles are used then it results into poor penetration.

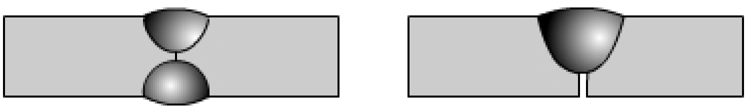


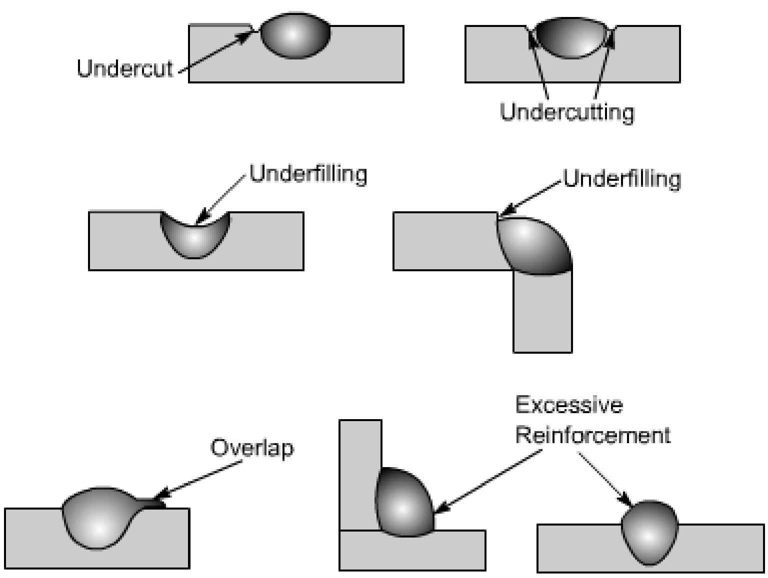
Fig 13.5: Examples of Inadequate Penetration

5. Imperfect Shape

Imperfect shape means the variation from the desired shape and size of the weld bead.

During undercutting a notch is formed either on one side of the weld bead or both sides in which stresses tend to concentrate and it can result in the early failure of the joint. Main reasons for undercutting are the excessive welding currents, long arc lengths and fast travel speeds.

Underfilling may be due to low currents, fast travel speeds and small size of electrodes. Overlap may occur due to low currents, longer arc lengths and slower welding speeds.



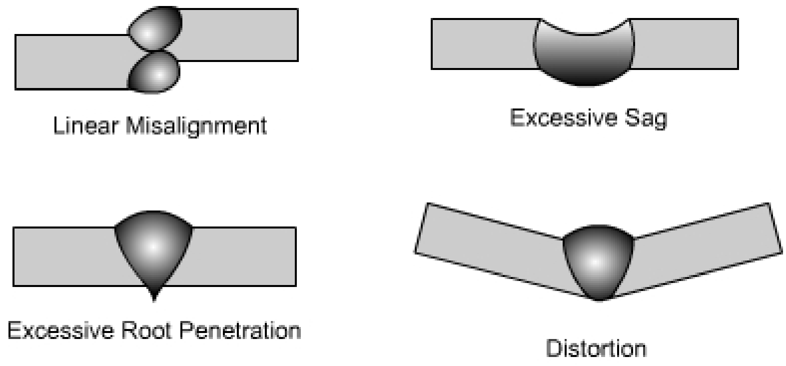


Fig 13.6: Various Imperfect Shapes of Welds

Excessive reinforcement is formed if high currents, low voltages, slow travel speeds and large size electrodes are used. Excessive root penetration and sag occur if excessive high currents and slow travel speeds are used for relatively thinner members.

Distortion is caused because of shrinkage occurring due to large heat input during welding.

6. Miscellaneous Defects

Various miscellaneous defects may be multiple arc strikes i.e. several arc strikes are one behind the other, spatter, grinding and chipping marks, tack weld defects, oxidized surface in the region of weld, unremoved slag and misalignment of weld beads if welded from both sides in butt welds.

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