Lectures notes

On

MANUFACTURING SCIENCE AND TECHNOLOGY

Prepared by

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SUB:- MANUFACTURING SCIENCE & TECHNOLOGY-I

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(Mechanical Engineering)

Module-I

Introduction

Improved civilization is due to improved quality of products, proper selection of design as well as manufacturing process from raw materials to finished goods.

Classification of manufacturing processes:-

(a) Casting
(b) Forming
(c) Fabrication
(d) Material Removal

Metal Casting Process:-

Metal Casting is one of the oldest materials shaping methods known. Casting means pouring molten metal into a mould 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 mould either by breaking the mould or taking the mould apart. The solidified object is called the casting. The process is also called foundry.

Advantages:-

- Any intricate shape can be produced.
- Possible to cast both ferrous and non ferrous materials
- Tools are very simple and expensive
- Useful for small lot production
- Weight reduction in design
- No directional property

Limitations:-

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

Application:-

Cylindrical bocks, wheels, housings, pipes, bells, pistons, piston rings, machine tool beds etc.

Casting terms:-

Flask- It holds the sand mould intact. It is made up of wood for temporary application and metal for long term use.

Drag- Lower moulding flask

Cope – Upper moulding flask

Cheek – Intermediate moulding flask used in three piece moulding.

Pattern - Replica of final object to be made with some modifications. Mould cavity is made with the help of pattern.

Parting line – Dividing line between two moulding flasks.

Bottom board – Board used to start mould making (wood)

Facing sand - Small amount of carboneous material sprinkled on the inner surface of the mould cavity to give better surface finish to casting.

Moulding sand – Freshly prepared refractory material used for making the mould cavity. (Mixture of silica, clay & moisture)

Backing sand – used and burnt sand

Core – Used for making hollow cavities in the casting

Pouring basin – Funnel shaped cavity on the top of the mould into which molten metal is poured

Sprue – Passage from pouring basin to the mould cavity. It controls the flow of molten metal into the mould.

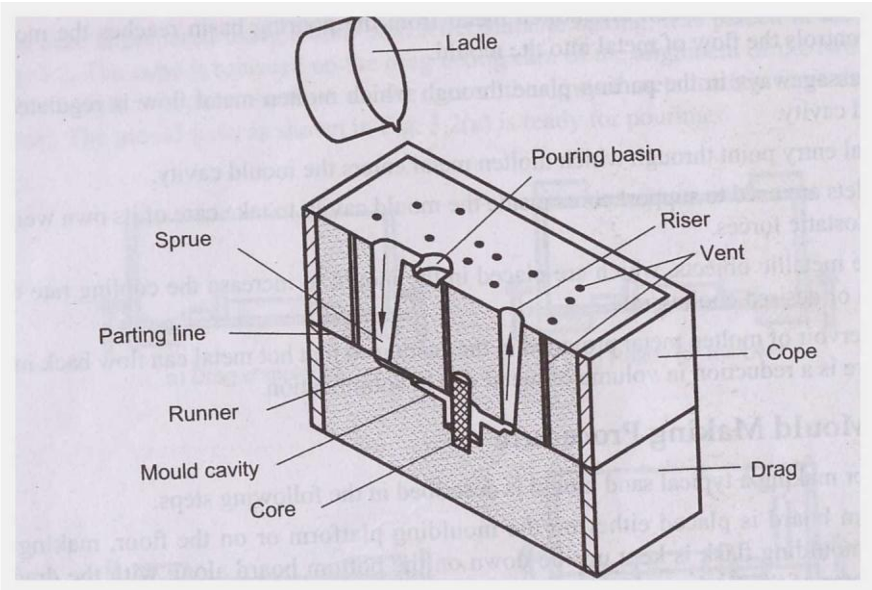


Figure 1 Cross-section of a sand mould ready for pouring

Runner – Passage ways in the parting plane through which molten metal flow is regulated before they reach the mould cavity

Gate – Actual entry point through which molten metal enters the mould cavity

Chaplet – Used to support the core to take of its own weight to overcome the metallostatic force.

Chill – Metallic objects to increase cooling rate of casting

Riser – Reservoir of molten metal in the casting so that hot metal can flow back into the mould cavity when there is a reduction in volume of metal due to solidification.

<u>Sand mould making procedure:-</u>

The first step in making mould is to place the pattern on the moulding board. The drag is placed on the board (figure 2 (a)). Dry facing sand is sprinkled over the board and pattern to provide a non sticky layer. Moulding 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 levelled 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 2 (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 mould cavity and runners which would give the finished casting a good surface finish. The mould is now assembled. The mould now is ready for pouring (Figure 2 (c)).

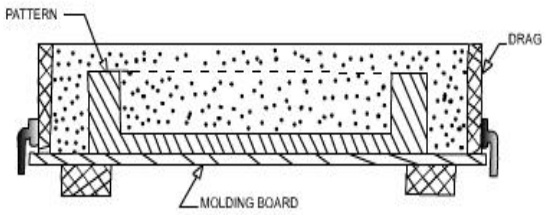


Figure 2 (a)

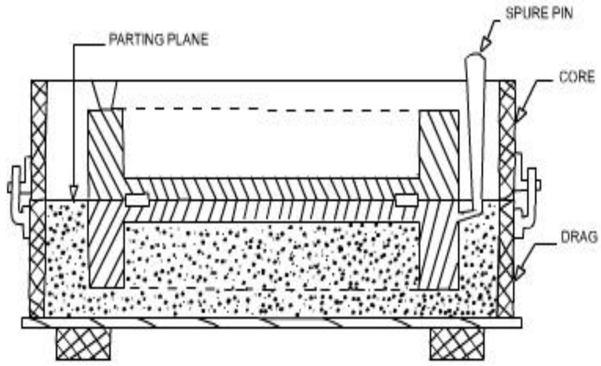


Figure 2 (b)

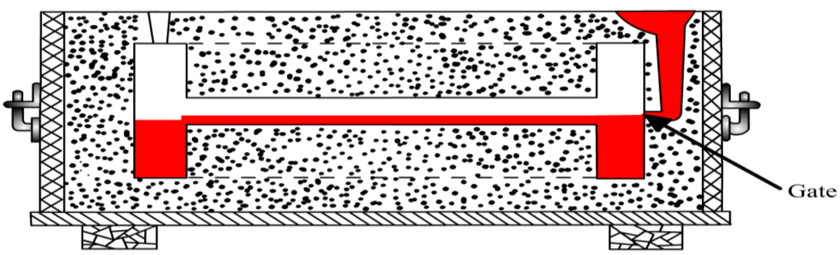


Figure 2 (c)

Pattern:-

Replica of the object to be made by the casting process with some modifications.

Modifications-

(a) Addition of pattern allowance
(b) Provision of core prints
(c) Elimination of fine details

(A) Pattern Allowances-

Pattern dimensions are different from final dimension of casting.

Shrinkage

All metals shrink when cooling except bismuth. This may be due to inter atomic vibrations amplified by increase in temperature.

Two types:-

Liquid shrinkage – Reduction in volume when metal changes from liquid to solid at solidus temperature.

Solid shrinkage – Reduction in volume when a metal loses temperature in solid state.

Actual value of shrinkage depends on

- Composition of alloy cast
- Mould materials used
- Mould design
- Complexity of pattern
- Component size

Metallic pattern casting – double shrinkage

***Finish/ machining allowance* –**

Extra material provided which is to be machined or cleaned for good surface finish and dimensional accuracy. It depends on

- type of casting material
- dimensions
- finishing required
- complexity of surface details

Range – 2 to 20 mm

To reduce the machining allowance, the entire casting should be kept in the drag flask such that dimensional variation and other defects due to parting plane can be reduced.

Draft –

Vertical faces of the pattern are to be made tapered to reduce the chances of damage to the mould cavity. It varies with the complexity of the job. Inner details require more allowance than outer. This allowance is more for hand moulding than machine moulding.

Shake allowance –

This is a negative allowance. Applied to those dimensions which are parallel to parting plane.

Distortion allowance –

Metals just solidified are very weak, which may be distorted. This allowance is given to the weaker sections like long flat portion, U & V sections, complicated casing, thin & long sections connected to thick sections. This is a trial and error method.

(B) Core prints:-

Core prints are required for casting where coring is required.

(C) Elimination of fine details:-

Type of details to be eliminated depends on

- Required accuracy
- Capability of the chosen casting process
- Moulding method employed

Pattern Materials:-

Usual materials – wood, metals & plastics

Wood-

Adv:-

Easy availability
Low weight
Easily shaped
Cheap

Disadv:-

Moisture absorption
Distortion
Dimensional change

Care to be taken – seasoning
Example – Pine, Teak, Deodar
Others – plywood boards and particle boards
Reason – Availability in various thicknesses
Higher strength
No need for seasoning
Use – Used for flat type and no three dimensional contour shapes
Large scale casting
Choice of pattern materials depends on

- Size of casting
- No. of castings to be made from pattern
- Dimensional accuracy required

Metals:-

Advantages- Durability
Smooth surface finish
Light weight
Easily worked
Corrosion resistant

Use - For large scale casting production
Closer dimensional tolerance

Plastics :-

Advantages - Low weight
Easier formability
Smooth surface, durability
Do not absorb moisture
Dimensionally stable
Can be easily cleaned

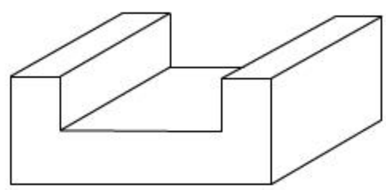
Example – Cold setting epoxy resin with filler
Polyurethane foam – Light weight
Easily formed into any shape
Used for light duty work for small no of casting
For conventional casting
For single casting

Plastics have low ash content and it can be burned inside the mould.

<u>TYPES OF PATTERNS:-</u>

Various types of patterns depends on
- Complexity of the job
- No of castings required
- Moulding procedure adopted

(a) ***Single piece pattern –*** Inexpensive and simplest one
Single piece
Simple job
Useful for Small scale production
Pattern will be entirely in the drag
One surface is flat and at the parting line
Used for very small scale production



(Figure 3)

(b) ***Split or two piece pattern –*** Used for intricate casting
Split along the parting line
Used where depth of job is too high
Aligned with dowel pins fitted to cope

(c) ***Gated pattern –*** Gating and runner system are integrated with the pattern
Improves productivity

(d) ***Cope and drag pattern -*** Similar to split pattern
For cope and drag, separately attached gating system to metal plate
Heavy and inconvenient for handling
Useful for Continuous production

(e) ***Match plate pattern –*** Similar to cope and drag patterns with gating and risering system mounted on a single matching plate
Pattern and match plate are made up of metal (Al)
Useful for small casting with high dimensional accuracy
Suitable for large scale production
Gating system is attached to the match plate
Expensive

(f) ***Loose piece pattern –*** Withdrawing of the pattern from the mould is difficult
Useful for highly skilled job
Expensive

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

(h) ***Sweep pattern –*** Useful for axi-symmetrical and prismatic shape
Suitable for large scale production

(i) ***Skeleton pattern –*** Stripes of wood are used for building final pattern
Suitable for large casting

<u>MOULDING MATERIALS</u>

Different types of moulding materials are

-moulding sand
-system sand (backing sand)
-rebonded sand
-facing sand
-parting sand
-core sand

Choice of moulding materials depends on processing properties.

Properties_-

1) Refractoriness- Ability to withstand high temperature of molten metal so that it does not cause fusion
   Refractory materials - silica, zirconia, alumina
2) Green strength- Moulding sand containing moisture is known as green sand. The strength of the green sand is known as green strength.
3) Dry strength- When moisture is completely expelled from the moulding sand, it is known as dry sand and the strength of the sand is the dry strength.
4) Hot strength- After moisture elimination, the sand is exposed to higher temperature of molten material. Strength of sand to hold the shape of mould cavity at this higher temperature is known as hot strength.
5) Permeability – Moulding sand is porous, so it escapes gases through it. This gas evolution capability of moulding sand is known as permeability.

Other properties include collapsibility, reusable, good thermal conductivity etc.

MOULDING SAND COMPOSITION-

Main ingredients of moulding sand are silica grain (SiO_2), Clay (binder) and moisture (to activate clay and provide plasticity)

(a) Silica sand- this is the major portion of the moulding sand. About 96% of this sand is silica grain. Rests are oxides (Al_2O_3), sodium (Na_2O +K_2O) and magnesium oxide (MgO +CaO). Main source of silica sand is river sand (with /without washing). Fusion point of sand is 1450^0C for cast iron and 1550^0C for steels. Grain size varies from micrometer to millimetre. The shape of the grains may be round, angular, sub angular or very angular.

(b) Zircon sand- The main composition is zirconium silicate ($ZrSiO_2$).

Composition- ZrO_2- 66.25%
SiO_2-30.96%
Al_2O_3-1.92%
Fe_2O_3-0.74%
Other - oxides

It is very expensive. In India, it is available at quilon beach, kerela. The fusion point of the sand is 2400^oC.

Advantage - High thermal conductivity
High chilling power
High density
Requires very small amount of binder (3%)

Use - Precision steel casting
Precision investment casting

(c) Chromite sand – The sand is crushed from the chrome ore. The fusion point of the sand is 1800^0C. It requires very small amount of binder (3%).

Composition- Cr_2O_3- 44%
Fe_2O_3 -28%
SiO_2 -2.5%
CaO -0.5%
Al_2O_3 +MgO -25%

Use – heavy steel castings
Austenitic manganese steel castings

(d) Olivine sand- This sand composed of the minerals of fosterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). It is versatile in nature.

CLAY :–

Clay is a binding agent mixed to the moulding sand to provide strength. Popular types of clay used are kaolinite or fire clay (Al_2O_3.2 SiO_2.2H_2O) and Bentonite (Al_2O_3.4 SiO_2.H_2O nH_2O). Kaolinite has a melting point from 1750 to 1787^0C where as Bentonite has a melting temperature range of 1250 to 1300^0C. Bentonite clay absorbs more water and has increased bonding power. To reduce refractoriness, extra mixtures like lime, alkalis and other oxides are added.

Bentonite is further of two types. (a) Western bentonite and (b) southern bentonite

Western bentonite – It is rich with sodium ion
It has better swelling properties
When it mixes with sand, the volume increases 10 to 20 times.
High dry strength, so lower risk of erosion
Better tolerance of variation in water content
Low green strength
High resistance to burn out

Southern Bentonite - It is rich with calcium ion
It has low dry strength and high green strength
Its properties can be improved by treating it with soda ash (sodium carbonate)

Water:- Used to activate the clay
Generally 2 to 8% of water is required

Other materials added:- Cereal binder – (2%) – to increase the strength
Pitch (by product of coke) – (3%) – to improve hot strength
Saw dust (2%) – To increase permeability

Testing sand properties:-

Sample preparation can be done by mixing various ingredients like sand, clay and moisture.

During mixing, the lump present in sand should be broken up properly. The clay should be uniformly enveloped and the moisture should be uniformly distributed.

The equipment used for preparation of moulding sand is known as Mueller. This is of two types.

(i) Batch Mueller- Consists of one/two wheels and equal no. of blades connected to a single driving source. The wheels are large and heavy.
(ii) Continuous Mueller- In this type, there are two bowls with wheel and ploughs. The mixture is fed through hopper in one bowl. After muelled, it is moved to another bowl. This type of Mueller is suitable for large scale production.

Moisture content:-

1st method - 50g of moulding sand sample is dried at 105^0C to 110^0C for 2hrs. The sample is then weighed.

Wt. diff * 2= % of moisture content

2nd method - Moisture teller can be used for measuring moisture content.

The Sand is dried suspending sample on fine metallic screen allowing hot air to flow through sample. This method takes less time in comparison to the previous one.

3rd method - A measured amount of calcium carbide along with moulding sand in a separate cap is kept in the moisture teller. Both should not come in contact with each other. Apparatus should be shaken vigorously such that the following reaction takes place.

$$CaC_2 + 2H_2O – C_2H_2 + Ca(OH)_2$$

The acetylene coming out will be collected in space above the sand raising the pressure. A pressure gauge connected to the apparatus would give directly the amount of acetylene generated, which is proportional to the moisture present.

Clay content:-

A 50g of sand sample is dried at 105^0C to 110^0C and is taken in a 1lt. glass flask. 475ml distilled water and 25ml of a 1% solution of caustic soda (NaOH 25g/l) is added to it. The sample is thoroughly stirred (5 mins). The sample is then diluted with fresh water upto 150 mm mark and then left undisturbed for 10mins to settle. The sand settles at bottom and the clay floats. 125mm of this water is siphoned off and again topped to the same level. The process is repeated till water above the sand becomes clear. Then the sand is removed and dried by heating. The difference in weight multiplied by 2 will give the clay % of sand.

Sand grain size:-

For sand grain size measurement, the moulding sand sample should be free from moisture and clay. The dried clay free sand grains are place on the top sieve of sieve shaker (gradually decreasing mesh size). The sieves are shaken continuously for 15 mins. After this the sieves are taken apart and the sand over each sieve is weighed. The amount retained on each sieve is multiplied by the respective weightage factor, summed up and then divided by the total mass f the sample which gives the grain fineness number.

$$GFN= \Sigma Mi\ fi/ \Sigma fi$$

Mi= multiplying factor for the i^{th} sieve

Fi= amount of sand retained on the i^{th} sieve

Permeability:-

Rate of flow of air passing through a standard specimen under a standard pressure is known as permeability number.

$$P = V\ H / p\ A\ T$$

V= volume of air= 2000cm^3

H= height of sand specimen= 5.08cm

P= air pressure, 980Pa (10g/cm^2)

A= cross sectional area of sand specimen= 20.268 cm^2

T= time in min. for the complete air to pass through

Inserting the above standard values in the expression we get, P= 501.28/ P.T

Permeability test is conducted for two types of sands

(a) Green permeability – permeability of green sand

(b) Dry permeability – permeability of the moulding sand dried at 105^0C to 110^0C to remove the moisture completely

Strength:-

Measurement of strength of moulding sand is carried out on the universal sand- strength testing M/C. The strength can be measured in compression, shear & tension. The types of sand that can be tested are green, dry, core sands.

Green compressive strength:-

Stress required to rupture the sand specimen under compressive loading refers to the green compressive strength. It is generally in the range of 30 to 160KPa.

Green shear strength:-

The stress required to shear the specimen along the axis is represented as green shear strength. The range is 10 to 50 KPa.

Dry strength:-

The test is carried out with a standard specimen dried between 105 to 110°C for 2 hours. The range found is from 140 to 1800KPa.

Mould hardness:-

A spring loaded steel ball (0.9kg) is indented into standard sand specimen prepared. If no penetration occurs, then the hardness will be 100. And when it sinks completely, the hardness will be 0 indicating a very soft mould.

Moulding sand properties:-

The properties of moulding sand depends upon the variables like –

- sand grain shape and size
- Clay types and amount
- moisture content
- method of preparing sand mould

Sand grains:-

The grain shape could be round or angular. Angular sand grains require high amount of binder, where as round sand grains have low permeability.

Similarly the grain size could be of coarse or fine. Coarse grains have more void space which increases the permeability. Fine grains have low permeability, but provide better surface finish to the casting produced. The higher the grain size of the sand, higher will be the refractoriness.

Clay and water:-

Optimum amount water is used for a clay content to obtain maximum green strength. During sand preparation, clay is uniformly coated around sand grains. Water reacts with the clay to form a linkage of silica - water – clay- water- silica throughout the moulding sand. Amount of water required depends on the type and amount of clay present. Additional water increases the plasticity and dry strength, but decreases the green strength. There is a maximum limit of green compression strength. This type of sand is known as clay saturated sand and used for cast iron and heavy non ferrous metal casting. This type of sand reduces some of the casting defects like erosion, sand expansion, cuts & washes. These sands have green compression strength in a range of 100 to 250 KPa.

CORES:-

Cores are used for making cavities and hollow portions. These are made up of sand and are used in permanent moulds. Core are surrounded by molten metal and therefore subjected to thermal and mechanical conditions. So the core should be stronger than the moulding sand.

Desired characteristics of a core:-

(1) Dry strength- It should be able to resist the metal pressure acting on it.
(2) Green strength- It should be strong enough to retain its shape.
(3) Refractoriness- Core material should have higher refractoriness.
(4) Permeability- Core materials should have high permeability.
(5) Collapsibility- (ability to decrease in size). It is likely to provide resistance against shrinkage.
(6) Friability- Ability to crumble
(7) Smoothness- good finish to the casting
(8) Low gas emission- minimum

Core sand:-

The core sand should contain grains, binders and additives.

Sand- The silica sand without clay is used as a core sand material. Coarse silica is used in steel foundries where as fine silica is used for cast iron and non ferrous alloys.

Binders:- The normal binders used are organic in nature, because this will burnt away by the heat of molten metal and make the core collapsible during cooling. The binders generally used are linseed oil, core oil, resins, dextrin, molasses etc. Core oils are the mixture of linseed, soy, fish, petroleum oils and coal tar.

Types of cores:-

Two types:-

(a) Green sand core:- This is obtained by the pattern itself during moulding. Green sand has low strength, so is not suitable for deep holes.

(b) Dry sand core:- This is made with special core sands in separate core box, baked & placed in mould. Different types of dry sand cores are
-Unbalanced core -cover core -drop core
-balanced core -vertical core

Core prints:-

Core prints are used to position the core securely and correctly in mould cavity. It should take care of the weight of the core and upward metallostatic pressure of molten metal.

Gating System For Casting

Gating system:- It refers to all those elements connected with the flow of molten metal from ladle to mould cavity.
Various elements:-

- pouring basin
- sprue
- sprue base well
- Runner runner extension
- Ingate
- Riser

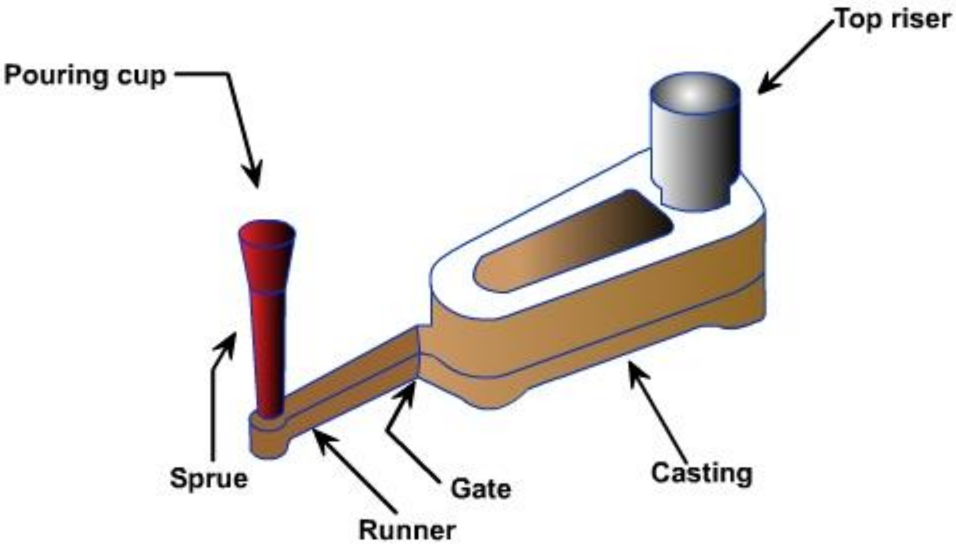


Figure 4 Typical gating system

Requirements for defect free casting :-

- Mould should be filled in smallest time
- Metal should flow without turbulence
- Unwanted material should not enter into the cavity
- Atmospheric air should be prevented
- Proper thermal gradient should be maintained
- No gating or mould erosion should take place
- Enough metal should be there inside the mould cavity
- Economical
- Casting yield should be maximized

Elements

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

Function:-This will reduce the momentum of liquid flowing into mould

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

Sprue:-

It is a channel through which molten metal is pours into the parting plane where it enters into the runner and gates to reach the mould cavity. When molten metal is moving from top to the cope, it gains velocity and requires a smaller amount of area of cross-section for the same amount of metal to flow. If the sprue is straight and cylindrical, then a low pressure area will be created at the bottom of the sprue. Since the sand is permeable, it will aspire atmospheric air into the mould cavity causing defects in the casting. That is why the sprue is generally made tapered to gradually reduce the cross-section.

Exact tapering can be obtained by equation of continuity

$A_tV_t= A_cV_c$ t denotes top section

$\Rightarrow A_t = Ac \frac{Vc}{Vt}$ c denotes choke section

By Bernoulli's equation

$A_t = Ac \sqrt{\frac{hc}{ht}}$ velocity α $(\text{potential head})^2$

The profile of the sprue should be parabolic. Metal at entry of the sprue is moving with a velocity of

$V=\sqrt{2gh}$. Hence $A_t = Ac \sqrt{\frac{ht}{h}}$

H= actual sprue height

$h_t = h + H$

<u>Sprue Base Well</u> :-

This is the reservoir for the metal at the bottom of sprue to reduce the momentum of the molten metal. Sprue base well area should be 5 times the sprue choke area and well depth should be approximately equal to that of the runner.

Runner:-

It is located at the parting plane which connects the sprue to its ingates. It traps the slag & dross from moving into the mould cavity. This is normally made trapezoidal in cross section. For ferrous metals, the runners should be kept in cope and ingates in drag.

Runner extension:-
This is provided to trap the slag in the molten metal.

GATES/ IN-GATES:-

These are the opening through which molten metal enters into the mould cavity. Depending on the application, the various types of gates are

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

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

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

Step gate:- These types of gates are used for heavy and large casting. The molten metal enters into the mould cavity through a number of ingates arranged in vertical steps. The size of ingates are increased from top to bottom ensuring a gradual filling of mould cavity.

RISER:-

Most alloys shrink during solidification. As a result of this volumetric shrinkage, voids are formed which are known as hot spots. So a reservoir of molten metal is maintained from which the metal can flow steadily into the casting. These reservoirs are known as risers.
Design considerations:- The metal in riser should solidify at the end and the riser volume should be sufficient for compensating the shrinkage in the casting. To solve this problem, the riser should have highervolume.
Types:-

(a) top riser- This type of riser is open to the atmosphere. It is very conventional & convenient to make. It looses heat to the atmosphere by radiation & convention. To reduce this, insulation is provided on top such as plaster of paris and asbestos sheets.
(b) blind riser :- This type of riser is surrounded by the moulding sand and looses heat very slowly.

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

Chill:- Metallic chills are used to provide progressive solidification or to avoid the shrinkage cavities. These are large heat sinks. Use of chill will form a hard spots, which needs further machining.

GATING SYSTEM DESIGN:-

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

$$h + \frac{P}{W} + \frac{V2}{2g} = \text{constant (ignore frictional losses)}$$

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

According to the Law of continuity, the volume of metal flow at any section is constant.

$$Q= A_1V_1 = A_2V_2$$

Q= rate of flow, m^3/s
A = Area, m^2
V = Velocity, m/s

Pouring time:-

It is the time required for complete filing of mould cavity. If it is too long, then it requires a higher pouring temp. and if is too short, there will be turbulent flow, which will cause defective casting. So the pouring time depends on casting material, complexity of casting, section thickness and casting size. Ferrous material requires less pouring time where as non-Ferrous materials require higher pouring time.

Some Standard methods for pouring time :-

(1) Grey cast iron, mass< 450 kg

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

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

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

(2) Grey cast iron, mass> 450 kg

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

(3) Steel casting

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

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

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

K_1 = 2.080 for thin section

= 2.670 for 10 – 25 mm thick sections

= 2.970 for heavier section

(5) Cu alloy castings

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

K_2 = constant given by

Top gating – 1. 30

Bottom gating – 1.80

Brass – 1.90

Tin bronze – 2.80

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

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

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

K_3 = constant

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

(7) Above 450 kg &upto 1000 kg

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

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

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

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

<u>Choke area</u>:-

The control area which meters the metal flow into the mould cavity so that the mould is completely filled up within the calculated pouring time is known as choke area. It is mainly considered at the bottom of the sprue.

The choke area by using Bernoulli’s equation,

$$A = \frac{1}{dtC\sqrt{2gH}}$$

A = choke area

W = casting mass, kg

t = Pouring time, s

d = mass density of molten metal, kg/mm^3

g = acceleration due to gravity, mm/s^2

H = sprue height, mm

C = efficiency factor

The effective sprue height, H depends on type of gating system.

Top gate, $H = h$ Bottom, $H = h - \frac{C}{2}$ Parting, $H = h - \frac{P^2}{2C}$

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

$$C = \frac{1}{\sqrt{1+K_1\frac{A^2}{A_1^2}+K_2\frac{A^2}{A_2^2}+-----}}$$

K_1, K_2 = loss coeff. – at changes of direction
A_1, A_2 = area down the stream from changes
A = choke area

Gating ratios:-
The gating ratios refers to the proportion of the cross-sectional areas between sprue, runner and ingate.

There can be Two types of gating system.

(a) Non pressurized gating system:-

This has a choke at bottom of the sprue having total runner area and in gates area >sprue area. This reduces the turbulence. This is useful for Al and Mg alloys. These have tapered sprue, sprue base well and pouring basin.

Sprue : runner : ingate :: 1:4:4

Disadvantages :-
- -Air inspiration
- -casting yield- less

(b) Pressurized gating system:-

In this type, the in gate areas are smallest, thus maintaining a back pressure. Beacause of this, the metal is more turbulent and flows full with a minimum air aspiration. This has a higher casting yield. Mostly useful for ferrous castings.

Sprue : runner : ingate :: 1:2:1

SLAG TRAP SYSTEM:-

Runner extension:- This is a blind alley ahead the gates. The clean metal will go into the mould after filling up the runner extension in which the slags and dross will be remained. This should be twice the runner width.

Whirl gate:-
It utilizes the principle of centrifugal action to throw the dense metal to the periphery and retain the lighter slag at the centre. The entry area should be 1.5 times the exit area.

Melting & casting Quality

Melting is a major factor which controls the quality of casting. The different methods for melting foundry alloys are pit furnace, open hearth furnace, rotary furnace and cupola furnace etc. The choice of furnace depends amount & type of alloy.

CUPOLA:-
It consists of a cylindrical steel shell with its interior lined with heat resisting fire bricks. There is a drop door at the bottom after closing which proper sand bed could be prepared. This sand bed provides proper refractory bottom for molten metal & coke. Above the sand bed, there is a metal tapping hole which will be initially closed with clay known as "bot". Opposite & above the metal tapping hole, there is a slag hole where slag is trapped. Above the slag hole, there is a wind box which is connected to air blowers. Air enters to the cupola through the tuyeres. Above the charging platform, there is a charging hole through which charge is put into the cupola. The charge consists of the pig iron, scrap iron, coke and fluxes.

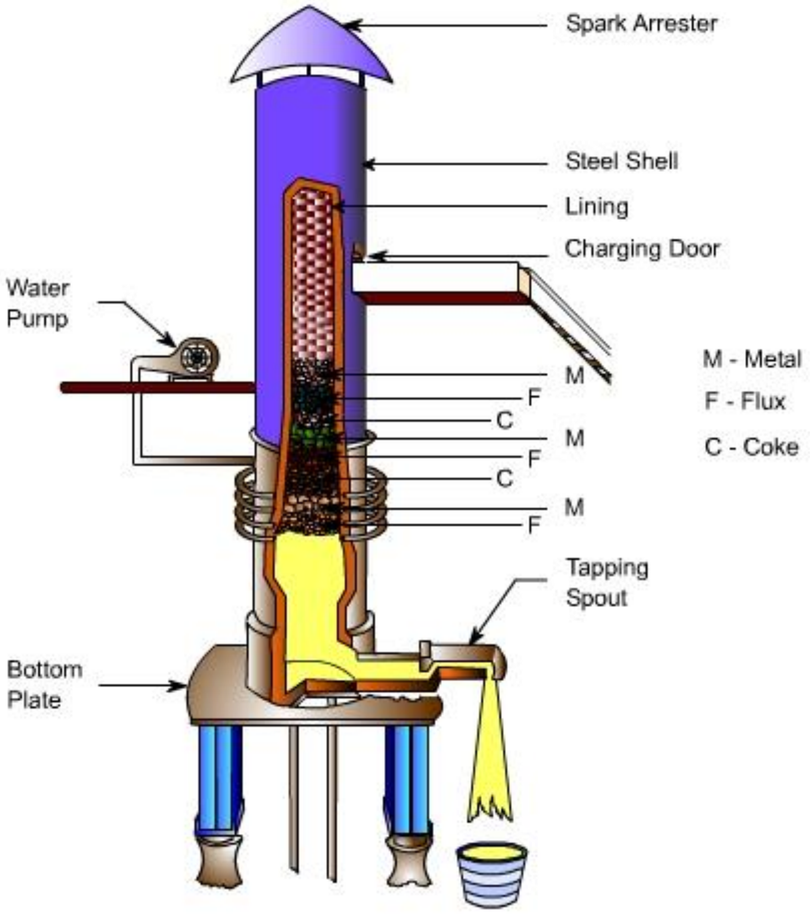


Figure 5 Schematic diagram of a cupola

Operation:-

First the drop door at the bottom is closed. Sand bed with slope towards tap hole is rammed. Coke bed of suitable height is prepared above the sand bed and is ignited through the tap hole. After proper ignition, alternate layers of charge, flux & coke are fed through the charge door. Then the charge is allowed to soak in the heat and the air blast is turned on. Within 5 to 10mins, the molten metal is collected through the tap hole. When enough metal is collected in the well of the cupola, the slag is drained off through the slag hole. Then the molten metal is collected in the ladles and is transported to the moulds with a minimum time loss.

Fluxes are added in the charge to remove the oxides & other impurities present in the metal. The flux commonly used is lime stone ($CaCO_3$) in a proportion of 2 to 4% of the metal charge. Others fluxes used are dolomite, sodium carbonate, calcium carbide. Flux reacts with oxides to form compounds having low melting point and lighter so that it will float on the metal pool.

Charge calculations:-

Carbon:- When charge comes through the coke bed, some amount of carbon is picked up by the metal depending on the temperature and the time when the metal is in contact with the coke. It is of the order of 0.15% carbon.

Silicon:- It is Oxidised in the cupola and there will be a loss of 10% silicon. It may be as high as 30%. To increase the silicon content, ferrosilicon is added to the metal.

Manganese:- There is a loss of 15 to 20% manganese during melting process. The content of manganese can be increased by the addition of ferromanganese.

Sulphur- There will a sulphur pick up in a range of 0.03 to 0.05%.

Other furnaces:

Other furnaces include

- Open hearth furnace
- Rotary furnace
- Crucible furnace
- Immersion heated furnace

Based on the source of heating, they can be classified as

- Electrical heating furnace (arc, resistance or induction)
- Fossil full fired furnace (solid, oil/gaseous fuel)

ELECTRIC ARC FURNACE:

For heavy steel castings, the open hearth type furnace with electric arc/oil fired would be suitable. These furnaces are suitable for ferrous materials. It consists of a bowl shaped bottom known as hearth lined with refractory bricks and granular refractory material. Heat is directly transferred to the charge by electric arc from the electrodes. Tilting mechanism forward is used for metal tapping and backward is for deslagging.

INDUCTION FURNACE:

This type of furnace is suitable for all types of materials. The heat source is isolated from charge and slag. The flux gets necessary heat directly from the charge instead of the heat source. The stirring effect of electric current would cause fluxes to be entrained in the melt.

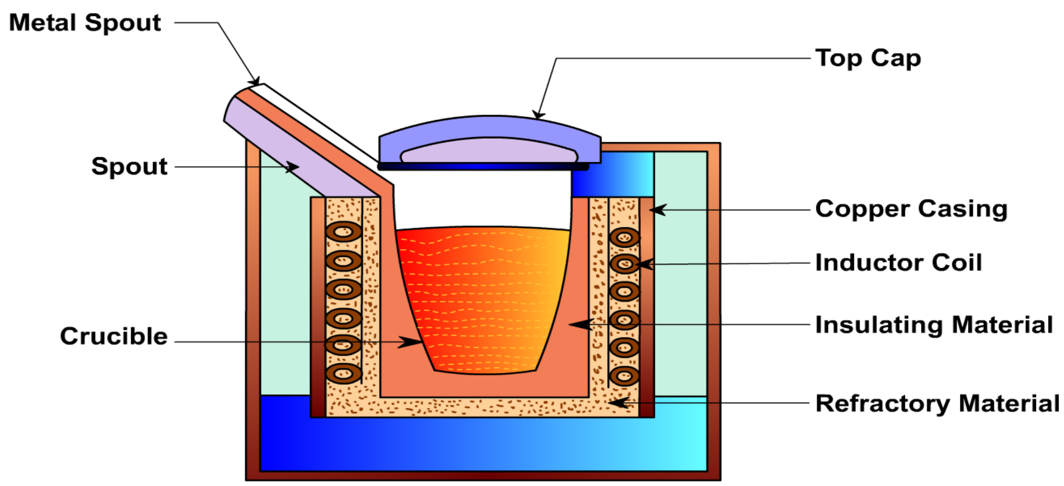


Figure 6 Induction Furnace

Module-II

CASTING CLEANING:-

The moulds should be broken at a temperature when no transformation occurs. For example, for ferrous alloys, breaking should be done below 700^0C, for thin and fragile casting, it should be below 400^0C and for heavier castings, it should be at 500^0C.

The process of cleaning of casting is known as fettling. This includes removal of cores, gates and risers, cleaning casting surface, chipping of unnecessary projections etc. Dry sand core can be removed by knocking off with iron bar, by means of core vibrator or by means of hydro blasting. The selection of the method depends on the size, complexity and core material used.

The gates and risers can be removed by hammering, chipping, hack sawing, abrasive cut off and by flame or by arc cutting. For brittle materials like grey cast iron, it can be done by hitting with hammer. For steels and other materials, sawing with hacksaw or band saw is more convenient. For large size gates and risers, flame or arc cutting is used. Similarly for removal of gates, abrasive cut off can be used. Fins and other small projections after removal of gates can be chipped off by using hand tools and pneumatic tools.

CASTING DEFECTS:-

a) Gas defects
b) Shrinkage cavities
c) Moulding material defects
d) Pouring metal defects
e) Metallurgical defects

(a) Gas defects:

A condition existing in a casting caused by the trapping of gas in the molten metal or by mould 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 mould, which may be due to lower venting, lower permeability of the mould or improper design of the casting. The lower permeability is caused by finer grain size of the sand, high percentage of clay in mould mixture, and excessive moisture present in the mould.

- Metal contains gas
- Mould is too hot
- Poor mould burnout

(b) 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 mould. 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.

(c) 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 moulding sand by the flowing metal. This is caused by the moulding 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 moulding 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 mould wash was applied on the surface of the mould. 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 mould wall may move back causing a swell in the dimension of the casting. A proper ramming of the mould 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 mould can prevent this defect.

(d) 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 mould cavity completely and thus leaves unfilled cavities. A mis-run results when the metal is too cold to flow to the extremities of the mould 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 mould cavity, do not fuse together properly thus forming a discontinuity in the casting. When the molten metal is poured into the mould 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 mould 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.

Mould Shift

The mould shift defect occurs when cope and drag or moulding boxes have not been properly aligned.

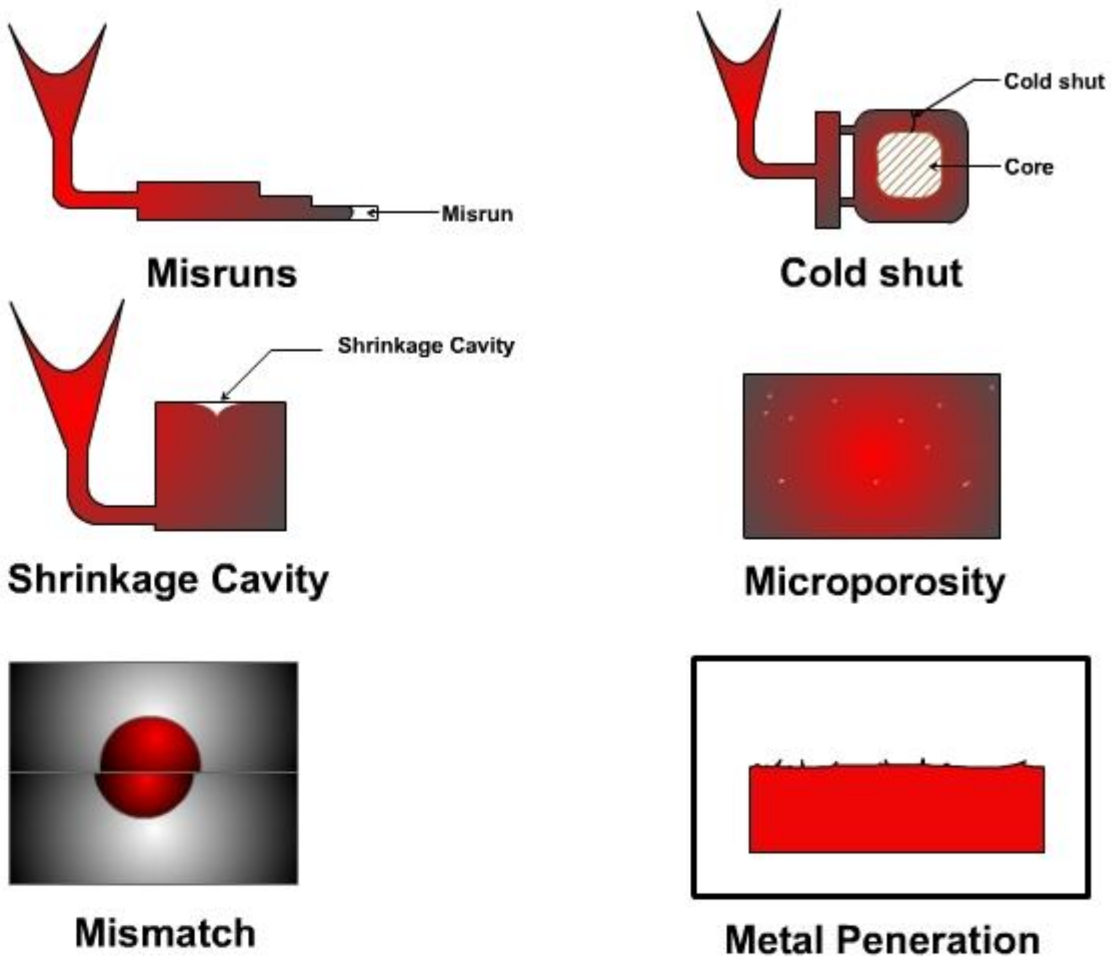


Figure 1 Casting defects

CONTINUOUS CASTING:

In this process the liquid steel is poured into a double walled bottomless water cooled mould where a solid skin is quickly formed having a thickness of 10 to 25 mm and a semi solid skin emerges from open mould bottom which will be further solidified by water sprays. Molten metal is collected in a ladle and is kept over a refractory lined intermediate pouring vessel called tundish and then poured into water cooled vertical copper mould of 450 to 750 mm long. Before starting casting, a dummy starter bar will be kept at the mould bottom. After starting casting process, as the metal level rises to a height, the starter bar will be withdrawn at equal rate that of the steel pouring rate. Initially metal freezes on to the starter bar as well as periphery of the mould. Solidified shell supports the steel liquid as it moves downwards. The steel shell is mechanically supported by rollers as it moves down through the secondary cooling zone with water.

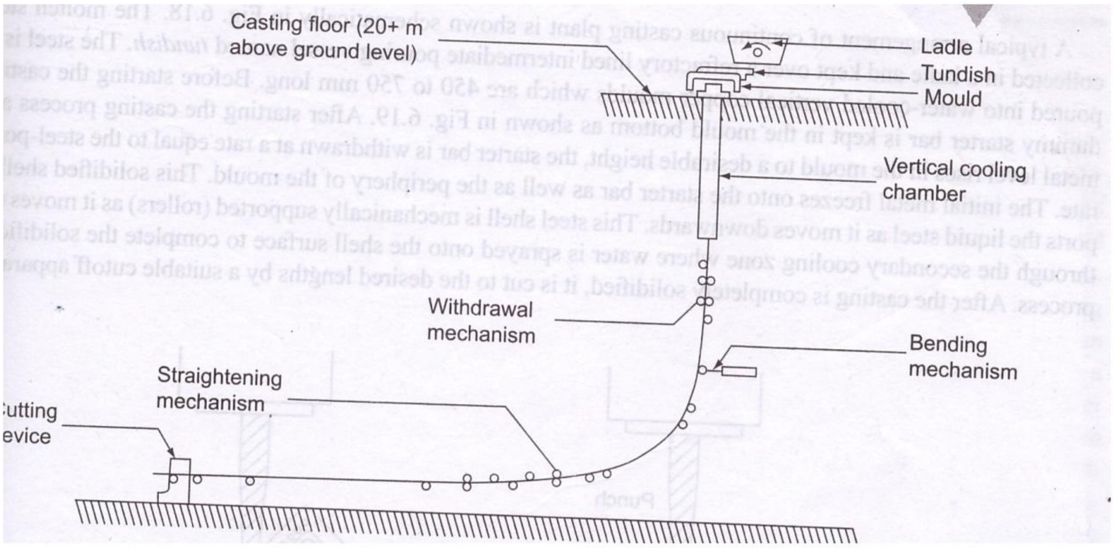


Figure 2 Continuous casting plant

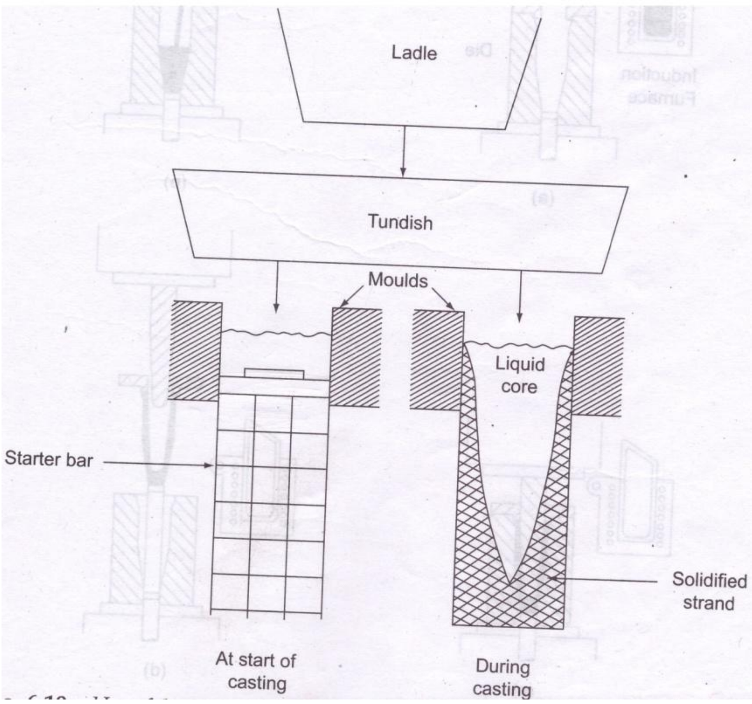
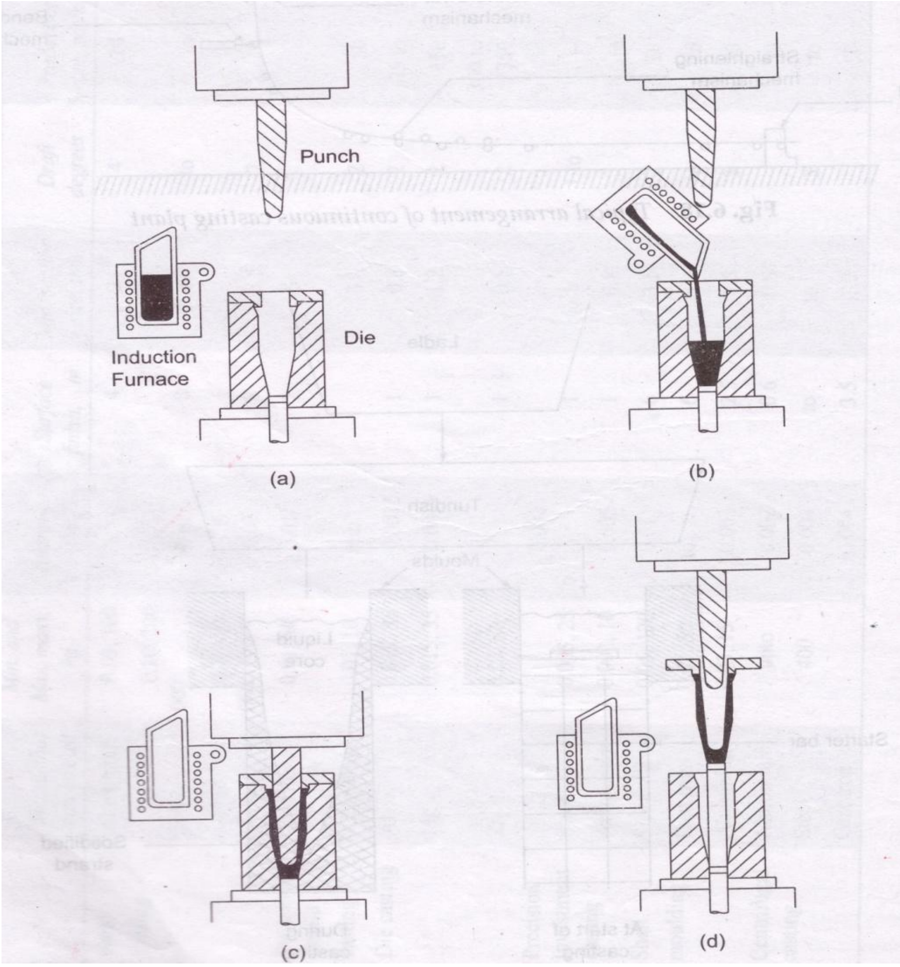


Figure 3 use of dummy starter bar at the start of continuous casting process

SQUEEZE CASTING:



It was first developed in Russia. It is a combination of casting and forging process. First the punch and die are separated. The furnace holds the liquid metal at a requisite temperature. Then the metal is put into the die cavity and the punch is lowered to its place forming a tight seal. The metal is under a pressure of 50 to 140 mpa and looses heat rapidly because of the contact with the metallic die. Once the casting is solidified, the punch is retracted.

Adv: very low gas entrapment.

Lower shrinkage cavity.

Lower die costs.

High quality surface.

Application: Mg, Al, Cu alloy

PRECESSION INVESTMENT CASTING:

The investment casting process also 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 an assembly. The mould is prepared by surrounding the pattern with refractory slurry that can set at room temperature. The mould 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 mould is broken and the casting taken out.

The basic steps of the investment casting process are:

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 mould to remove the last traces of the pattern material
6. Pouring

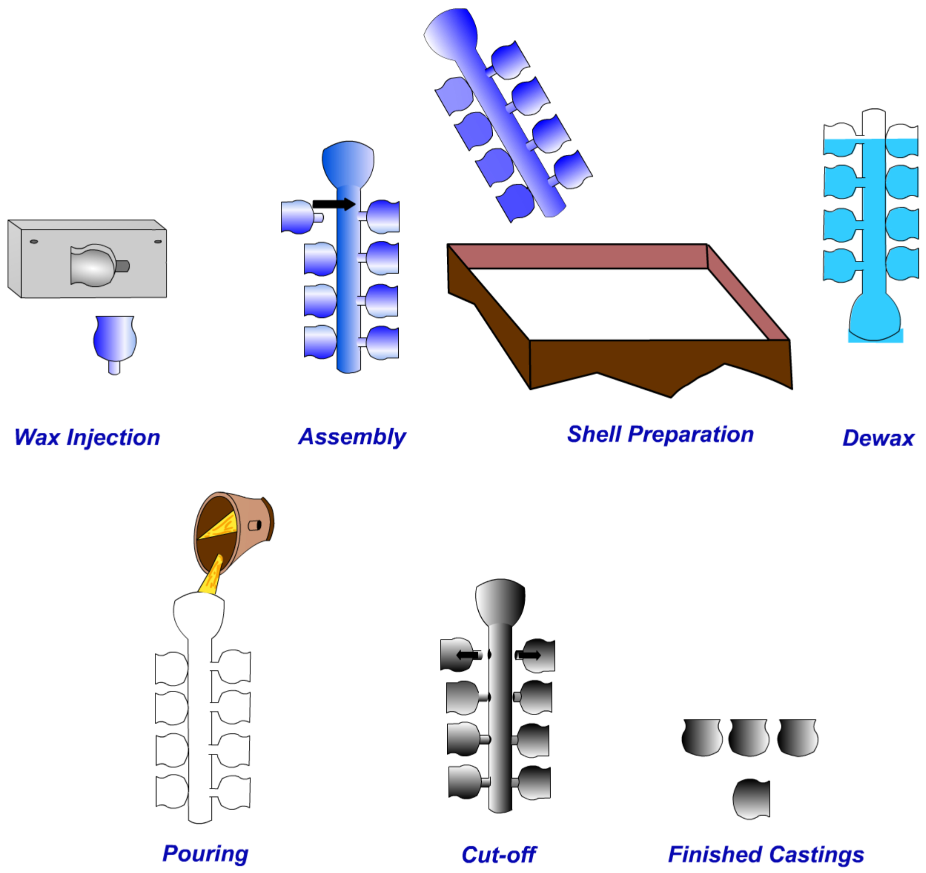
7. Knockout, cut off and finishing.

Adv: complex shapes, very fine details, close tolerance, better surface finish, no machining

Limitation: size and mass – maximum 5 kg

-expensive

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



SHELL MOULD CASTING:

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 mould.

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.

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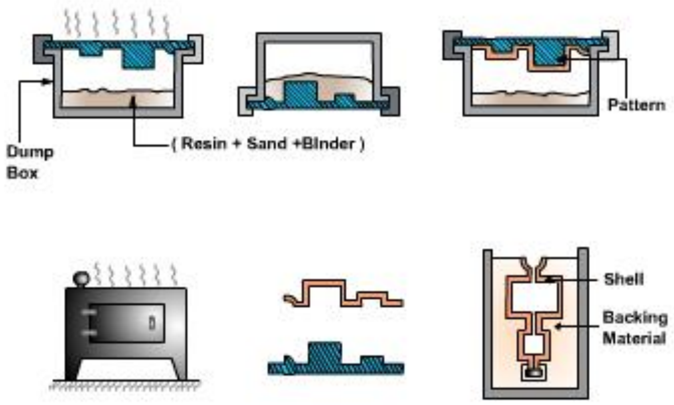
This process can produce complex parts with good surface finish 1.25 µm to 3.75 µm, and dimensional tolerance of 0.5 %. A good surface finish and good size tolerance reduce the need for machining. The process overall is quite cost effective due to reduced machining and cleanup costs. The materials that can be used with this process are cast irons, and aluminium and copper alloys.



Moulding Sand in Shell Moulding Process

The moulding 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.

Adv: dimensionally accurate
Smoother surface
Lowered draft angle
Thin section
No gas inclusion
Small amount of sand needed
Simple processing

Limitation: patterns are expensive
Size of casting – limited
Complicated shapes
Sophisticated equipments needed.

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

PERMANENT MOULD CASTING:

For large-scale production, making a mould, for every casting to be produced, may be difficult and expensive. Therefore, a permanent mould, called the die may be made from which a large number of castings can be produced. , the moulds are usually made of cast iron or steel, although graphite, copper and aluminium have been used as mould materials. The process in which we use a die to make the castings is called permanent mould casting or gravity die casting, since the metal enters the mould 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.

Adv: fine casting
Good surface finish
Close dimensional tolerance
Small core holes

Limitation: limited size
Not for complicated shapes
High cost
Not for all materials

Application: automobile piston
Gear blanks
Connecting rods
Aircraft fittings

CENTRIFUGAL CASTING:

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

There are three types of centrifugal casting.

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

a) True centrifugal casting:

- Hollow pipes, tubes, hollow bushes – axi-symmetric with concentric holes

- Axis of rotation – horizontal, vertical or any angle.
- Sand moulds/ metal moulds
- Water cooling

Adv: superior mechanical properties
Directional solidification
No cores
No gates and runners

Limitation: - only for axi-symmetric concentric holes
- Expensive

b) Semi-centrifugal casting:
- More complicated- axi-symmetric jobs
- Vertical

c) Centrifuging:
- Not axi-symmetrical jobs
- Small jobs of any shape – joined by radial runners with a central sprue on revolving table.

DIE CASTING:

Die casting involves preparation of components by injecting molten metal at high pressure into a metallic dies. It is also known as pressure die casting. Narrow sections, complex shapes, fine surface details can be produced by using this casting process.

The dies have two parts. 1st one is a stationary half (cover die) which is fixed to die casting m/c. The other one is a moving half (ejector die) which is moved out for extraction of casting. At the starting of the process, two halves of the die should be placed apart. The lubricant is sprayed on die cavity and then the dies are closed and clamped. The metal is injected into the die. After solidification, the die will be opened and the casting will be ejected.

Vacuum die casting:

The major problem of die casting is that the air left in the cavity when the die is closed. Also back pressure exists on the molten metal in the die cavity. It can be overcome by evacuating the air from the die after the die is closed and metal is injected.

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

These are of two types:

(a) Hot chamber die casting
(b) Cold chamber die casting

(a) **Hot chamber die casting**:

A Gooseneck is used for pumping of the liquid metal in to the die cavity. It is made up of grey C.I., ductile iron, cast steel. A plunger made up of alloy C.I., hydraulic operated moves up in the gooseneck to uncover the entry port for the entry of liquid metal into the gooseneck.

(b) Cold chamber process:

- Used for zinc, lead and tin (low melting temp. alloys)
- Operation same as hot chamber
- Molten metal is poured in to shot chamber of m/c by either manually or by hand ladle / auto ladle.

Adv: complex casting
Small thickness
High production rate (200 pieces/hr)
Good surface finish (1 micron)
Closer dimension tolerance
Long life of die
Economic

Limitation: maximum size
Not all materials
Air trapped

Application: carburettors
Crank cases
Magnetos
Automobile parts

WELDING AND CUTTING PROCESS

Module-III

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

Fabrication process can be classified as follows.

- Mechanical joining
- Adhesive bonding
- Welding, brazing and soldering

A particular fabrication method depends on number of factors

- Type of assembly

  Permanent, semi permanent or temporary

  Joining those obtained by bolts or screws and can be disassembled whenever necessary are temporary in nature. Rivets are semi-permanents fastening devices that involve making holes in the mating parts. Here joints can be separated by destroying the rivet without harming the parent elements.
- Materials being joined

  Steel, cast irons, aluminium, similar or dissimilar metals
- Type of service required

  Assembly subjected to heavy loading, impact loading, high temperatures

Principle of welding

The welding process is a complex process that involves heat and liquid-metal transfer, chemical reactions. A gradual formation of the welded joint is obtained through liquid-metal deposition and subsequently there is a transformation from cooling into the solid state.

Brazing

Brazing is a coalescence of a joint with the help of a filler metal whose liquidus temperature is above 450^0 and is below the solidus temperature of base metal. In brazing the base metal is not melted. Dissimilar metals can be joined by brazing. Except aluminium and magnesium, brazing can join almost all metals. Brazed joint is not useful for high temperature welding because of the low melting temperature of the filler metal. Here the filler metal reaches the joint by capillary action, it is necessary to control the clearance between two parts. The temperature at which filler metal is entering the joint is also important. Too much clearance doesn't allow capillary force to draw the filler metal into the joint and also insufficient clearance may be too small to allow the filler metal to give rise to an effective strength.

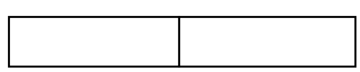
Soldering

Soldering is the method of joining similar or dissimilar metals by means of a filler metal whose liquidus temperature is below 450^0.The joint design used for soldering is similar to that of brazing as in both cases filler metals enter the joint by capillary action. Like brazing, soldering also needs solvent cleaning, acid pickling and mechanical cleaning of the joint surface. In order to remove the oxides from the joint surface for avoiding filler metal from oxidizing, fluxes are generally used in soldering.

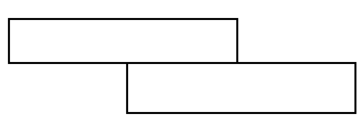
General Considerations:

Types of joints

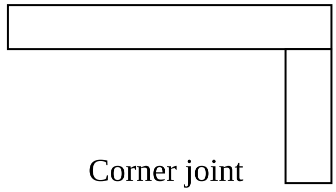
Different types of welding joints are classified as butt, lap, corner, tee and edge joints.



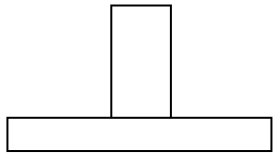
Butt joint



Lap joint



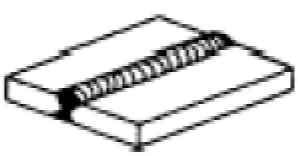
Corner joint



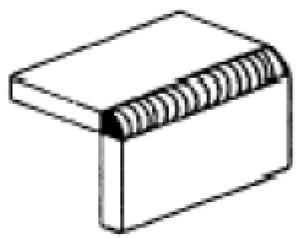
Tee joint

Fig.1. Types of welded joints

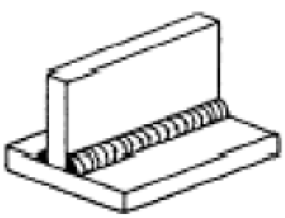
Tensile strength of butt joint depends upon the contact area. In case of lap joint, depending upon the strength requirement, the bonding area chosen. But the limitation of lap joint is that the thickness of joint increases for overlapping of the parts.



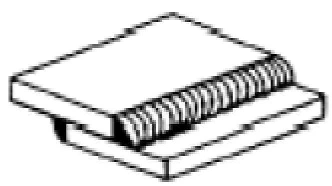
A. Butt joint



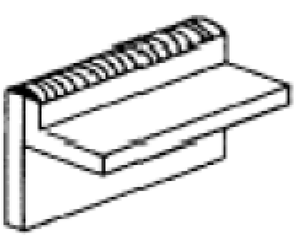
B. Corner joint



C.Tee joint



D.Lap joint



E.Edge joint

Fig.2. Welding positions

- For small thickness, Straight edge joints are done and for that edge is prepared in such a way that heat of welding can penetrate the entire depth. To facilitate the process, the joint is widened.
- For very thick plates, the welding needs to be done from both sides.
- The V- joint is easier to make and the amount of extra metal to be filled in the joint increases greatly with an increase in the thickness.
- A U joint is preferable when the amount of extra metal to be added to fill the joint is less beyond a certain thickness.

Necessary Considerations during fusing

It is essential to clean the interface to remove any oil, dirt, paint or grease. These would interfere during proper fusing of metals and weaken the joints.

- To remove the oily substances from the surface, organic solvents such as acetone and carbon tetra chlorides are used.
- Foreign substances are removed by means of cleaning with a rag soaked in the solvent.
- Heavier oxide films are removed by acid pickling, wire brushing or emery. Also the oxides present on the surfaces can be removed by the use of fluxes. The type of flux used depends upon the operations and parent metal that is being welded.

  Flux is a material that is expected to react with oxides present and form low density slag which would float on the top of molten metal pool protecting it from further oxidation.
- Another requirement for welding is a filler metal. All the welding process except resistance welding requires a filler metal to fill the gap between the parts to be joined.

GAS WELDING

Gas welding is also named as oxy-fuel gas welding (OFW).Gas welding derives heat from the combustion of fuel gas such as acetylene in combination with oxygen. The process is a fusion welding process where the joint is completely melted to obtain the fusion.

Necessary considerations for gas welding

Fuel Gases

Fuel gas for Gas welding used is acetylene due to its high temperature in the flame. Thereby the gas welding may be known as oxy-acetylene welding (OAW).

Following table shows the useful fuel gases for gas welding with their calorific values and temperatures.

Table.1. Characteristics of fuel gases

Gas	Chemical Formula	Heat content, MJ/m^3			Flame temperature, ^0C
		Primary	Secondary	Total	
Acetylene	C_2H_2	18.97	36.03	55	3100
Propylene	C_3H_6	16.38	71.62	88	2500
Propane	C_2H_8	9.38	83.62	93	2450
Methyl acetylene propadiene	C_3H_4	21.00	70.00	91	2927
Hydrogen	H_2	-	-	10	2390
Natural gas	CH_4+H_2	0.41	36.59	37	2350

In oxy fuel gas-welding processes, the combustion takes place in two stages.

Reaction 1- Initial reaction starts when acetylene and oxygen mixture burns releasing heat and showing a small white cone.

Reactions for oxy-acetylene welding

$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + 448 \, {}^{KJ}\!/_{mol} \left(18.75 \, {}^{MJ}\!/_{m^3} \text{ of acetylene}\right)$$

The inner white cone temperature is of order 3100^0

Reaction 2-The carbon monoxide (CO) and hydrogen produced in the first stage further combine with the atmospheric oxygen and gives rise to the outer bluish flame, with the following reaction.

$$4CO + 2H_2 + 3O_2 \rightarrow 4CO_2 + 2H_2O + 812 \, {}^{KJ}\!/\!_{mol} \left(35.77 \, {}^{MJ}\!/\!_{m^3}\right)$$

In the second reaction higher amount of heat is produced but due to distribution over large area, the temperature (1200 to 2000^0) achieved is very small in the flame. The temperature produced in second stage is used for preheating the steels and the temperature produced in the first stage is used for melting the steel joint. Flame appearance varies with the oxygen supply. A neutral flame is obtained with the complete combustion of acetylene and thus a complete heat in the acetylene is released.

Fig.3. Neutral Flame

When less oxygen is provided, a part of combustible matter left resulting a carburizing flame. In this case a third phase of reddish intermediate flame feather is formed in between outer blue flame and inner white zone. The length of this flame feather indicates the presence of excess acetylene. The unburned carbon makes the steel excess hard and brittle. The carburizing flame is not suggested for general use. But since the flame provides a strong reducing atmosphere in the welding zone materials that readily oxidized such as high carbon steel, cast iron, cemented carbides and hard surfacing with high speed steel, the carburizing flame is useful.

Fig.4. Carburizing Flame

When the oxygen is in excess,the carburizing flame is called as oxidizing flame.The flame is similar to neutral flame with the exception that the inner white cone is some what small giving rise to highest tip temperature.

Fig.5. Oxidizing Flame

Welding equipment

Oxyacetylene carries associated regulators and torch that mixes oxygen and acetylene. The oxygen stored in cylinder at a pressure ranging from 13.8MPa to 18.2MPa.

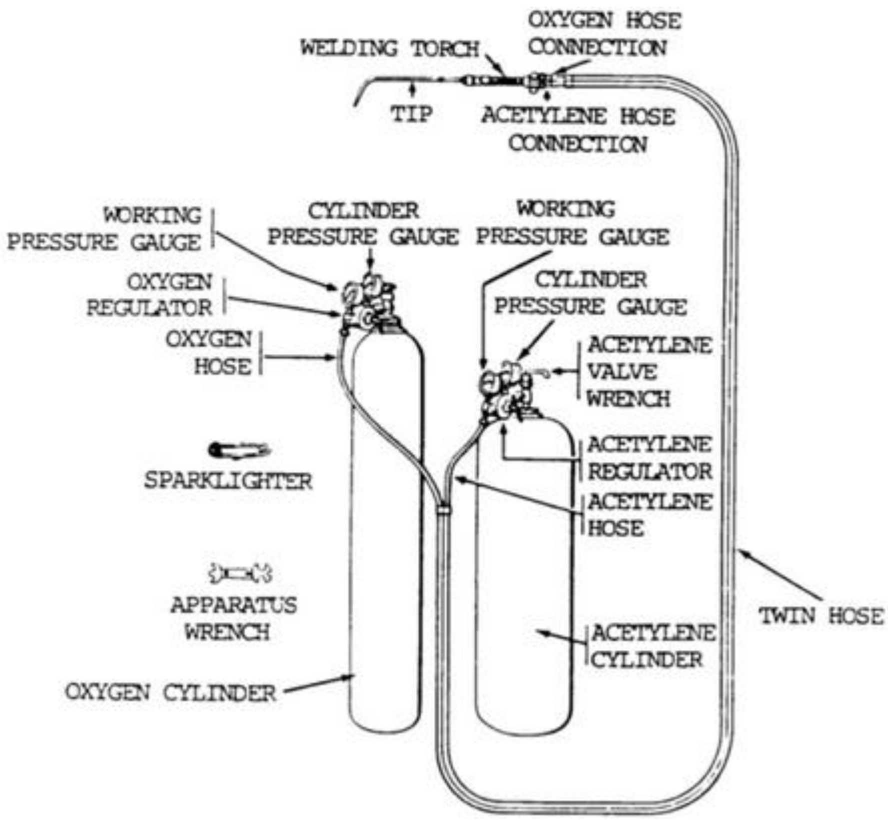


Fig.6. Oxy acetylene welding

As acetylene is highly explosive at a pressure more than 200 kPa, hence it is stored in a cylinder filled with 80 to 85% porous material such as calcium silicate and then filled with acetone which helps in storing acetylene at a much higher pressure than permitted. The presence of acetone in flame gives a purple colour which is not desirable as it reduces the flame temperature. Therefore during release of acetylene care should be taken so that acetone should not come with acetylene. Also acetylene can be produced by acetylene generator in place of acetylene cylinder.

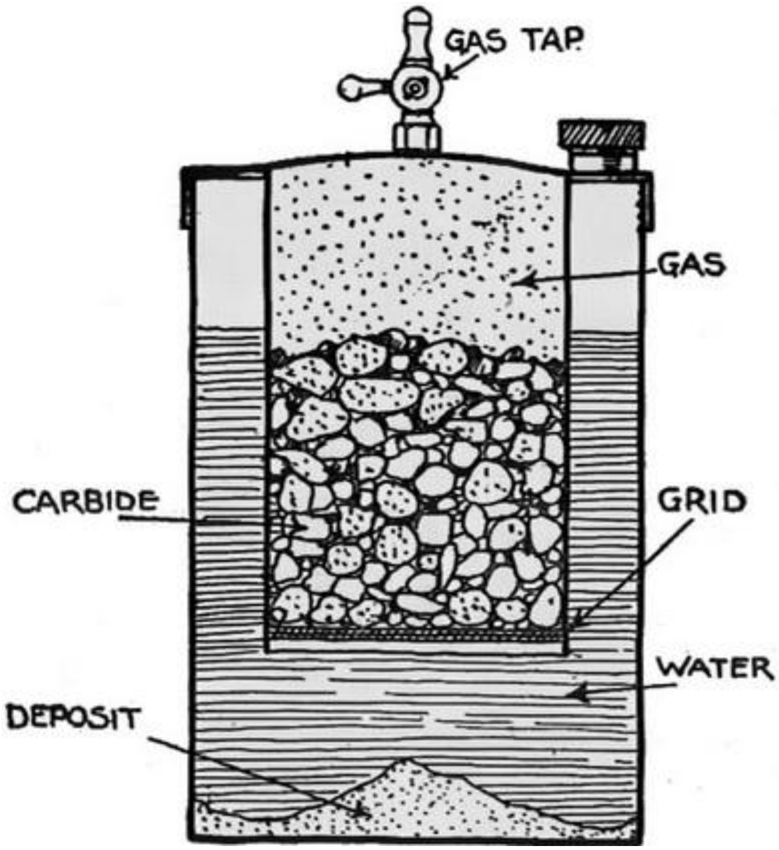


Fig.7. Acetylene generation

Acetylene generator consists of a cylinder partially filled by water. A pressure regulated valve controls the flow of calcium carbide into water, depending upon the pressure of acetylene in the cylinder. The generator would be permitted to produce acetylene to a safe pressure of 100kPa.

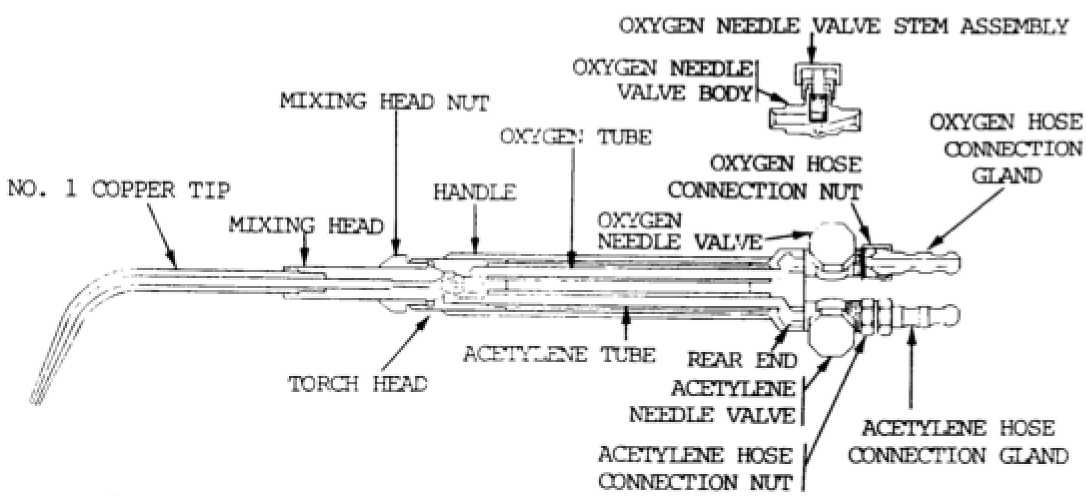


Fig.8. Oxyacetylene welding torch

The acetylene valve on the torch is opened slightly with the help of a friction spark lighter.The acetylene valve is opened to get the required flow of acetylene..The oxygen valve is slowly opened till the intermediate flame feather of the reducing flame.

- The choice of torch size depends upon the thickness of metal to be joined.
- Torch should be held at an angle of 30 to 50 degrees from the horizontal plane.
- Torch movement either oscillatory or circular.
- Torch tip should be positioned above the metal plate so that the white cone is at a distance of 1.5 to 3.0mm from the plate.
- For forehand welding the torch is moved in the direction of tip.

Electric arc welding

Arc welding

Arc welding processes uses the heat generated by an electric arc to melt the faying surfaces of the base metal in order to develop a weld joint.

Manual metal arc welding

In this process, the heat is generated by an electric arc between base metal and a consumable electrode. As the electrode movement is manually controlled hence it is termed as manual metal arc welding. This process is extensively used for depositing weld metal because it is easy to deposit the molten weld metal at right place where it is required and it doesn’t need separate shielding. This process is commonly used for welding of the metals, which are comparatively less sensitive to the atmospheric gases. This process can use both AC and DC. The constant current DC power source is invariably used with all types of electrode (basic, rutile and cellulosic) irrespective of base metal (ferrous and non-ferrous). However, AC can be unsuitable for certain types of electrodes and base materials. Therefore, AC should be used in light of manufacturer’s recommendations for the electrode application. In case of DC welding, heat liberated at anode is generally greater than the arc column and cathode side. The amount of heat generated at the anode and cathode may differ appreciably depending upon the flux composition of coating, base metal, polarity and the nature of arc plasma. In case of DC welding, polarity determines the distribution of the heat generated at the cathode and anode and accordingly the melting rate of electrode and penetration into the base metal are affected.

Tungsten Inert-Gas Welding (TIG)

Tungsten inert-gas (TIG) welding or gas tungsten arc is an inert gas shielded arc welding using a non-consumable electrode. This electric arc is produced by the passage of current trough a conductive ionized inert gas that provides shielding of the electrode, molten weld pool and solidifying weld metal from contamination by the atmosphere. The process may be used with or without the addition of filler metal using metal rods.

Electrode: In TIG welding, tungsten refers to the element used on the electrode. The function of the electrode is to serve as one of the electric terminals which supplies the heat required to the weld. Care must be taken so that the tungsten electrode does not come contact with the weld pool in any way in order to avoid its contamination resulting on faulty weld. Pure tungsten is less expensive and will carry less current. Some other elements may be added to the tungsten, like cerium, lanthanum, thorium and zirconium creating electrode alloys in order to improve arc stability, emissivity and bring higher mellting points. The electrode may contain 1 to 2% thoria(thorium oxide) mixed along with the core tungsten or tungsten with 0.15 to 0.40% zirconia (zirconium oxide).The thoriated tungsten electrodes carry high current and more desirable as they can strike and maintain a stable arc. The zirconia added with tungsten is better than pure tungsten but inferior to thoriated tungsten electrode.

Tungsten inert gas welding set up:

It consists of a welding torch at the center of which is the tungsten electrode.The inert gas supplied to the welding zone through the annular path surrounding the tungsten electrode to effectively displace the atmosphere around the weld puddle.

GAS METAL ARC WELDING (GMAW)

This is also known as Metal inert-gas arc welding (MIG) because it utilizes a consumable electrode. There are other gas-shielded arc- welding processes utilizing consumable electrodes such as flux-cored arc welding, all of which coming under MIG. It’s quite suitable for thicker sheets because filler metal requirement in welding process makes gas-tungsten arc welding (GTAW or TIG) difficult to use, which is more suitable for thin sheets.

The consumable electrode is in the form of wire reel fed at a constant rate through the feed rollers. The welding torch is connected to the gas supply cylinder, which provides the necessary inert gas. The electrode and the work piece are connected to the welding power supply. The power supply is always of the constant voltage type. The current from the welding machine is changed by the rate of feeding of electrode wire. Normally, DC arc-welding machine are used for GMAW with electrode positive (DCEP). The DCEP increases the metal- deposition rate and also provides a stable arc and smooth electrode metal transfer. With DCEN the arc become highly unstable and also results in spatter. But special electrodes having calcium and titanium oxide mixtures as coatings are found to be good for steel with DCEN.

Metal Transfer

Metal transfer takes place from the electrode to the joint in GMAW process. The metal transfer is done in different ways depending on the current and voltage used for a given electrode.

- Short circuit or dip transfer,
- Spray transfer,
- Pulsed spray transfer, and
- Rotating spray transfer.

The short-circuiting metal transfer occurs with relatively low current settings of the order of 75 to 175 A for an electrode diameter of 0.9 mm. The number of times that the pinching takes place depends on the inductance of welding machine used and the parameters set. The rate at which the short-circuiting current increases is controlled by inductance of the welding machines. Too low an inductance gives rise to very high short-circuiting current and consequently high pinching rate. With high inductance, the short-circuiting becomes low and results in somewhat lower pinching force. The effect of inductance is measured in terms of response rate (raising rate of current due to short-circuiting, kA/s). It can be observed that the optimum response rate depends on electrode wire size. Hence, he welding machines to be used for short-circuiting transfer make use of a variable choke system which can be tuned for different wire sizes. The frequency of metal transfer may be of the order of 50 to 200per second. This rate also depends on the open-circuit voltage and wire-feed rate employed.

SHIELDING GASES

Argon, helium, nitrogen, oxygen, carbon dioxide and mixture of the above gases in various proportions are used in GMAW as shielding gases.

Argon is the most widely used of all the shielding gases, because it reduces the spatter and concentrates the arc, which in turn gives deep penetration welds. In addition, argon ionizes easily requiring smaller arc voltages and also has lower thermal conductivity and hence conducts heat very slowly from the arc to the weld zone. Thus, it is good for welding thin sheets. Because of the lower voltages employed, it is suitable for out-of-position welding. For spray transfer of metal a large percentage of argon is required. Helium is the most expensive of all the shielding gases. Due to its better thermal conductivity it is suitable for thicker sheets as well as for metals having higher thermal conductivity such as copper and aluminium. The filler metal-deposition rate by helium is much higher compared to argon because of the higher current-carrying capacity.

The arc in carbon dioxide shielding gas is unstable and therefore a short arc is to be used to reduce the metal spatter. It is the least expensive of all the shielding gases. Since about 7.5% of the carbon dioxide decomposes into carbon monoxide and oxygen in the arc, deoxidizers such as aluminium and silicon are to be used while using carbon dioxide. It is a heavy gas and therefore it covers the weld zone very well. The metal transfer is globular only with the carbon dioxide shielding gas.

Sometimes the mixtures of gases such as argon-helium, argon-carbon dioxide, argon-oxygen are used for special applications. Shielding gases should always flow in a laminar manner without causing any turbulence because turbulence causes weld contamination. The gas flow rates to be used depend upon the thickness of the sheet being welded, the position of the weld as well as the base material.

ELECTRODES

The electrode wire comes generally in the form of coils and of normal sizes may be of the order of 0.5 to 3.2 mm. Depending upon the base material, various wire compositions are available. For steels, electrodes wire having deoxidizers are used because, the deoxidizers help in the reduction of oxidation of the weld metal as well as the porosity. The electrode wire is produced by wire drawing, and uniform diameter throughout otherwise the arc may saunter.

SUBMERGED ARC WELDING (SAW)

It is used for faster welding jobs. It is possible to use larger welding electrodes (12 mm) as well as very high currents (4000 A) so that very high metal deposition rates of the order of 20 kg/h or more can be achieved with this process. Also, very high welding speeds (5 m/min) are possible in saw. Some submerged arc welding-machines are able to weld plates of thicknesses as high as 75 mm in butt joint in a single pass. Though it can weld very small thickness, of the order of 1 mm, it is very economical for larger welds only.

The arc is produced in the same manner as in GMAW. The welding zone is completely covered by means of large amount of granulated flux, which is delivered ahead of welding electrode by means of flux-feed tube. The arc between the electrode and the work-piece is completely submerged under the flux and is not visible from outside. A part of the flux melts and forms the slag, which covers the weld metal. The unused flux can be recycled.

The power source used with submerged arc welding can either be AC or DC. Both constant voltage and constant current type machines can effectively used though, for larger electrode a constant current type power supply is used. The current ratings of the SAW machines are, in general, two to three times higher that of the GMAW machines.

Arc blow is not encountered with AC supply with a single wire SAW. But sometimes two wires may be used to deposit larger amounts of metal. These two electrode being connected to two separate power sources, the arc blow is likely to occur because of the interference of the two magnetic fields surrounding the two electrodes, if the two currents are in phase. In order to avoid the setting of opposite magnetic fields, the two power supplies are adjusted in such a way that, one of the supply is in peak, and the other is set to zero current. One of the electrodes is called leading and the other called trailing. In this way the aforementioned problem is reduced.

There is no spatter of the molten metal since the arc is completely submerged in the flux. Because of the usage of loose granulated flux to cover the joint, it is difficult to carry out in any position other than the flat or down-hand position. Also, because of large metal pools generation in the SAW process, the out-of-position welds are difficult to carry out.

The electrode wires normally used are of sizes 1.6, 2, 2.5, 3.15, 4, 5, 6.3 and 8mm. The wires should be smooth with no surface imperfections or contaminants. It is difficult to manually feed the wire into the joint because of very high wire-feed rate. As SAW process produces large amount of molten weld metal, it takes sometimes for solidification. Hence, it is imperative in SAW to provide some way of containing this molten metal. Weld metal backing is normally used. The backing slaves can be with or without grooves, but in general, copper plates are used, which can easily be cooked with internal running water, when necessary. For thin plates, plain copper backing plates without any cooling water, would be enough. Pure copper removes heat quickly from the molten weld pool because of its high thermal conductivity.

PLASMA ARC WELDING

Plasma is the state of matter present in between electrodes in any arc. In this part, gas is ionized to make it a conductor of electric current. - PAW uses a non- consumable tungsten electrode and a shielding gas such as argon, helium or a mixture of both with hydrogen. - Plasma torch:- Pure argon gas is allowed through the inner orifice surrounding the tungsten electrode to form plasma gas. The constraining nozzle squeezes the gas to form a concentrated and straight arc and also increases the heat contained per unit volume of the arc (~110000C).Ionization of the arc occurs through a low current pilot arc between electrode and constricting nozzle. This initiates the PAW arc. Due to constriction the plasma gas attains a very high temperature and also provides a low resistance path to initiate the welding arc between electrode and work piece. This is called transferred arc. Inert shielding gas is allowed to flow through outer gas nozzle which protects the weld metal.Higher ampere rating Constant current or drooper type of dc power supplies are used as power sources. Electrode is taken as negative.PAW is done by"key hole" technique. Due to high temperature the base metal beneath the arc melts completely forming a thin keyhole. With the advancement of the torch the metal melted ahead (down hand welding position) flows into the keyhole. Thus the keyhole travels continuously along the torch direction. Advantages:- Because of arc concentration heat input can be properly controlled and the heat affected zone around the weld metal is small. - Uniform deep penetration can be obtained. - Greater distance between electrode tip and work piece makes use of filler metal rod easier without contamination of electrode. Higher metal deposit rate. Disadvantages:- Expensive frequent replacement requirement of nozzle.

THERMIT WELDING

In thermite welding, weld metal is melted externally using exothermic heat generated by chemical reactions and the melt is supplied between the components to be joined.

ELECTROSLAG WELDING

In electroslag welding weld metal is melted by electrical resistance heating and then it is allowed to cool very slowly for solidification similar to that of casting.

ELECTRON BEAM WELDING

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

Principles:

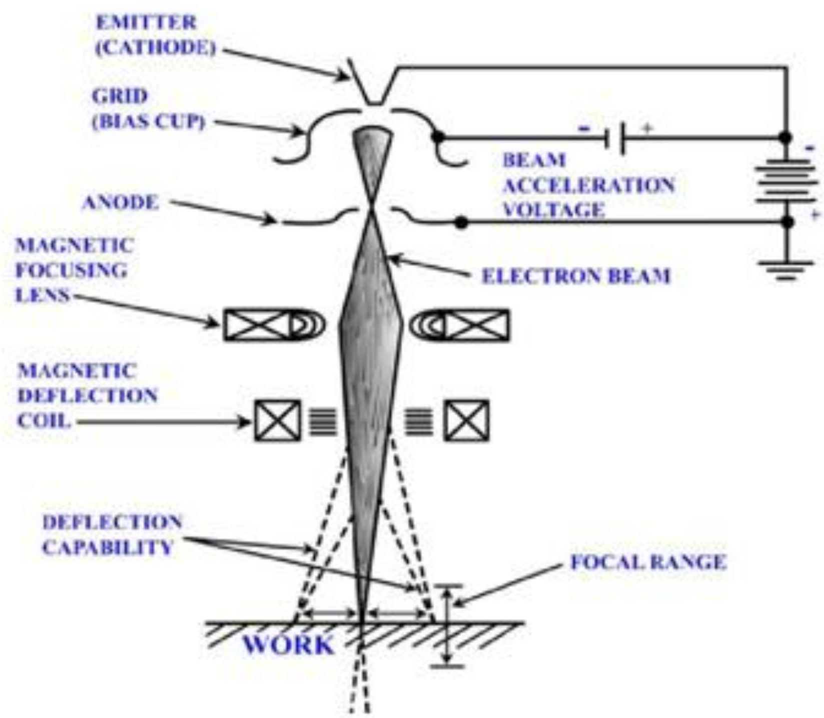
In general, electron beam welding process is carried out in vacuum. In this process, electrons are emitted from the heated filament called electrode. These electrons are accelerated by applying high potential difference (30 kV to 175 kV) between cathode and anode. The higher the potential difference,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

EBW Equipment:

An EBW set up consists of the following major equipment:

- Electron gun
- Power supply
- Vacuum Chamber
- Work pie e handling device.

Electron -Gun: An electron gun generates, accelerates and aligns the electron beam in required direction and spots onto the work piece. The gun is of two types: Self accelerated and work accelerated. The work accelerated gun accelerates the electrons by providing potential difference between the workpiece and cathode. In the self accelerate gun,the electrons are accelerated by applying potential difference between cathode and anode. The anode and cathode are enclosed within the gun itself. The control of electron density is better in this type of electron gun. A schematic of an electron beam gun used in EBW is shown in Fig. 4.5.1. Major parts of an electron gun are briefly introduced in the following sections.



Schematic of an electron beam gun used in EBW

Emitter/Filament: It generates t he electrons on direct or indirect heating.

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

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

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

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

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

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

Advantages of EBW:

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

- Reactive materials like beryllium, titanium etc. can be welded.
- Materials of high melting point like columbium, tungsten etc. can be welded.
- Inaccessible joints can be made.
- Very wide range of sheet thickness can be joined (0.025 mm to 100 mm)

Disadvantages of EBW:

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

Applications of EBW:

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

LASER BEAM WELDING PROCESS

Laser Beam Welding (LBW) is a fusion joining process that produces coalescence of materials with the heat obtained from a concentrated beam of coherent, monochromatic light impinging on the joint to be welded. In the LBM process, the laser beam is directed by flat optical elements, such as mirrors and then focused to a small spot (for high power density) at the work piece using either reflective focusing elements or lenses. It is a non-contact process, requiring no pressure to be applied. Inert gas shielding is generally employed to prevent oxidation of the molten puddle and filler metals may be occasionally used. The Lasers which are predominantly being used for industrial material processing and welding tasks are the Nd-YAG laser and 1.06 μm wavelength CO_2 laser, with the active elements most commonly employed in these two varieties of lasers being the neodymium (Nd) ion and the CO_2 molecules respectively.

WELD DEFECTS AND TESTING

In welding, the defects often found in fusing due to lack of fusion, lack of penetration, inclusion of slag or oxide, presence of cracks, porosity and uncut and excessive penetration. These are the defects generally shown in butt welds.

The defects like cracking, lack of fusion, porosity, slag inclusion, bad profile and oxide inclusion alters the static strength of the welded joint under ductile conditions but have a serious consequences if the joint is subjected to fatigue loading. The presence of crack enhances the probability of brittle fracture. Similarly a lack of fusion causes a lack of discontinuity and hence diminishes the fatigue strength.

Gas cutting

Shearing can be used straight line cut and thickness up to 40 mm. For thicker plates and contour ,oxy fuel cutting is used. The difference in oxy acetylene gas cutting and acetylene welding is a torch tip which is used for preheating the plate as well as providing oxygen jet. The tip has a central hole for oxygen jet and surrounded holes for preheating flames.

When high pressure oxygen jet with a pressure of order 300kPa is directed against a heated steel plate, the oxygen jet burn the metal and blows it away causing the kerf(cut).Larger the size of the orifice,wider is the kerf width and larger is the volume of the oxygen consumed.

Table.1.Tip sizes for cutting carbon steel

Plate thickness,mm	Oxygen orifice diameter,mm
Up to 3	0.65
3 to 6	0.90
6 to 250	1.25
25 to 5	1.60
50 to 100	2.25
100 to 200	3.00
200 to 300	4.25
300 to 400	5.00
400 to 500	6.00

Arc cutting

In arc cutting, the metal is simply melted by heat of arc and then blown away by force of arc or by any other gases such as air or shielding gases.Depending upon source of heat input, many arc cuttings are there.

- Carbon arc cutting(CAC)
- Air carbon arc cutting(AAC)
- Oxygen arc cutting(AOC)
- Shielded metal arc cutting(SMAC)
- Gas metal arc cutting(GMAC)
- Gas tungsten arc cutting(GTAC)
- Plasma arc cutting(PAC)

In all these processes, the equipment used is similar except the torch.The torch holds the electrode and supply high pressure gas where needed.

Carbon arc cutting

The process carries a carbon electrode to obtain the required arc.The metal that is cut is blown away by arc force and gravity.

Air carbon –arc cutting

Here the arc is obtained between copper coated graphite or carbon electrode and the work piece with molten metal being forced out by means of a compressed air at pressure of 550 to 690kPa.

Oxygen arc cutting

It carries a hollow tubular electrode to obtain the arc. Compressed oxygen is forced through a hollow portion so that metal is oxidized and blown in a similar manner as oxy fuel gas cutting (OFC).