MATERIALS PROCESSING

B. Tech 3rd Semester

LECTURES NOTE

BY

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BPUT SYLLABUS

Materials Processing

Module I (16 hours)

Introduction to metal casting, Molding methods, materials and processes, with special reference to patterns, sand and binders. Solidification of short & long freezing range alloy castings, Gating and Risering of castings.

Melting practices for ferrous and non-ferrous alloys-Cupola, rotary furnace, induction furnace, crucible furnace melting.
Casting defects and remedy. Special casting processes.

Module II (13 hours)

Introduction to metal joining processes. Theory and classification of welding processes. Metallurgical principles involved in welding of carbon and alloy steels and important nonferrous alloys. Welding defects and their remedies.

Module III (13 hours)

Basic processes in Powder Metallurgy, Characteristics of powders. Compaction in rigid dies. Sintering of metal powders. Application of powder metallurgy products-their relative advantages.

Module I

Introduction to metal casting: Casting, one of the oldest manufacturing processes, dates back to 3500 B.C in Mesopotamia. Casting is a process of forming metallic products by melting the metal, pouring it into a cavity known as mould, and allowing it to solidify. Casting sizes range from few mm (teeth of a zipper) to 10 m (Ship propellers).

The Casting Industry

- 6.5 million kg of castings are produced every year
- The most common materials cast are gray iron, ductile iron, aluminum alloys, an d copper alloys
- 35% of the market is in automotive and light truck manufacturing
- Castings are used in applications ranging from agriculture to railroad equipment, automobiles and aircrafts components, and heating and cooling equipments.

Capabilities and Advantages of Casting

1. Parts with very intricate shapes can be produced by casting at a cheaper rate.
2. Can create both external and internal shapes
3. Some casting processes are net shape; others are near net shape
4. Cast material is isotropic. It has the same physical and mechanical properties along any direction.
5. It is economical, with very little wastage: the extra metal in each casting is remelted and re-used
6. Can produce a wide variety of sized parts: – Large parts: engine blocks, cylinder heads, railway wheels, pipes……etc. – Small parts: dental crowns, jewellry, gears, brake c

Limitations of Casting

1. Limitations on mechanical properties

2. Poor dimensional accuracy and surface finish for some processes (sand casting)
3. Safety hazards to workers due to hot molten metals
4. Porosity (empty spaces within the metal - reduces the strength of metal)

Moulding methods, materials and processes

Important casting terms:

Flask: A metal or wood frame, without fixed top or bottom, in which the mould is formed. Depending upon the position of the flask in the moulding structure, it is referred to by various names such as drag – lower moulding flask, cope – upper moulding flask, cheek – intermediate moulding flask used in three piece moulding.

Pattern: It is the replica of the final object to be made. The mould cavity is made with the help of pattern. Parting line: This is the dividing line between the two moulding flasks that makes up the mould.

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.

Facing sand: The small amount of carbonaceous material sprinkled on the inner surface of the mould cavity to give a better surface finish to the castings.

Core: A separate part of the mould, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.

Pouring basin: A small funnel shaped cavity at the top of the mould into which the molten metal is poured.

Sprue: The passage through which the molten metal, from the pouring basin, reaches the mould cavity. In many cases it controls the flow of metal into the mould.

Runner: The channel through which the molten metal is carried from the sprue to the gate. Gate: A channel through which the molten metal enters the mould cavity.

Chaplets: Chaplets are used to support the cores inside the mould cavity to take care of its own weight and overcome the metallostatic force.

Riser: A column of molten metal placed in the mould to feed the castings as it shrinks and solidifies. Also known as “feed head’’.

Vent: Small opening in the mould to facilitate escape of air and gases.

Steps in making sand castings:

The six basic steps in making sand castings are, (i) Pattern making, (ii) Core making, (iii) Molding, (iv) Melting and pouring, (v) Cleaning

Pattern making - Pattern: Replica of the part to be cast and is used to prepare the mould cavity. It is the physical model of the casting used to make the mould. Made of either wood or metal. -The mould is made by packing some readily formed aggregate material, such as molding sand, surrounding the pattern. When the pattern is withdrawn, its imprint provides the mould cavity. This cavity is filled with metal to become the casting. - If the casting is to be hollow, additional patterns called 'cores', are used to form these cavities.

Core making: Cores are placed into a mould cavity to form the interior surfaces of castings. Thus the void space is filled with molten Core making Cores are placed into a mould cavity to form the interior surfaces of castings. Thus the void space is filled with molten metal and eventually becomes the casting.

Molding: Molding is nothing but the mould preparation activities for receiving molten metal. Molding usually involves: (i) preparing the consolidated sand mould around a pattern held within a supporting metal frame, (ii) removing the pattern to leave the mould cavity with cores. Mould cavity is the primary cavity. The mould cavity contains the liquid metal and it acts as a negative of the desired product. The mould also contains secondary cavities for pouring and channeling the liquid material in to the primary cavity and will act a reservoir, if required.

Melting and Pouring: The preparation of molten metal for casting is referred to simply as melting. The molten metal is transferred to the pouring area where the moulds are filled.

Cleaning: Cleaning involves 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

Sand Molding Method:

1. First a bottom board is placed either on the molding platform or on the floor, making the surface even. The drag molding flask is kept upside down on the bottom board along with the drag part of the pattern at the centre of the flask on the board. There should be enough clearance between the pattern and the walls of the flask.
2. Dry facing sand is sprinkled over the board and pattern to provide a non-sticky layer.
3. Freshly prepared molding sand of the required quantity is now poured into the drag and onto the pattern.
4. The ramming of the sand should be done properly so as not to compact it too hard, which makes the escape of gases difficult, not too loose, so that the mould would have enough strength.
5. After ramming is over, the excess sand in the flask is completely scraped using a flat bar to the level of the flak edge.
6. With the help of a vent wire, vent holes are made in the drag to the full depth of the flask as well as to facilitate the removal of the gases during casting solidification.
7. The finished drag flask is now rolled over to the bottom board exposing the pattern.
8. With the help of dowel pins the cope half of the flask is aligning again with the help of the pins.
9. The dry parting sand is sprinkled all over the drag and on the pattern.
10. A sprue pin for making the sprue passage is located at a small distance from the pattern.
11. A riser pin if required is kept at an appropriate place and freshly prepared molding sand similar to that of the drag along with the backing sand is sprinkled.
12. The sand is thoroughly rammed, excess sand scraped and vent holes are made all over in the cope as in the drag.

13. The sprue pin and riser pin are carefully withdrawn from the flask. Later the pouring basin is cut near the top of the sprue. The cope is separated from the drag and any loose sand on the cope and drag interface of the drag is blown off with the help of bellows.

14. The cope and drag halves are withdrawn by using the draw spikes and rapping the pattern all around to slightly enlarge the mould cavity so that the mould walls are not destroyed.

15. The runners and gates are cut in the mould carefully without spoiling the mould. Any excess or loose sand found in the runners and mould cavity are blown away using bellows. The mould is now ready for pouring.

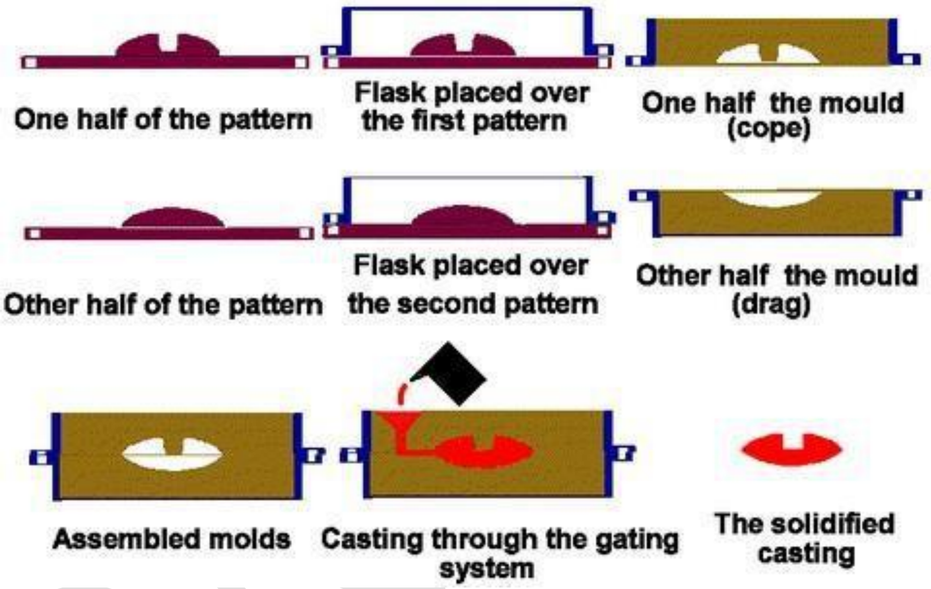


Figure. Sand mould making procedure

The pattern and the part to be made are not same. They differ in the following aspects.

A pattern is always made larger than the final part to be made. The excess dimension is known as Pattern allowance.

1. **Pattern allowance => shrinkage allowance**: will take care of contractions of a casting which occurs as the metal cools to room temperature. Liquid Shrinkage: Reduction in volume when the metal changes from liquid state to solid state. Riser which feed the liquid metal to the casting is provided in the mould to compensate for this. Solid Shrinkage: Reduction in volume caused when metal looses temperature in solid state. Shrinkage allowance is provided on the patterns to account for this. Shrink rule is used to compensate solid shrinkage depending on the material contraction rate.

Shrink rule for other materials

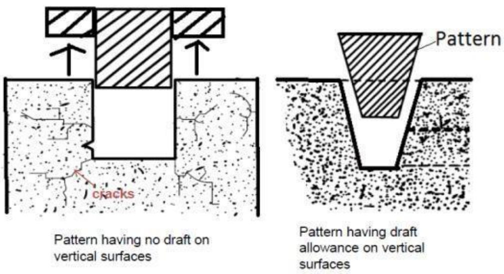
Material	Dimension	Shrinkage allowance (inch/ft)
Grey Cast Iron	Up to 2 feet 2 feet to 4 feet over 4 feet	0.125 0.105 0.083
Cast Steel	Up to 2 feet 2 feet to 6 feet over 6 feet	0.251 0.191 0.155
Aluminum	Up to 4 feet 4 feet to 6 feet over 6 feet	0.155 0.143 0.125
Magnesium	Up to 4 feet Over 4 feet	0.173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

2. **Machining allowance:** will take care of the extra material that will be removed to obtain a finished product. In this the rough surface in the cast product will be removed. The machining allowance depends on the size of the casting, material properties, material distortion, finishing accuracy and machining method. For internal surfaces, the allowances should be negative.

Machining allowances of various metals

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

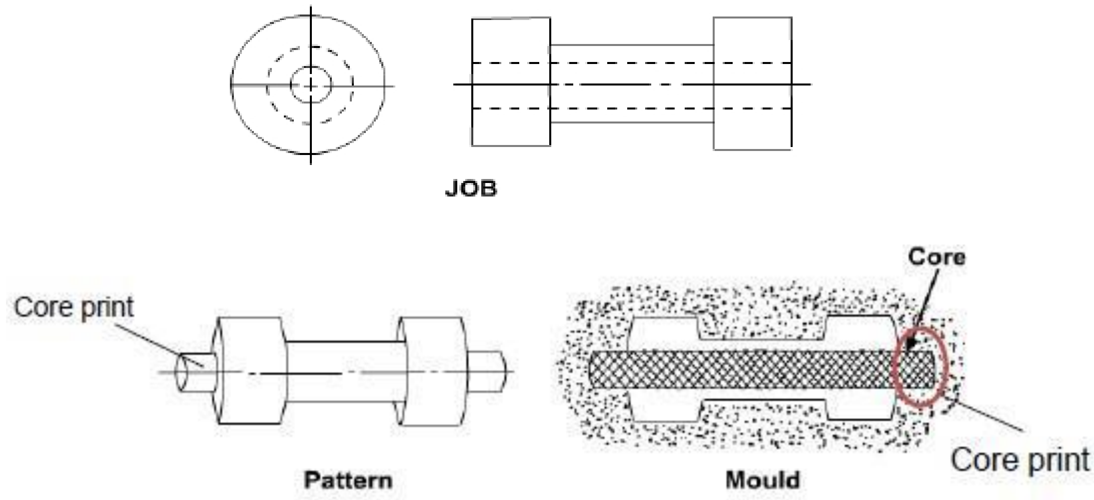
3. **Draft allowances:** All the surfaces parallel to the direction in which the pattern will be removed are tapered slightly inward to facilitate safe removal of the pattern. This is called 'draft allowance'. General usage: External surfaces ; Internal surfaces, holes, pockets



Typical Draft Allowances

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

4. **Core and core print:** - Cores are used to make holes, recesses etc. in castings - So where coring is required, provision should be made to support the core inside the mould 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 mould on which the sand core rests during pouring of the mould. - The core print must be of adequate size and shape so that it can support the weight of the core during the casting operation.



5. **Distortion allowance (camber**) - Vertical edges will be curved or distorted - This is prevented by shaped pattern converge slightly (inward) so that the casting after distortion will have its sides vertical - The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different sections of the casting and hindered contraction. Prevention: - providing sufficient machining allowance to cover the distortion affect - Providing suitable allowance on the pattern, called camber or distortion allowance (inverse reflection)

Pattern material:

Patterns for sand castings are subjected to considerable wear and tear due to ramming action that is required and the abrasive action of the sand • Should be impervious to moisture because of changing surroundings • Made of: wood, metal, plastics, plaster and synthetic materials

- Woods => white pine, sugar pine; The wood should be straight grain, light, easy to work, little tendency to develop crack and warp. • More durable: Mahogany

• For large castings: metal such as cast iron or aluminium • When metal pattern are cast from the wooden master pattern, double shrinkage must be provided on the wooden master pattern • Assume metal pattern is made of aluminium and castings are made of CI, the shrinkage allowance for the wooden master pattern is: 5/32 inch per foot for Al+ 1/8 inch per foot CI = 9/32 inch per foot

Types of patterns

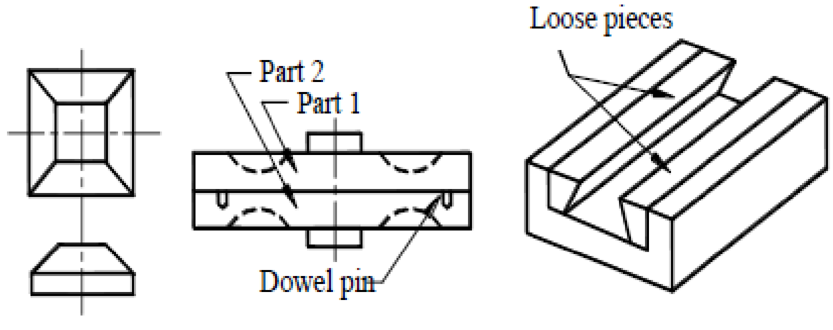
(a) Solid pattern: Simple shape castings are produced by this type of patterns

(b) Split pattern: Used when patterns cannot be made as a single piece

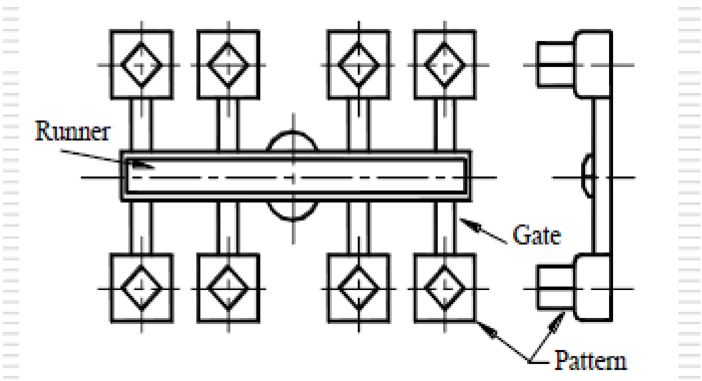
(c) Loose piece pattern: Used when 1. Withdrawal of pattern from mould is not possible 2. Castings is having projections, undercuts, etc.. After ramming first main pattern is removed and then the loose pieces

(d) Gated pattern: used for producing small sized cavities in one mould

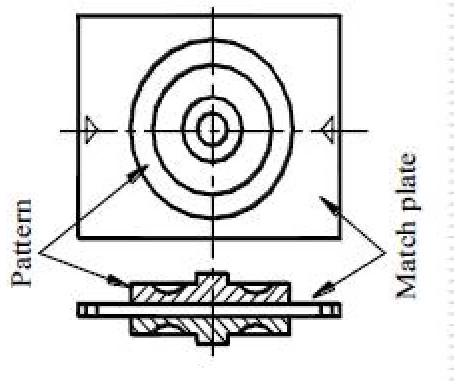
(e) Match plate pattern: 1. Split patterns attached on either side is known as Match plate pattern. 2. It increases production and helps in maintaining uniformity in the size and shape of the castings.



(a) Solid pattern (b) Split pattern (c) Loose piece pattern



(d) Gated pattern



(e) Match plate pattern

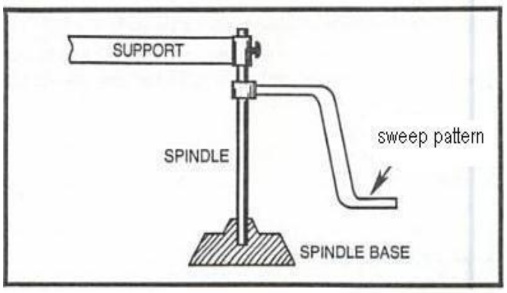
Low cost patterns for large molding:

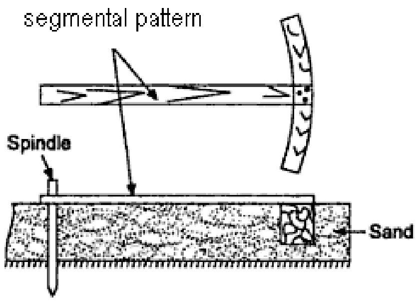
Meant for large, but few, castings: sweep, segmental pattern, partial pattern, skeleton pattern

(f) Sweep pattern: A sweep pattern consists of a board having a profile of the desired mold, which is revolved around a spindle or guide produces the mold. Two are used – one for sweeping the cope and other for drag.

(g) Segmental pattern: meant for circular ring shaped large sections. Instead of using a full pattern, part pattern is used. Once molding is done at one place, it is rotated to the adjacent region and molding is done.

(h) Skeleton pattern: This consists of frame of wood representing the interior and exterior forms. Strickles (like strike off bars) are used to remove excess sand which is purposely rammed with extra thickness than required for desired mold surfaces.





<u>Molding materials:</u>

A large variety of molding materials are used in the casting process for manufacturing the moulds and cores. They are molding sand, baking sand, rebounded sand, facing sand, parting sand and core sand.

The properties that are generally required in molding materials are:

Refractoriness: It is the ability of the molding material to withstand the high temperature of the molten metal so that it does not cause fusion.

Green strength: The molding sand that contains moisture is termed as green sand. The green sand should have enough strength so that the constructed mould retains its shape.

Dry strength: When the moisture in the molding sand is completely expelled, it is called dry sand. When molten metal is poured into the mould, the sand around the mould cavity is quickly converted into dry sand as the moisture content in the sand immediately evaporates due to the heat in the molten metal.

Hot strength: After all the moisture is eliminated, the sand would reach a high temperature when the metal in the mould is still in the liquid state. The strength of the sand that is required to hold the shape of the mould cavity is called hot strength.

Permeability : During the solidification of a casting, large amount of gases are to be expelled from the mould. The gases are those absorbed by the metal in the furnace, air absorbed from the atmosphere and steam and other gases that are generated by the molding and core sands.

Ingredients used in sand for making molds/cores

Refractory sand grains	Binder	Facing material	Cushion
Silica Zircon (has chilling properties) Olivine Magnesite Dolomite Sillimanite Carbon Coke	For bonding materials see next table *Note:* Cle: required with practically all binders.	Sea coal Pitch (dry powder) Graphite Coke Silica flour	Wood flour Cereal hulls Cereal Cellulose Sea coal Coke Perlite (a siliceous lava, quick heating causes bubbles of steam, also has insulating properties)

Reference: J S Campbell, Principles Of Manufacturing Materials And Processes

Silica sand:

The sand which forms the major portion of the molding sand (up to 96%) is essentially silica grains, the rest being the other oxides such as alumina, sodium(Na_2O+K_2O) and magnesium(MgO+ CaO).

Binders Used in Sand Casting for Molds, Cores:

Clays:

Fire clay (kaolinite)

Southern bentonite (calcium montmorillonite)

Western bentonite (sodium montmorillonite)

Secondary mica clays (illite)

Oils:

Vegetables (e.g. linseed oil)

Marine animal (e.g., whale oil)

Mineral (used for diluting oils given above)

Synthetic resins, thermosetting:

Urea formaldehyde

Phenol Formaldehyde

Cereal binders made from corn:

Gelatinized starch (made by wet milling, contains starch and gluten)

Gelatinized corn flour (made by dry-milling hominy)

Dextrin (made from starch, a water-soluble sugar)

Wood –product binders: Natural resin (e.g., rosin, thermoplastic) Sulfite binders (contain lignin, produced in the paper pulp process) Water-soluble gums, resins, and organic chemicals

Protein binders (containing nitrogen): Glue and Casien

Other binders: Portland cement, Pitch (a coal-tar product), Molasses (usually applied in water as a spray), Cements (e.g., rubber cement) and Sodium silicate (water glass, CO2 hardening binders).

Sand testing

Criteria used for sand testing: Moisture content, green and dry sand permeabilities, compression, tension, transverse and shear strengths, deformation during compression tests, green and dry hardness, clay content, grain-size distribution, combustible content, pressure, volume of gases evolved, flowability, sintering point, resistance to spalling etc.

Molding sand preparation and moisture content determination:

The moisture content controls practically all other properties of the sand. It is a varying property since water content constantly evaporates during mold preparation. Purpose: adding sufficient water to bring the moisture content to within desired limits, uniform distribution of water, adequate coating of colloidal clay to each sand grain.

Moisture content determination:

The simplest method is to dry a sample thoroughly at a few degrees above 212oF and to consider its loss in weight as moisture.

- Drying can be done in a thermostatically controlled oven or in a instrument designed for this purpose

- There is one MOISTURE TELLER which blows air through a 50 gm sample of sand that is placed in a plate.

Testing rammed sand:

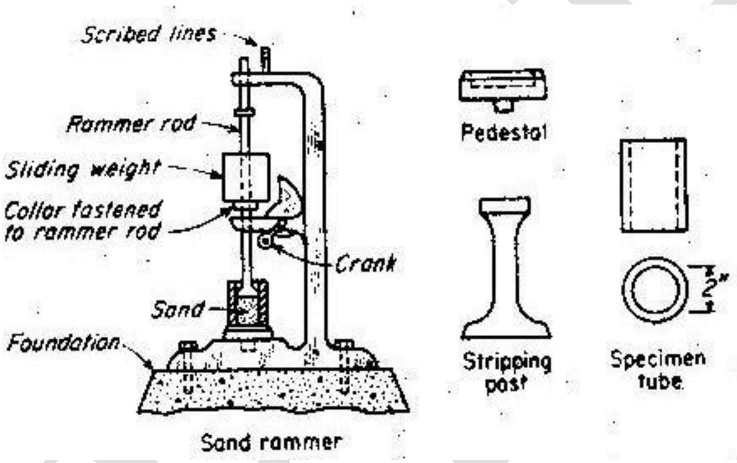
- Green permeability, green compression and few other properties are tested when the sand is in rammed condition.

- The rammed densities should be within some range which is actually encountered in the sand molds

- A predetermined weight of sand is placed into the hardened steel tube, which is closed at the bottom by a pedestal

- Actually the tube filled with sand and the pedestal are weighed

- The entire set up is placed into the sand rammer and the rammer is dropped few times depending on particular standards, like three times etc.



J S Campbell, *Principles Of Manufacturing Materials And Processes*

- the weight used will be a standard one. Depending on the ramming times, a standard density is obtained.

- once the ramming is completed, the height of the rammed sand is evaluated and this should be equal to 2 inches in length. If it is equal to this height, required density is expected to be in the rammed sand.

- If the sand height is outside the range, the entire procedure will be repeated.

Clay content:

The clay content of molding sand is determined by dissolving or washing it off the sand. to determine the clay percentage, a 50g sample is dried at 105 to 110°c and the dried sample is taken in a 1 liter flask and added with 475ml of distilled water and 25ml of a 1% solution of caustic soda. After stirring for a period of 5mins, the sample is diluted with fresh water up to a 150mm graduation mark and the sample is left undisturbed for 10mins to settle. The sand settles at the bottom and the clay particles wash from the sand would be floating in the water. 125mm of this is siphoned off the flask and it is again topped to the same level and allowed to settle for 5 mins. The above operation is repeated till the water above the sand becomes clear, which is an indication that all the clay in the molding sand has been removed. Now the sand is removed from the flask and dried by heating. The difference in weight of the dried sand and 50g when multiplied by two gives the clay percentage in the molding sand.

Sand grain size:

To find out the sand grain size, a sand sample from which moisture and clay are removed used for the testing. The dried clay free sand grains are placed on the top sieve of a sieve shaker, which contains a series of sieves one upon the other with gradually decreasing mesh size. The mesh sizes are standardized and the sieves are shaken continuously for a period of 15mins. After this shaking operation, the sieves are taken apart and the sand left over on each of the sieve is carefully weighed. The sand retained on each of the sieve expressed as a percentage of the total mass cab be plotted against the sieve number. Grain fineness number each sieve has been given a weightage factor. The amount retained on each sieve is multiplied by the respective weightage factor, summed up and then divided by the total mass of the sample, which gives the grain fineness number.

GFN=

M_i- multiplying factor for the i th sieve

f_i- amount of sand retained on the i th sieve

Permeability:

The rate of flow of air passing through a standard specimen under a standard pressure is termed as permeability number.

P=Vh / pat

V= volume of air=2000cm3

H=height of the sand specimen

P=air pressure, g/cm3

A = cross sectional area of the sand specimen

T= time in minutes for the complete air to pass through

Green compression strength

The sand specimen is compressed between two plates connected to the ram of the universal testing machine. The load at which the sand sample breaks will give the compression strength. The same tests can be performed at high temperatures in furnaces to find the compression strength at elevated temperatures.

Deformation and green hardness: During compression tests, the deformation of the sample can be recorded. The toughness can be obtained from its ultimate strength times its corresponding deformation. Green hardness is the hardness of the rammed sand that is measured by hardness tester like Brinell hardness tester. A ½ inch diameter, spring loaded

ball indenter is forced into the rammed sand surface. The resistance to penetration will give the hardness of the sand surface.

CORES

Why Cores are used?

Cores are the materials used for making cavities and hollow projections, which cannot normally be produced by the pattern alone. Any complicated contour or cavity can be made by means of cores so that really intricate shapes can be easily obtained. These are generally made of sand and are even used in permanent moulds.

CORE PROPERTIES:

-It must be strong to retain the shape while handling,

- It must resist erosion by molten metal,

- It must be permeable to gases,
- It must have high refractoriness,

-It must have good surface finish to replicate it on to the casting.

Core sands:

The core sand should contain sand grains, binders and other additives to provide specific properties.

Sand: The silica sand which is completely devoid of clay is generally used for making core sands.

Binder: Core sands need to be stronger than the molding sand and therefore the clay binder used in molding sands is not enough but somewhat better binders need to be used. The binders generally used are linseed oil, core oil, resins, dextrin, mol

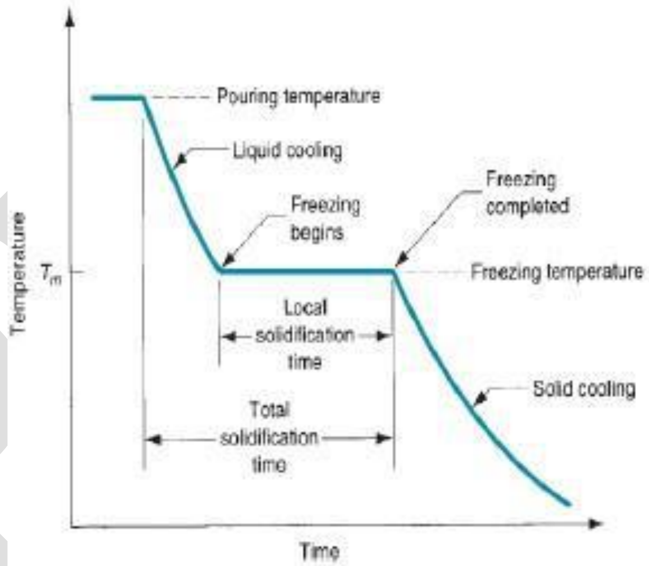
Solidification of short & long freezing range alloy castings

Solidification of pure metals

- Change of molten metal to solid state
- Solidification of pure metals and alloys are different
- The cooling curve of pure metals is shown in figure. Here solidification occurs at constant temperature equal to its freezing point.

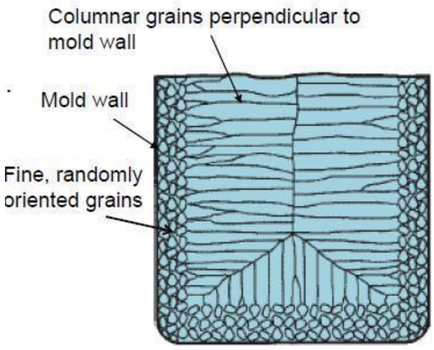
-The solidification occurs at prescribed time duration.

- Local solidification time: time between freezing start and freezing completion. In this time, the molten metal heat of fusion is delivered into mould.
- Total solidification time: time between pouring and final solidification
- First liquid cooling occurs till freezing starts. Then solidification occurs for a time duration, till freezing completes. Even after solidification is over, solid cooling occurs at a particular rate as shown in the figure.

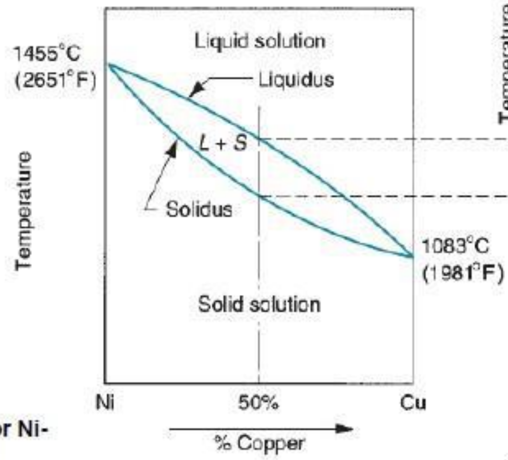


M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

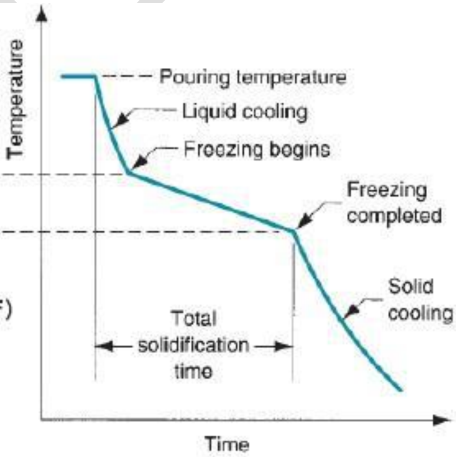
The grain structure in pure metals depends on the heat transfer into the mold and thermal properties of the metal. The mold wall acts as a chiller and hence solidification starts first in the molten metal closer to the mold wall. A thin skin of solid metal is first formed near the mold wall. The solidification continues inwards towards the mold center. The initial skin formed near the mold wall has gone through fast removal of heat and hence fine, equiaxed and randomly oriented grains are formed. When the solidification continues inwardly, heat is removed through the mold wall and thin solid skin. Here the grains grow as needles with preferred orientation. As these needles enlarge, side branches develop, and as these branches grow, further branches form at right angles to the first branches. **This type of grain growth is referred to as dendritic growth.** It occurs at the freezing of pure metals and in alloys.



Grain structure in casting of pure metals



Phase diagram for Ni-Cu alloy system



Cooling curve for 50%Ni-50% Cu during casting

A good gating design should ensure proper distribution of molten metal without excessive temperature loss, turbulence, gas entrapping and slags. If the molten metal is poured very slowly, since time taken to fill the mould cavity will become longer, solidification will start even before the mould is completely filled. This can be restricted by using super heated metal, but in this case solubility will be a problem. If the molten metal is poured very faster, it can erode the mould cavity. So gating design is important and it depends on the metal and molten metal composition. For example, aluminium can get oxidized easily. Gating design is classified mainly into two (modified: three) types: Vertical gating, bottom gating, horizontal gating.

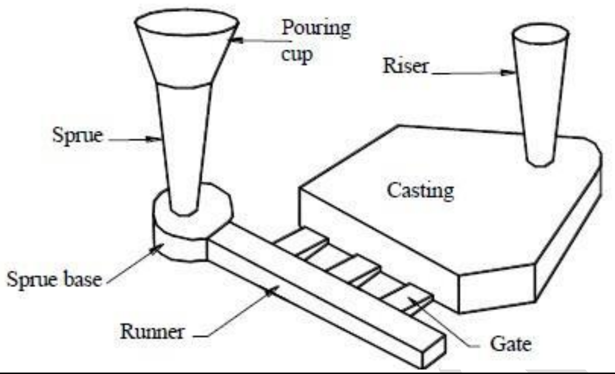


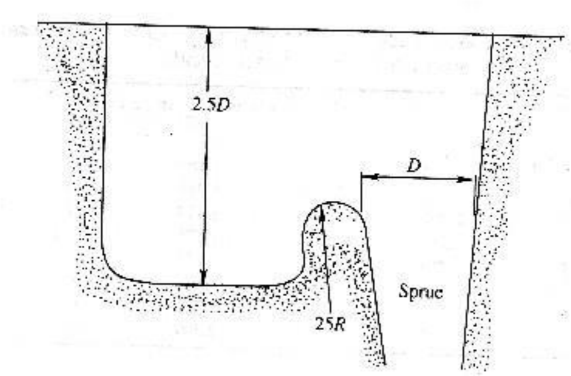
Figure: Typical gating system

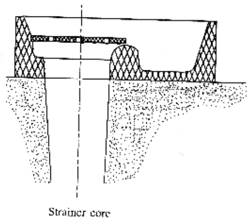
The various elements that are connected with a gating system are

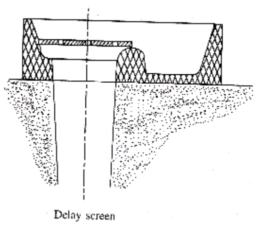
1) **Pouring basin-** The molten metal is not directly enters into the mould cavity because it may cause mould erosion. The molten metal is poured into a pouring basin, which acts as a reservoir from which it moves smoothly into the sprue. One of the walls of the pouring basin is made inclined at about 45°C to the horizontal. The molten metal is poured on this face such that momentum is absorbed and vertex formation is avoided.

The main function of a pouring basin is to reduce the momentum of the liquid flowing into the mould by settling into it.

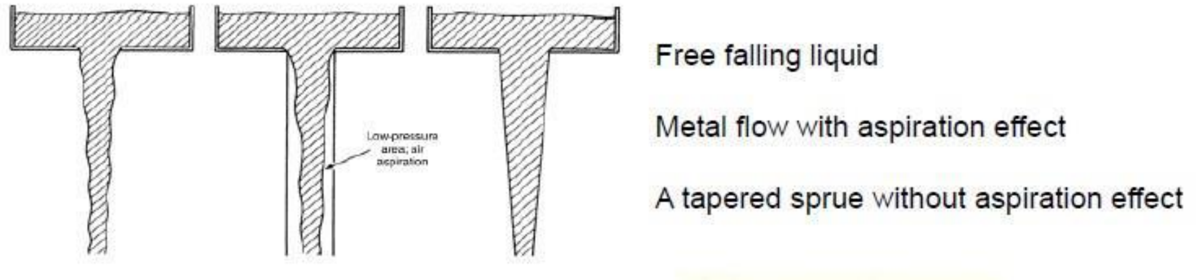
Delay screen/Strainer core: A delay screen is a small piece of perforated screen placed on top of the sprue. This screen actually melts because of the heat from the metal and this delays the entrance of metal into the sprue, maintaining the pouring basin head. This also removes dross in the molten metal. Strainer core is a ceramic coated screen with many small holes and used for same purpose. **Splash core:** provided at the end of the sprue length which reduces the eroding force of the liquid metal **Skim bob:** this traps lighter and heavier impurities in the horizontal flow.







2) **Sprue: -** The channel through which molten metal is brought into the parting plane where it enters the runners and gates to ultimately reach the mould cavity. The molten metal when moving from the top of the cope to the parting plane gains in velocity and as a consequence requires a smaller area of cross section for the same amount of metal to flow at the top. To eliminate the air aspiration problem the sprue is tapered to gradually reduce the cross section as it moves away from the top of the cope.



The exact tapering can be obtained by the continuity. Denoting the top and choke sections of the sprue by the subscript 't' and 'c' respectively,

$A_t V_t = A_c V_c$ Or $A_t = A_c V_c / V_t$

$$R = \frac{A_3}{A_2} = \sqrt{\frac{h_c}{h_t}}$$

3) Sprue base well: - This is a reservoir for metal at the bottom of the sprue to reduce the momentum of the molten metal. The molten metal as it moves down the sprue gains in velocity, some of which is lost in the sprue base well by which the mould erosion is reduced. This molten metal then changes direction and flows into the runner in a more uniform way. A general guideline could be that the sprue base well area should be five times that of the sprue choke area and the well diameter should be 2.5 times the width of the runner in a two-runner system and twice its width in a one runner system.

4) Runner: - It is generally located in the horizontal plane(parting plane), which connects the sprue to its gates, thus allowing the metal enter the mould cavity. The runners are normally made trapezoidal in cross section. It is a general practice for ferrous metals to cut the runners in the cope and the gates in the drag. The main reason for this is to trap the slag and dross, which are lighter and thus trapped in the upper portion of the runners.

5) Runner extension: - The runner is extended a little further after it encounters the in-gates. This extension is provided to trap the slag in the molten metal. The metal initially comes along with the slag floating at the top of the ladle and flows straight, going beyond the in- gates and then is trapped in the runner extension.

6) Gates or In-gate: - These are the openings through which the molten metal enters the mould cavity. The shape and the cross section of the in-gate should be such that it can readily be broken off after casting solidification and also that it allows the metal to enter quietly into the mould cavity. Depending on the application various types of gates are used in the casting design.

Top Gate: this is the type of gating through which the molten metal enters the mould cavity from the top. As the metal falls directly into the mould cavity, it is prone to form dross and as such, the top gate is not advisable for those materials, which are likely to form excessive dross.

Bottom gate: when metal enters the mould cavity slowly, it would not cause any mould erosion. Bottom gate is generally used for very deep moulds. It takes somewhat higher time for filing of the mould. These gates may cause unfavourable temperature gradients compared to the top gating.

Parting gate: the metal enters the mould at the parting plane when a part of the casting is in the cope and a part in the drag. For the mould cavity in the drag, it is a top gate and for the cavity in the cope it is a bottom gate.

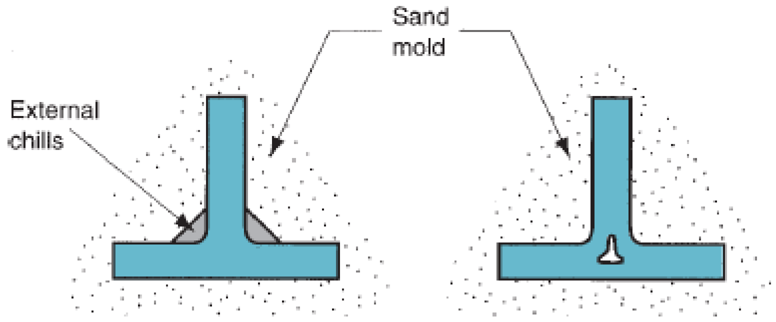
Step gate: the molten metal enters mould cavity through a number of in-gates, which are arranged in vertical steps. The size of the in gates are normally increased from top to bottom such that the metal enters the mould cavity from the bottom-most gate and then progressively moves to the higher gates. This ensures a gradually filling of the mould without any mould erosion and produces a sound casting.

7) Riser:- As a result of volumetric shrinkage during solidification, voids are likely to form in the casting, if additional metal is not provided. Hence a reservoir of molten metal is to be maintained from which the metal can flow readily into the casting when the need arises. These reservoirs are called risers. The riser has the following functions:

1) The metal in the riser should solidify in the end
2) The riser volume should be sufficient for compensating the shrinkage in the casting.

Risers are three types: top risers which are open to the atmosphere, blind risers which are completely concealed inside the mould cavity itself and internal risers which are enclosed on all sides by the casting.

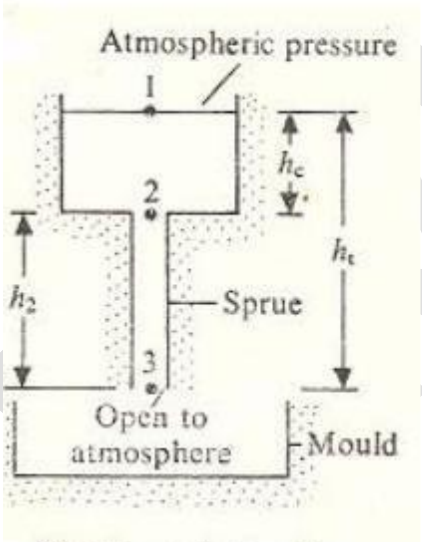
Chill: in a casting metallic chills are used in order to provide progressive solidification or to avoid the shrinkage cavities. Chills are essentially large heat sinks. Whenever it is not possible to provide a riser for a part of the casting which is heavy, a chill is placed close to it, so that more heat is quickly absorbed by the chill from the larger mass making the cooling rate equal to that of the thin sections.



Gating system design

Analysis of pouring and filling up mould

Vertical gating:



Simple vertical gating

The liquid metal that runs through the various channels in the mould obeys the Bernoulli's equation, which states that the total energy head remains constant at any section.

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^{\;2}}{2g} + F_1 = h_3 + \frac{p_3}{\rho g} + \frac{v_3^{\;2}}{2g} + F_3$$

Assuming p1 = p3 and level at 1 is maintained constant, so v1 = 0; frictional losses are neglected. The energy balance between point 1 and 3 gives,

$$gh_t = v_3^2 / 2 \qquad v_3 = \sqrt{2gh_t}$$

Another law of fluid mechanics, which is useful in understanding the gating system behaviour is the law of continuity which says taht the volume of metal flowing at any section in the mould is constant.

Here v3 can be referred as velocity at the sprue base or say gate, **Continuity equation:**

Volumetric flow rate, Q = A1v1 = A3v3

Gating ratio: sprue area : runner area : gate area Non-pressurized: has choke at the bottom of the sprue base, has total runner area and gate areas higher than the sprue area. No pressure is present in the system and hence no turbulence. But chances of air aspiration is possible. Suitable for Al and Mg alloys. In this, Gating ratio = 1 : 4 : 4 Pressurized: Here gate area is smallest, thus maintaining the back pressure throughout the gating system. This backpressure generates turbulence and thereby minimizes the air aspiration even when straight sprue is used. Not good for light alloys, but good for ferrous castings. In this, Gating ratio = 1 : 2 : 1

Risering design

It is desirable for the regions of the casting far away from the liquid metal supply to freeze first and for solidification to progress from these remote regions toward the location of riser. In this way, molten metal will continually be available from the risers to prevent shrinkage voids during freezing. For example, the regions of the cast with lower V/A ratios should be placed far away from the riser location. Solidification will start from these locations and it will progress towards the riser location where bulkier sections of the cast are present. Hence the bulkier sections will continually received molten metal from the risers till freezing.

Caine's method:

Solidification of the casting occurs by losing heat from the surfaces and the amount of the heat is given by the volume of the casting, the cooling characteristics of a casting can be represented by the surface-area-to-volume ratio. Since the riser is also similar to the casting in its solidification behaviour, the riser characteristic can also be specified by the ratio of its surface area to volume. If this ratio of the casting is higher, then it is expected to cool faster. **Chvorinov** has shown that the solidification time of a casting is proportional to the square of the ratio of volume-to-surface area of the casting. The constant of proportionality called mould constant depends on the pouring temperature, casting and mould thermal characteristics.

t_s =K —

t_s = solidification time, s

V= volume of the casting

SA = surface area

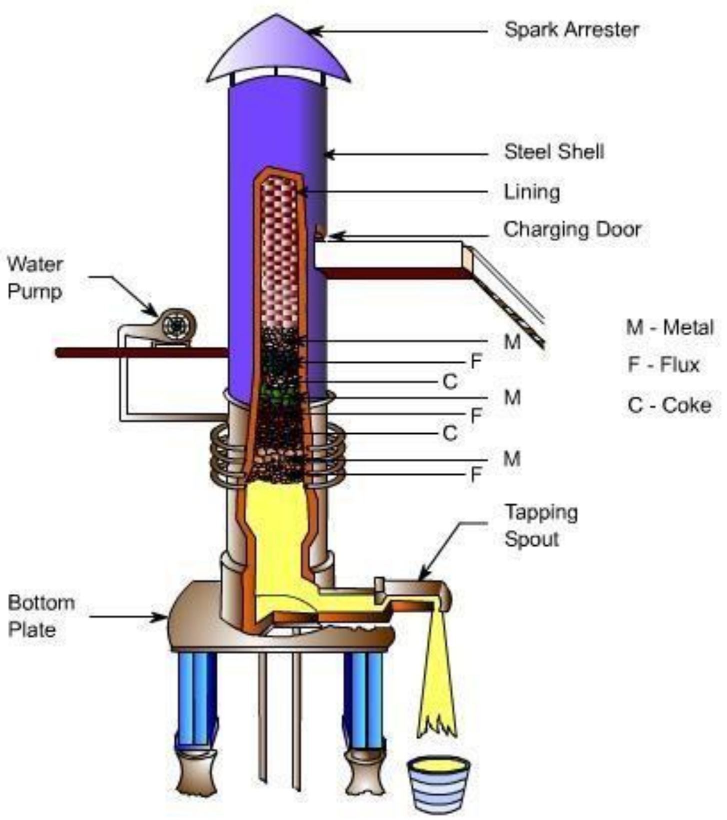
K = mould constant

The freezing ratio’, X, of a mould is defined as the ratio of cooling characteristics of castingto the riser

X = ————————

Melting practices for ferrous and non-ferrous alloys-Cupola

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. 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

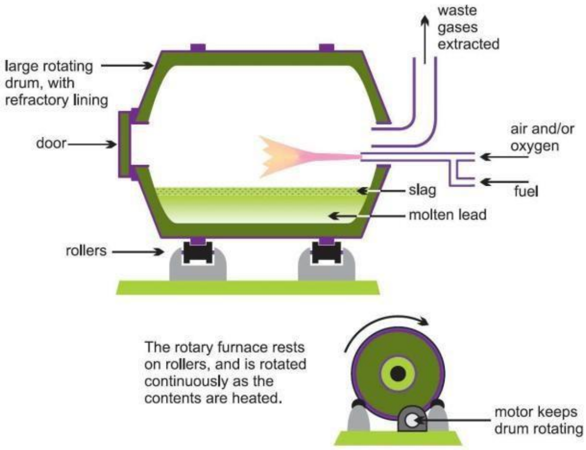
The cupola is charged with wood at the bottom. On the top of the wood a bed of coke is built. Alternating layers of metal and ferrous alloys, coke, and limestone are fed into the furnace from the top. The purpose of adding flux is to eliminate the impurities and to protect the metal from oxidation. Air 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.

Model questions

1. What are the function of flux in melting metals and alloys?
2. Describe the constructional features of a cupola furnace?

Rotary furnace

Rotary furnace is also called as tube furnace or drum furnace, a cylindrical furnace that rotates about its longitudinal axis. It is designed for the heating of the loose materials for physiochemical process. The main types of rotary furnace are those in which pulverised, solid, liquid or gaseous fuel is burned directly in the working section of the furnace, and the heating gases flow towards the material to be processed. The metal drum, which is lined with refractory brick, is mounted at a slight angle to the horizontal on the supporting rollers. In some cases, the diameter of the drum varies along its length. The drum is rotated (1-2rpm) by an electric motor through a reduction gear and an unlished toothed transmission. The blend is loaded through a port at the head. Dry blend arre loaded by mechanical feeders, but blends in the form of pulp are poured in or injected through nozzles. The fuel 10-30% of the mass of the charge is injected through burners (nozzles) located in the heating cap. This is also the point from which the processed material is unloaded for cooling. The gases from the rotary furnace are cleaned of dust. The basic dimensions of rotary furnaces vary widely: the length from 50 to 230m and diameter from 3 to 7.5m. The output of a rotary furnace may be as much as 150 tons per hour. There is a trend to increase the efficiency and economy of the furnaces while reducing their size.



Induction furnace:

The principle of induction melting is that a high voltage electrical source from a primary coil induces a low voltage, high current in the metal, or secondary coil. Induction heating is simply a method of transferring heat energy.

Uses alternating current passing through a coil to develop magnetic field in metal

- Induced current causes rapid heating and melting
- Electromagnetic force field also causes mixing action in liquid metal
- Since metal does not contact heating elements, the environment can be closely controlled, which results in molten metals of high quality and purity
- Melting steel, cast iron, and aluminum alloys are common applications in foundry work

Induction furnaces are ideal for melting and alloying a wide variety of metals with minimum melt losses, however, little refining of the metal is possible. There are two main types of induction furnace: **coreless and channel.**

Advantages:

Higher yield, Faster start up, Cleaner melting, Natural stirring, Compact installation

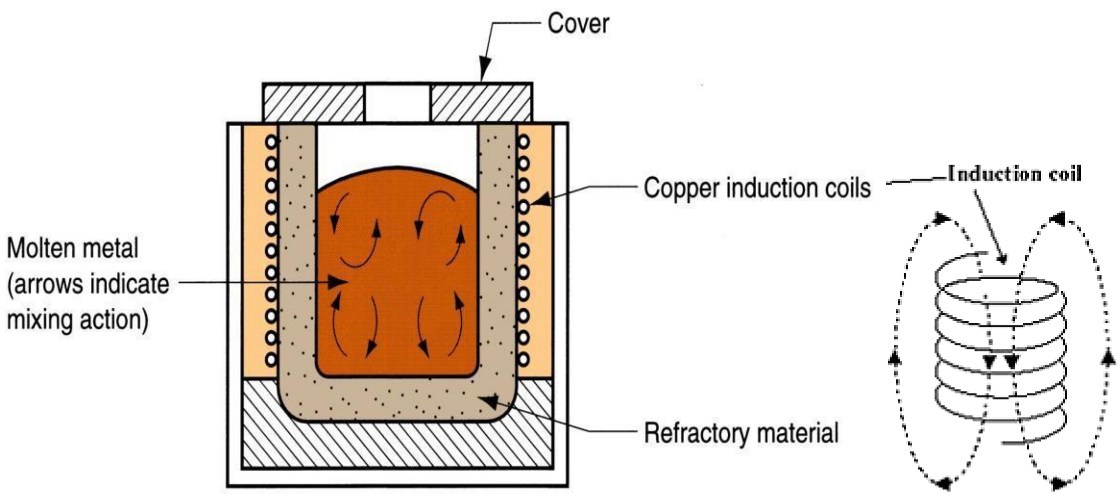


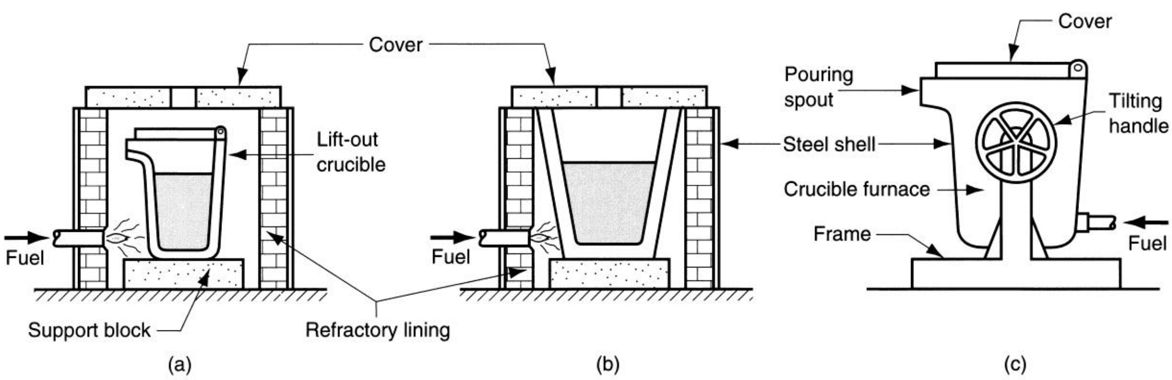
Figure. Induction furnace

Crucible Furnaces

Crucible furnaces are one of the oldest and simplest types of melting unit used in the foundry. The furnace uses a refractory crucible which contains the metal charge. The charge is heated via conduction of heat through the walls of the crucible. The heating fuel is typically coke, oil, gas or electricity. Crucible melting is commonly used where small batches of low melting point alloy are required. The capital outlay of these furnaces makes them attractive to small non-ferrous foundries.

Metal is melted without direct contact with burning fuel mixture

- Sometimes called *indirect fuel-fired furnaces*
- Container (crucible) is made of refractory material or high-temperature steel alloy
- Used for nonferrous metals such as bronze, brass, and alloys of zinc and aluminum



Three types of crucible furnaces:

(a) lift-out crucible,

(b) stationary pot, from which molten metal must be ladled, and

(c) tilting-pot furnace

Casting defects and remedy

Any irregularity in the moulding process causes defects in castings which may sometimes may voided sometimes eliminated with proper moulding practice or repaired using methods such as welding and metallization.

The following defects which are generally occur in sand casing:

1) Gas defects
2) Shrinkage cavities
3) Moulding material defects
4) Pouring material defects
5) Metallurgical defects

1) Gas defect:

Cause due to the lower gas-passing tendency of the mould which may be due to lower venting, lower permeability of the mould and improper design of the casting. The lower permeability of the mould is caused by finer grain size of the sand, high clay, higher moisture or by excessive ramming of the moulds.

Blow holes and open blows:

These are spherical, flattened or elongated cavities present inside the casting or on the surface. On the surface they are open blows and inside blow holes.

Causes

-moisture left in the mould and core.

-lower venting

-lower permeability

Remedy

-proper venting

Air inclusions:

The atmospheric and other gases absorbed by the molten metal in the furnace, in the ladle and during the flow in the mould, when not allowed to escape, would be trapped inside the casting and weaken it.

Causes:

-Higher pouring temperature

-poor gating design increase the air aspiration

-lower permeability

Remedy

-appropriate pouring temperature

Improve gating practices by reducing turbulence

1.3) Pin hole porosity:

This is caused by hydrogen in the metal. The main reason for this is the high pouring temperature which increases the gas pick-up.

2) Shrinkage cavities

These are caused by the liquid shrinkage occurring during the solidification of the casting. To compensate this, proper feeding of liquid metal is required as also proper casting design.

3) Moulding Material defect

3.1Cuts and washes

Appear as rough spots and areas of excess metal

Causes:

-Erosion of moulding sand

-Moulding sand not having enough strength

-molten metal flowing at high velocity

Remedy

Proper choice of moulding sand

Alternating the gating design to reduce turbulence by increasing the size of gates or by using multiple in gates

Metal penetration

Causes:

Grain size of the sand grains too coarse

No mould wash has been applied to the mould cavity

Higher pouring temperature

Remedy

Choosing appropriate grain size together with a mould wash

Fusion

Cause

Fusion of sand grains with molten metal giving a brittle, glassy appearance on the casting surface

Clay in the moulding sand is of lower refractoriness

Pouring temperature is too high

Remedy

Choice of an appropriate type and amount of bentonite would cure this defect

Runout

Cause

When molten metal leaks out of the mould Faulty
mould making

Remedy

Faulty moulding flask

Rat tails and buckles

Causes

Compression failure of the skin of the mould cavity because of the excessive heat in the molten metal.

Under the influence of the heat, the sand expands, thereby moving the mould wall backwards and in the process when the wall gives away, the casting surface may have this marked as a small line. With a number of such failures, the casting surface may have a number of criss-crossing small lines. Buckles are the rat tails which are severe.

Causes

-moulding sand has poor expansion properties and hot strength

-the heat in the pouring metal is too high

Facing sand does not have enough carbonaceous material to provide the cushioning effect

Remedy

Proper choice of facing sand ingredients and the pouring temperature are the measure to reduce the incident of these defects.

Swell

Due to metallostatic forces the mould wall may move back causing a swell in the dimensions of the casting. As a result of the swell, the feeding requirements of the castings increase which should be taken care of by proper choice of risering.

Cause

Faulty mould making

Remedy

A proper ramming of the mould should correct this defect

Drop

The dropping of loose moulding sand or lump normally from the cope surface into the mould cavity is responsible for this defect.

Cause

Due to improper ramming of the cope flask

4) **Pouring metal defect**

Misruns and cold shuts: Misrun is caused when the metal is unable to fill the mould cavity completely and thus leaves unfilled cavities. A cold shut is caused when two metal streams while meeting in the mould cavity do not fuse together properly, thus causing a discontinuity or weak spot in the casting.

Causes:

-Lower fluidity of the molten metal

-Section thickness of the casting is too small

Remedy

-Increase the fluidity of the metal

-proper casting design

-Castings with large surface to volume ratio

-Improving the mould design

Slag inclusions

During the melting process, flux is added to remove the undesirable oxides and impurities present in the metal.

At the time of tapping, the slag should be properly removed from the ladle, before the metal is poured into the mould. Otherwise any slag entering the mould cavity will be weakening the casting and also spoil the surface of casting.

Remedy

By adoptiong some slag trapping method

5) **Metallurgical defect**

5.1Hot tears

Since metal has low strength at gigher temperatures, any unwanted cooling stree may cause rupture of the casting.

Cause

Poor casting design

5.2Hot spots

Cause

Chilling of the casting

Remedy

Proper metallurgical control and chilling practices

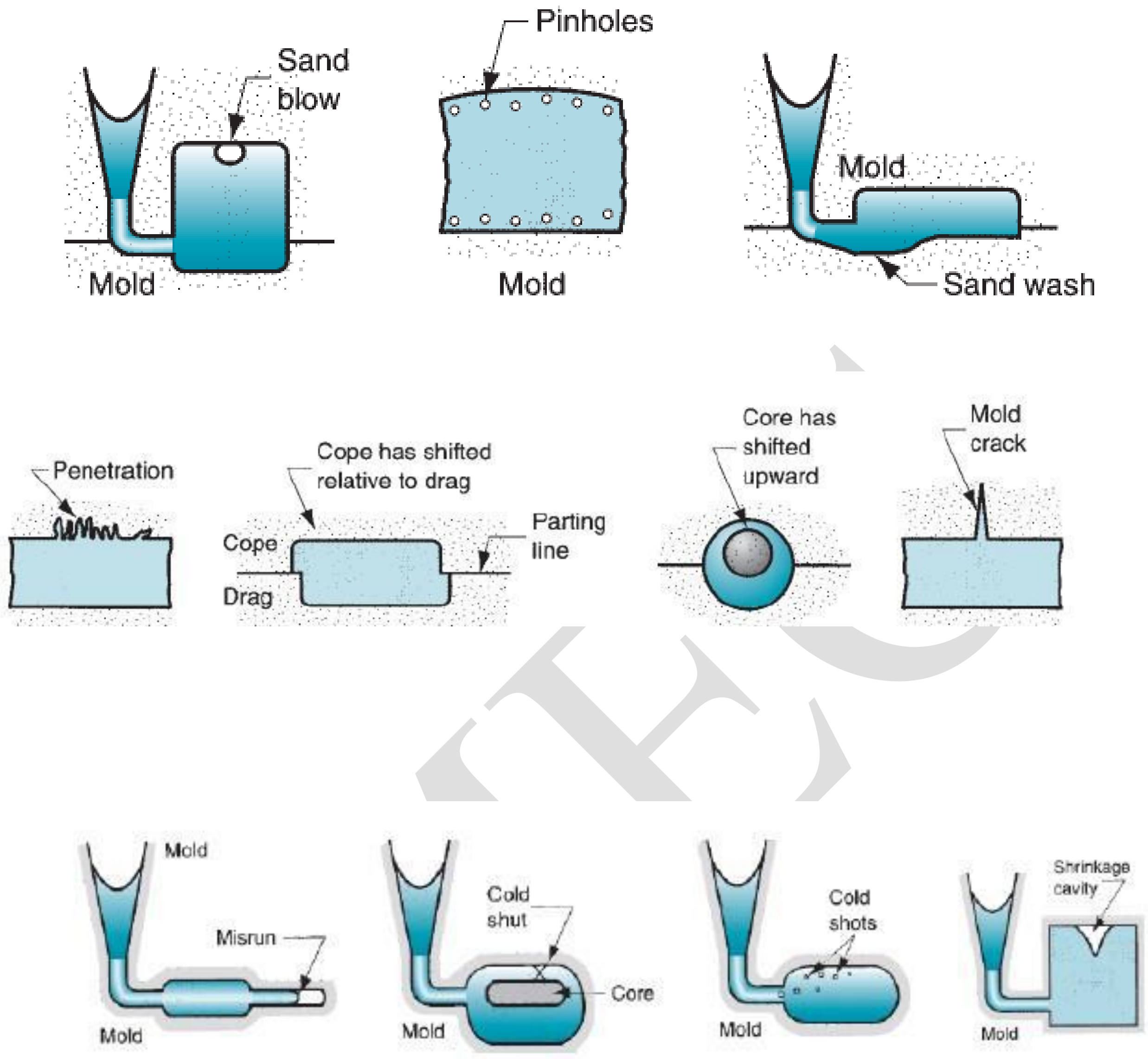


Figure Various sand casting defects

Differentiate between

(a) cold shut and misrun

(b) blow hole and pin hole porosity

(c) metal penetration and fusion

(d) rat tails and cuts, washes

Special casting processes

Shell moulding:

The shell moulding is a casting process in which the mould is a thin shell of 9 mm thick. This is made of sand held together by thermosetting resin binder.

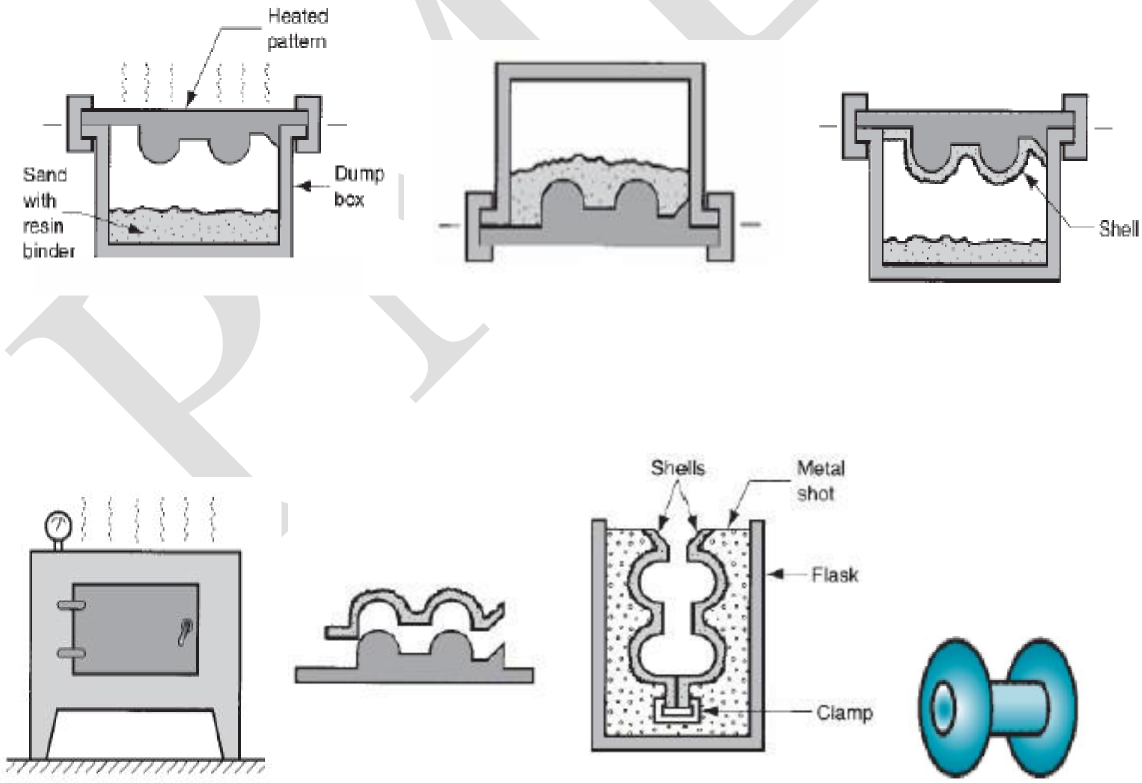
- A metal pattern is heated and placed over a box containing sand mixed with thermosetting resin.

- The dump box is inverted so that sand and resin mixture fall on the hot pattern, causing a layer of the mixture to partially cure on the pattern surface to form a hard shell.

- The box is positioned to the previous stage, so that loose, uncured particles drop away.

-Sand shell is heated in oven for several minutes to complete curing.

- The shell mold is removed from the pattern and two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is completed.



Advantages of shell moulding process

- The surface of the shell mould is smoother than conventional green sand mould. This permits easier flow of molten metal during pouring and better surface finish on the final casting.

- Surface finish of the order of 2.5 µm can be obtained. Good dimensional tolerances of the order of ± 0.25 mm can be reached in a small to medium sized parts.

- Machining operations are reduced because of good surface finish.

Disadvantages

- Expensive metal pattern is required, and hence not suitable for small quantities.

- Can be mechanized for mass production and will be economical too.

Examples of parts made using shell molding include gears, valve bodies, bushings, and camshafts.

Precision Investment casting

In this casting process, a pattern made of wax is coated with a refractory material to make the mold surface, after which the wax is melted away while pouring the molten metal. “Investment” means “to cover completely” which refers to the coating of the refractory material around the wax pattern. This is a precision casting process. Using this we can make castings of high accuracy with intricate details.

Steps in investment casting process

1• Wax patterns are first made

2• several patterns can be attached to a sprue to form a pattern tree, if required

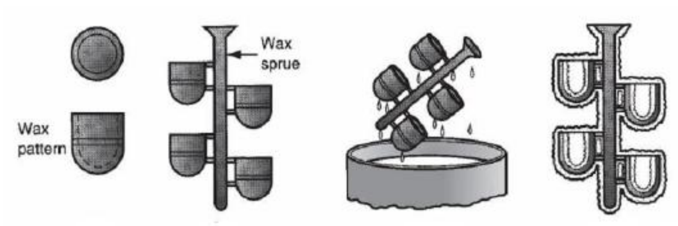
3• the pattern tree is coated with a thin layer of refractory material and later covered with thick coating to make the rigid full mold

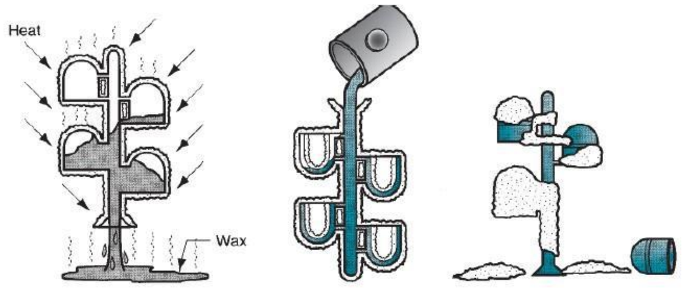
4• Heating of mold in inverted position to melt the wax and permit it to drip out of the cavity

5• the mold is preheated to a high temperature so that contaminants are eliminated from the mold

6• the molten metal is poured and it solidifies

7• the mold is removed from the finished casting





Refractory coating:

• Slurry of very fine grained silica or other refractory, in powder form, mixed with plaster to bond the mold into shape. The small grain size of the refractory material delivers smooth surface and captures the intricate depths of the wax pattern.

• Mold is allowed to dry in air for about 8 hours to harden the binder.

Advantages:

(1) Complex and intricate parts can be cast

(2) Tolerances of 0.075 mm are possible

(3) Good surface finish is possible

(4) In general, additional machining is not required – neat net shaped part Applications: - Steels, stainless steels, high temperature alloys can be cast - Examples of parts: machine parts, blades, components for turbine engines, jewelry, dental fixtures

Permanent mold process

Disadvantage of expendable molding processes is that for every casting a new mold is required. **Permanent mold processes:**

• using only metal mold for casting

• Molds are generally made of steel, CI

• Materials that can be cast: Al, Mg, Cu based alloys, CI (affect the mold life, hence not used)

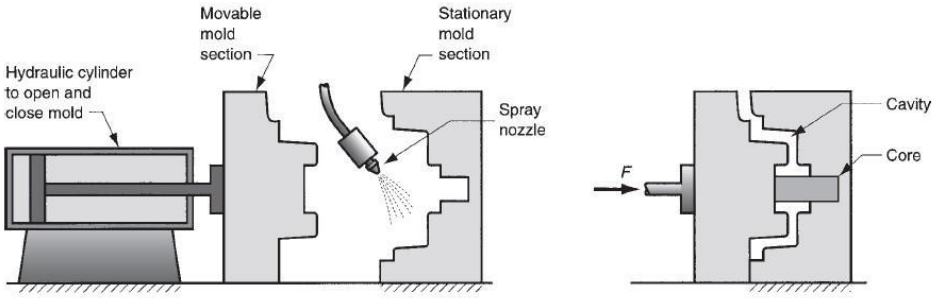
• Cores are also made of metal, but if sand is used then called semi permanent-mold casting

• Advantages: good surface finish, dimension tolerance, rapid solidification causes fine grains to form giving stronger products

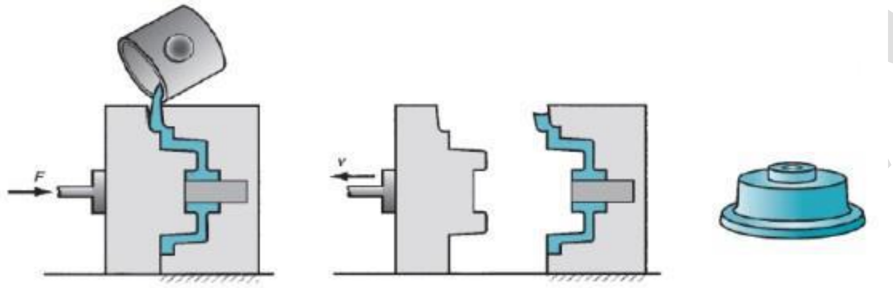
•Limitations: restricted to simple part geometries, low melting point metals, mold cost is high. Best suitable for small,

large number of parts.

Steps in permanent mold process



Preheating facilitates metal flow through the gating system and into the cavity. The coatings aid heat dissipation and lubricate the mold surfaces for easier separation of the cast product.

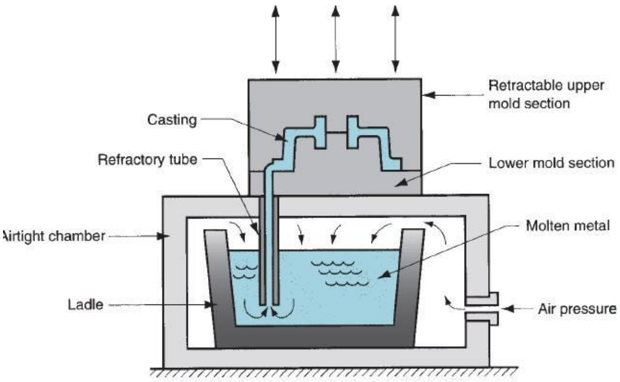


Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

Variations of permanent mold casting

Low pressure casting:

- In the earlier casting process, metal flow in mold cavity is by gravity pull, but in low pressure casting, liquid metal is forced into the cavity under low pressure, app. 0.1 MPa, from beneath the surface so that metal flow is upward.
- Advantage: molten metal is not exposed to air; gas porosity and oxidation defects are minimized Vacuum permanent mold casting: variation of low pressure casting, but in this vacuum is used to draw the molten metal into the mold cavity.



Low pressure casting

Die casting

A permanent mold casting process in which molten metal is injected into mold cavity under high pressure

- Pressure is maintained during solidification, then mold is opened and part is removed
- Molds in this casting operation are called *dies*; hence the name die casting
- Use of high pressure to force metal into die cavity is what distinguishes this from other permanent mold processes
- In diecasting the die consists of two parts. One part is called the stationary half or cover die which is fixed to the diecasting machine. The second part is called the moving half or ejector die that is moved out for the extraction of the casting. The casting cycle start when the twp parts of the die are apart. The lubricant is sprayed on the die cavity manually or by the auto lubrication system so that the casting will not stick to the die. The two die halves are closed and clamped. The required amount of metal is injected into the die. After the casting is solidify under pressure, the die is opened and the casting is ejected. The die casting die needs to have the provision of ejectors to push the casting after it gets solidify.

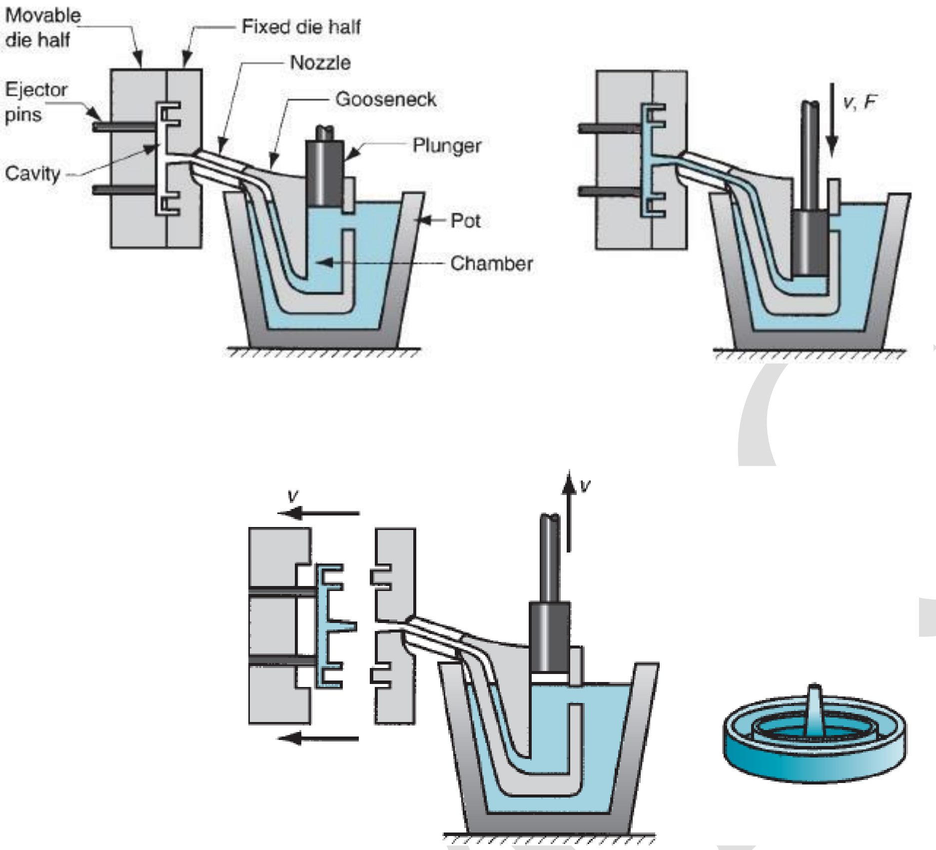
Die Casting Machines

- Designed to hold and accurately close two mold halves and keep them closed while liquid metal is forced into cavity
- Two main types:

1. Hot-chamber machine
2. Cold-chamber machine

Hot chamber machines: - Molten metal is melted in a container attached to the machine, and a piston is used to pressurize metal under high pressure into the die. Typical injection pressures are between 7 and 35 MPa. - Production rate of 500 parts/hour are common. - Injection system is submerged into the molten metal and hence pose problem of chemical attack on the machine components. Suitable for zinc, tin, lead, Mg.

Steps in hot chamber casting

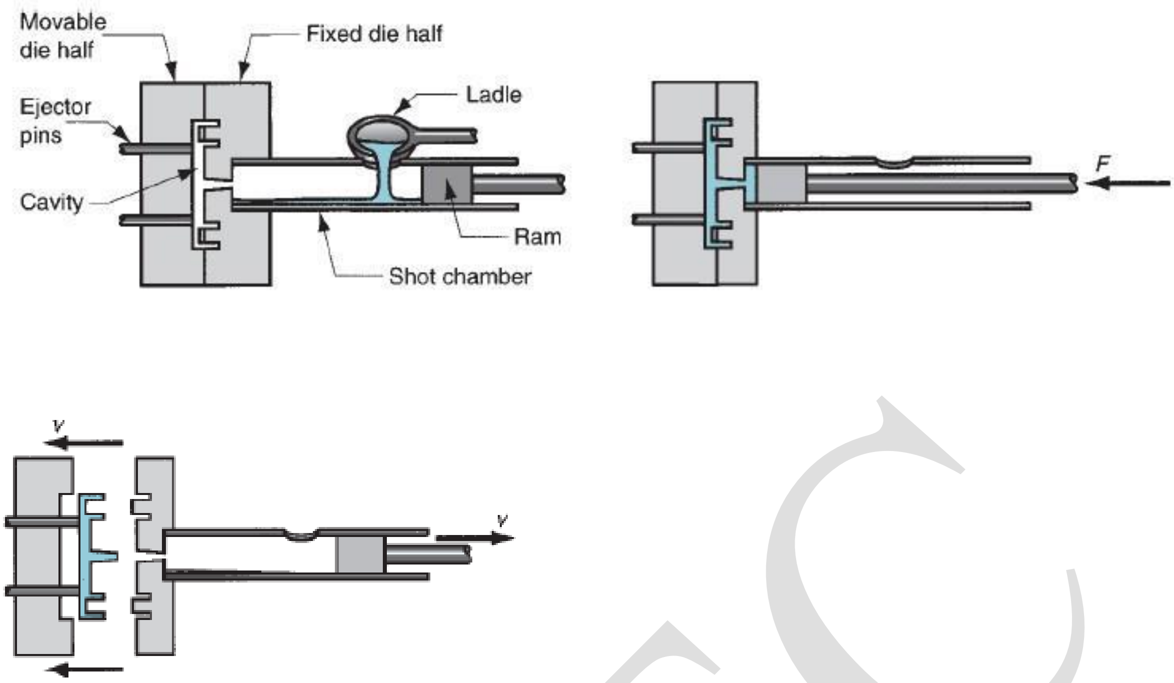


Cold chamber machines:

- Molten metal is poured from an external unheated container into the mold cavity and piston is used to inject the molten metal into the die cavity.
- Injection pressure: 14 to 140 MPa.
- Though it is a high production operation, it is not as fast as hot chamber machines.

Steps in cold chamber casting

Die casting molds are made of tool steel, mold steel, maraging steels. Tungsten and molybdenum with good refractory qualities are also used for die cast steel, CI.



Advantages of die casting: - high production rates and economical

- Close tolerances possible of the order of ±0.076 mm

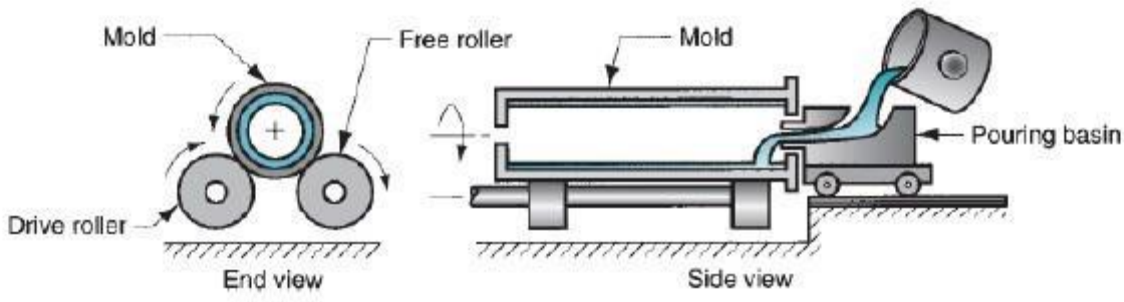
- Thin section with 0.5 mm can be made

- Small grain size and good strength casting can be made because of rapid cooling

In this method, the mold is rotated at high speed so that the molten metal is distributed by the centrifugal force to the outer regions of the die cavity

- includes : true centrifugal casting, semicentrifugal casting

True centrifugal casting:



Molten metal is poured into a rotating mold to produce a tubular part (pipes, tubes, bushings, and rings)

- Molten metal is poured into a horizontal rotating mold at one end. The high-speed rotation results in centrifugal forces that cause the metal to take the shape of the mold cavity. The outside shape of the casting can be non-round, but inside shape of the casting is perfectly round, due to the radial symmetry w.r.t. forces

- Orientation of the mold can be **horizontal or vertical** For horizontal centrifugal casting:

For horizontal centrifugal casting:

$$\text{centrifugal force} = F = \frac{mv^2}{R}$$

Where F – force in N, m – mass in kg, v – velocity in m/s, R – inner radius of mold in m

Here we define G-factor (GF) as the ratio of centrifugal force to weight.

$$GF = \frac{\left(\frac{mv^2}{R}\right)}{mg} = \frac{v^2}{Rg}$$

For horizontal centrifugal casting, GF is equal to 60 to 80

Putting $v = 2\pi RN/60$ in the above eqn. and after rearrangement gives,

$$N = \frac{30}{\pi}\sqrt{\frac{2g(GF)}{D}}$$

Where N is rotational speed in rev/min., D is inner diameter of mold in m

If the G-factor is very less, because of the reduced centrifugal force, the liquid metal will not remain forced against the mold wall during the upper half of the circular path but will go into the cavity. This means that slipping occurs between the molten metal and the mold wall, which indicates that rotational speed of the metal is less than that of the mold.

Vertical centrifugal casting: In this because of the effect of gravity acting on the liquid metal, casting wall will be thicker at the base than at the top. The difference in inner and outer radius can be related to speed of rotation as,

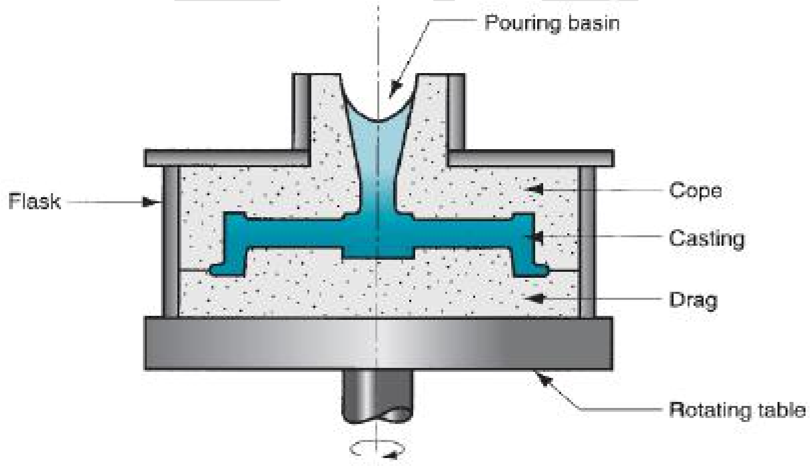
$$N = \frac{30}{\pi}\sqrt{\frac{2gL}{R_{it}^{2} - R_{ib}^{2}}}$$

where
L - vertical length of the casting in m,
R_{it} - inner radius at the top of the casting in m,
R_{ib} - inner radius at the bottom of the casting in m

It is observed from the eqn. that for $Rit = Rib$, the speed of rotation N will be infinite, which is practically impossible.

Solidification shrinkage at the exterior of the cast tube will not be an issue, because the centrifugal force continually moves molten metal toward the mold wall during freezing. Impurities in the casting will be on the inner wall and can be removed by machining after solidification.

Semicentrifugal casting:



In this process, centrifugal force is used to produce non-tubular parts (solid), and not tubular parts. GF will be around 15 by controlling the rotation speed. Molds are provided with riser at the center. Generally the density of metal will be more at the outer sections and not at the center of rotation. So parts in which the center region (less denser region) can be removed by machining (like wheels, pulleys) are usually produced with this method.

Advantages:

1. The mechanical properties of centrifugally cast jobs are better compared to other processes, because the inclusions such as slag and oxides get segregated towards the centre and can be easily removed by machining.
2. The pressure acting on the metal throughout the solidification, causes the porosity to be eliminated giving rise o dense metal.
3. No cores are required for making concentric holes in case of true centrifugal casting.

Disadvantages:

1. Only certain shapes which are axi-symmetric and having concentric holes are suitable for true centrifugal casting.
2. The equipment is expensive and thus is suitable only for large scale production.

Continuous casting of steel

Introduction

In the continuous casting, molten steel is poured from the tundish in the water cooled mold and partially solidified bloom/billet or slab (hereafter called strand) is withdrawn from the bottom of the mold into water spray so that solidified bloom/billet or slab is produced constantly and continuously. Continuous casting is widely adopted by steelmakers. The advantages of continuous casting over ingot casting are

-Quality of the cast product is better

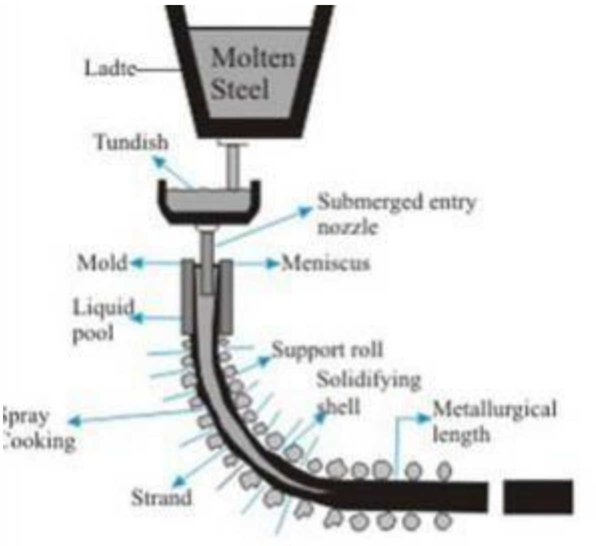
-No need to have slabbing/blooming or billet mill as required when ingot casting is used.

-Higher extent of automation is possible

-Width of the slab can be adjusted with the downstream strip mill.

-Continuously cast products show less segregation.

-Hot direct charging of the cast product for rolling is possible which leads to energy saving.



Arrangement of tundish, mold and water spray in a curved mold machine

How casting is done continuously?

The essential components of a continuous casting machine are tundish, water cooled mold, water spray and torch cutters. Tundish, mold and water spray are arranged such that molten stream is poured from tundish to mold and solidified strand (billet/bloom/billet) is produced continuously. The required length of the strand is cut by torch cutter. In figure, the arrangement of tundish, mold and water spray is

Tundish

Tundish is a refractory lined vessel. Liquid steel is usually tapped from ladle into tundish. The stream is shrouded as it enters from ladle to tundish. The functions of the tundish are:

Reservoir of molten steel

Tundish acts as a reservoir for molten steel. It supplies molten steel in presence of a slag cover to all continuous casting molds constantly and continuously at constant steel flow rate. The flow rate is maintained constant by maintaining a constant steel bath height in the tundish through teeming of molten steel from the ladle. The number of mold is either one or more than one. Normally bloom and billet casting machines are multi-strand i.e. number of molds are either 4 or 6 or 8. Slab casters usually have either single or two molds. During sequence casting and ladle change- over periods, tundish supplies molten steel to themolds.

Distributor

Tundish distributes molten steel to different molds of the continuous casting machine at constant flow rant and superheat which is required for stand similarly with reference to solidification microstructure. Control of superheat is required in all the moulds to reduce break-out. Location of ladles stream in the tundish is important. It may be located symmetric or asymmetric to the centre of the tundish depending on the number of mold. For single strand machines, molten stream enters from one side and exits the other side of the tundish. In multi-strand tundishes, ladle stream is either at the centre of the tundish or displaced to the width side of the tundish.

Inclusion removal

Tundish helps to remove inclusions during the process of continuous casting. For this purpose liquid steel flow in the tundish is modified by inserting dams, weirs, slotted dams etc. The whole idea is to utilize the residence time available before steel leaves the tundish. For example, if capacity of tundish is 40 tons and casting speed is 5 tons/min, then the average residence time of molten steel in the tundish is 8 minutes. During this average residence time., inclusion removal can be exercised .For this purpose flow of steel melt in the tundish has to be modified so as to accelerate the inclusion removal. The Inclusion removal is a two step step unit operation, namely floatation and absorption by a flux added on the surface of the tundish. Flux is usually rice husk, or fly ash or some synthetic powder. The readers may see the references given at the end of this lecture for further reading.

Module II

Introduction to metal joining processes

Joining of two or more elements to make single part is termed as fabrication process. Common examples are aircraft, ship bodies ,bridges , welded machine frames etc.The various fabrication processes can be classified as follows:

a. Mechanical joining by means of bolts , screws and rivets.

b. Adhesive bonding by employing synthetic glues such as epoxy resins.

c. Welding , brazing , soldering.

- Adhesive are capable of providing the necessary strength to withstand the applied loads for some applications. The most commonly used adhesive are

a. Thermosetting resin

b. Thermoplastic resin

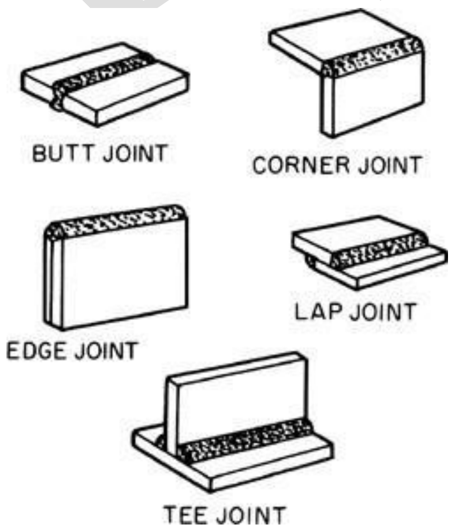
c. Silicone resin

d. Elastomer

- Welding is a metallurgical fusion process. Here the interface of the two parts to be joined are brought to a temperature above the melting point and then allowed to solidify so that a permanent joining takes place because of permanent of the joint and its strength being equal or something greater than that of parent metal.

Before going to study the welding process some general consideration:

- **Types of joints:** Different types of welding joints are classified as butt , lap, tee and



edge:

- It is necessary that the interface should be clean. If the interface is not clean and have any oil , dirt then these would interfere with the proper fusing of the metal and thus weaken the joint to remove the oily substance organic solvents such as acetone and carbon tetra chloride may be used.

- Sometimes the oxide that are present in the surface would also interfere proper fusing. Hence they are to be eliminated by use of fluxes.
- Another requirement of welding is filler metal. Ideally the composition of the filler metal should be same as that of base metal which are being joined.

Some important definition in the welding are

- **Backing:** It is the material support provided at root side of a weld to aid in the control of penetration.
- **Base Metal:** The metal to be joined or cut is termed the base metal.
- **Bead or weld bead:** Bead is metal added during a single pass welding.The bead appears as a separate material from the base metal.
- **Crater:** In Arc welding , a crater is the depression in the weld –metal pool at the point where the arc strikes their base metal plate.
- **Puddle:** The portion of the weld joint that is melted by the heat of welding is called puddle.
- **Weld face:** It is the exposed surface of the weld.
- **Root:** It is the point at which the two pieces to be joined by welding are nearest.

The weld joint and quality of welding

There are three distinct zones formed in a typical weld joint.

Fusion zone

The area of base metal and filler metal that has been completely melted

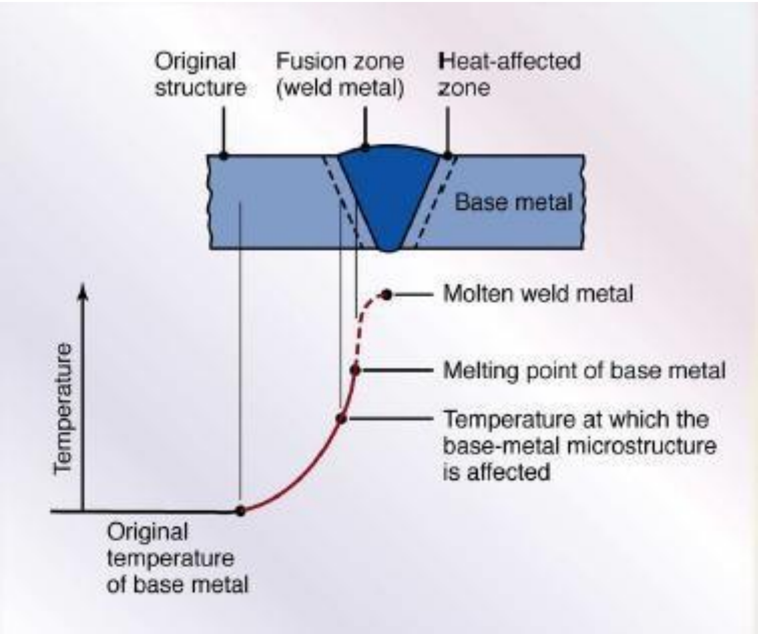
Weld interface

A thin area of base metal that was melted or partially melted but did not mix with the filler metal

Heat affected zone

The surrounding area of base metal that did not melt, but was heated enough to affect its grain structure

The metallurgy and properties of the heat affected and weld quality greatly depend on the type of metals joined, the particular joining process, the filler metals used (if any), and welding process available. Characteristics of s typical fusion weld zone in oxyfuel-gas and arc welding is shown in Figure



Heat affected zone

The heat-affected zone is the narrow region of the base metal adjacent to the weld bead, which is metallurgically altered by the heat of welding. It has a microstructure different from that of base metal prior to welding. The heat-affected zone is usually the major source of metallurgical problems in welding. The width of the heat-affected zone depends on the amount of heat input during welding and increases with the heat input. The properties and microstructure of the HAZ depends on the rate of heat input and cooling and the temperature to which this zone was raised.

Effect of HAZ

If the workpiece material was previously cold worked, this HAZ may have experienced recrystallization and grain growth, and thus a diminishment of strength, hardness, and toughness. The strength and hardness of HAZ depend partly on how the original strength and hardness of the base metal was developed prior to the welding. Upon cooling, residual stresses may form in this region that weakens the joint. It can also lead to loss of corrosion resistance in stainless steels and nickel-base alloys. For steels, the material in this zone may have been heated to temperatures sufficiently high so as to form austenite. Upon cooling to room temperature, the microstructural products that form depend on cooling rate and alloy composition. For plain carbon steels, normally pearlite and a proeutectoid phase will be present. For alloy steels, one micro-structural product phase may be martensite, which is ordinarily undesirable because it is so brittle.

Grouping of welding processes

-The grouping of welding processes has been made according to the mode of energy transfers a primary consideration.

-Other terms and factors, such as the type of current, whether the electrodes are continuous or incremental or the method of application are not considered.

-**Coalescence**: It is defined as the growing together or growth into one body of the materials being welded and is applicable to all types of welding.

Classification of welding processes

Welding process are classified as-

1. **Gas welding:-**
   - **-Air acetylene welding**
     - **-Oxy acetylene welding**
     - **-Oxy hydrogen welding**
   - **-pressure gas welding**
2. **Arc welding:-**
   - **-Carbon arc welding**
   - **-Shielded metal work welding**
   - **-Flux cored arc welding**
   - **-Submerged arc welding**
   - **-TIG(GTAW) welding**
   - **-MIG(GMAW) welding**
   - **-Plasma arc welding**
   - **-Electro slag welding or electro gas welding**
3. **Resistance welding:-**
   - **-Spot welding**
   - **-Seam welding**
   - **-Percussion welding**
   - **-Flash butt welding**
   - **-Resistance butt welding**
4. **Solid state welding:-**
   - **-Cold welding**
   - **-Diffusion welding**

-Explosive welding

-Friction welding

-Hot pressure welding

-Ultrasonic welding

5. **Thermo chemical welding:-**

   -Thermit welding

   -Atomic hydrogen welding

6. **Radiant energy welding:-**

   -Electron beam welding

   -Laser beam welding

According to modern method the welding may be classified as

I. **Pressure welding(plastic welding)**

II. **Non pressure welding(fusion welding)**

Pressure welding:-

In pressure welding the piece of metal to be joined are heated to a plastic state and then force together by external pressure.

Ex:-Resistance welding, Hot pressure welding, Diffusion welding

Non pressure welding:-

In non pressure welding the material at the joint is heated to the molten state and allowed to solidify.

Ex:-Gas welding, Arc welding

Advantages of welding process:-

I. A good weld is formed which is as strong as the base metal.

II. General welding equipments are not very costly.

III. A large number of metals or alloys can be joined by welding .

Dis advantages of welding process:-

I. It gives harmful radiation and fumes.

II. Edge preparation of the workpiece is needed before welding.

III. The welding heat produces metallurgical changes in the base metal.

Definition of welding groups

Arc welding → A group of welding processes that produce coalescence of workpieces by heating them with an arc. The processes are used with or without the application of pressure and with or without filler metal.

Oxyfuel welding → A group of welding processes that produces coalescence of workpieces by heating them with an oxyfuel gas flame. The processes are used with or without the application of pressure and with or without filler metal.

Resistance welding → A group of welding processes that produces colescence of the faying surfaces with the heat obtained from resistance of workpieces to the flow of the welding current in a circuit of which the workpieces are a part, an by the application of pressure.

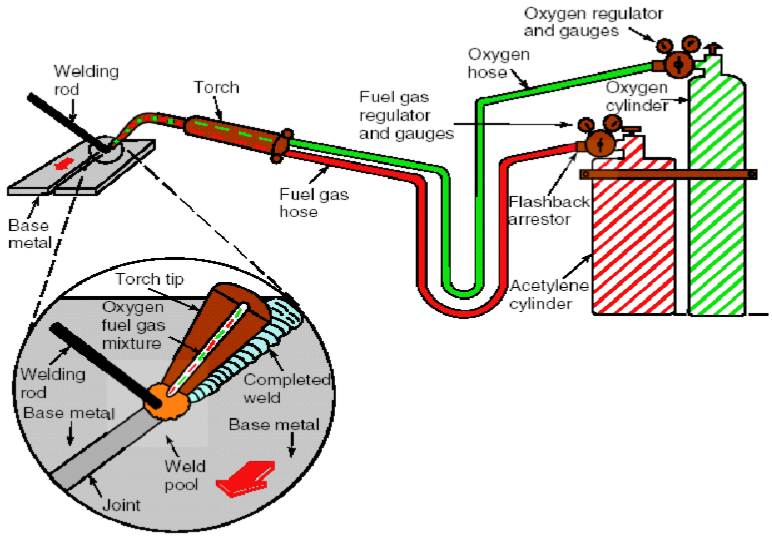
Solid state welding → A group of welding processes that produces colescence by the application of pressure without melting any of the joint components

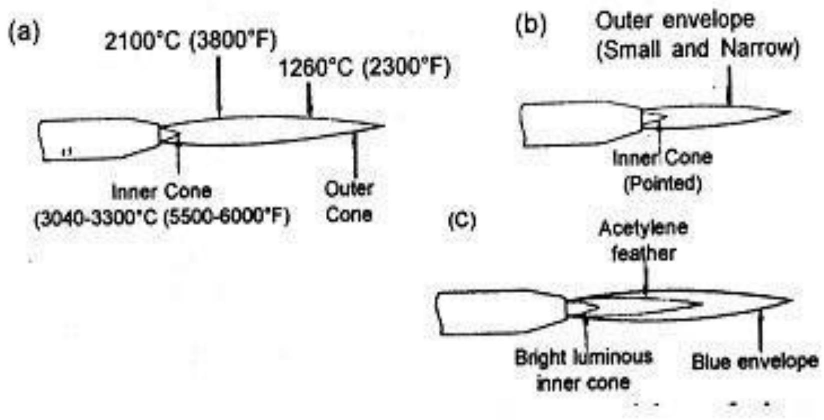
GAS WELDING

As the name implies gas welding is also called oxy fuel gas welding, derives the heat from the combustion of fuel gas such as acetylene in combustion with oxygen.The procress is called fision welding process where the join is completely melted to obtain the fusion. The heat produced by the combustion of gas is sufficient to melt and as such ,is universally applicable.

Oxy-acetylene welding(OAW)

The oxyacetylene welding process uses a combination of oxygen and acetylene gas to provide a high temperature flame.





As we know that acetylene has the high calorific value and high flame temperature.

The first reaction takes place when the fuel gas such as acetylene and oxygen mixture burns releasing intense heat.

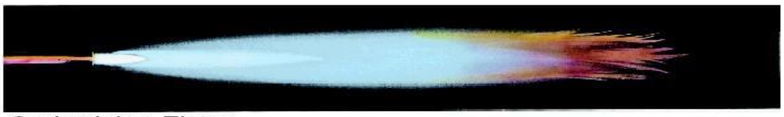
For oxy acetylene welding ,the following reaction takes place C_2
H_2+O_2 ----------> 2CO+H_2+448kj/mol
The carbon monoxide(CO) and hydrogen produced in the first stage ,further combine with atmospheric oxygen and gives rise the outer bluish flame, with the following reaction.
4CO+2H_2+3$0_2$ ------------->4CO_2 +2H_2O+812kj/mol

Though higher amount of heat is produced in the second stage ,since it is distributed over a large area ,the temperature achieved is small(of the order of 1200 to 2000^0c) in the flame, which may be used for the preheating the steels. The inner white cone is of the order of 3100^0c which is used for directly melting the steel.

There are three types of flame

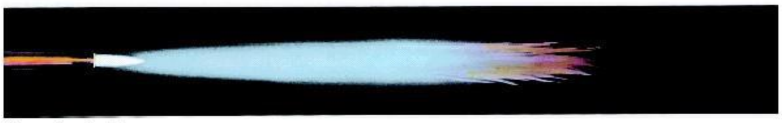
1) Neutralizing flame
2) Carburizing flame

Acetylene Burning in Atmosphere
Open fuel gas valve until smoke clears from flame.



Carburizing Flame
(Excess acetylene with oxygen.) Used for hard-facing and welding white metal.

3) Oxidizing flame



Neutral Flame
(Acetylene and oxygen.) Temperature 5589˚F (3087˚C). For fusion welding of steel and cast iron.

Oxidizing Flame
(Acetylene and excess oxygen.) For braze welding with bronze rod.

Flame definition

- The **neutral** flame is produced when the ratio of oxygen to acetylene, in the mixture leaving the torch, is almost exactly one-to-one. It's termed "neutral" because it will usually have no chemical effect on the metal being welded. It will not oxidize the weld metal; it will not cause an increase in the carbon content of the weld metal.

- The **excess acetylene** flame as its name implies, is created when the proportion of acetylene in the mixture is higher than that required to produce the neutral flame. Used on steel, it will cause an increase in the carbon content of the weld metal.

The **oxidizing flame** results from burning a mixture which contains more oxygen than required for a neutral flame. It will oxidize or "burn" some of the metal being welding.

Welding Equipment

Acetylene gas

- Virtually all the acetylene distributed for welding and cutting use is created by allowing calcium carbide (a man made product) to react with water.
- The nice thing about the calcium carbide method of producing acetylene is that it can be done on almost any scale desired. Placed in tightly-sealed cans, calcium carbide keeps indefinitely. For years, miners' lamps produced acetylene by adding water, a drop at a time, to lumps of carbide.

Before acetylene in cylinders became available in almost every community of appreciable size produced their own gas from calcium carbide.

Acetylene Cylinder

- Acetylene is stored in cylinders specially designed for this purpose only.
- Acetylene is extremely unstable in its pure form at pressure above 15 PSI (Pounds per Square Inch)
- Acetone is also present within the cylinder to stabilize the acetylene.

Acetylene cylinders should always be stored in the upright position to prevent the acetone form escaping thus causing the acetylene to become unstable.

- Cylinders are filled with a very porous substance "monolithic filler" to help prevent large pockets of pure acetylene form forming
- Cylinders have safety (Fuse) plugs in the top and bottom designed to melt at 212° F (100 °C)

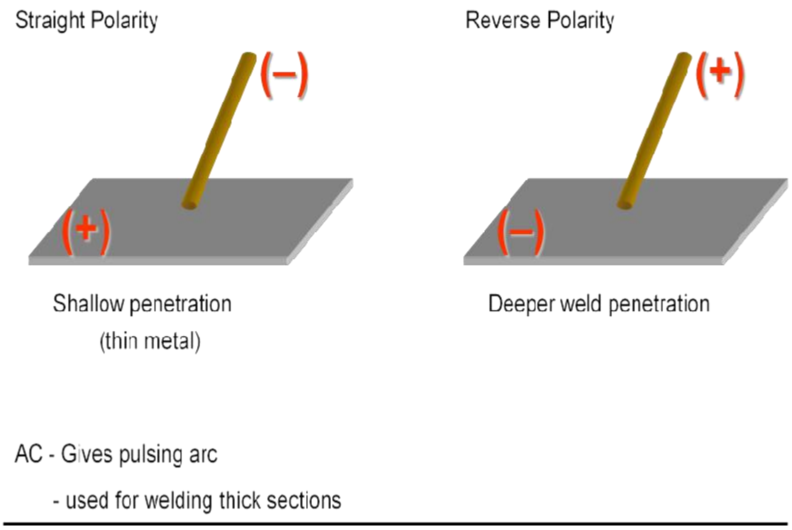
- **Acetylene Valves**
- Acetylene cylinder shut off valves should only be opened 1/4 to 1/2 turn
- This will allow the cylinder to be closed quickly in case of fire.
- Cylinder valve wrenches should be left in place on cylinders that do not have a hand wheel.

Typical torch styles

- A small welding torch, with throttle valves located at the front end of the handle. Ideally suited to sheet metal welding. Can be fitted with cutting
- attachment in place of the welding head shown. Welding torches of this general design are by far the most widely used. They will handle any oxyacetylene welding job, can be fitted with multiflame (Rosebud) heads for heating applications, and accommodate cutting attachments that will cut steel 6 in. thick.
- A full-size oxygen cutting torch which has all valves located in its rear body. Another style of cutting torch, with oxygen valves located at the front end of its handle.

Manual metal arc welding

Welding arc: The arc occurs when electrons are emitted from the surface of the negative pole (cathode) and flow across a region of hot electrically charged plasma to the positive pole (anode), where they are absorbed. The polarity change affects the weld penetration DCEN. Deep penetration (narrow melted area). DCEP Shallow penetration (wide melted area).



Arc welding Arc welding processes fall under a larger category labeled as fusion welding, with an electrical energy source

General characteristics of arc welding processes

These processes are associated with molten metal. Arc welding processes use an electric arc as a heat source to melt metal. The arc is struck between an electrode and the workpiece to be joined. The electrode can consist of consumable wire or rod, or may be a non-consumable tungsten electrode. The process can be manual, mechanized, or automated. The electrode can move along the work or remain stationary while the workpiece itself is moved. A flux or shielding gas is employed to protect the molten metal from atmosphere. If no filler metal is added, the melted weld is referred to as autogenous. If the filler metal matches the base metal, it is referred to as homogenous. If the filler metal is different from the base metal, it is referred to as heterogeneous. The common arc welding processes used to weld metals are: shielded metal arc welding or SMAW, gas metal arc welding GMAW, sometimes called MIG welding; flux cored arc welding FCAW; submerged arc welding SAW; and gas tungsten arc welding GTAW, sometimes called TIG welding. Shielded Metal Arc Welding (SMAW) Gas Metal Arc Welding (GMAW) Flux Cored Arc Welding (FCAW) Submerged Arc Welding (SAW) Gas Tungsten Arc Welding (GTAW).

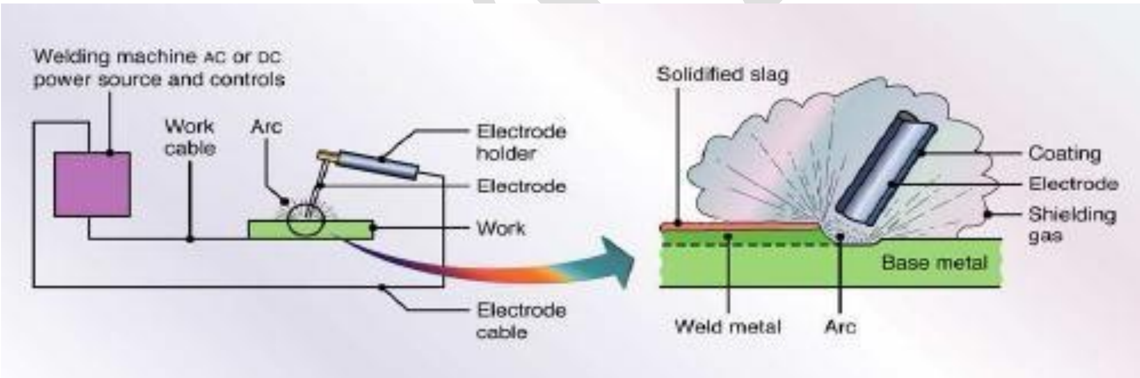
Shielded metal arc welding (SMAW)

Arc is developed between electrode and the component.

Flux creates a gas shield and the metal slag prevents oxidation of the underlying metal.

Typical uses: Pressure vessels, structural steel, and in general engineering Economics: Versatile and low cost (easy to transport) but can't be automated.

SMAW is the most widely used welding process for joining metal parts because of its versatility, its less complex, more portable and less costly equipment Metals commonly welded by SMAW Carbon and low alloy steels Stainless steels and heat resistance steels. DCEN (Direct Current Electrode Negative) (reverse polarity) can be used of all steels. Melting and deposition rates are higher than with DCEP (Direct Current Electrode Positive) (straight polarity). The multiple-pass approach requires that the slag be cleaned after each weld bed. 3- 20 mm thick.



A schematic illustration of SMAW is shown in Figure (Source: Manufacturing Engineering and Technology, Fifth Edition, by Serope Kalpakjian and Steven Schmid.

This is typically a manual welding process where the heat source is an electric arc which is formed between a consumable electrode and the base material. The electrode is covered by a coating, which is extruded on the surface of the electrode. During welding, the electrode coating decomposes and melts, providing the protective atmosphere around the weld area and forming a protective slag over the weld pool.

Advantages of SMAW

Equipment relatively easy to use, inexpensive, portable Filler metal and means for protecting the weld puddle are provided by the covered electrode Less sensitive to drafts, dirty parts, poor fit-up Can be used on carbon steels, low alloy steels, stainless steels, cast irons, copper, nickel, aluminium.

Disadvantages of SMAW Discontinuities associated with manual welding process that utilise flux for pool shielding Slag inclusions Lack of fusion Other possible effects on quality are porosity, and hydrogen cracking. These points would be discussed separately in the welding defects section.

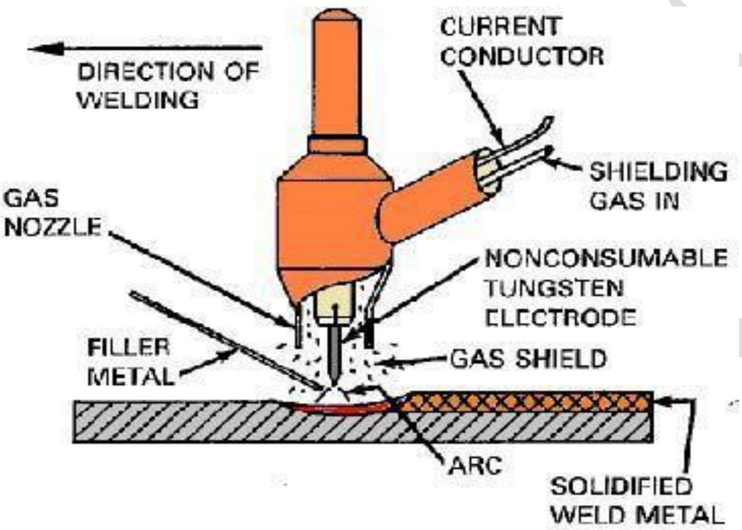
Limitations of SMAW

SMAW has a low weld metal deposition rate compared to other processes. This is because each welding rod contains a finite amount of metal. As each electrode is used, welding must be stopped and a new rod inserted into the holder. A 12-inch electrode may be able to deposit a bead 6-8 inches long. The overall productivity of the process is affected by: Frequent changing of electrodes, Inter pass cleaning (grinding, brushing, etc.), Grinding of arc initiation points and stopping points, Slag inclusions which require removal of the defect and re-welding of the defective area. The heat of the welding arc is too high for some lower melting metals. And the shielding of metals that react aggressively with the atmosphere is inadequate.

Tungsten Inert Gas welding (TIG)

Principle of TIG: The process utilizes the heat (≈6100 ºC)of an arc between a nonconsumable tungsten electrode and the base metal, that is melted to form a melted pool. Filler metal is not added when thinner materials, edge joints and flange joints are welded. This is called as autogenous welding. For thicker materials an externally fed or cold filler rod is generally used. The arc area is protected from the atmosphere by the inert shielding gasflownfrom the nozzle of the torch. The shielding gas displaces the air, so that the oxygen and the nitrogen of the air do not come in contact with the molten metal or the hot tungsten electrode. There is little or no spatter and little or no smoke. The resulting weld is smooth and uniform and requires minimum finishing.

Tungsten Inert Gas Welding, also known by its acronym as TIG welding, is a welding process that uses the heat produced by an electric arc created between non consumable tungsten electrode and the e weld pool. This electric arc is produced by the passage of current trough a conductive ionized inert gas that also 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.



Electric arc:

Pulsed-current GTAW:

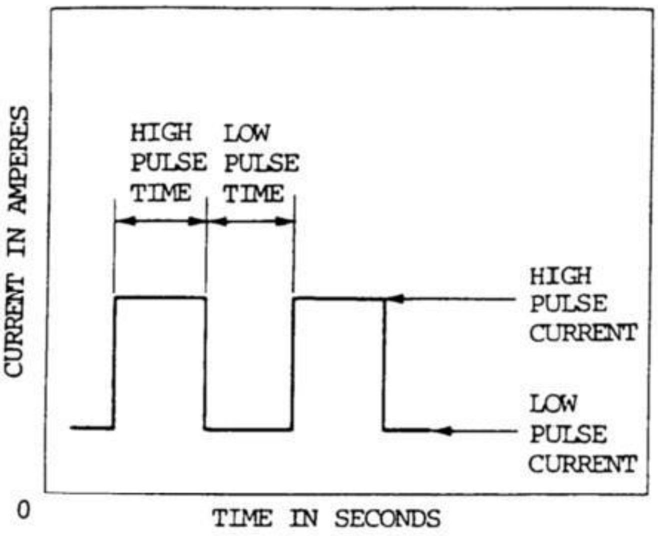


Figure 10-6. Pulsed current welding.

the welding current continiously changesbetween two levels. During the period of high- pulsed current, heating and fusion take place, during the low-pulsed current period, cooling and solidification take place.

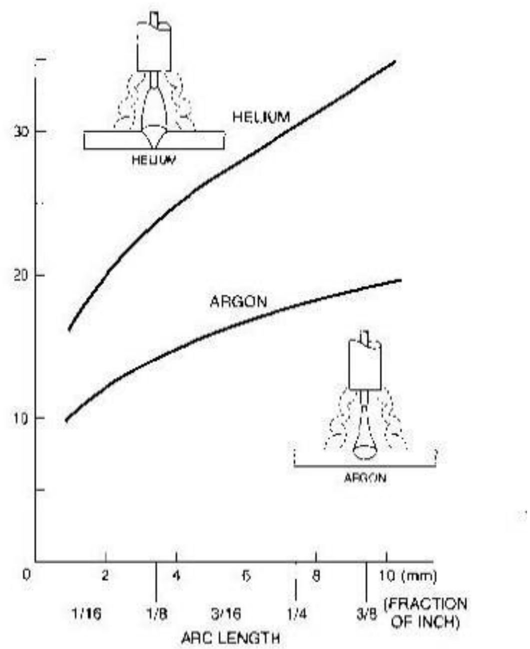
Electrode:

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 t required to the weld, for this reason tungsten is chose en because, as a pure element, it as the highest melting point in close to which it gets thermionic becoming a ready source of electrons. Great care must be taken so that the tungsten electrode does not contact the weld pool in any way or the gas flow rate is sufficient to protect it, in order to avoid its contamination resulting on faulty weld. Some other elements may be added to the tungsten, like cerium, lanthanum, thorium and zirconium creating g electrode alloys that improve arc stability, emissivity and bring higher melting points. Tungsten electrodes may be uses with a variety of tip configurations and finishing's depending on its welding applications

Shielding gases:

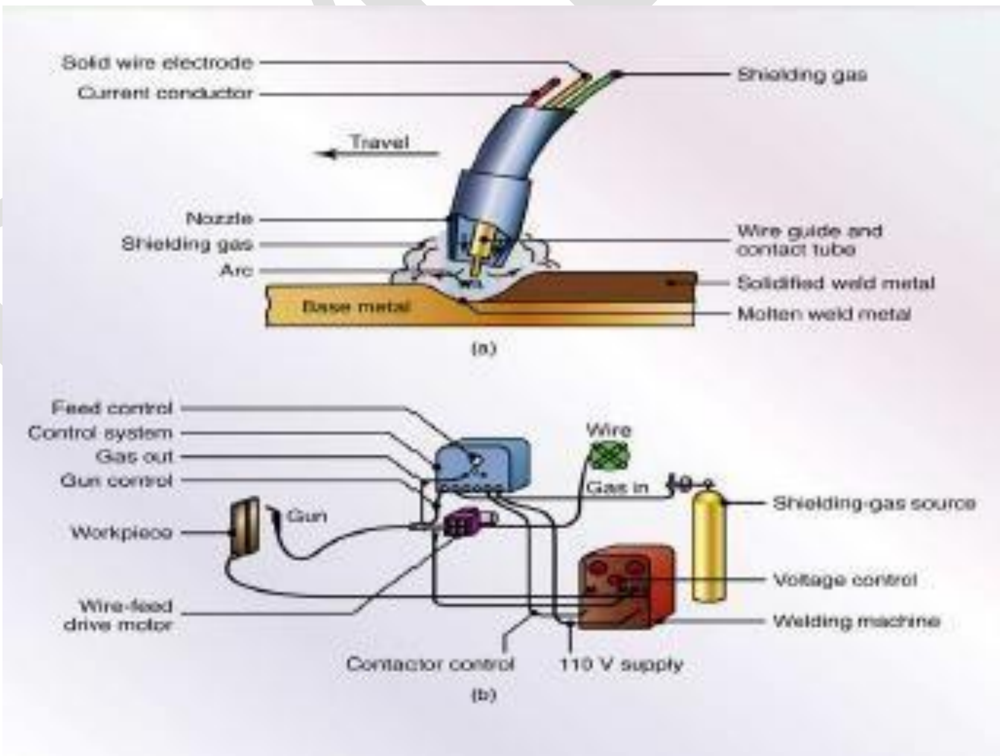
Argon and helium or mixtures of both are the most common inert gases used for shielding, although argon is more extendedly used providing excellent arc stability and h having a cleaning action in certain materials. Helium, unlike argon, as a high t thermal conductivity which results in a deeper penetrating arc, however because helium is a light gas it is less higher than argon in order to provide the same shielding, adding the fact helium cost is considerably more higher then argon, helium welding becomes more expensive and as to be weighed against the penetration increase and increased travel speeds, making it more suitable for thick materials, metals with high thermal conductivity or high speed mechanized welding. Mixtures of both the gases are used when is useful to balance the two gas characteristics.

The arc shielded with helium has more power (heat) and can do more work. The helium shielded arc column is; **Larger, More penetration, Higher travel speed, Weld heavier base metals.**



Arc voltage and arc length

Gas metal arc welding (GMAW)



Schematic illustration of GMAW

In GMAW, formerly known as metal inert-gas (MIG) welding is an arc welding process in which the heat for welding is generated by an arc between a consumable electrode and the work metal. The consumable bare wire is fed automatically through a nozzle into the weld arc by a wire-feed drive motor. In GMAW, the weld area is shielded by an effectively inert atmosphere of argon, helium, carbon dioxide or various other gas mixtures.

Advantages: If GMAW Can weld almost all metals and alloys, aluminum and aluminum alloys, stainless steel. All positions of welding DCEP which provides stable arc, smooth metal transfer, relatively low spatter and good weld bed characteristics. Due to automatic feeding of the filling wire (electrode) the process is referred to as a semi-automatic. The operator controls only the torch positioning and speed. No slag produced High level of operator skill is not required.

Further advantages of GMAW High productivity All positions of welding and reliability Wide area applications All ferrous and nonferrous can be welded Limitations of GMAW Expensive and non-portable equipment Less skilled workers can operate this process, however this can lead to poor setup of the welding parameters, in turn this can lead to defects in the finished weld such as lack of fusion and porosity. More heat is generated in MIG than TIG; this will mean that the HAZ is larger around a weld of this type. Equipment is heavy and not particularly portable; the operator is limited to about 4.5m to 6m from the power source due to potential complications with the wire feed. Extended-reach wire feeders are now available which means the operator can be up to 15m away from the power source (Smith, 1986), but the extra equipment means that portability is further restricted.

Methods of metal transfer in GMAW

Spray transfer: small, molten metal droplets from the electrode are transferred to the weld area at a rate of several hundred droplets per second. Spray is achieved at higher welding currents and voltages with argon or argon- rich gas mixture Helium based shielding gas (over 80% Ar). The average current required in GMAW process can be reduced by using a pulsed arc, which superimposes high-amplitude pulses onto a low, steady current. Pulsing the current allows for better control for out of position welding. This mode produces little or no spatter and is known for the high deposition rate (higher productivity).

Globular transfer: carbon-dioxide rich gases are utilised, and globules are propelled by the forces of the electric arc transfer of the metal, resulting in considerable spatter. High currents are used, making it possible for greater weld penetration and higher welding speed than are achieved in spray transfer. Heavier sections commonly are joined by this method.

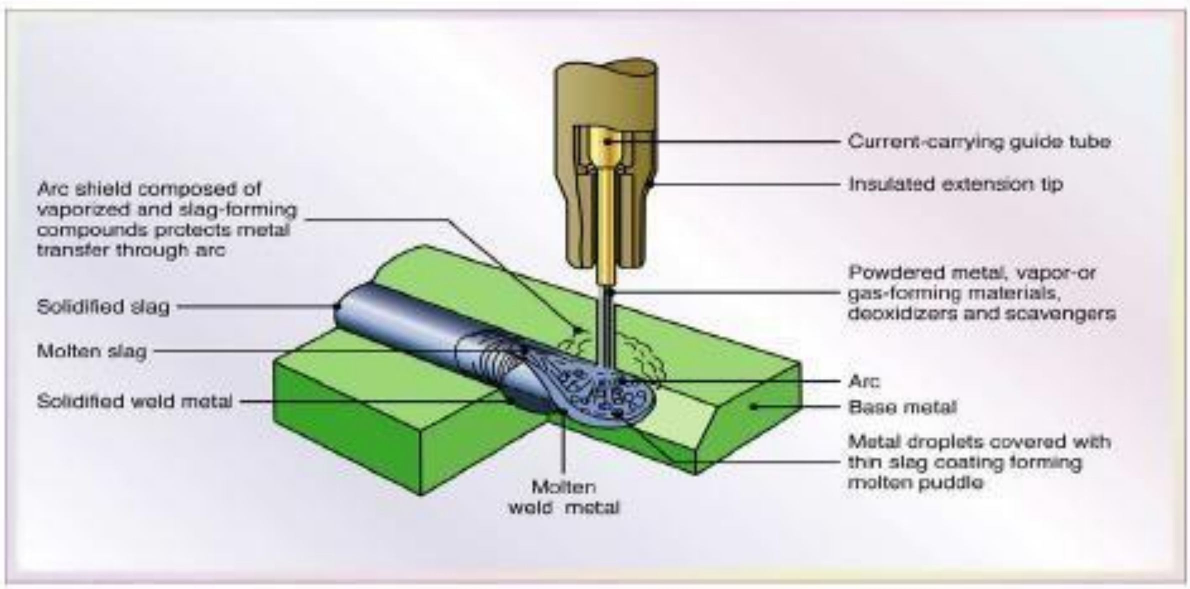
Short circuiting transfer: the metal is transferred in individual droplets (more than 50 per second), as electrode tip touches the molten weld metal and short circuits. At low current and voltages, short circuit transfer occurs. The weld is a shallow penetrating weld with low heat input. Using GMAW in this mode allows welding in all positions since the weld puddle is so small. In comparison to the other modes of transfer, this method is slowest (low productivity). Used primarily for sheet metal applications. This mode produces large amounts of spatter if welding variables are not optimized. This mode is also known as short arc or dip transfer.

Shielded gases Contamination of the weld pool, by the atmosphere, can cause weld defects. These defects can have an adverse effect on the joint efficiency, which may lead to failure. Therefore, the weld pool should be protected from the atmosphere until it has completely solidified. The primary purpose of shielding gases is to protect the molten weld metal and the HAZ from oxidisation and other contamination. Shielding gas forms a protective atmosphere over the molten weld pool to prevent contamination Inert shielding gases, argon or helium, keep out oxygen, nitrogen, and other gases Active gases, such as oxygen and carbon dioxide, are sometimes added to improve variables such as arc stability and spatter reduction Shielding gas can be a single pure gas or a mixture of two or more gases. Inert gases, as the name implies, do not react with the weld metal. Argon is often used in the flat and horizontal position, since it is heavier than air. Helium can be used in the overhead position, since it is lighter than air. Helium has a characteristic of producing a “hotter” arc than argon. Active gases, such as oxygen and carbon dioxide, are often added to inert gases in order to improve arc properties. These properties include arc stability and spatter reduction. Shielding gases should be free of moisture, which decompose to hydrogen and oxygen in the arc. Moisture in the gas can result in porosity, and in steels, hydrogen can lead to cracking.

Main shielded gases used in GMAW Argon: Argon is 38% heavier than air, which is advantageous for welding in flat and horizontal fillet positions. Pure argon virtually can be used in all metals. Helium: It is lighter than air and because of this, high gas flow rate must be used to maintain adequate shielding. Helium is used primarily on Aluminum, magnesium and copper. Carbon-dioxide: This is widely used in the welding of steel by the short circuiting mode of metal transfer. Mixtures: Argon-carbon dioxide mixtures, argon helium mixtures, argon oxygen mixtures, helium-argon-carbon dioxide mixtures.

Flux- cored arc welding (FCAW)

Flux Cored Arc Welding (FCAW) uses a tubular wire that is filled with a flux. FCAW is similar to GMAW, except the electrode is tubular in shape and filled with flux (hence the term flux-cored). The arc is initiated between the continuous wire electrode and the workpiece. The flux, which is contained within the core of the tubular electrode, melts during welding and shields the weld pool from the atmosphere. Direct current, electrode positive (DCEP) is commonly employed as in the FCAW process. Cored electrode produces a more stable arc, improve weld contour, and produce a better mechanical properties of the weld metal. Figure 5: Schematic illustration of the flux-cored arc-welding process. The FCAW process combines the versatility of SMAW with the continuous and automatic electrode- feeding feature of GMAW.



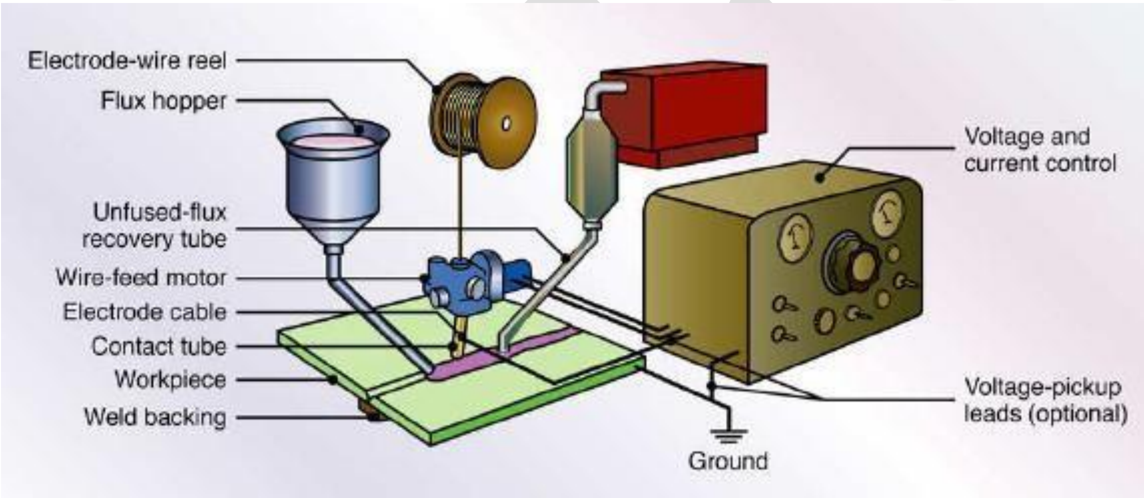
A schematic illustration of FCAW is shown in the above Figure.

Advantages of FCAW: Specific weld-metal chemistries can be developed by adding alloying elements to the flux core, all alloy composition can be produced. Easy to automate and readily adaptable to flexible manufacturing and robotics.

Disadvantages of FCAW: The slag formed during welding must be removed between passes on multipass welds. This can reduce the productivity and result in possible slag inclusion discontinuities. For gas shielded FCAW, porosity can occur as a result of insufficient gas coverage. Large amounts of fume are produced by the FCAW process due to the high currents, voltages, and the flux inherent with the process. Increased costs could be incurred through the need for ventilation equipment for proper health and safety. FCAW is more complex and more expensive than SMAW because it requires a wire feeder and welding gun. The complexity of the equipment also makes the process less portable than SMAW.

Submerged-arc welding (SAW)

Submerged-arc welding (SAW) In SAW, the weld arc is shielded by a granular flux consisting of lime, silica, manganese oxide, calcium fluoride, and other compounds. A schematic illustration of submerged-arc welding process is shown in the Figure.



Characteristics of submerged-arc welding:

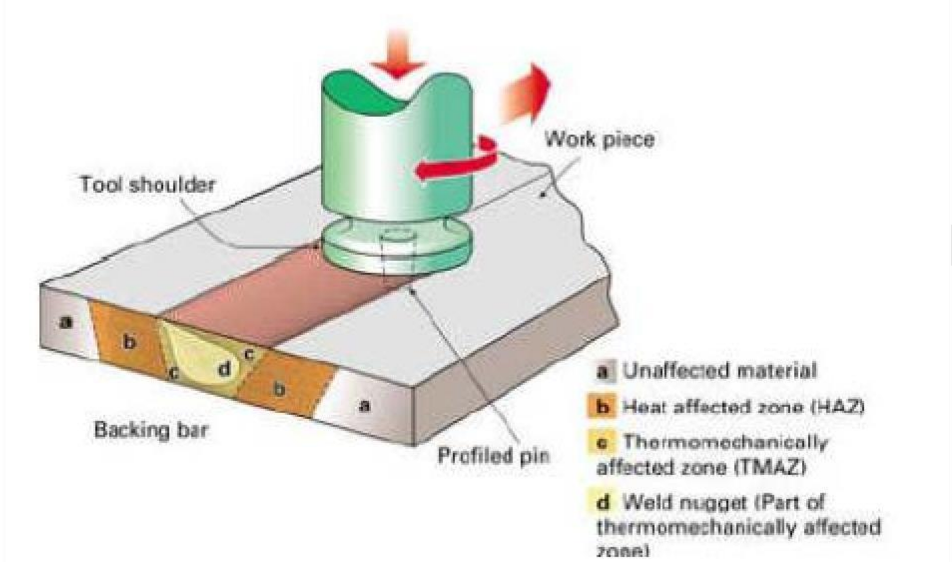
The flux is fed into the weld zone from a hopper by gravity through a nozzle: The functions of the flux: Prevents spatter and sparks; Suppresses the intense ultraviolet radiation and fumes characteristics of the SMAW. It acts as a thermal insulator by promoting deep penetration of heat into the workpiece. The unused flux can be recovered, treated and reused. The filler metal is a continuously-fed wire electrode like GMAW and FCAW. However, higher deposition rates can be achieved using SAW by using larger diameter electrodes and higher currents (650-1500 Amperes). Since the process is almost fully mechanized, several variants of the process can be utilized such as multiple torches and narrow gap welding. -14- Because of the flux is gravity fed, the SAW process is limited largely to welds in flat or horizontal position This process can be automated and use to weld a variety of carbon and alloy steel and stainless steel sheets or plates as high as 5m/min. The quality of weld is very high, provides high productivity in ship building and for pressure vessels.

Advantages of submerged welding (SAW): This process can be automated and use to weld a variety of carbon and alloy steel and stainless steel sheets or plates as high as 5m/min. The quality of weld is very high, provides high productivity in ship building and for pressure vessels. High deposition rates No arc flash or glare Minimal smoke and fumes Flux and wire added separately - extra dimension of control Easily automated Joints can be prepared with narrow grooves Can be used to weld carbon steels, low alloy steels, stainless steels, chromiummolybdenum steels, nickel base alloys SAW has the highest deposition rate of the entire deep penetrating arc welding processes making it ideal for thick section and multi-pass welding. Variations of the process can utilize dual arc welding, twin arc welding, multiple torches, and narrow groove welding to increase productivity. Since the arc is completely submerged in the flux, there is no arc radiation. Screens or light filtering lenses are not needed. Additionally, the smoke and fumes are trapped within the flux and thus minimizing smoke and fumes. Since the process is simple to mechanize and easily automated, it is extremely consistent once a procedure is qualified. And it can be used on a wide variety of materials.

Limitations of submerged welding (SAW): Because of the flux is gravity fed, the SAW process is limited largely to welds in flat or horizontal position The flux which shields the arc and weld pool in SAW also obstruct the operator's view of the joint and molten weld pool. This makes observation of the pool and joint impossible during welding; thus, correction of problems during welding can be very difficult. Because of the high current levels common to this process, it is normally not suited for thinner materials. Due to the presence of a granulated flux, submerged arc welding is limited to the flat and horizontal positions. As with SMAW and FCAW, SAW produces a slag which must be completely removed after each pass. Finally, additional flux handling equipment is required.

Friction Stir Welding (FSW)

FSW is a relatively new process developed and patented in England by The Welding Institute of Cambridge (TWI UK). The process works by lowering the pin of a shouldered tool into the gap between the two materials to be welded at a high rotational speed and under significant down force (see Figure). This creates friction between the tool and work, generating enough heat for the metal to change to a plasticised state. Subsequently the plasticised shaft of metal around the pin is stirred together to create a forged bond, or weld, between the materials.



Advantages of FSW

Since gravity has no influence on the solid-phase welding process, it can be used in all positions, viz:

Horizontal
Vertical
Overhead
Orbital

The process advantages result from the fact that the FSW process (as all friction welding of metals) takes place in the solid phase below the melting point of the materials to be joined. The benefits therefore include the ability to join materials which are difficult to fusion weld, for example 2000 and 7000 aluminium alloys. Friction stir welding can use purpose-designed equipment or modified existing machine tool technology. The process is also suitable for automation and adaptable for robot use.

Main characteristics/advantages of FSW

-The FSW process works below the melting temperature of the weld material in the solid state phase. This means that the work has a significantly smaller heat affected zone (HAZ) than conventional fusion welding techniques where weld defects can occur.

- FSW creates a very strong bond between materials.

- FSW can be easily automated and subsequently can be programmed to perform complex shape welds.

- Defects such as solidification cracking and gas porosity caused by absorption of hydrogen during welding do not occur in FSW, although they are common in fusion welding processes.

Limitations of FSW

Two drawbacks to the FSW procedure are the requirement for different length pin tools when using the process on materials which vary in thickness, and the fact that a keyhole is left at the end of the weld where the welding tool is removed. This is particularly a problem when welding cylindrical items such as pipe which require a continuous weld. The workpiece in FSW also requires to be clamped rigidly. If metal deposition is required, this process is not good.

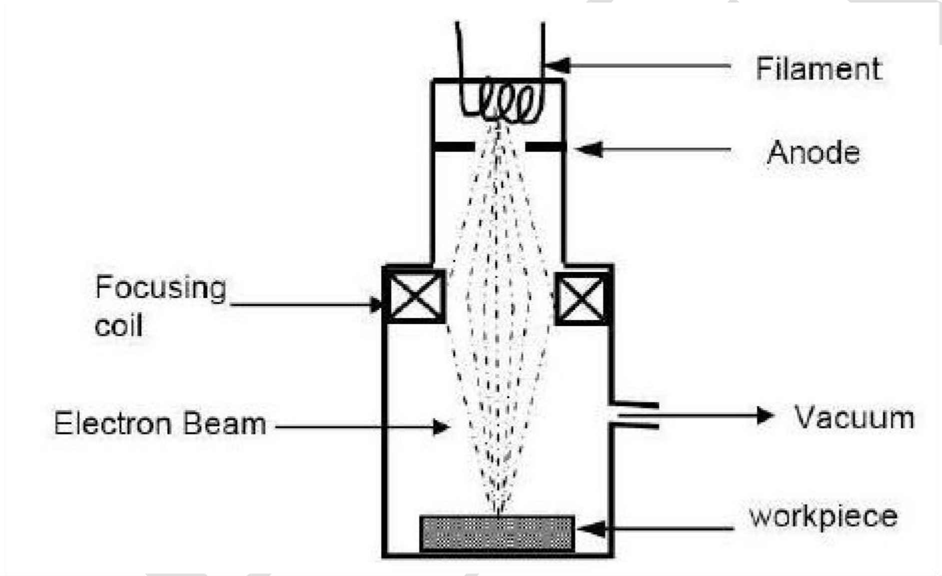
Electron-Beam Welding (EBW)

In EBW, developed in 1960s, the heat used for welding the two materials is generated by high velocity narrow-beam (concentrated) electrons is fired through the work, this transfers kinetic energy to the particles of metal causing them to heat up and melt to form a weld. A schematic illustration of EBW is shown in Figure. EBW process requires special equipment to focus the beam on the workpiece, typically in a vacuum. The higher the vacuum, the more the beam penetrates, and the greater the depth-to-width ratio can be achieved. There are three methods in EBW as far as vacuum is concerned:

EBW-HV (for high vacuum)

EBW-MV (medium vacuum)

EBW-NV (no vacuum)



Some characteristics of EBW

In aircraft industry alloy grade Ti is used. Electron Beam Welding (EBW) is extensively employed. Much better joints can be obtained by EBW of alloy grade Ti. By welding in a vacuum chamber, gas absorption is prevented. The HAZ is very narrow and influence of welding on structure is minimal. Complicated work-pieces can be welded without distortion. Components with large wall thickness as well as thin walled components can also be successfully welded.

Advantages of EBW

-Narrow welds can be made on thicker sections with deeper penetration with minimal thermal disturbances.

-This makes the process suitable for welding in titanium, niobium, tungsten, tantalum, beryllium, nickel alloys and magnesium, mostly in aerospace and space research sectors.

-Because welding is performed in a vacuum, there is no atmospheric contamination; accurate control of welding parameters is possible by controlling the electron beam power and accurate beam focus.

-Excellent welds can be made even on more reactive metals.

-Lack of thermal disturbance in the process means that there is minimum shrinkage and distortion.

Limitations of EBW

-The process usually takes place in a vacuum; this means that the work piece must be setup in a vacuum chamber which then must be evacuated before the welding can take place. This can be time consuming and reduces the production efficiency of the system.

- Electron beam equipment is very expensive compared to conventional welding equipment.

- If welding in a vacuum the size of the material to weld must be smaller than that of the vacuum chamber, meaning larger and more expensive equipment is required to weld large pieces.

Laser Beam Welding (LBW)

LBW utilizes a high-power laser beam as the source of heat, to produce a fusion weld. Because the beam can be focused on to a very small area, it has high energy density and deep-penetrating capability.

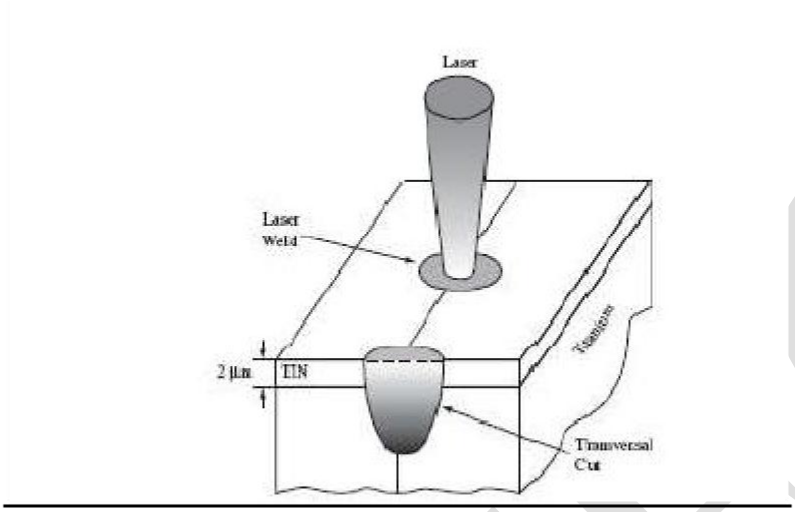


Figure : Schematic illustration of laser welding

Advantages of LBW

-LBW produces welds of good quality with minimum shrinkage and distortion

-Laser welds have good strength, generally low hardness (ductile) and free of porosity

-The process can be automated

-Narrow welding seam

-Low energy input per seam length

-Reduced heat affected zone (HAZ)

-Very high welding speed (ranges from 2.5 m/min to as high as 80 m/min)

Friction welding

Friction welding uses pressure and frictional heat caused by mechanical rubbing, usually by rotation. In this process, the parts are rotated at high speed and brought together. The heat generated on contact causes the parts to fuse together.

Typical use: Automotive components, agriculture equipment, joining high speed steel ends and twist drills. Process can be automated. Economics: Capital costs are high but tooling costs are low.

Resistance welding (RW)

Resistance Welding is a welding process in which work pieces are welded due to a combination of a pressure applied to them and a localized heat generated by a high electric current flowing through the contact area of the weld.

Different metals and alloys such as low carbon steels, aluminium alloys, alloy steels, medium carbon and high carbon steels can be welded by resistance welding. However, for high carbon contained steels, the weld bed can be harder (less brittle).

Resistance Welding (RW) is used for joining vehicle body parts, fuel tanks, domestic radiators, pipes of gas oil and water pipelines, wire ends, turbine blades, railway tracks.

The most popular methods of Resistance Welding are:

Spot welding
Flash welding
Resistance butt welding
Seam welding

Advantages of resistance welding

-High welding rates;

-Low fumes;

-Cost effectiveness;

-Easy automation;

-No filler materials are required;

-Low distortions.

Disadvantages of resistance welding

-High equipment cost;

-Low strength discontinuous welds;

-Thickness of welded sheets is limited - up to 6 mm.

Spot welding

Spot Welding is a Resistance Welding process, in which two or more overlapped metal sheets are joined by spot welds. The method uses pointed copper electrodes providing passage of electric current. The electrodes also transmit pressure required for formation of strong weld. Diameter of the weld spot is in the range 3 - 12 mm. Spot welding is widely used in automotive industry for joining vehicle body parts.

Flash welding

Flash Welding is a Resistance welding process, in which ends of rods (tubes, sheets) are heated and fused by an arc struck between them and then (brought into a contact under a pressure) producing a weld. The welded parts are held in electrode clamps, one of which is stationary and the second is movable. Flash Welding method permits fast (about 1 min.) joining of large and complex parts. Welded parts are often annealed for improvement of toughness of the weld. Steels, Aluminium, Copper alloys, Magnesium alloys and Nickel alloys may be welded by flash welding. Thick pipes, ends of band saws, frames, and aircraft landing gears are produced by Flash Welding.

Resistance butt welding

Resistance Butt Welding is a Resistance Welding process, in which ends of wires or rods are held under a pressure and heated by an electric current passing through the contact area and producing a weld. The process is similar to Flash Welding however in Butt Welding pressure and electric current are applied simultaneously in contrast to Flash Welding where electric current is followed by forging pressure application.

Resistance seam welding

Seam welding is a Resistance Welding process of continuous joining of overlapping sheets by passing them between two rotating electrode wheels. Heat generated by the electric current flowing through the contact area and pressure provided by the wheels are sufficient to produce a leak-tight weld.

The major discontinuities found in arc welded joints are:

Slag inclusions

Porosity

Grove overfill or underfill

Cracks

Lamellar tears

Embrittlement

Slag inclusions

Slag inclusions are compounds such as pieces of slag trapped inside solidified weld pool; may result from excessive stirring in weld pool, or failure to remove slag from prior weld. If shielding gases are not effective during welding, contamination from the environment also may contribute to such inclusions.

Slag inclusions can be prevented by:

Cleaning weld bed surface before the next layer deposited By
providing sufficient shielded gases
Proper designing of joints

Porosity

Porosity or fine holes or pores within the weld metal can occur by absorption of evolved gases and chemical reaction. Metals susceptible to porosity are those which can dissolve large quantities of gas contaminates (hydrogen, oxygen, nitrogen etc) in the molten weld pool and subsequently reject most of the gas during solidification. Aluminium alloys are more susceptible to porosity than any other structural material. Weld cooling rates substantially affects the volume of porosity.

remedy

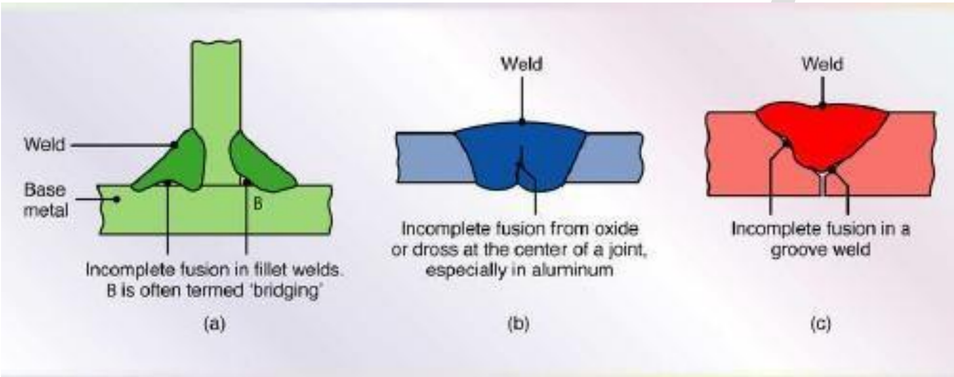
-At fast cooling rates, the level of porosity can be low

-Similarly, at slow cooling rates, porosity is minimal because bubbles have ample time to coalesce, float, and escape from the weld pool.

-At intermediate cooling rates, the greatest volume of porosity in a weld is observed, as conditions are optimum for both formation and entrapment of virtually all of the evolved gases in the weld.

Incomplete fusion and penetration

-Incomplete fusion is termed as fusion which does not occur over the entire base metal surfaces intended for welding and between adjoining weld beads. Incomplete fusion can result from insufficient heat input or the improper manipulation of the welding electrode. While it is a discontinuity more commonly associated with weld technique, it could also be caused by the presence of contaminants on the surface being welded. Incomplete penetration occurs when the depth of welded joint is insufficient. A schematic illustration of various discontinuities in fusion welds is shown in Figure.



Incomplete fusion and penetration can be improved by:

-By raising the temperature

-Cleaning the weld area before welding

-Modifying the weld design

-Providing sufficient shielding gases

-Reducing the travel speed during the welding

Cracks

Cracks in welding occur is various locations and directions in the weld area as a result from hot tearing or cold cracking. Hot tearing or hot cracks (solidification crack) occurs when shrinkage during solidification tears mushy (liquid – solid) weld – physical constraints against shrinkage may exacerbate the problem. Hot cracking results from internal stress developed on cooling following solidification. This defect occurs at a temperature above the solidus of an alloy. Cold cracking or hydrogen cracking typically occurs after weld freezes, and residual stresses are sufficient to cause cracks – hours/days later.

Cause of crack formation

-by welding fixtures that do not permit contraction of the weld during cooling,

-by narrow joints with large depth-to-width ratios,

-by poor ductility of the deposited weld metal, or by a high coefficient of thermal expansion coupled with low-heat conductivity in the parent metal

Methods to minimize hot cracking

Maintenance of adequate manganese-to-sulfur ratio

Reduction of sulfur, phosphorus, carbon and niobium to minimal amounts

Reduction of the tensile restraint exerted on the weld

Hydrogen cracking or **cold cracking** occurs in the heat-affected zone of some steels as hydrogen diffuses into this region when the weld cools. Hydrogen cracking is caused by atomic hydrogen.

Methods of minimising hydrogen cracking

-Using low-hydrogen electrodes, which includes baking and storing them in a low temperature oven.

-Preheating the surface of the steel before welding to remove moisture

Undercut and underfill

Undercut – combination of underfill and overly aggressive arc; leaves a sharp- edged hole in surface. Underfill – insufficient filler metal used in welding; may result from excessive welding velocity.

Residual stresses

Due to localised heating and cooling during welding, the expansion and contraction of the weld area causes residual stresses. At completion of the weld thermal cycle the weldament either distorts or if restrained will contain residual stress. Residual stress fields are complex, Stresses may need to be removed by a stress relief heat treatment process.

MODULE III

Basic processes in Powder Metallurgy, Characteristics of powders. Compaction in rigid dies. Sintering of metal powders. Application of powder metallurgy products-their relative advantages.

Basic processes in Powder Metallurgy

- Powder metallurgy may defined as, “the art and science of producing metal powders and utilizing them to make serviceable objects.”

OR

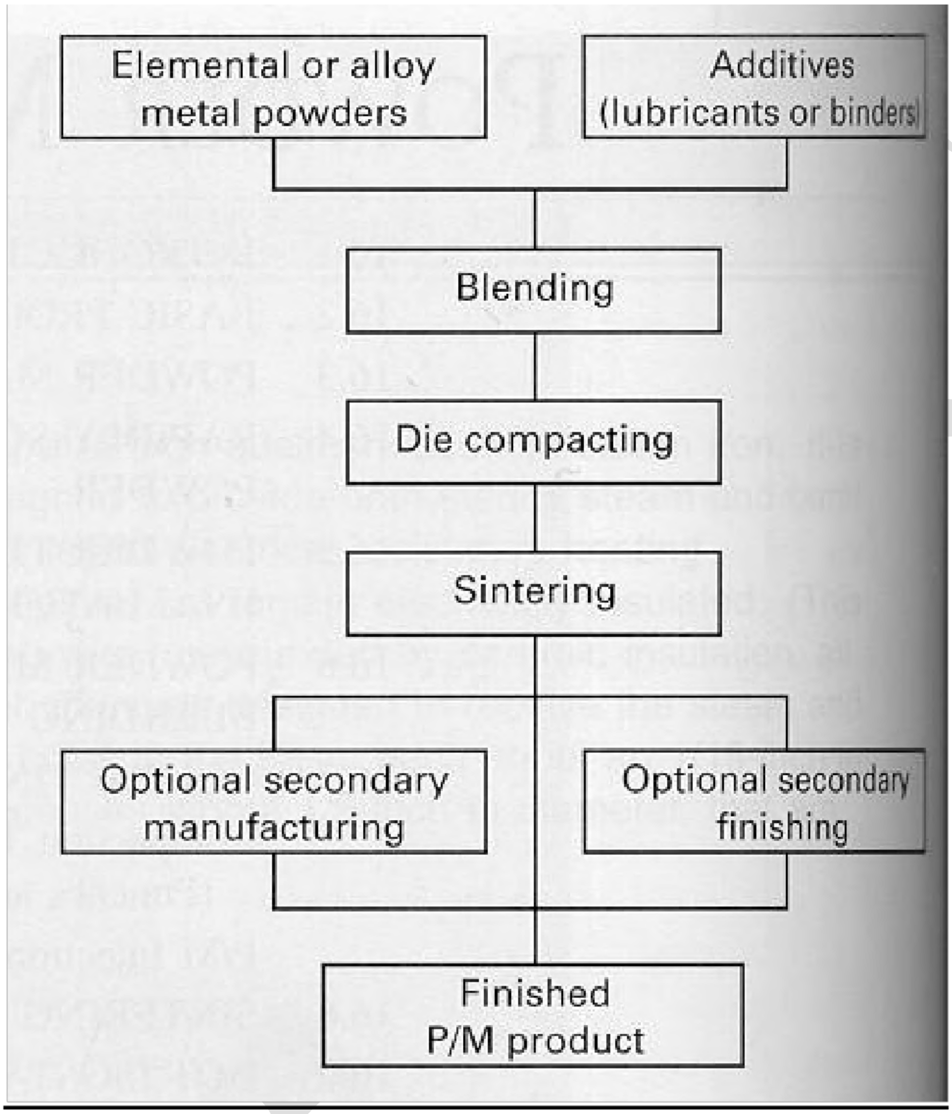
- It may also be defined as “material processing technique used to consolidate particulate matter i.e. powders both metal and/or non-metals.”

IMPORTANCE OF POWDER METALLURGY

- The methods of powder metallurgy have permitted the attainment of compositions and properties not possible by the conventional methods of melting and casting.
- Powder metallurgy is an alternative, economically viable mass production method for structural components to very close tolerance.
- Powder metallurgy techniques produce some parts which can’t be made by any other method.
- The process of P/M is the process of producing metallic parts from metallic powders of a single metal, of several metals or of a combination of metals and non-metals by applying pressure. The powders are mixed mechanically, compacted into a particular shape and then heated at elevated temperature below the melting point of the main constituent.

Powder Metallurgy Processes

The powder metallurgy process first start with the production of metal powders of requisite size and distribution. The metal or alloy powders need to be blended with suitable additives and lubricants. The thorough blending of powders and additives ensures that the additives are uniformly distributed which facilitates the compaction process later. This blended powder is placed in the die and then pressed or compacted by punch. After compacting, the material is termed as green compact. This has the overall shape required but not having engouh strength. To achieve the bonding, the green compact is kept in a furnace with the requisite atmosphere and heated for a finite time. During this process the lubricants in the compact get evaporated while bonding takes place. This is termed as sintering. After sintering, the P/M part can be optionally made for other manufacturing operations such as repressing, coining, sizing, resintering, forging, rerolling or metal infiltration or machining operations such as machining, heat treating, steam sintering, plating, tumbing, shot peening or oil impregnation.



Production of metallic powders

There are a number of processes used for the manufacture of metal/alloy powders:

-Solid state reduction

-Atomization

-Chemical

-Electrolysis

1) Solid state reduction: this process is generally used for producing iron powder. In this process, the selected metal/alloy is crushed, mixed with carbon and passed through a continuous furnace where a reaction takes place, which leaves a cake of sponge metal. This sponge metal is then crushed after separating from all non-metallic material. Then it is sieved to produce powder.

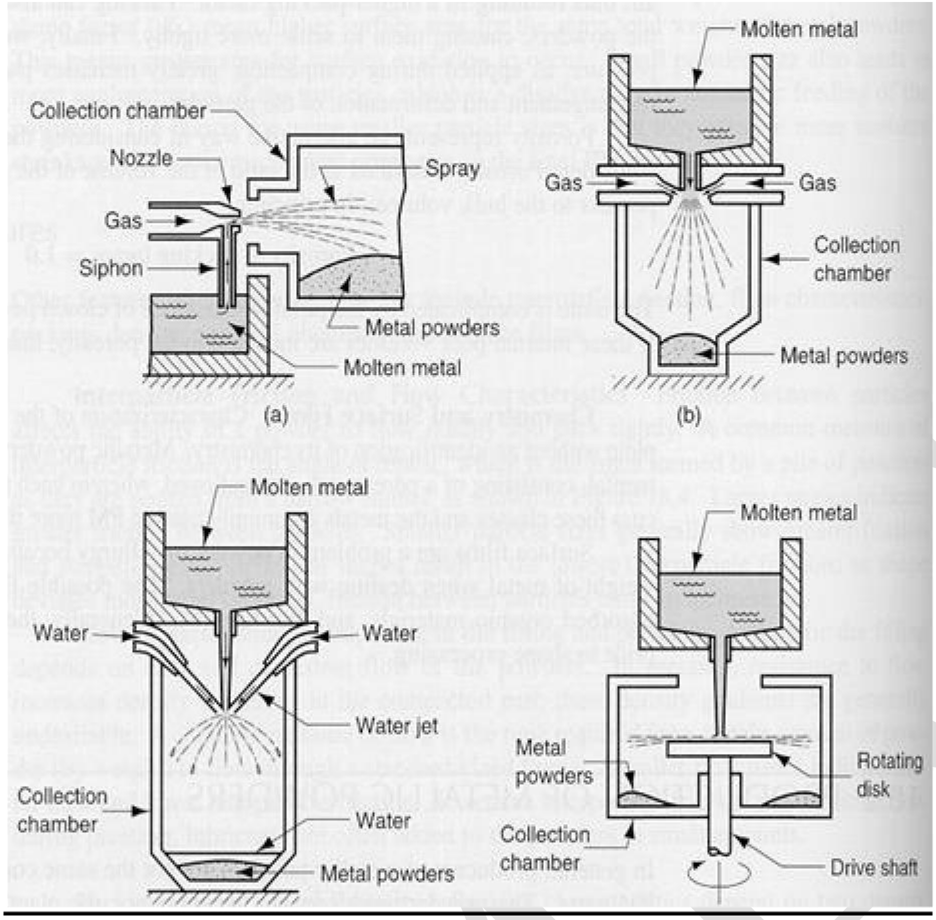
2) Atomization: Atomization breaks molten metal into small droplets by rapidly freezing them before the droplets come into contact with each other or with a solid surface. The atomization is achieved by bringing the thin molten metal stream in contact with the impact of high energy jets of gas or liquid. Air, nitrogen and argon are commonly used gases and water is the most widely used liquid. In atomization, the particle shape is determined largely by the rate of solidification and varies from spherical, if a low-heat-capacity gas is employed, to highly irregular if water is used. By varying the design and configurations of the jets, pressure and volume of the atomization fluid, thickness of the stream of metal etc., it is possible to control the particle size distribution over a wide range.

This technique is applicable to all metals that can be melted and is used commercially for production of iron, copper, alloy steels, brass, bronze, aluminium, tin, lead, zinc and cadmium. It can also be used in selected instances for high melting-point materials such tungsten, titanium and rhenium.

Another variation of the gas atomization process. The molten metal flows by gravity into a thin stream, which is immeadiately atomized by the high-pressure gas jet coming from both dides thereby forming spherical particles, which are then collected in the collection chamber.

-a high pressure water jet is used in place of gas. Water provides higher cooling rate, however the particles produced are not spherical, but are irregular in shape.

Disadvantage of this process is that surfaces of the powder particles get oxidized. This can ba avoided by using synthetic oils in place of water.



Several atomization methods for producing metallic powders: (a) and (b) two gas atomization methods; (c) water atomization; and (d) centrifugal atomization by the rotating disk method.

- rotating disk method: molten metal falls on to a disk that is rotating at high speeds. The liquid metal that is impinging on the disk will be thrown out rapidly into small droplets by the disk, which are solidified and collected in the collection chamber.

Rotating consumable electrode method:

Here the metal is melted by the arc between the rotating consumable electrode and the stationary electrode. Since the electrode is rotating, the molten metal is atomized by centrifugal force and collected in the chamber in which inert gas is filled.

Electrolysis: the desired metal is made as anode in an electrolytic cell, such that it is dissolved by the electrolyte in the cell and then transported and deposited on the cathode in a spongy or powdery form. The deposit is removed, washed and dried to get the metal powder. Copper is the primary metal produced by electrolysis but iron, chromium and magnesium powders are also using this process.

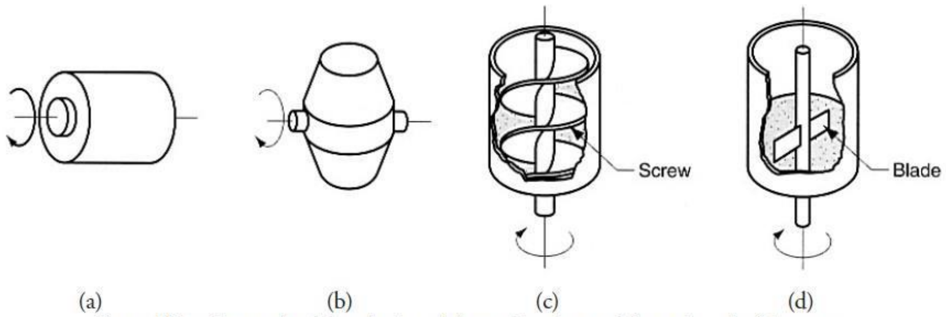
Processing methods

Mixing and blending:

To achieve the required properties a number of different powders with the requisite properties are mixed to achieve the necessary balance of the properties. Blending refers to the mixing of the same metal or alloy powders of different size distributions to reduce the porosity levels in the P/M product.

The main function of the lubricant is to reduce the friction between the powder and the die walls, core rods etc., where the powder slides during the compaction process. This ensures the desired uniformity of density from top to bottom of the contact. The lubricant will also help in reducing the friction for easy ejection of the compact and minimizes the tendency to form cracks. Popular lubricants are stearic acid, stearin metallic stearates, zinc stearate and organic compounds of a waxy nature.

Blending and mixing is normally done by using mechanical processes.

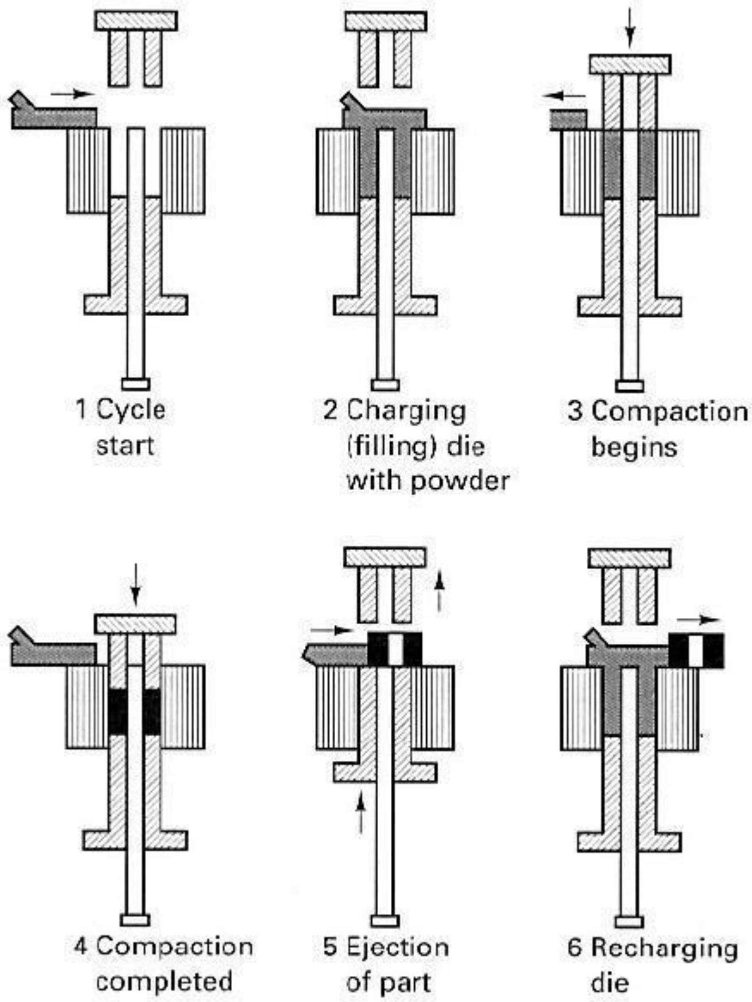


Several blending and mixing devices: (a) rotating drum, (b) rotating double cone, (c) screw mixer, (d) blade mixer

Except for powders, some other ingredients are usually added: v Lubricants: to reduce the particles-die friction v Binders: to achieve enough strength before sintering v Deflocculants: to improve the flow characteristics during feeding.

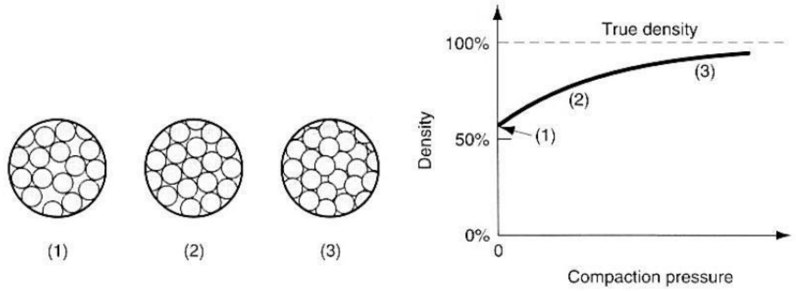
Compacting:

In compacting loose powder is compressed into a shape known as green compact, which is a very important step in powder metallurgy. The desired characteristics to be achieved by compacting are high product density and uniformity of that density throughout the compact.



Typical steps in compaction

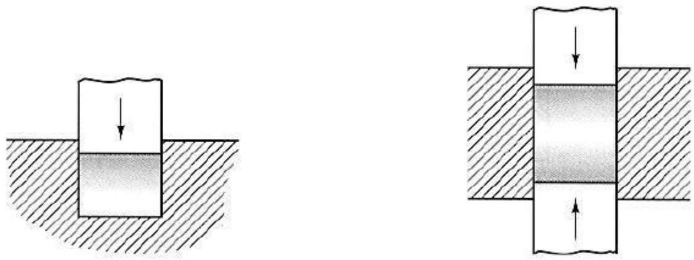
As a result of compaction, the density of the part, called the green density is much greater than the starting material density, but is not uniform in the green. The density and therefore mechanical properties vary across the part volume and depend on pressure in compaction:



Effect of applied pressure during compaction: (1) initial loose powders after filling, (2) repacking, and (3) deformation of particles.

There are different ways to improve the density distribution:

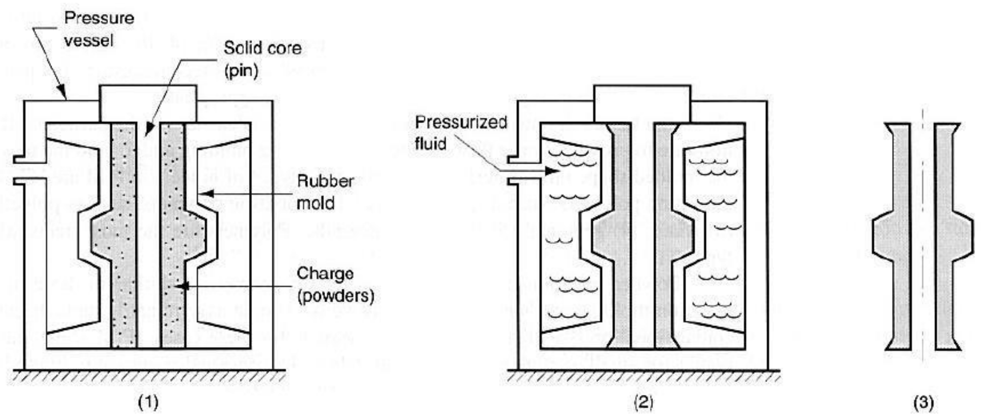
- Application of double acting press and two moving punches in conventional compaction.



Compaction with a single punch, showing the resultant nonuniform density

Density distribution obtained with a double-acting press and two moving punches

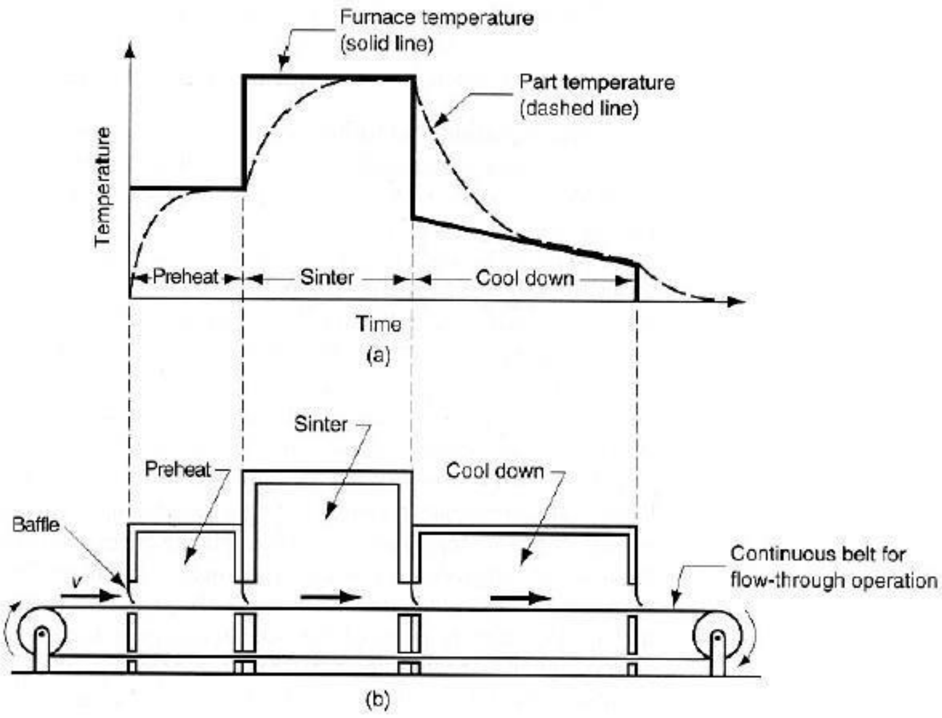
Isostatic pressing Pressure is applied from all directions against the powder, which is placed in a flexible mold:



Cold isostatic pressing: (1) powders are placed in the flexible mold; (2) hydrostatic pressure is applied against the mold to compact the powders; and (3) pressure is reduced and the part is removed.

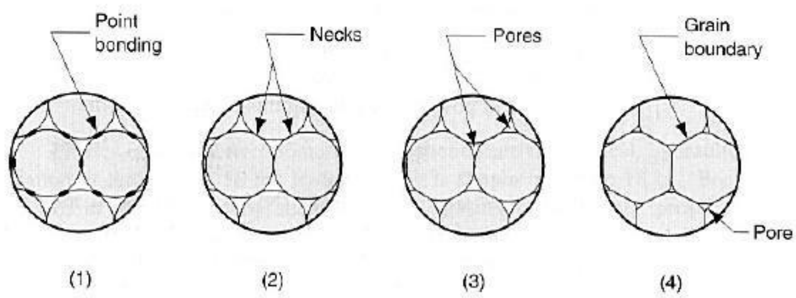
Sintering

Compressed metal powder is heated in a controlled-atmosphere furnace to a temperature below its melting point, but high enough to allow bounding of the particles. Or Heats the powder below the melting point to allow solid-state diffusion and bond the particles together.

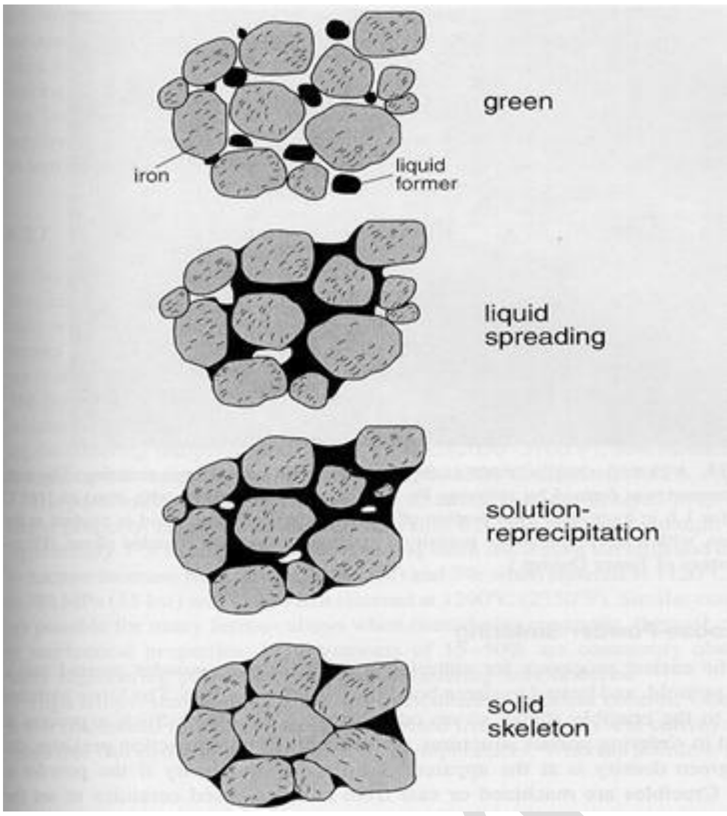


(a) Typical heat treatment cycle in sintering; and (b) schematic cross-section of a continuous sintering furnace

The primary driving force for sintering is not the fusion of material, but formation and growth of bonds between the particles, as illustrated in a series of sketches showing on a microscopic scale the changes that occur during sintering of metallic powders.



Sintering on a microscopic scale. The illustration shows different stages in development of grain boundaries between particles.



. Liquid-phase sintering usually involves mixing an iron powder with a liquid forming powder (boride, carbide, phosphide, copper, tin) and heating to a temperature where the liquid forms, spreads, and contributes to particle bonding and densification.

Other Powder Metal Processes

Sizing: cold pressing to improve dimensional accuracy

Coining: cold pressing to press details into surface

Impregnation: oil fills the pores of the part Infiltration: pores are filled with a molten metal

Heat treating, plating, painting

Isostatic Pressing

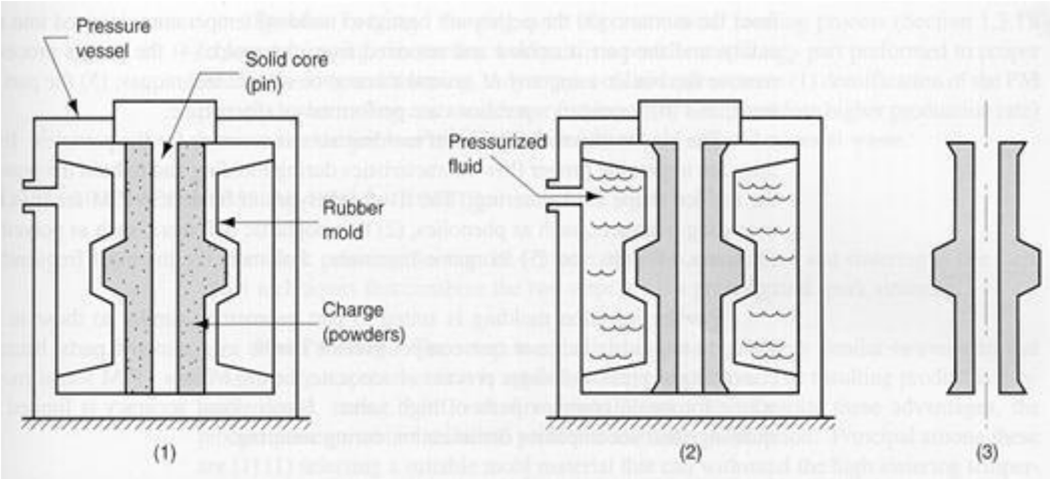
Uses pressurized fluid to compress the powder equally in all directions

Cold Isostatic Pressing

Compaction performed at room temperature

Hot Isostatic Pressing

Performed at high temperatures and pressures



Cold isostatic pressing: (1) powders are placed in the flexible mold; (2) hydrostatic pressure is applied against the mold to compact the powders; and (3) pressure is reduced and the part is removed.

Injection Molding:

The powder is mixed with a binder and molded, and the binder is removed before sintering.

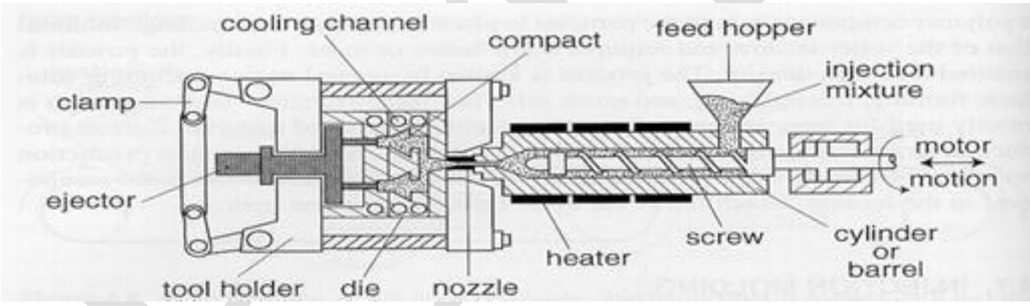
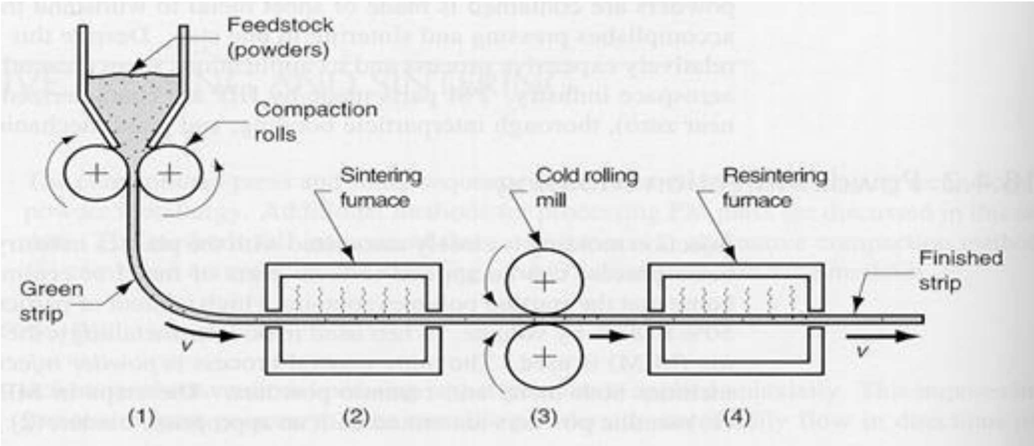


Fig. Cross section of a injection moulding machine

Powder Rolling

Powder is compressed in a rolling mill to form a strip



Powder rolling: (1) powders are fed through compaction rolls to form a green strip;

(2) sintering; (3) cold rolling; and (4) resintering.

Powder Extrusion

The powder can be extruded within a container or after being formed into billets.

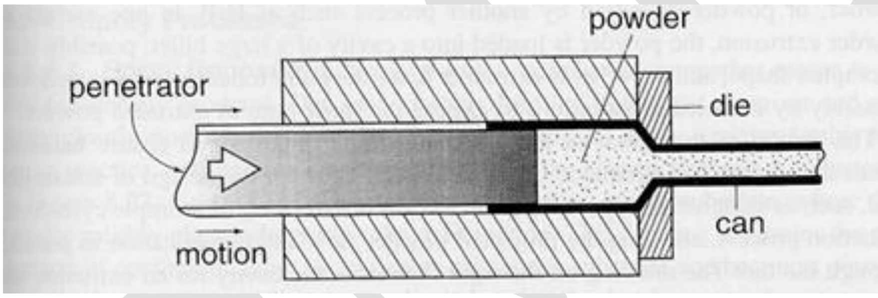


Figure Hot powder extrusion involves forcing a can filled with powder though a die at the end of the extrusion barrel. Pressure is applied by a plunger or penetrator. With a large reduction in cross-sectional area, the powder is fully densified.

Characteristics of powders

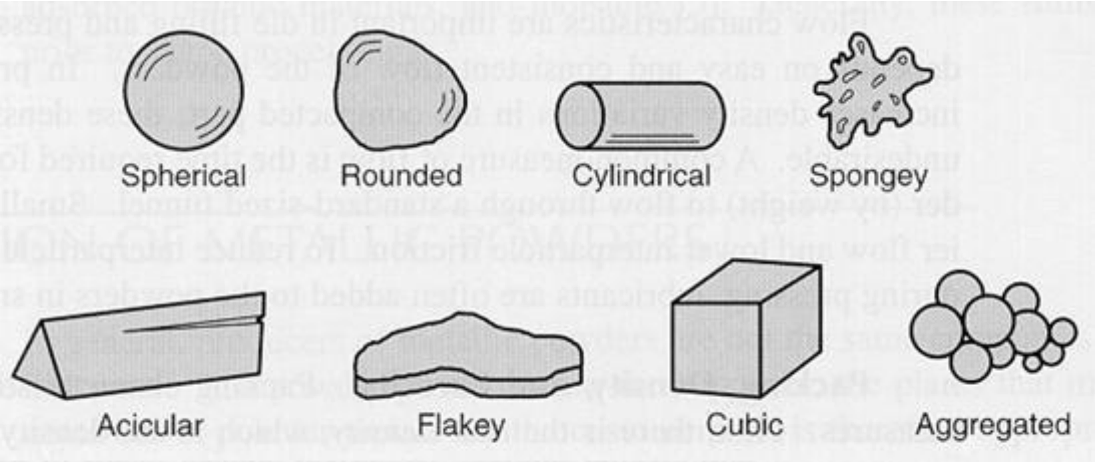
P/M materials – Alloys of iron, steel, and aluminum, copper, nickel, and refractory metals such as molybdenum and tungsten and metallic carbides

- Geometric feature – Particle shape – Particle size – Particle distribution

– They affects surface area, packing density, porosity, interparticle friction (Flow Characteristics), Green Strength

- Other Factors – (Chemistry and Surface Film)

Particle Shapes



Several of the possible (ideal) particle shapes in powder metallurgy.

Particle Size

The process of separating particles by size is called classification

Mesh count refers to the number of openings perlinear inch of screen. Thus, higher mesh count means smaller particle size.

$$PS = \frac{1}{MC} - t_w$$

where PS = particle size

MC = mesh count

t_w = wire thickness

$$V = \frac{\pi D^3}{6}; \qquad \frac{A}{V} = \frac{6}{D}$$

• Surface Area (SA) For spherical powder, $A = \pi D^2$;

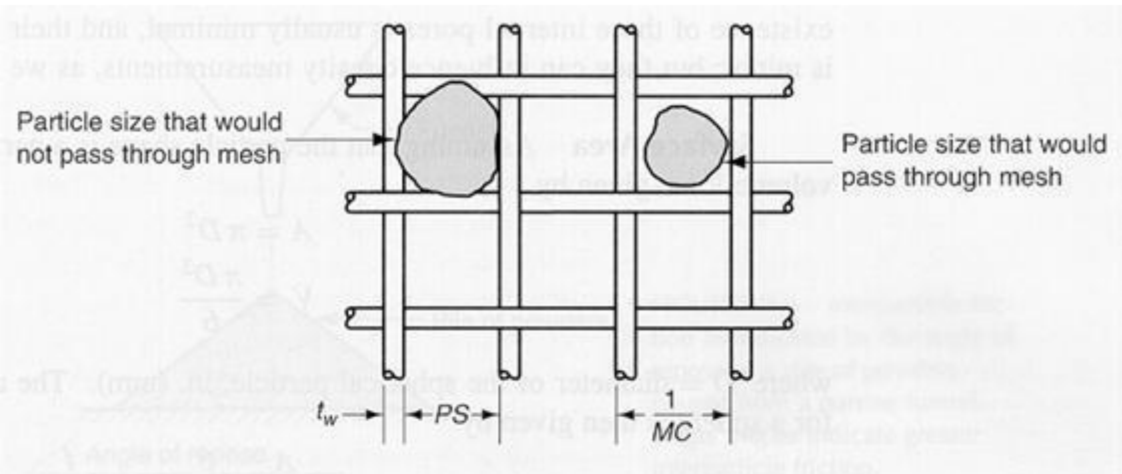


FIGURE Screen mesh for sorting particle sizes.

Mixing particles of different sizes allows decreased porosity and a higher packing ratio

Powder Metallurgy Advantages

1. Elimination/reduction of machining
2. High production rates
3. Complex shapes can be produced
4. Wide composition variations are possible
5. Wide property variations are possible
6. Scrap is eliminated or reduced

Powder Metallurgy Disadvantages

1. Inferior strength properties
2. Relatively high die cost

Registration No: | 1 | 5 | 0 | 1 | 1 | 0 | 9 | 5 | 4 | 5 |

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B.TECH
PMT3I104

3rd Semester Regular Examination 2016-17
MATERIALS PROCESSING
BRANCH(S): METTA, MME
Time: 3 Hours
Max Marks: 100
Q.CODE: Y643

Answer Part-A which is compulsory and any four from Part-B.
The figures in the right hand margin indicate marks.

Part – A (Answer all the questions)

Q1 **Answer the following questions:** (2 x 10)

a) The small amount of carbonaceous material sprinkled on the inner surface of the mould cavity to give a better surface finish to the castings is called ____ and a separate part of the mould, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings is called core.

b) The upper part of the sand mould is called facing sand and that of lower part is called backing sand.

c) The temperature at which metal starts to melt during heating is called melting temp. and the temperature at which the metal starts to solidify during solidification is called freezing temp.

d) sintering process is used for removing the volatile materials of shell at around ________ ^{0}C in investment casting process.

e) Gating ratio of pressurized casting is ______ and that of unpressurised casting is ______.

f) electrode, spark, smoke and molten metals are hidden in submerged arc welding.

g) Pressure and ac supply (high current) are the most dependable factors for resistance welding process.

h) ________ is the invested materials which can be surrounded with ______ to making the mould in investment casting.

i) molten pattern is used for making of pattern.

j) DC, (+) polarity current is preferred for single carbon arc welding to restrict the colascence.

Q2 **Answer the following questions:** (2 x 10)

a) Draw the cooling curves of alloy and pure metal.
b) What are chaplets and give its function?
c) Define weldability.
d) Define Apparent density.
e) What is backing sand?
f) What is the difference between impregnation and infiltration?
g) Express the term "long freezing range'.
h) Define 'core'.
i) What do you mean by "misrun"?
j) Why tapered sprue is more suitable than a straighter sprue?

Part – B (Answer any four questions)

Q3 a) Describe the different moulding processes. Explain the purpose of using different fluxes, binders with examples. **(10)**

b) Explain the elements of gating systems with sketches. Describe their functions in the casting process. **(5)**

Q4 a) Describe the different types of pattern and pattern allowances required in casting process. **(10)**

b) In casting experiments performed using a certain alloy and type of sand mold, it took 155 sec for a cube shaped casting to solidify. The cube was 50mm on a side. **(5)**
a) Determine the value of mould constant in Chvorinov's Rule.
b) If the same alloy and mould type are used find the total solidification time for a cylindrical casting in which the diameter r=15mm and height h=50mm.

Q5 a) Describe the defects that are generally found in welding. And explain the causes of the welding defects and their remedies. **(10)**

b) Express the advantages and disadvantages of welding process over other manufacturing process. **(5)**

Q6 a) Explain the powder metallurgy process with block diagram. What are the advantages and disadvantages of powder metallurgy process over other manufacturing processes? **(10)**

b) A copper alloy powder has an apparent density of $3000 kg/m^3$ and tap density of $4000 kg/m^3$. The powder is compacted in a cylindrical die at 300 MPa to a green density of $6000 kg/m^3$. Subsequently the compact is sintered to a density of $7500 kg/m^3$. The theoretical density of the alloy is $9000 kg/m^3$. **(5)**
a) Determine the initial fill height in mm if the powder is compressed to 10mm height.
b) Determine the densification parameter of the sintered compact.

Q7 a) Explain the different types of fabrication processes. Explain the advantages and disadvantages of casting process over other manufacturing process. **(10)**

b) Explain the Hot Isostatic Pressing (HIP) process of compaction of metal powders with the help of a suitable diagram. **(5)**

Q8 a) Describe the metallurgical principles of gas welding process. Explain the types of flames used for gas welding process. **(10)**

b) Explain the metallurgical principles involved in welding of alloy steel. **(5)**

Q9 a) Describe the different types of material transport mechanisms of sintering. **(10)**

b) What are the stages of liquid phase sintering? Explain the mechanism of liquid phase sintering. **(5)**

Registration No. : | 1 | 4 | 2 | 1 | 1 | 0 | 5 | 0 | 5 | 5 |

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B. Tech
PCMT 4204

Fourth Semester Regular Examination – 2015

MATERIALS PROCESSING

BRANCH (S) : MM, MME

QUESTION CODE : J478

Full Marks – 70

Time : 3 Hours

*Answer Question No. 1 which is compulsory and any **five** from the rest.*
The figures in the right-hand margin indicate marks.

1. Answer the following questions : 2 ×10

   (a) Why strainer cores are used in the pouring basing ?

   (b) What is permeability of a moulding sand ?

   (c) What do you mean by chilling of a casting ?

   (d) What is Chvorinov's rule ?

   (e) What is pin hole porosity ?

   (f) How polarity is defined in case of DC welding power supply ?

   (g) What is SMAW ?

   (h) Why an AC power supply is not suitable for TIG welding process ?

   (i) What is the difference between infiltration and impregnation ?

   (j) Why sintering is required in power metallurgy process ?

2. Describe briefly the die-casting process. With the help of neat sketch compare a cold chamber die casting process with a hot chamber die casting process. 10

P.T.O.

3. Describe the TIG welding technique. What are the limitations of TIG over GMAW welding method.Explain the process of metal transfer in GMAW process with the help of neat sketches. 10

4. (a) What are the various methods used for making metal powders ? 5

   (b) What are the processing methods used for the synthesis of the powder metallurgy product ? 5

5. (a) Briefly describe the allowances which are used in the casting process. 5

   (b) Compare the top gating system with respect to the bottom gate. 5

6. (a) What are the advantages and disadvantages of permanent mould casting as compared to that of sand castings ? 5

   (b) What are the major casting defects which are likely to occur in a sand castings ? 5

7. (a) Differentiate between pressurized and unpressurised gating system. 5

   (b) State the principle and types of resistance welding. 5

8. Write short notes on any **two** : 5 × 2

   (a) Oxy acetylene welding

   (b) Investment casting

   (c) Induction furnace

   (d) Cold Iso-static pressing.

Registration No. : | 1 | 3 | 2 | 1 | 1 | 0 | 5 | 0 | 4 | 9 |

Total number of printed pages – 2

B. Tech
PCMT 4204

Fourth Semester Regular Examination – 2014

MATERIALS PROCESSING

BRANCH : MM, MME

QUESTION CODE : F 208

Full Marks – 70

Time : 3 Hours

Answer Question No. **1** *which is compulsory and any* **five** *from the rest.*
The figures in the right-hand margin indicate marks.

1. Answer the following questions : 2×10

   (a) What do you mean by "short freezing range" ?

   (b) What are the materials to be used for core making ?

   (c) What is facing sand ?

   (d) What is flour moulding ?

   (e) Why AC current supply is used in double carbon arc welding ?

   (f) What is "GTAW".

   (g) Define the slip casting process.

   (h) State the three main stages of sintering.

   (i) What are the advantages of powder metallurgy process ?

   (j) State the basic characteristics of a metal powder.

2. (a) Explain the different types of fabrication process. 5

   (b) Express the advantages and disadvantages of welding process over other manufacturing process. 5

P.T.O.

3. (a) Describe the melting practice of Al-alloy in sand mould casting methods. 5

(b) What are the advantages and disadvantages of investment casting over other casting processes ? 5

4. What is sintering ? Describe the four important material transport mechanisms of sintering. 10

5. (a) Classify the welding processes. 5

(b) Describe the principles of an oxy-fuel gas welding process. 5

6. (a) What is meant by patterns ? Discuss different pattern materials. 5

(b) Describe the different types of patterns with their sketches that can be used in casting process. 5

7. (a) Discuss the casting defects which may be shown in case of cast iron castings. 5

(b) Explain the remedial measures you would like to adopt to overcome these casting defects. 5

8. Write short notes on any **two** of the following : 5×2

(a) Vacuum die casting

(b) MIG welding

(c) Cold pressure shaping technique

(d) Spot welding.