MODULE-3

SOLIDIFICATION & NON FERROUS FOUNDRY PRACTICE

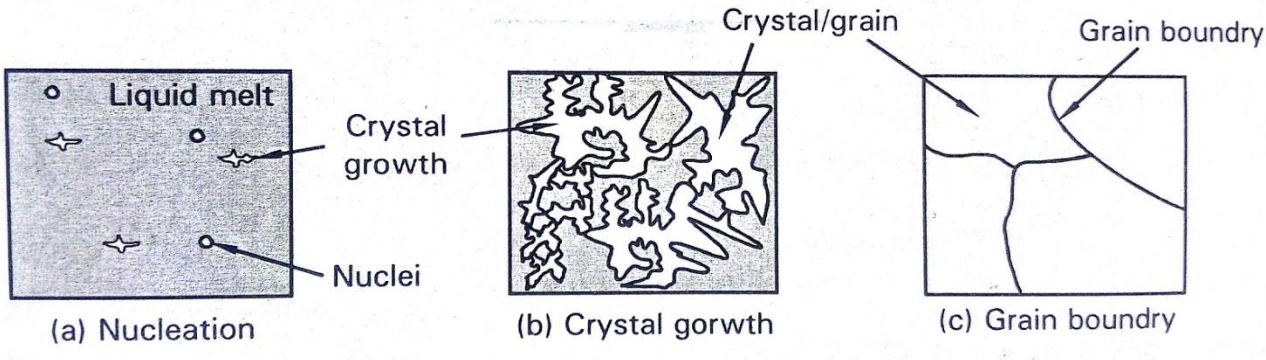
3.1 INTRODUCTION TO SOLIDIFICATION

Solidification is the process by which substance undergoes phase transformation from liquid state to solid state. Water converting to ice is a simple example of solidification process. In a casting process, as the molten metal (liquid) is poured into the mould cavity, it begins to cool. When the temperature drops below the freezing point (melting point) of the material, solidification starts.

As known, all metals shrink during change of phase from liquid to solid state. However different metals at different rates and as such proper understanding of the solidification mechanism are essential to prevent defects due to shrinkage of metal. Further, during solidification, the atoms in the material are re-arranged leading to change in the microstructure of the material. The change in the microstructure results in changes in the properties of the material like strength, toughness, ductility, etc. By controlling the solidification process suitably, the microstructure, and hence the properties of the material can be altered as desired.

3.2 NUCLEATION

When a liquid cools below its freezing point (melting point), it starts to solidify, and the atoms of the liquid metal begin to bond together forming a very small sized crystal called nuclei. This process takes place at several locations as shown in figure 3.1 (a).



(a) Nucleation (b) Crystal gorwth (c) Grain boundry

Figure 3.1

The formation of new crystals is known as nucleation, and the point where it occurs is the nucleation point. As the solidification progresses, the crystal increase in size by the progressive addition of atoms and grow until they impinge upon adjacent growing crystal. Crystal growth continues in three dimensions forming a tree like appearance known as dendrites. Refer figure 3.1 (b). The dendrites grow in different directions in each crystal and finally when one dendrite impinges upon the adjacent growing dendrite, a grain boundary is formed as shown in figure 3.1(c). The crystal growth ceases when all the available liquid metal has solidified.

Types of Nucleation

It is observed that nucleation is helped by the presence of foreign elements or impurities present in the molten metal. Depending on the role of these foreign elements, nucleation is classified into types: Homogeneous nucleation and Heterogeneous nucleation.

When nucleation takes place in the liquid metal without the help of any impurities, then it is known as homogeneous nucleation or self-nucleation. Nucleation based on this mechanism takes place in pure liquid metals only.

On the other hand, when nucleation takes place with the help of impurities, it is known as heterogeneous nucleation. Impurities can be in the form of sand particles, alloy additions, oxides, or even the surface of the mould wall. Thus in the usual casting process, nucleation is heterogeneous.

3.3 SOLIDIFICATION VARIABLES

The solidification process by which a liquid metal freezes in a mould plays a crucial role, because different solidification conditions give rise to different microstructures and hence the properties of the as-cast alloy. The variables affecting the solidification behavior of a casting include:

1) The type or composition of casting alloy

An alloy consists of a base metal to which other elements are added to obtain favourable properties. When an element is added to the base metal, it significantly alters the solidification process. This is because, an alloy freezes over a range* of temperatures. Thus proper control of alloying elements promotes constitutional supercooling^ and further the additional use of inoculating agents promotes heterogeneous nucleation resulting in fine grained structures in the cast metal.

2) Thermal properties of both the alloy and the moulding material & cooling rate

The heat released during solidification is very large, and as such it must be extracted quickly. The higher the melting point and thermal conductivity of materials used in casting process, the larger is the latent heat (energy released/absorbed) of fusion.

Further, the heat extracted per unit time, which is defined as the cooling rate depends mainly on the mould material and the air gap formed at the metal mould interface. High

---

** Pure metals freezes (solidifies) at a constant temperature.*

A Constitutional supercooling, which occurs during solidification, is due to compositional changes, and results in cooling a liquid below the freezing point ahead of the solid—liquid interface.

Inoculation refers to the introduction of another metal into the melt in order to influence the solidification process or structural formation in the casting in a specific way.

cooling rate promotes directional solidification at a faster rate with finer grains, while low cooling rate exhibits larger grains. It is important to note that the grain size affects the strength and hardness of the casting. Also, metallic moulds produce higher cooling rate than a sand mould under the same operating conditions.

3) Mould thickness and shape

The thickness of mould influences solidification time (or heat removal rate). In case of sand moulds, heat removal rates are increased by a decrease in mould thickness below a certain critical thickness. However, for the same thickness, solidification is faster in metallic moulds.

4) Chills, Gating, and other Casting design factors

Solidification takes place at a certain rate relative to the thickness of the casting. A casting should be designed to achieve controlled progressive directional solidification so that it becomes free from solidification related defects. Location of gates and risers, use of chills and other means for controlling the freezing process must be adopted suitably for complete solidification to take place.

5) Pouring temperature

The pouring temperature of the molten metal must be higher than the solidification temperature of the metal. This will help the molten metal to flow into all regions of the mould before solidifying and overcomes the solidification related defects. However the temperature of the melt must not be very high, as this might saturate the gases resulting in the formation of oxides. Also the molten metal at high temperature has the ability to penetrate into the surface of the mould material.

3.4 DIRECTIONAL SOLIDIFICATION & ITS NEED IN CASTING

As the molten metal cools and solidifies in the mould, it shrinks or contracts in volume. Due to varying sections of the cast part and different rates of heat loss to adjoining mould walls, some portion of the molten metal tends to solidify more quickly resulting in voids and cavities than other portions. These voids must be filled with the incoming liquid metal from the feeder head (riser). Hence the casting must be so designed with respect to the feeding system such that the part of the mould that is farthest from the feeder head must solidify first and then proceed through the casting towards the feeder head. The solidification which is made to occur in this particular direction is known as Directional Solidification.

Directional solidification can be described as the solidification of molten metal taking place in such a manner that liquid feed metal is always available for that portion of the metal that is just solidifying. It can also be described as the solidification of molten metal taking place progressively from the thinnest part, which solidifies first, and towards the feeder head (riser), which solidifies last.

Note: Directional solidification and Progressive solidification (parallel solidification) are the two types of solidification in castings and hence not to be confused with each other. Although these processes share some common traits, the difference lies in that, in progressive solidification, the cooling and solidifying process begins at the walls of the casting and works its way inward. With directional solidification, the process of solidification begins at the bottom of the casting and works its way to the top.

3.4.1 Methods/Factors Controlling Directional Solidification:

The various methods of directionally solidifying a molten metal and hence to obtain a sound casting is listed and discussed as follows:

- Proper design and positioning of the gates and risers.
- Use of insulating pads and sleeves for risers.
- Use of chills in the mould
- Incorporating blind riser, and
- Use of exothermic riser compounds

a) Proper design and positioning of the gates and risers.

The shape of the riser must be such that it must lose minimum heat keeping the metal in the molten state. This can be met with a spherical shaped riser, however its incorporation in the mould is difficult. The next best shape is cylinder sand than a square.

Cylindrical riser is the commonly used and it must be at least 15 to 20% larger in diameter than the section it is required to feed. The riser height is usually 1.5 times greater than its diameter. To increase volume to surface area ratio, the bottom of the cylindrical riser can be shaped as hemisphere. The riser must be positioned suitably so that solidification is directional from the casting extremities towards the riser.

(b) Use of insulating pads and sleeves for risers:

The sides of the riser are insulated with sleeves made from suitable materials so as to achieve lower solidification rate in the riser. This enhances better feeding of the casting. Sleeves made from plaster of Paris are used for non-ferrous castings, while pearlite sleeves or fireclay sawdust sleeves are used for ferrous castings. Cellulose materials like rice hulls are also used. Insulating pads can also be employed in various parts of the mould to decrease the cooling rate in thin sections so as to promote directional solidification.

(c) Use of chills in the mould:

A chill is a metallic object of suitable shape inserted in the sand mould to improve solidification of a region of the casting inaccessible to a riser thereby promoting directional solidification. A chill will produce local chilling and equalize the rate of solidification throughout the casting.

A chill may be classified as internal chill or external chill depending on its location in the mould. Chills placed inside the mould cavity are called internal chills. When the cavity is filled with molten metal, the chill will melt and become part of the casting. Thus internal chills are made from the same material as the cast part. On the other hand, external chills having high thermal conductivity are placed on the edge of the mould cavity thereby forming a part of the wall of the mould cavity. External chills are used to increase the feeding distance of a riser or reduce the number of risers.

(d) Use of Blind riser:

A conventional riser is open to atmosphere, whereas a blind riser is completely enclosed in the sand mould. As a result, the molten metal in the blind riser cools slowly an stay liquid longer thereby promoting directional solidification. Refer figure 3.17.

(e) Use of exothermic riser compounds:

Exothermic riser compounds are loose materials, essentially mixture of a metal oxide (Fe, Mn, Co, Ni, Cu, etc.) and aluminum, sprinkled on the top of riser in place of insulating powder. Their function is to prevent heat loss from the top of riser and also add some heat to the molten metal in the riser thereby allowing the metal to stay hotter necessary for achieving directional solidification.

3.5 DEGASIFICATION IN LIQUID METALS

As known, gases are much more soluble in liquid metal than in solid metal. As the liquid metal is poured into the mould and solidifies, it absorbs gases from various sources. These gases dissolve in molten metal as elements (H, C, 0, etc.,) and not as molecules (H2, CO2, etc.). On solidification, the elements may recombine to form molecular gases, and in doing so, form gas holes like blow holes, pin holes, etc., resulting in casting defects. Since it is not possible to completely prevent the absorption of gases in the melt, it is required to remove the dissolved gases, and the process adopted is known as degasification. Vacuum melting is used nowadays for preventing the dissolution of gases in metals.

3.5.1 Sources of Gases in Liquid Metals & Its Prevention

Gases are absorbed in molten metal from various sources as listed below:

1) Furnace atmosphere:

The atmosphere inside the furnace may contain water vapour, CO, CO2, and SO2 as products of combustion of fuel, in addition to the normal atmospheric gases such as nitrogen and oxygen. The amount of gas absorption depends on the conditions and the type of melting furnace. Maintaining clean and dry atmosphere inside the furnace and furnace walls helps in reducing gas absorption.

2) Furnace charge:

Wet or oily materials or contaminated scrap, charged into the furnace contribute to gas absorption Alloying additions containing hydrogen resulting from the reducing conditions employed in smelting fluxes, and slag making additions are other sources. Use of dry and clean charge helps in reducing gas absorption.

3) Ladles:

Incompletely dried linings and surface of spouts, tundishes, and ladles, when brought in contact with the molten metal may help gas absorption through dissociation of steam at the contact surface. Use of clean, dry and preheated tools helps in reducing gas absorption.

4) Furnace to ladle or Ladle to mould:

Molten metal may absorb gases while it is transferred through air from ladle to mould, or during tapping from furnace to ladle. The gas absorption can be minimized by providing a protective atmosphere to the molten metal by means of slag, inert gas, exothermic compounds, etc. Further, pouring metal at temperatures as low as practically possible, and maintaining metal handling conditions like skimming, stirring, and re-ladling helps in reducing gas absorption.

5) In the mould:

Molten metal may absorb gases inside the mould, in case if the mould materials contain excess moisture or volatile hydrocarbons. Moulding materials free of volatile matter and proper venting system in the mould helps in reducing gas absorption.

3.6 DEGASIFICATION METHODS

Following are the different methods of degassing:

1) Flushing
2) Vacuum degassing
    - Static bath treatment
    - Induction degassing
    - Stream droplet degassing
    - Fractional degassing

3.6.1 Flushing

Flushing or Gas scavenging with an inert gas* is one of the most effective methods of extracting dissolved gases from the molten metal. Inert gases such as chlorine, nitrogen, helium or argon are used in practice for degassing non ferrous metals, while carbon monoxide is used for ferrous metals and Ni based alloys. Figure 3.2 illustrates the principle of flushing with inert gas.

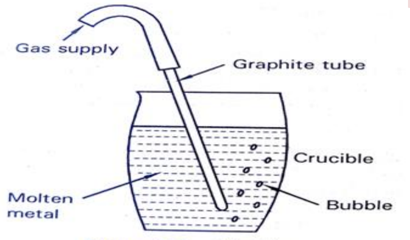


Figure 3.2 Flushing

In this method, the inert gas is simply piped from storage tanks through graphite tubes directly into the liquid metal. The piping of inert gas creates bubbles, which move upwards and any dissolved gas in the liquid melt migrates readily to the bubble where it collects and is flushed from the melt and to the atmosphere. The rate of degassing depends on the rate at which the gas diffuses in to the gas bubbles.

Note: For ferrous metals and Ni based alloys, nitrogen cannot be used as inert gas. They form nitrides that affect the grain size.

3.6.2 Vacuum Degassing

As the name suggests, vacuum degassing is a technique of removing dissolved gas from the liquid melt by lowering the pressure inside the vessel containing the liquid melt, in the presence of vacuum. It is particularly used in steel foundries for degassing hydrogen and oxygen from liquid steel. Steels refined in vacuum are characterized by homogeneous

---

** An inert gas, also called as noble gas is a gas which does not undergo any chemical reactions when allowed to react with many substances. Purified nitrogen and argon gases are widely used as inert gases due to their availability and low cost. Inert gases are generally used in those applications in order to avoid unwanted chemical reactions especially oxidation and hydrolysis reactions with the oxygen and* structure, low content of non-metallic inclusions and low gas porosity.

Vacuum degassing is typically performed in a specially designed chamber or vessel known as vacuum degasser. There are a number of variants followed in the vacuum degassing process, however working on the same principle by exposing the molten metal to a low-pressure environment. The reduced pressure inside the vessel or chamber causes the dissolved gas to become less soluble and separate from the liquid melt. When the vacuum degassing process is complete, the gas is removed from the vessel, and the pressure is returned to normal. It must be noted that the effectiveness of any vacuum degassing operation depends upon the surface area of liquid melt that is exposed to low pressure. Hydrogen removal is a diffusion and partial pressure phenomenon, while Oxygen removal is a function of chemical reaction of oxygen with carbon and the partial pressure of carbon monoxide. The different variants of vacuum degassing with respect to hydrogen gas removal are discussed as follows:

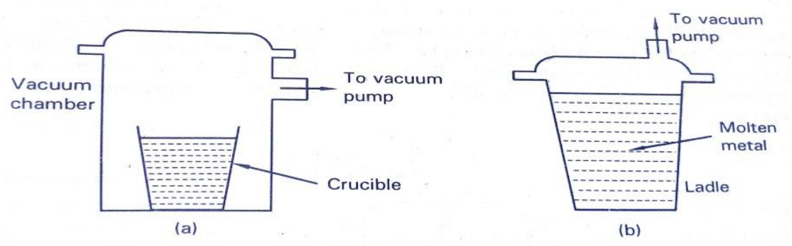


Figure 3.3 Static bath degassing technique

1) Static bath degassing: Static bath technique is the simplest form of degassing technique, wherein the ladle tapped with the molten metal is placed within a chamber, sealed and evacuated as shown in figure 3.3(a). The process although time consuming and requiring additional equipments may be simplified by sealing the tapped ladle itself with a cover as shown in figure 3.3(b). The space above the molten metal in the ladle forms the vacuum chamber. The reduced pressure inside the chamber causes the dissolved gas to become less soluble and separate from the liquid melt. Once the degassing process is completed, the pouring of metal is carried out. This system gives the advantage of a small pump down volume, reducing the vacuum pump capacity requirement. However, since the system does not utilize any circulation of the melt other than that provided by the natural convection, degassing proceeds at a slower rate.

2) Induction degassing:

Induction degassing technique overcomes the disadvantages of static bath technique. The system as shown in figure 3.4 consists of a crucible surrounded by induction heating coil, the entire assembly located within a chamber that can be sealed and rapidly evacuated. Molten metal is transferred from the melting unit into the crucible, wherein the current flowing through the coils create a magnetic field that induces eddy currents and circular electric currents producing a stirring action within the molten metal. The bath agitation which takes place at normal frequency is just sufficient for hydrogen gas removal from the melt to take place. The effect of removing dissolved gas is enhanced to a greater extent in the presence of vacuum atmosphere.

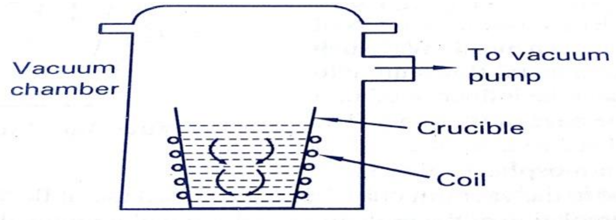


Figure 3.4 Induction degassing

Vacuum induction process is more efficient, except cost of the furnace being a major drawback. However, foundries operating with induction furnaces have the advantage, since all the operations like melting metal under vacuum, refining, degassing, heating, alloying, etc., are done in one single unit (melting furnace). The process is relatively flexible, featuring the independent control of time, temperature, pressure, and mass transport through melt stirring.

3) Stream droplet degassing:

In stream degassing technique, the molten metal from the ladle is poured down in to another preheated ladle placed in an evacuated chamber as shown in figure 3.5.

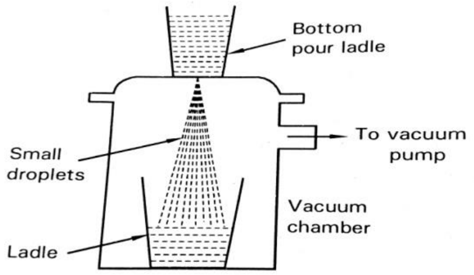


Figure 3.5 Stream droplet degassing technique

Bottom pouring of molten metal is desirable as it creates a stream of flow in to the vacuum chamber. The sudden exposure of liquid stream in the vacuum chamber leads to very rapid degassing due to the increased surface area created by break-up of stream into droplets. The process helps the hydrogen gas dissolved in steel to be evacuated by a vacuum pump. The major amount of degassing occurs during the fall of liquid stream, and as such the height of the pouring stream forms an important design parameter in the process.

4) Fractional Degassing:

In fractional degassing technique, the molten metal to be tapped in the ladle is progressively degassed by treatment of fractions of the metal in a separate pump metal vacuum vessel as shown in figure 3.4. The system makes use of two tubes connected at the bottom of the vacuum chamber with one of the tubes Argon - connected to a pipe supplying argon gas through its refractory lining. Both the tubes are immersed into the ladle containing molten metal. With such an arrangement, the liquid metal flows up in to the vacuum chamber under the influence of inert gas bubbles bled into the base of the tube.

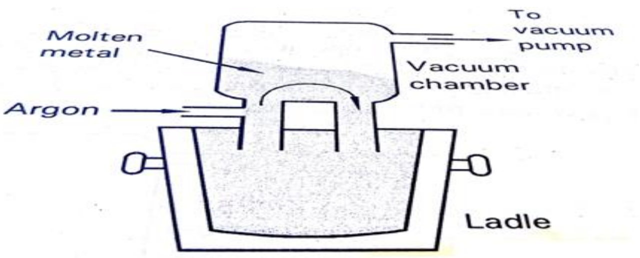


Figure 3.6 Fractional degassing

The Figure 3.6 Fractional degassing level of the molten metal in the vacuum chamber is determined by the atmospheric pressure. Through the second tube in the vacuum chamber, the molten metal flows down back to the ladle producing continuous circulation of the melt and resulting in the removal of gases.

Fettling and cleaning is carried out following the shakeout (removal of casting from sand mould) and knockout (removal of sand core from casting) operations. Fettling includes the following steps:

a) Removal of sand and other impurities: The rough casting removed from the mould consists of adhering moulding sand, core sand, oxides and scale which has to be cleaned. This is achieved manually, mechanically or by chemical means. Wire brush, files and other tools are used in manual operations, while air blasting, hydro-blasting, tumbling etc., are a few equipments used in mechanical operations. Chemical cleaning methods utilize baths of molten caustic soda containing additional reagents to react with and break the surface oxide layer. This loosens adhering sand also.

b) Removal of excess metal:

This step includes removing excess metal such as fins*, blisters, stumps of gates and risers, and other unwanted projections from the castings. This is achieved by chipping, sawing, flame cutting, grinding and other operations.

c) Finishing of castings:

Finishing is carried out to smoothen parts of the casting where gates and risers were attached, and also improve the surface finish and appearance of the casting. Different finishing operations like Grinding, Polishing, Buffing, etc., are used for the purpose.

3.7 FETTLING / CLEANING OF CASTINGS

Fettling and cleaning is carried out following the *shakeout* (removal of casting from sand mould) and *knockout* (removal of sand core from casting) *operations*. Fettling includes the following steps:

a) Removal of sand and other impurities

The rough casting removed from the mould consists of adhering moulding sand, core sand, oxides and scale which has to be cleaned. This is achieved manually, mechanically or by chemical means. Wire brush, files and other tools are used in manual operations, while air blasting, hydro-blasting, tumbling etc., are a few equipments used in mechanical operations. Chemical cleaning methods utilize baths of molten caustic soda containing additional reagents to react with and break the surface oxide layer. This loosens adhering sand also.

b) Removal of excess metal

This step includes removing excess metal such as fins*, blisters, stumps of gates and risers, and other unwanted projections from the castings. This is achieved by chipping, sawing, flame cutting, grinding and other operations.

c) Finishing of castings

Finishing is carried out to smoothen parts of the casting where gates and risers were attached, and also improve the surface finish and appearance of the casting. Different finishing operations like Grinding, Polishing, Buffing, etc., are used for the purpose.

3.8 CASTING DEFECTS

Casting process involves a number of variables, and a loss of control in any of these variables can cause defects' under certain circumstances. Some of the common casting defects, their features and remedies to prevent such defects are discussed below.

(a) Shrinkage defect

Shrinkage is a void on the surface of the castings resulting from contraction or shrinkage of metal during solidification. Refer figure 3.7. Although a riser is used to overcome the shrinkage effect, in some cases it fails to feed the molten metal efficiently to the casting as it solidifies.

** Fin - Metal on a casting caused by* an *imperfect joint in the mould or die.*

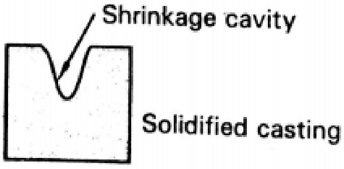


Figure 3.7 Shrinkage defect

Remedies

- Use large sprue and riser to promote directional solidification.
- Locate risers and gating systems in correct positions.
- Gates to be cut as wide as possible.

(b) Porosity defect (Blow hole and Pin hole)

Molten metal absorb gases from various sources such as fluxes, moisture in sand, binders, additives and normal atmospheric gases like oxygen and nitrogen. If these gases are not allowed to escape, they get entrapped in the mould cavity forming small balloon shaped voids or cavities leading to porosity defect in castings. Two types of gas related defects occur in castings. They are: blow hole and pin hole defect.

Blow holes occur below the surface of the castings and are not visible from the outside surface. Refer figure 3.8 (a). On the other hand, pin holes are small gas cavities, many in number at or slightly below the surface of the casting. Refer figure 3.8 (b).

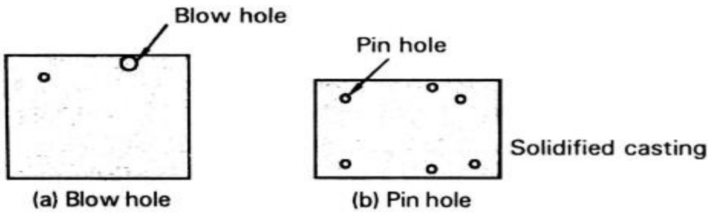


Figure 3.8 Porosity defect

Remedies

- Avoid excess ramming of mould.
- Provide proper vent holes.
- Avoid use of excess carbonaceous or other organic material in the sand/core binders, because these materials react with the molten metal producing large amount of gases.

(c) Misrun

Misrun occur when the mould cavity is not completely filled with molten metal. In other words, it is a defect wherein a casting solidifies before the molten metal completely fills the cavity. Refer figure 3.9.

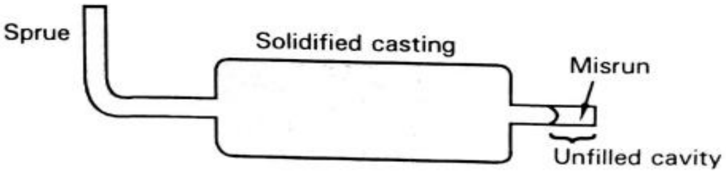


Figure 3.9 Misrun

Remedies

- Fluidity of metal should be maintained suitably.
- Pouring rate and time should be controlled.
- Thin sections should be suitable designed.

(d) Penetration

When fluidity of liquid metal is high, it may penetrate into the sand mould/core (into the voids between the sand particles). A fused aggregate of metal and sand appears on the surface of the casting leading to defect. Refer figure 3.10.

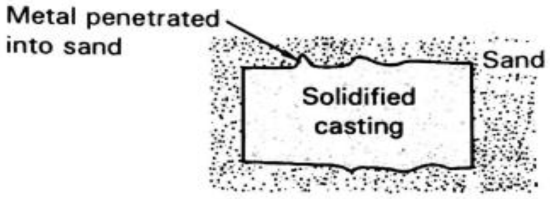


Figure 3.10 Penetration

Remedies

- Sand should be properly rammed.
- Moulding sand/core sand should not be too coarse to promote metal penetration.
- Control proper metal temperature. Fluidity of molten metal should be maintained suitably.

(t) Mould shift

It is a *step* produced in the cast product along the parting line due to the sidewise relative displacement of cope and drag box. Refer figure 3.11.

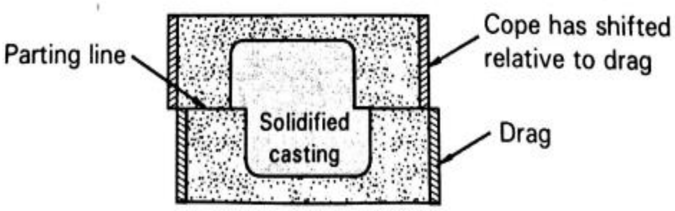


Figure 3.11 Mould shift

Remedies

- Proper alignment of cope and drag box.
- Proper handling of assembled cope and drag box during operations.

(g) **Cold shut**

Two portions of metal flow together, but lack of fusion due to premature freezing results in a defect known as cold shut. Refer figure 3.12.

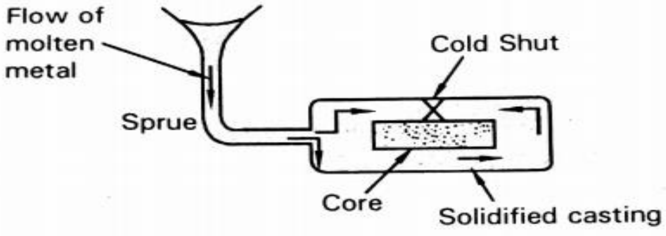


Figure 3.12 Cold shut

Remedies

- Place gates and risers at proper locations.

- Metal fluidity should be high.

(h) Hot tears

A hot tear is an internal or external ragged discontinuity formed in the casting due to the pulling action of the metal just after it has solidified. Refer figure 3.13.

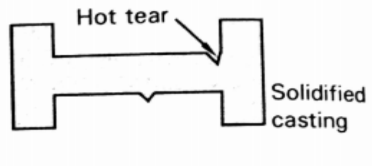


Figure 3.13 Hot tear

Remedies

- Provide adequate fillets at sharp corners while designing the component.
- Proper metallurgical and pouring temperature to be maintained.
- Place gates and risers at suitable locations.

3.9 ADVANTAGES & LIMITATIONS OF CASTING PROCESS

Advantages

a) Large hollow and intricate shapes can be easily cast.
b) Quick process, and hence suitable for mass production.
c) No limit to size and shape. Parts ranging from few millimeters to meters and few grams to tons can be cast efficiently and economically.
d) Better dimensional tolerances and surface finish can be obtained by good casting practice.
e) Castings exhibit uniform properties in all the directions—longitudinal, lateral & diagonal.

Limitations

a) Presence of defects in cast parts is a major disadvantage.
b) Casting process is not economical for small number of parts.
c) Properties of cast materials are generally inferior when compared to those made by machining or forging process.
d) Process parameters are many, right from pattern making to pouring and solidification of molten metal. Monitoring these parameters to produce a good casting is a tough task.

3.10 INTRODUCTION TO NON FERROUS FOUNDRY PRACTICE

As known, ferrous metals contain iron as its chief constituent element, while non-ferrous metals do not contain iron. Ferrous metals are preferred owing to their high strength and durability, while non ferrous metals are preferred due to their light weight and corrosion resistance. Although the technique of casting remains the same for both types of metals, the foundry practice varies to a larger extent and hence there is a need to study the various aspects related to non ferrous foundry practice. However from the syllabus point of view, the discussions presented in this chapter is confined to Aluminum, alloy — the most widely used non ferrous metal in casting technology.

3.11 ADVANTAGES & LIMITATIONS OF ALUMINUM CASTINGS

Advantages

1) Of all the non ferrous castings, aluminum castings exhibit high-strength-to-weight ratio.
2) Aluminum casting alloys display excellent fluidity characteristics for casting thin sections and fine

details.

3) Aluminum casting alloys melt at relatively low temperatures thereby reducing the problems related to melting, pouring, and essential furnace requirements.

4) Aluminum castings can be produced almost by every known process thereby offering a broad range of volume, productivity, quality, mechanization and specialized capabilities.

5) Metallurgically or mechanically bonded bimetal parts can be routinely cast.

6) Aluminum castings require low capital requirements.

7) Owing to its high-strength-to-weight ratio, and corrosion resistance, aluminum castings are preferred in aerospace and automotive industries.

Further, due to its non-toxicity, aluminum castings are used for cooking utensils, food handling and medical equipments;

Limitations

1) Aluminum castings are more expensive than ferrous based castings.

2) Aluminum castings exhibit poor resistance to abrasion and wear.

3) Variation in alloying elements affects properties to greater extent.

For example: - Al—Cu alloy castings exhibit greater strength and hardness, while decreased castability; Al—Si alloy castings exhibit outstanding castability and wear resistance, however prone for gas porosity. Optimum properties can be achieved with proper inclusion of alloying elements.

3.12 MELTING OF ALUMINUM ALLOYS

Aluminum alloys can be melted in direct or indirect fuel fired furnace or in electrically heated furnace like crucible furnace, induction furnace etc. The present section describes the details of Lift-out type crucible furnace.

Lift-out type Crucible furnace

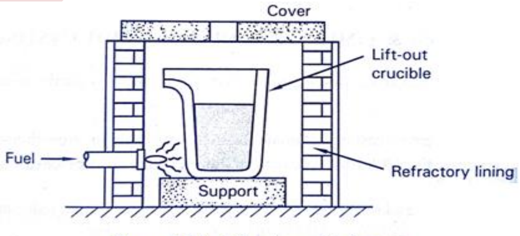


Figure 3.14 Lift-out crucible furnace

The lift-out type of crucible furnace is one of the oldest and simplest type of furnace used for melting aluminum alloys (also other non ferrous alloys) in small volumes. The furnace as illustrated in its simplest form in figure 3.14 consists of a crucible made from a refractory material, usually a clay-graphite mixture, or of a high temperature steel alloy. The crucible itself acts as a ladle. The charge placed inside the crucible is heated through the walls of the crucible by means of heat sources like oil,gas, or electricity. After the melt has reached the desired state, the crucible is lifted out of the furnace with tongs and the molten metal is directly poured into the mould.

3.13 HARDENERS USED, IN ALUMINUM CASTINGS

The mechanical and physical properties of Aluminum castings are enhanced with the use of alloying elements. However, aluminum is a low melting point (660°C) metal, and most of the alloying elements having favourable properties have comparatively greater melting points. In such a case, the alloying elements do not mix readily with the low melting point aluminum metal, and hence master alloys or hardeners are often used. Hardeners are available in a number of alloys including Ca, Co, Cu, Cr, Mn, Mg, Ni, Si, Ti, V, Zr, Zr- V, and more.

For example, chromium has a melting point of about 1875°C. is used as a hardener with the aluminum melt in order to impart strength, hardness, and oxidation resistance; the aluminum-chromium alloy combination is called as master alloy and chromium as hardener. Initially chromium is allowed to reach the molten state, and in this condition, solid aluminum is added and is quickly dissolved in the liquid chromium.

Aluminum-based master alloys which contain the hardener elements in high concentrations, now provide a convenient and economical way to add them to molten aluminum to achieve the desired final properties. These master alloys readily go into solution at lower liquid aluminum temperatures, thus minimizing dross formation and solubility of hydrogen. The amount of aluminum and hardeners used is calculated during the course of melting so as to bring the final aluminum casting to the desired specification.

3.14 DROSSING

Dross is a mass of solid impurities floating on the surface of low melting point metals such as aluminum, tin, lead, zinc, etc., as a result of oxidation of the molten metal. With reference tc aluminum castings, the term Drossing is specially used to denote the formation of aluminum oxide and other oxides * that collect on the surface of the molten aluminum metal when coming in contact with air.

Dross can be minimized when melting is made faster, or protecting the molten metal coming in contact with the products of combustion or atmospheric air. However, even with its formation, the dross product need not be considered a waste material, instead can be recycled either mechanically or chemically and reused.

Oxide Separation and Removal

Drossing fluxes are designed for chemical means (Fluxing) to promote separation of the aluminum oxide (Al203) dross layer that forms on the surface of the melt from the molten metal. Either solid or chemically active gaseous fluxes containing chlorine, fluorine, chlorides, and/or fluorides are used for the purpose. The drossing flux reacts with Al203 in the dross layer by de-wetting of the oxide-melt interface to provide effective separation of oxides and other included matter thereby helping in recovering aluminum metal.

In the mechanical process, the hot dross is placed into a press that squeezes and separates into aluminum metal rich particles and aluminum oxide rich particles based on density. The metal rich particles are then melted in a furnace to remove the remaining oxide particles.

3.15 GAS ABSORPTION IN ALUMINUM CASTINGS

Hydrogen is the only gas that is appreciably soluble in aluminum and its alloys. Its solubility varies directly with temperature and the square root of pressure. During the cooling and solidification of molten aluminum, dissolved hydrogen in excess of the extremely low solid solubility may precipitate in molecular form, resulting in the formation of primary and/or secondary voids like pin holes or gas porosity.

Fluxing and Flushing of aluminum melts are practiced mainly for two purposes as listed below:

1) To separate molten aluminum metal from the aluminum oxide dross layer

2) To remove dissolved hydrogen and entrapped dross from the melt.

In the flushing method as also discussed in section 3.6.1, inert gases like chlorine, nitrogen, helium or argon gas is simply piped from storage tanks through graphite tubes directly into the liquid metal. The piping of inert gas creates bubbles, which move upwards and the hydrogen gas dissolved in aluminum melt migrates readily to the bubble where it collects and is flushed from the melt and to the atmosphere. Dross separation by fluxing is due to the mechanical action of the inert gas bubbles carrying oxides to the surface.

Fluxing means adding suitable agents in order to achieve the following:

1) To react with the dross so that it can float up,

2) To prevent reaction of the melt of aluminum with atmosphere by acting as a barrier, and

3) To absorb impurities in the melt.

All aluminum alloys, in general, are melted under flux cover of halide salts. These fluxes contain salt mixtures that are liquid at normal aluminum melting temperatures.

Typical fluxes are:

a) 47.5% sodium chloride, 47.5% potassium chloride, and 5% sodium aluminum fluoride, or

b) 45% KC1, 45 % NaCland 10 % NaF.

Other cover flux combinations include aluminum and zinc chlorides. Some manufacturers of cover flux recommend that the flux should be stirred in the melt to be effective, so that the dross can be easily separated from the metal.

** Most oxides are of aluminum, but alloying elements such as magnesium, iron, copper and titanium also can form their oxides.*

3.16 GRAIN REFINEMENT IN ALUMINUM ALLOYS

Grain size in an aluminum alloy refers to size of individual aluminum crystals in the solidified part. The size of these crystals is directly related to the number of grains or nuclei formed during the initial stages of solidification or during pouring of metal. The more the number of grains, the finer the grain size will be, thereon having the ability to promote improved casting soundness by minimizing shrinkage, hot cracking, and hydrogen porosity. Also, the mechanical properties are greatly enhanced with fine grain structure.

Grain size in aluminum alloys can be refined by the following three methods:

1) Thermal method:

Thermal method involves rapid cooling (chilling) of liquid metal and subsequently variation of process variables. A fine equiaxed grain structure arises when casting is carried out in cold molds and under low superheating conditions.

2) Chemical method:

Chemical methods involve the addition of some elements called grain refiners that promote nucleation and hindering crystal growth. Inoculation is a typical example of this method and is the most common practice by adding Al-Ti-C orAl-Ti-B ternary master alloys to the liquid melt before casting. These particles act as a-Al grains, resulting in a uniformly fine equiaxed grain structure in aluminum castings.

3) Mechanical method: Mechanical refining method involves stirring or agitation of the melt during solidification by using ultrasonic, electromagnetic & mechanical stirring methods. Since most of the techniques require long processing time and special devices, this method is usually applied to semisolid metal processing.

3.17 POURING TEMPERATURE

Pouring temperature refers to the temperature of the molten metal before it is poured into the mold. The pouring temperature has to be higher than the solidification temperature of the metal in order to allow the free flow of molten metal in to all regions of the mould cavity well before solidification is completed. However, it must noted that the temperature difference must not be too high as heat from the mould cavity has to be quickly removed in order to speed up the solidification process. The difference between the solidification temperature and the pouring temperature of the metal is designated by the term superheat, which is the most important parameter to be considered in melting and pouring operations. For example, aluminum alloy has melting temperature of 660°C with its corresponding pouring temperature range between 700°C — 750°C. For better end results, it is desired to pour the metal at the lowest possible pouring temperature.

The pouring temperature is estimated by taking into consideration, the various factors like melting and freezing temperature of metal, heat loss due to the transfer of metal through ladles, and mould, the shrinkage behaviour of the pouring metal, and thinnest sections of cast part. In order to protect the molten metal from losing its heat, it is always covered by exothermic compounds, which are mixtures of metal oxides and aluminum.

3.18 STIR CASTING

Foundry practice has led to various technological advances with respect to materials and processes from which metals can be efficiently and economically cast. Stir casting is one of the advanced liquid cast metal technology in producing aluminum based metal matrix composites by employing stirring principle of liquid metal. The concept and benefits of stirring or agitation of molten metal goes back to the foundry age where stirring of liquid metal was accomplished by lance gas injection in to the liquid metal. Stirring action within the molten metal helps in easy mixing and melting of alloys as well as homogenizing of temperature throughout the furnace. Although successful to a quite extent, the process suffered from limited effectiveness as well as increased dross formation.

However, the concept gave way to new technologies and today advanced subsurface stirring technologies like pneumatic jet stirring, electromagnetic approaches and rotary devices have been employed for stirring purpose.

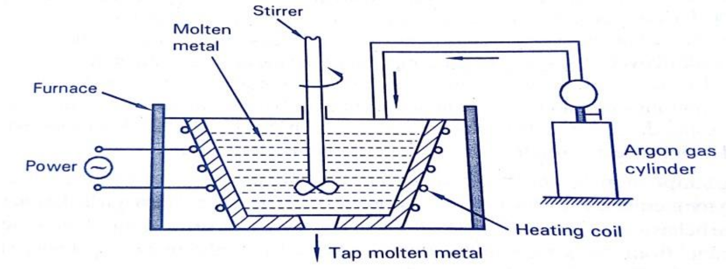


Figure 3.15 Stir casting set-up

Operation

The schematic representation of stir casting process is illustrated in its simplest form in figure 3.15. The arrangement consists of a furnace inside which a graphite or cast iron crucible surrounded by a coil of copper wire is placed. The crucible holds the charge of metal to be melted. A powerful alternating current flows through the coil of the wire creating a rapidly reversing magnetic field that penetrates the metal. The magnetic field induces eddy current, and circular electric currents inside the metal by electromagnetic induction thereby producing stirring action within the molten metal.

Meanwhile, the reinforcements or alloying elements are added to the molten metal and then stirred continuously by means of a stirrer for a short duration to create a vortex that forces the slightly lighter particles into the melt. The molten metal is then transferred in to a preheated ladle and then poured in to the mould of the desired shape. Since aluminum reacts rapidly with the surrounding oxygen, an inert gas like argon gas is used as the carrier gas to assist injection of the alloying elements (reinforcements) and pouring metal in a clean form.

Note: An interesting development in stir casting is a two-step mixing process. In this process, the aluminum matrix material is heated to above its liquids temperature so that the metal is totally melted. The melt is then cooled down to a temperature between the liquids and solidus points and kept in a semi-solid state. At this stage, the preheated reinforcement or alloying particles are added and mixed. The slurry is again heated to a fully liquid state and mixed thoroughly. This two-step mixing process has been used in the fabrication of aluminum

Advantages of stir casting

- Stirring action within the molten metal helps in easy mixing and melting of alloys as well as homogenizing of temperature throughout the furnace leading to sound castings.
- Stirring action helps in removal of hydrogen gas.
- Eliminates porosity
- Better dimensional control and tolerances in castings
- Clean and sound castings can be obtained.

Disadvantages

- Equipment is costlier.
- Excessive stirring can increase gas pick up, furnace lining wear, and oxidation of alloys.
- Stirring speed and time has to be monitored appropriately, as it has a direct influence on the

hardness of the cast metal.

- Monitoring an inert gas atmosphere is an additional requirement.