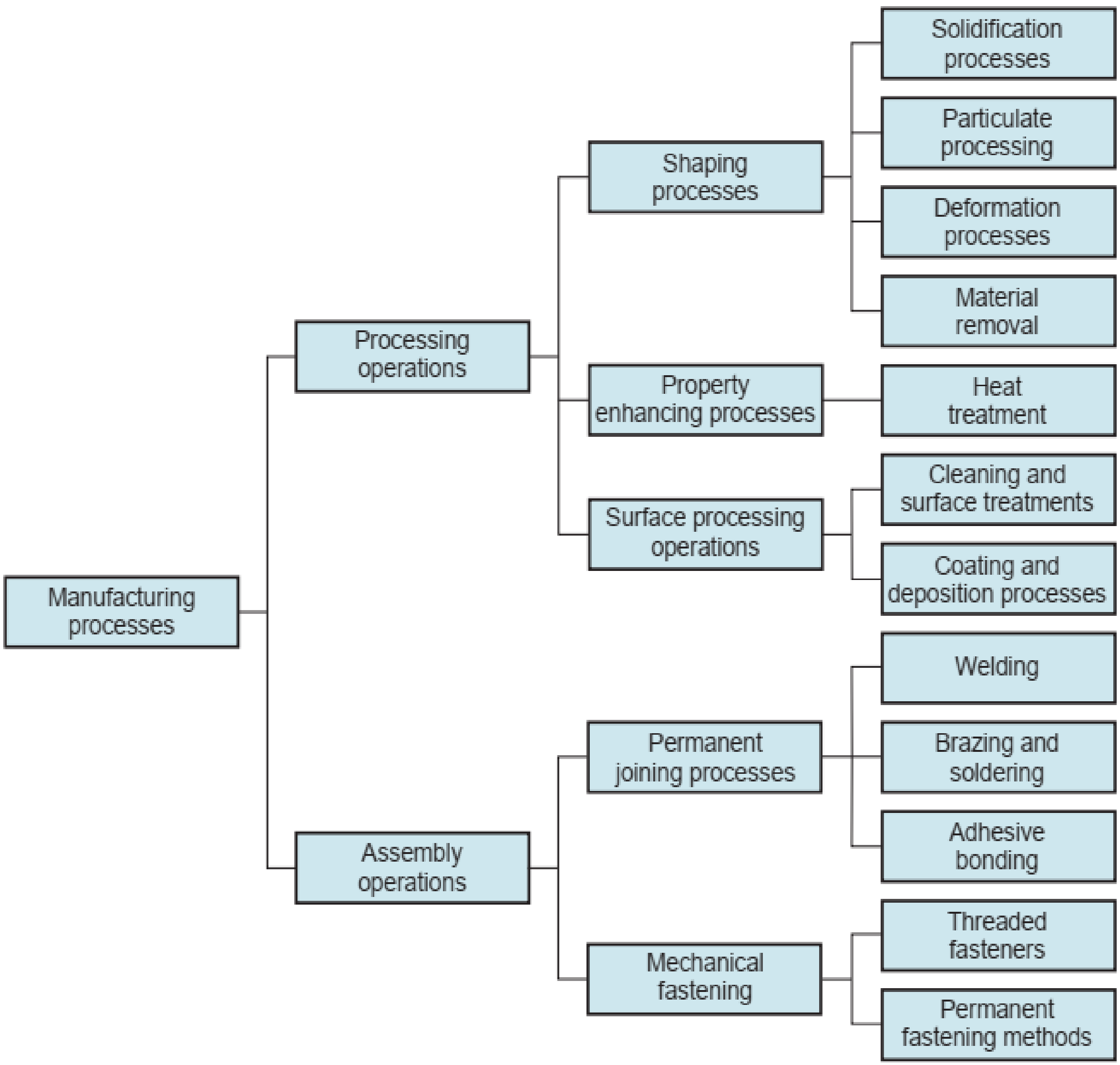
Chapter 1

WHAT IS MANUFACTURING?

The word manufacture is derived from two Latin words, manus (hand) and factus (make); the combination means made by hand. The English word manufacture is several centuries old, and “made by hand” accurately described the manual methods used when the word was first coined.1 Most modern manufacturing is accomplished by automated and computer-controlled machinery.

SELECTION OF MANUFACTURING PROCESS



(1) solidification processes, in which the starting material is a heated liquid or semifluid that cools and solidifies to form the part geometry;
(2) particulate processing, in which the starting material is a powder, and the powders are formed and heated into the desired geometry;
(3) deformation processes, in which the starting material is a ductile solid (commonly metal) that is deformed to shape the part; and

(4) material removal processes, in whichthe starting material is a solid (ductile or brittle), from which material is removed so that the resulting part has the desired geometry.

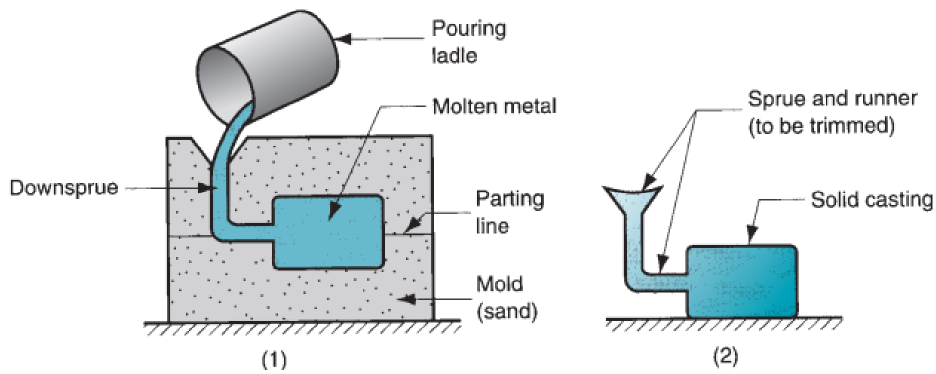


FIGURE 1.5 Casting and molding processes start with a work material heated to a fluid or semifluid state. The process consists of: (1) pouring the fluid into a mold cavity and (2) allowing the fluid to solidify, after which the solid part is removed from the mold.

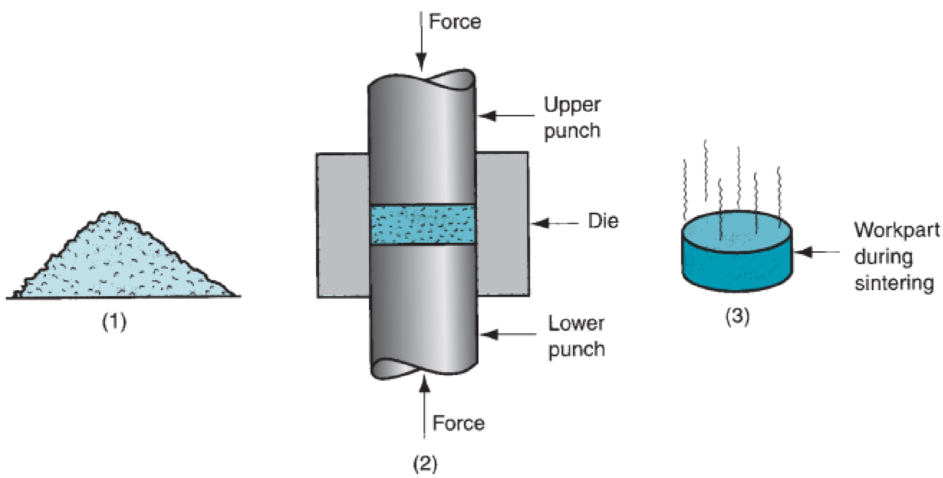


FIGURE 1.6 Particulate processing: (1) the starting material is powder; the usual process consists of (2) pressing and (3) sintering.

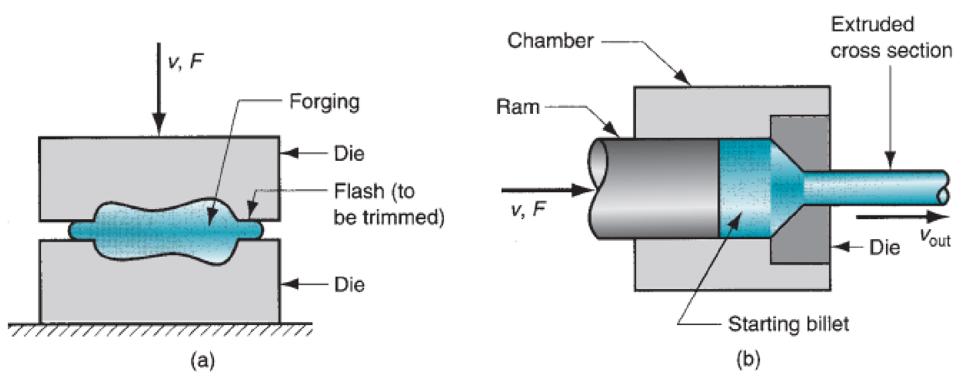


FIGURE 1.7 Some common deformation processes: (a) **forging**, in which two halves of a die squeeze the workpart, causing it to assume the shape of the die cavity; and (b) **extrusion**, in which a billet is forced to flow through a die orifice, thus taking the cross-sectional shape of the orifice.

Material removal processes are operations that remove excess material from the starting workpiece so that the resulting shape is the desired geometry. The most important processes in this category are machining operations such as turning, drilling, and milling, shown in Figure 1.8. These cutting operations are most commonly applied to solid metals, performed using cutting tools that are harder and stronger than the work metal. Grinding is another common process in this category. Other material removal processes are known as nontraditional processes because they use lasers, electron beams, chemical erosion, electric discharges, and electrochemical energy to remove material rather than cutting or grinding tools

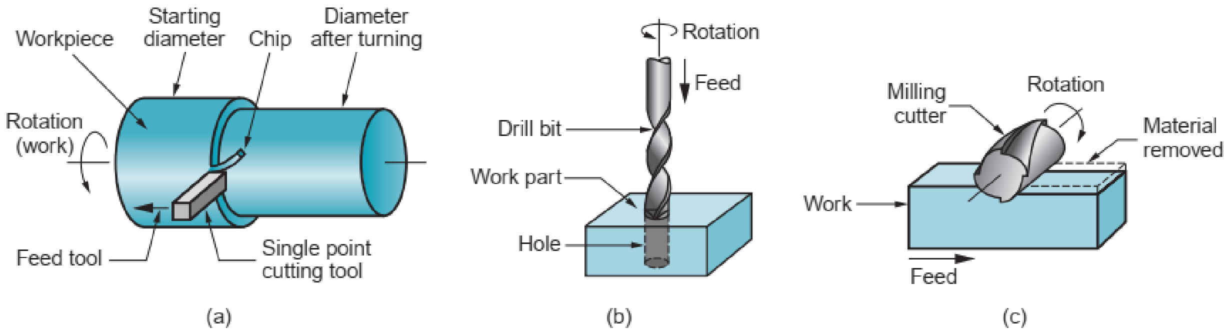


FIGURE 1.8 Common machining operations: (a) ***turning,*** in which a single-point cutting tool removes metal from a rotating workpiece to reduce its diameter; (b) ***drilling,*** in which a rotating drill bit is fed into the work to create a round hole; and (c) ***milling,*** in which a workpart is fed past a rotating cutter with multiple edges.

Property-Enhancing Processes The second major type of part processing is performed to improve mechanical or physical properties of the work material. These processes do not alter the shape of the part, except unintentionally in some cases. The most important property-enhancing processes involve heat treatments, which include various annealing and strengthening processes for metals and glasses. Sintering of powdered metals and ceramics is also a heat treatment that strengthens a pressed powder metal workpart.

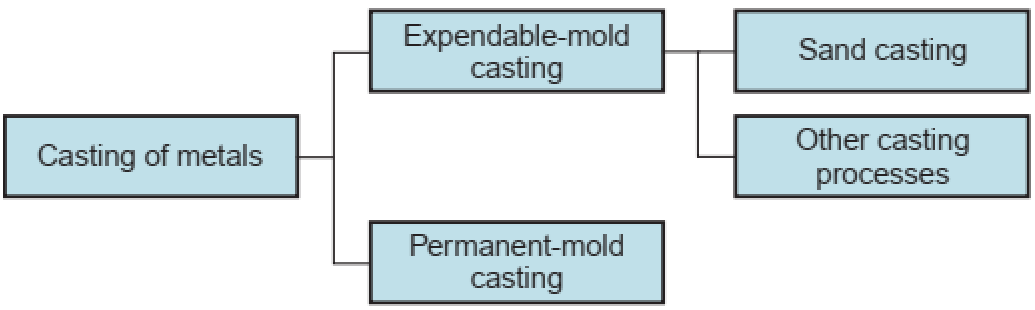
Surface Processing Surface processing operations include (1) cleaning, (2) surface treatments, and (3) coating and thin film deposition processes. **Cleaning** includes both chemical and mechanical processes to remove dirt, oil, and other contaminants from the surface. **Surface treatments** include mechanical working such as shot peening and sand blasting, and physical processes such as diffusion and ion implantation. Coating and thin film deposition processes apply a coating of material to the exterior surface of the workpart. Common coating processes include electroplating, anodizing of aluminum, organic coating (call it painting), and porcelain enameling. Thin film deposition processes include physical vapor deposition and chemical vapor deposition to form extremely thin coatings of various substances.

ASSEMBLY OPERATIONS

The second basic type of manufacturing operation is assembly, in which two or more separate parts are joined to form a new entity. Components of the new entity are connected either permanently or semipermanently. Permanent joining processes include welding, brazing, soldering, and adhesive bonding. They form a joint between components that cannot be easily disconnected. Certain mechanical assembly methods are available to fasten two (or more) parts together in a joint that can be conveniently disassembled. The use of screws, bolts, and other threaded fasteners are important traditional methods in this category. Other mechanical assembly techniques form a more permanent connection; these include rivets, pressfitting, and expansion fits. Special joining and fastening methods are used in the assembly of electronic products. Some of the methods are identical to or are adaptations of the preceding processes, for example, soldering. Electronics assembly is concerned primarily with the assembly of components such as integrated circuit packages to printed circuit boards to produce the complex circuits used in so many of today's products.

Introduction to Casting

Casting processes divide into two broad categories, according to type of mold used: expendable-mold casting and permanent-mold casting. An expendable mold means that the mold in which the molten metal solidifies must be destroyed in order to remove the casting. These molds are made out of sand, plaster, or similar materials, whose form is maintained by using binders of various kinds. Sand casting is the most prominent example of the expendable-mold processes. In sand casting, the liquid metal is poured into a moldmade of sand. After the metal hardens, the mold must be sacrificed in order to recover the casting.
A permanent mold is one that can be used over and over to produce many castings. It is made of metal (or, less commonly, a ceramic refractory material) that can withstand the high temperatures of the casting operation. In permanent-mold casting, the mold consists of two (or more) sections that can be opened to permit removal of the finished part. Die casting is the most familiar process in this group.



Classification of casting process

Among its capabilities and **advantages** are the following:

- Casting can be used to create complex part geometries, including both external and internal shapes.
- Some casting processes are capable of producing parts to net shape. No further manufacturing operations are required to achieve the required geometry and dimensions of the parts. Other casting processes are near net shape, for which some additional shape processing is required (usually machining) in order to achieve accurate dimensions and details.
- Casting can be used to produce very large parts. Castings weighing more than 100 tons have been made.
- The casting process can be performed on any metal that can be heated to the liquid state.
- Some casting methods are quite suited to mass production.

Casting: Casting is a process in which the liquid molten metal is poured in to the casting cavity whose shape is same as that of the casting to be produced, allowing to solidify and after solidification the casting can be taken out by breaking the mould.

Steps in Casting Process:

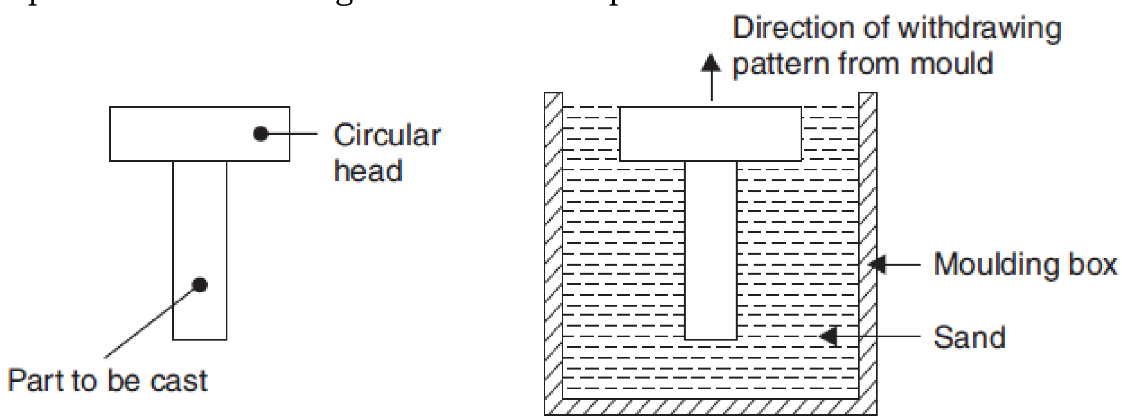
I. Preparation of a pattern,
II. Preparation of a mould with the help of the pattern,
III. Melting of metal or alloy in a furnace,
IV. Pouring of molten metal into mould cavity,
V. Breaking the mould to retrieve the casting,
VI. Cleaning the casting and cutting off risers, runners etc., (this operation is called 'fettling'), and
VII. Inspection of casting.

Pattern

Pattern is a replica of the final object to be made by casting process, with some modifications.

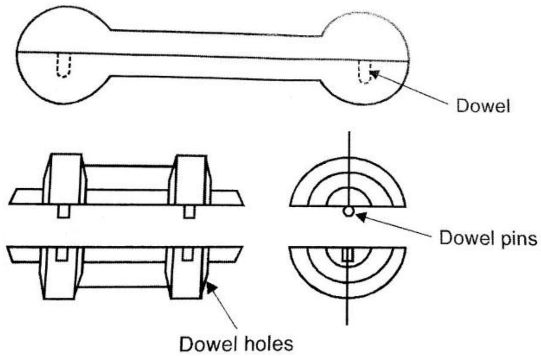
Types of Patterns

(*i*) Solid or single piece pattern: Such patterns are made in one piece and are suitable only for very simple castings. There is no provision for runners and risers etc. Moulding can be done either in the foundry floor (called pit moulding) or in a moulding box. There is no difficulty in withdrawing the pattern from the mould as the broadest portion of the pattern is at the top. As an example, if a cylindrical pin with a circular head has to be cast, a one piece pattern shown in Fig. 6.1 will be adequate.

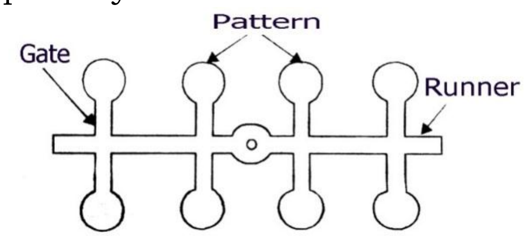


(*ii*) Split pattern: It is not practical to have one piece pattern for parts of complicated shapes, because it would not be possible to withdraw the pattern from the mould. For example, if a circular head was added to the bottom of the pin shown in Fig. 6.1, it would make it necessary to go in for a split pattern as shown in Fig. 6.2.

One-half of the impression in the mould will be made by using piece no. 1 in one moulding boxand the other half of the impression will be made by using piece no. 2 in a second moulding box. Afterwithdrawing the pattern halves from the respective moulding boxes, the two boxes will be assembledand clamped together, so that the complete impression is available for pouring the metal.



(*iii*) Gated patterns: Sometimes alongwith the pattern for the casting, another portion is added so that when the impression is made in the moulding box, the cavity contains a shallow channel along with the main cavity for the object to be cast. This channel will be used for feeding molten metal into the main cavity and is known as the “gate”. Such patterns where provision for gating has been made are called gated patterns. It removes the necessity of making a gate separately.



Pattern Material Properties

1) It should be light weight material for easy handling.
2) It should not absorb moisture (due to moisture absorption dimension of pattern increases).
3) Good surface finish can be produced on the pattern.
4) It should be easy for fabrication.
5) It should be cheaper.

Note: Commonly used Pattern Materials are wood, plastic, metals and wax.

Moulding Sand

Basic constituents of molding sand

I. Silica Sand Particles:It provides sufficient strength to moulding sand (70% to 75%).
II. Clay: Used for producing bond between silica sand particles (15% to 20%).
III. Water/Sodium Silicate: It increases bonding capability of moulding sand (6% to 8%).

Types of Sand

Green Sand → Silica sand + Clay + Water

Dry Sand → $\underbrace{\text{Silica sand+ Clay + Sodium silicate}}_{\text{Used along with } CO_2}$

In riser when CO_2 has been supplied, CO2 chemically reacts with sodium silicate and produce silica gel which gives sufficient strength to moulding sand.

Properties possessed by moulding sand:

Porosity: Capability of Escaping air or gases through the moulding sand is called porosity property. While pouring molten metal in to cavity, the air should escape to avoid blow formation.

Cohesiveness: Ability of forming the bond between the same material particles is called as cohesiveness.

Adhesiveness:Ability of sand to stick to other bodies. If the moulding sand does not stickto the walls of moulding box, the whole mould will slip through the box.

Refractoriness:It should be able to with stand high temperatures.

Flowability:when it is packed around a pattern in a moulding box, it should be ableto fill all nooks and corners, otherwise the impression of pattern in mould would not be sharp and clear.

Collapsibility: it should collapse easily after the casting has cooled down and hasbeen extracted after breaking the mould. It is particularly important in case of core making.

Core

A core is a predetermined shaped mass of dry sand which is made separately from the mould.

The core is used to obtain desired cavities and recesses, which otherwise could not be obtained by normal moulding

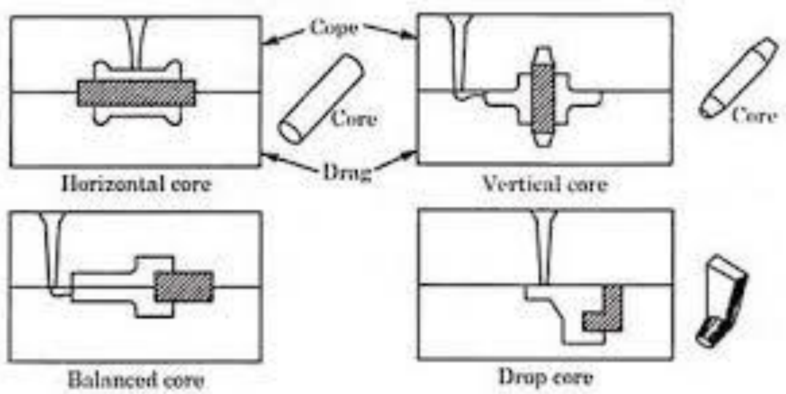
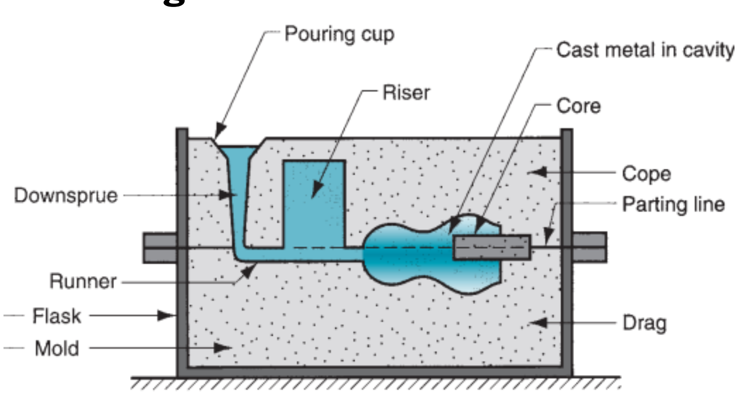


Fig. 3.33. Types of Cores.

Sand-Casting Molds



Cross-sectional view of a typical sand-casting mold

Sand casting is by far the most important casting process. A sand-casting mold will be used to describe the basic features of a mold. Many of these features and terms are common to the molds used in other casting processes. Figure shows the cross-sectional view of a typical sand-casting mold, indicating some of the terminology. The mold consists of two halves: cope and drag. The ***cope*** is the upper half of the mold, and the ***drag*** is the bottom half. The two halves of the mold separate at the ***parting line***.

In sand casting (and other expendable-mold processes) the mold cavity is formed by means of a pattern, which is made of wood, metal, plastic, or other material and has the shape of the part to be cast. The cavity is formed by packing sand around the pattern, about half each in the cope and drag, so that when the pattern is removed, the remaining void has the desired shape of the cast part. The pattern is usually made oversized to allow for shrinkage of the metal as it solidifies and cools. The sand for the mold is moist and contains a binder to maintain its shape.

Sand casting, also known as sand-mold casting, consists of pouring molten metal into a sand mold, allowing the metal to solidify, and then breaking up the mold to remove the casting. The casting must then be cleaned and inspected, and heat treatment is sometimes required to improve metallurgical properties. The cavity in the sand mold is formed by packing sand around a pattern (an approximate duplicate of the part to be cast), and then removing the pattern by separating the mold into two halves. The mold also contains the gating and riser system. In addition, if the casting is to have internal surfaces (e.g., hollow parts or parts with holes), a core must be included in the mold. Since the mold is sacrificed to remove the casting, a new sand mold must be made for each part that is produced. From this brief description, sand casting is seen to include not only the casting operation itself, but also the fabrication of the pattern and the making of the mold.

The gating system in a casting mold

Pouring Basin: Pouring basin acting as reservoir for suppling the molten metal to the casting.

Sprue: It is a connecting passage between pouring basin and runner. The height of the sprue is responsible for producing required velocity of molten metal in gating system.

Runner: It is a connecting passage between bottom of the sprue and ingate. It is horizontal in position. It is used to avoid sand erosion.

InGate:Last point of gatting system from where molten metal is entering into casting cavity.

Solidification and Cooling

After pouring into the mold, the molten metal cools and solidifies. In this section we examine the physical mechanism of solidification that occurs during casting. Issues associated with solidification include the time for a metal to freeze, shrinkage, directional solidification, and riser design.

Solidification of Metals

Solidification involves the transformation of the molten metal back into the solid state. The solidification process differs depending on whether the metal is a pure element or an alloy.

Pure Metals A pure metal solidifies at a constant temperature equal to its freezing point, which is the same as its melting point. The melting points of pure metals are well known and documented (Table 4.1). The process occurs over time as shown in the plot of Figure

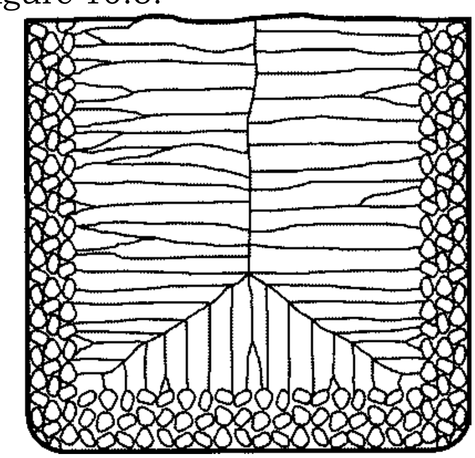
10.4, called a cooling curve. The actual freezing takes time, called the **local solidification** time in casting, during whichthe metal's latent heat of fusion is released into the surrounding mold. The total solidification time is the time taken between pouring and complete solidification.

After the casting has completely solidified, cooling continues at a rate indicated by the downward slope of the cooling curve.

Because of the chilling action of the mold wall, a thin skin of solid metal is initially formed at the interface immediately after pouring. Thickness of the skin increases to form a shell around the molten metal as solidification progresses inward toward the center of the cavity. The rate at which freezing proceeds depends on heat transfer into the mold, as well as the thermal properties of the metal.

It is of interest to examine the metallic grain formation and growth during this solidification process. **The metal which forms the initial skin has been rapidly cooled by the extraction of heat through the mold wall. This cooling action causes the grains in the skin to be fine and randomly oriented.** As cooling continues, further grain formation and growth occur in a direction away from the heat transfer**. Since the heat transfer is through the skin and mold wall, the grains grow inwardly as needles or spines of solid metal.** As these spines enlarge, lateral branches form, 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, and it occurs not only in the freezing of pure metals but alloys as well. The resulting grain formation is illustrated in Figure 10.5.

FIGURE 10.5 Characteristic grain structure in a casting of a pure metal, showing randomly oriented grains of small size near the mold wall, and large columnar grains oriented toward the center of the casting.



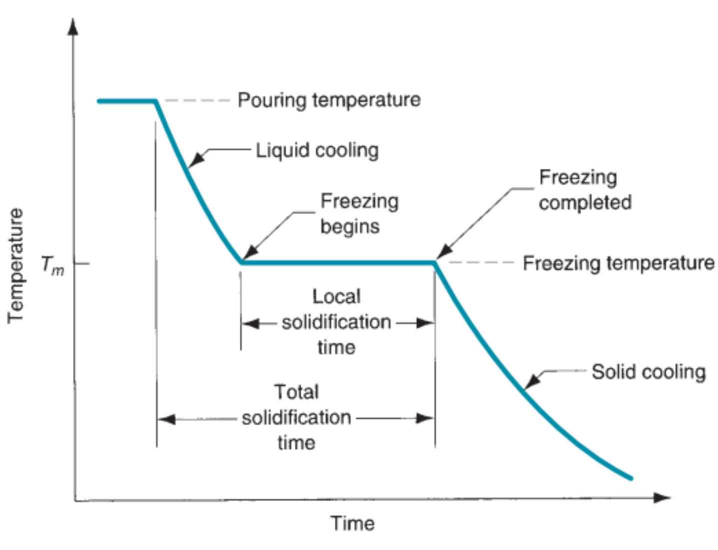


FIGURE 10.4 Cooling curve for a pure metal during casting

Most Alloys Most alloys freeze over a **temperature range rather than at a single temperature**. The exact range depends on the alloy system and the particular composition. The start of freezing is similar to that of the pure metal. **A thin skin is formed at the mold wall due to the large temperature gradient at this surface.** Freezing then progresses as before through the **formation of dendrites that grow away from the walls**. However, owing to the temperature spread between the liquidus and solidus, the nature of the dendritic growth is such that an advancing zone is formed in which both liquid and solid metal coexist. The solid portions are the dendrite structures that have formed sufficiently to trap small islands of liquid metal in the matrix. This solid–liquid region has a soft consistency that has motivated its name as the ***mushyzone***.

Another factor complicating **solidification of alloys is that the composition of the dendrites as they start to form favors the metal with the higher melting point**. As freezing continues and the dendrites grow, there develops an imbalance in composition between the metal that has solidified and the remaining molten metal. This composition imbalance is finally manifested in the completed casting in the form of segregation of the elements.

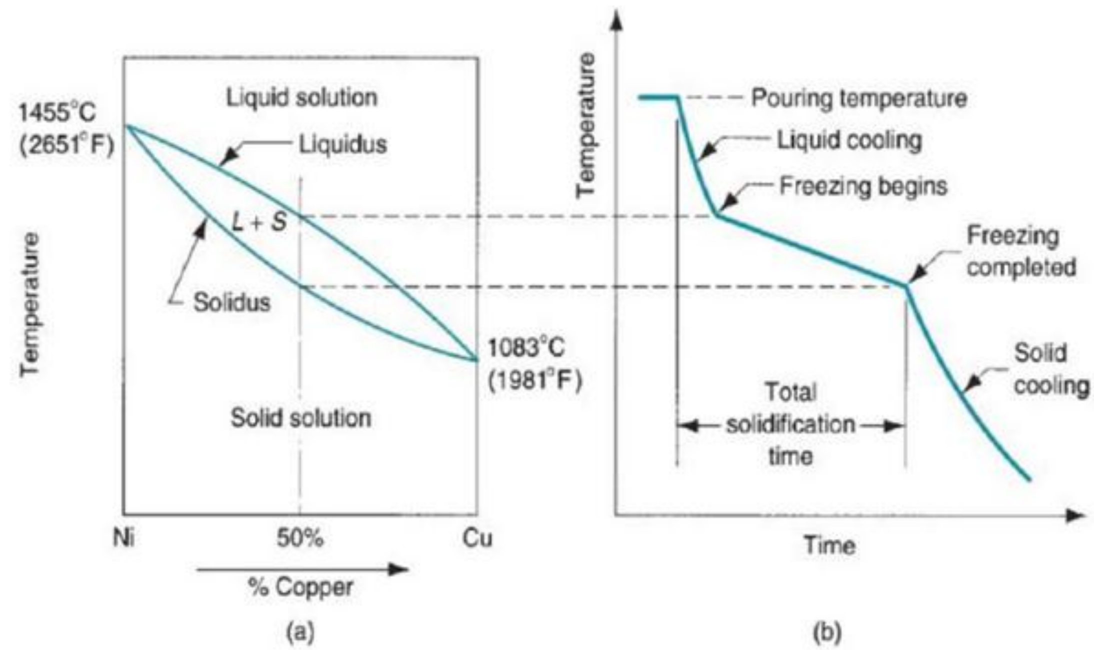
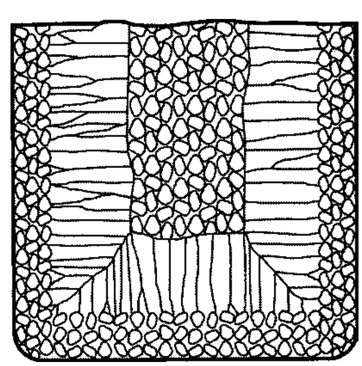


FIGURE 10.7 Characteristic grainstructure in an alloycasting, showing segregation of alloying components inthecenter of casting



Fluid Flow

There are several relationships that govern the flow of liquid metal through the gating system and into the mold. An important relationship is Bernoulli's theorem, which states that the sum of the energies (head, pressure, kinetic, and friction) at any two points in a flowing liquid are equal. This can be written in the following form:

$$h_1 + \frac{p_1}{\rho} + \frac{v_1^2}{2g} + F_1 = h_2 + \frac{p^2}{\rho} + \frac{v_2^2}{2g} + F_2$$

where h = head, cm (in), p = pressure on the liquid, $\mathrm{N/cm^2}$ $(\mathrm{lb/in^2})$; ρ = density, $\mathrm{g/cm^3}$ $(\mathrm{lbm/in^3})$; v = flow velocity, cm/s (in/sec); g = gravitational acceleration constant, 981 cm/s/s ($32.2 \times 12 = 386$ in/sec/sec); and F = head losses due to friction, cm (in). Subscripts 1 and 2 indicate any two locations in the liquid flow.

Bernoulli's equation can be simplified in several ways. If we ignore friction losses (to be sure, friction will affect the liquid flow through a sand mold), and assume that the system remains at atmospheric pressure throughout, then the equation can be reduced to

$$h_1 + \frac{v_1^2}{2g} = h_2 + \frac{v_2^2}{2g}$$

This can be used to determine the velocity of the molten metal at the base of the sprue. Let us define point 1 at the top of the sprue and point 2 at its base. If point 2 is used as the reference plane, then the head at that point is zero ($h_2 = 0$) and h_1 is the height (length) of the sprue. When the metal is poured into the pouring cup and overflows down the sprue, its initial velocity at the top is zero ($v_1 = 0$). Hence, Eq. (10.3) further simplifies to

$$h_1 = \frac{v_2^2}{2g}$$

which can be solved for the flow velocity:

$$v = \sqrt{2gh}$$

where v = the velocity of the liquid metal at the base of the sprue, cm/s (in/sec); g = 981 cm/s/s (386 in/sec/sec); and h = the height of the sprue, cm (in).

$$T_{MF} = \frac{V}{Q}$$

where T_{MF} = mold filling time, s (sec); V = volume of mold cavity, $\mathrm{cm^3}$ $(\mathrm{in^3})$; and Q = volume flow rate, as before. The mold filling time computed by Eq. (10.6) must be considered a minimum time.

Example:

A mold sprue is 20 cm long, and the cross-sectional area at its base is 2.5 cm^2. The sprue feeds a horizontal runner leading into a mold cavity whose volume is 1560 cm^3. Determine: (a) velocity of the molten metal at the base of the sprue, (b) volume rate of flow, and (c) time to fill the mold.

Solution: (a) The velocity of the flowing metal at the base of the sprue is given by Eq. (10.4):

$$v = \sqrt{2(981)(20)} = 198.1 \text{ cm/s}$$

(b) The volumetric flow rate is

$$Q = \left(2.5 \text{ cm}^2\right)(198.1 \text{ cm/s}) = 495 \text{ cm}^2/\text{s}$$

(c) Time required to fill a mold cavity of 100 in^3 at this flow rate is

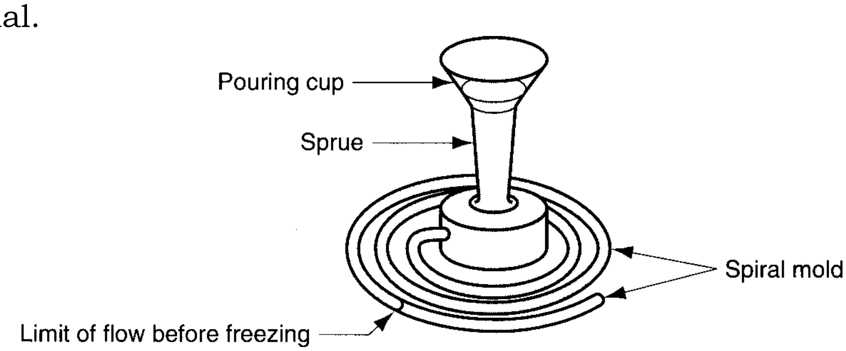
$$T_{MF} = 1560/495 = 3.2\text{s}$$

Fluidity

The molten metal flow characteristics are often described by the term fluidity, a measure of the capability of a metal to flow into and fill the mold before freezing. Fluidity is the inverse of viscosity (Section 3.4); as viscosity increases, fluidity decreases. Standard testing methods are available to assess fluidity, including the spiral mold test shown in Figure 10.3, in which fluidity is indicated by the length of the solidified metal in the spiral channel. A longer cast spiral means greater fluidity of the molten metal.

Factors affecting fluidity include pouring temperature relative to melting point, metal composition, viscosity of the liquid metal, and heat transfer to the surroundings. A higher pouring temperature relative to the freezing point of the metal increases the time it remains in the liquid state, allowing it to flow further before freezing. This tends to aggravate certain casting problems such as oxide formation, gas porosity, and penetration of liquid metal into the interstitial spaces between the grains of sand forming the mold. This last problem causes the surface of the casting to contain imbedded sand particles, thus making it rougher and more abrasive than normal.

FIGURE 10.3 Spiral mold test for fluidity, in which fluidity ismeasured as the lengthof the spiral channel thatis filled by the moltenmetal prior tosolidification.



Composition also affects fluidity, particularly with respect to the metal's solidification mechanism. The best fluidity is obtained by metals that freeze at a constant temperature (e.g., pure metals and eutectic alloys). When solidification occurs over a temperature range (most alloys are in this category), the partially solidified portion interferes with the flow of the liquid portion, thereby reducing fluidity. In addition to the freezing mechanism, metal composition also determines heat of fusion—the amount of heat required to solidify the metal from the liquid state. A higher heat of fusion tends to increase the measured fluidity in casting.

Solidification Time

Whether the casting is pure metal or alloy, solidification takes time. The total solidification time is the time required for the casting to solidify after pouring. This time is dependent on the size and shape of the casting by an empirical relationship known as Chvorinov's rule, which states:

$$T_{TS} = C_m \left(\frac{V}{A}\right)^n$$

where T_{TS} = total solidification time, min; V = volume of the casting, cm^3 (in^3); A = surface area of the casting, cm^2 (in^2); n is an exponent usually taken to have a value = 2; and C_m is the ***mold constant.*** Given that $n = 2$, the units of C_m are min/cm^2 (min/in^2), and its value depends on the particular conditions of the casting operation, including mold material (e.g., specific heat, thermal conductivity), thermal properties of the cast metal (e.g., heat of fusion, specific heat, thermal conductivity), and pouring temperature relative to the melting point of the metal. The value of C_m for a given casting operation can be based on experimental data from previous operations carried out using the same mold material, metal, and pouring temperature, even though the shape of the part may be quite different.

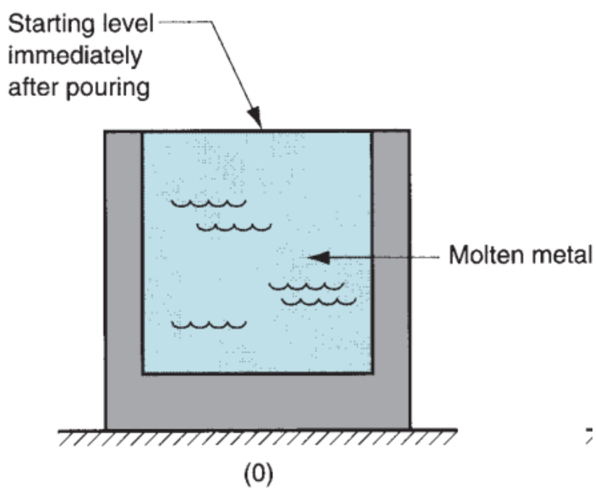
Chvorinov's rule indicates that a casting with a higher volume-to-surface area ratio will cool and solidify more slowly than one with a lower ratio. This principle is put to good use in designing the riser in a mold. To perform its function of feeding molten metal to the main cavity, the metal in the riser must remain in the liquid phase longer than the casting. In other words, the T_{TS} for the riser must exceed the T_{TS} for the main casting. Since the mold conditions for both riser and casting are the same, their mold constants will be equal. By designing the riser to have a larger volume-to-area ratio, we can be fairly sure that the main casting solidifies first and that the effects of shrinkage are minimized. Before considering how the riser might be designed using Chvorinov's rule, let us consider the topic of shrinkage, which is the reason why risers are needed.

Shrinkage

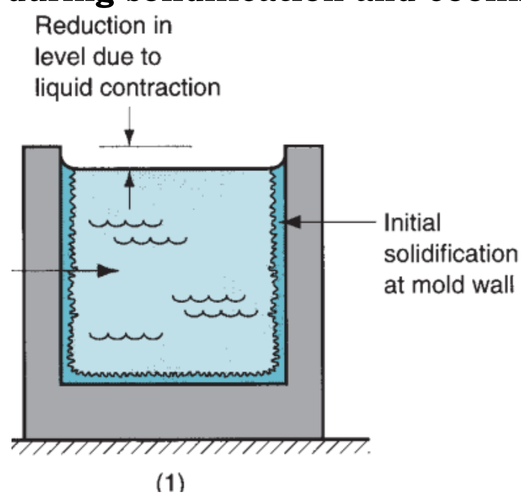
Our discussion of solidification has neglected the impact of shrinkage that occurs during cooling and freezing. Shrinkage occurs in three steps: (1) liquid contraction during cooling prior to solidification; (2) contraction during the phase change from liquid to solid, called solidification shrinkage; and (3) thermal contraction of the solidified casting during cooling to room temperature. The three steps can be explained with reference to a cylindrical casting made in an open mold, as shown in Figure 10.8. The molten metal immediately after pouring is shown in part (0) of the series. Contraction of the liquid metal during cooling from pouring temperature to freezing temperature causes the height of the liquid to be reduced from its starting level as in (1) of the figure. The amount of this liquid contraction is usually around 0.5%. Solidification shrinkage, seen in part (2), has two effects. First, contraction causes a further reduction in the height of the casting. Second, the amount of liquid metal available to feed the top center portion of the casting becomes restricted. This is usually the last region to freeze, and the absence of metal creates a void in the casting at this location. This shrinkage cavity is called a pipe by foundry men. Once solidified, the casting experiences further contraction in height and diameter while cooling, as in (3). This shrinkage is determined by the solid metal's coefficient of thermal expansion, which in this case is applied in reverse to determine contraction.

Pattern-makers account for thermal contraction by making the mold cavities oversized. The amount by which the mold must be made larger relative to the final casting size is called the pattern shrinkage allowance. Although the shrinkage is volumetric, the dimensions of the casting are expressed linearly, so the allowances must be applied accordingly. Special "shrink rules" with slightly elongated scales are used to make the patterns and molds larger than the desired casting by the appropriate amount. Table 10.1 lists typical values of linear shrinkage for various cast metals; these values can be used to determine shrink rule scales.

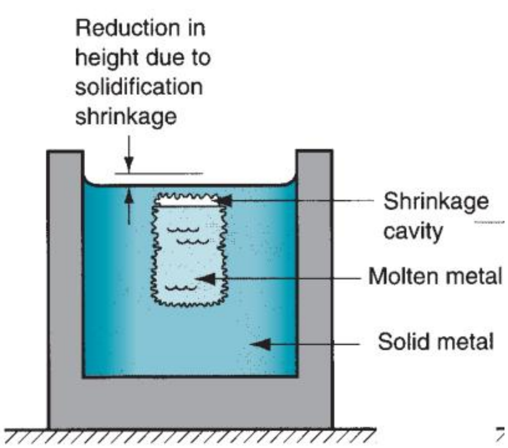
Shrinkage of a cylindrical casting during solidification and cooling



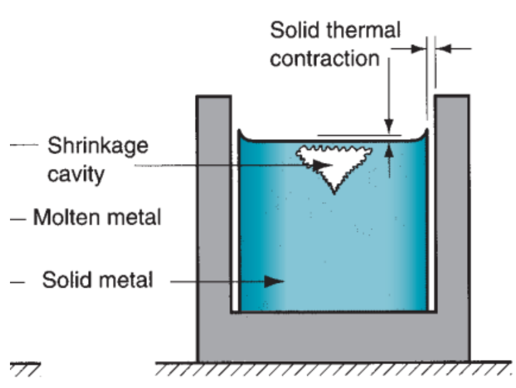
starting level of molten metalimmediately after pouring;



reduction in level caused by liquid contraction during cooling



reduction in height and formation of shrinkage cavity caused by solidification shrinkage



Further reduction in height and diameter due to thermal contraction during cooling of the solid metal

Sand Casting

Sand casting, also known as sand-mold casting, consists of pouring molten metal into a sand mold, allowing the metal to solidify, and then breaking up the mold to remove the casting. The casting must then be cleaned andinspected, and heat treatment is sometimes required to improve metallurgical properties. The cavity in the sand mold is formed by packing sand around a pattern (an approximate duplicate of the part to be cast), and then removing the pattern by separating the mold into two halves. The mold also contains the gating and riser system. In addition, if the casting is to have internal surfaces (e.g., hollow parts or parts with holes), a core must be included in the mold. Since the mold is sacrificed to remove the casting, a new sand mold must be made for each part that is produced. From this brief description, sand casting is seen to include not only the casting operation itself, but also the fabrication of the pattern and the making of the mold. The production sequence is outlined in Figure 11.2 Our video clip on casting contains a segment on sand casting.

Shell Molding

Shell molding is a casting process in which the mold is a thin shell (typically 9 mm or 3/8 in)made of sand held together by a thermosetting resin binder.

Step 1: Making of Metal Pattern

The first and most important step involves in every casting process is pattern making. Pattern is replica of the final product. It can made by wood, plastic, metal etc. **Shell moulding uses a metal pattern** along with all pattern allowance. This pattern is made by either **aluminium of cast iron**.

Step 2 : Heating of Pattern

The metal pattern created by other casting process is now heated at a temperature range **between 180 – 250 degree centigrade**. This heating is essential which allows to solidify thermosetting resin binder when poured on it.

Step 3 : Shell Mould Creation

Pattern is clamped over a **dump box**. Now this assembly is turned face down. A mixture of sand and resin is filled into dump box. Mostly fine grade green sand is used for mixture.

Now this whole assemble is inverted which allow to sand resin mixture fall over heated pattern. A layer of mixture, which is in direct contact with pattern is become hard and form a shell. The thickness of shell is mostly depends on the temperature of the pattern and time duration of contact.

Now the dump box is again inverted which allow to remove extra sand resin mixture.

After it, metallic pattern is removed from dump box and shell is separated from it. The other half of the mold is also created using same technic.

Step 4 : Mold Assembly

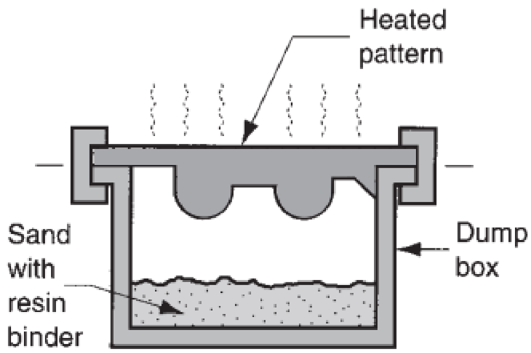
This step assemble all shells created by the shell moulding. The all required **shell assembled into a flask** and supported by a baking material.

Step 5 : Casting formation

Now the cavity is filled with a molten metal and allow to solidify. After solidification the metal cast is removed by breaking the shell. The casting formed by this process is highly accurate and well finished. Generally it does not required further machining.

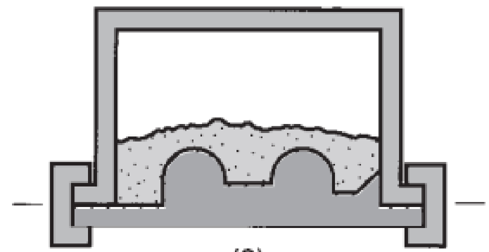
Application:

Most of industrial products like **gearbox housing, connecting rod, small size boats, truck hoods, cylindrical head, Camshaft, valve body** etc. are made by shell moulding.



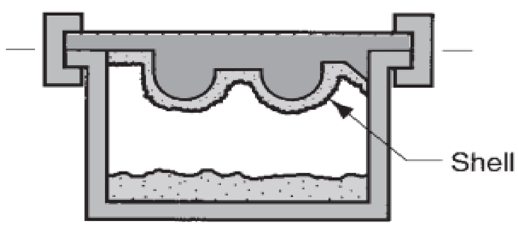
(1)

(1) a match-plate or cope-and-drag metal pattern is heated andplaced over a box containing sand mixed with thermosetting resin



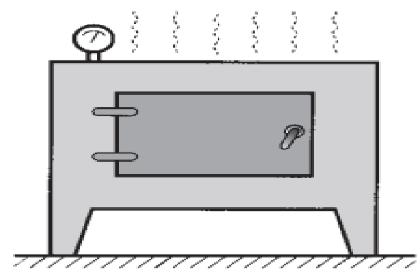
(2)

(2) box is inverted so that sand andresin fall onto the hot pattern, causing a layer of the mixture to partially cure on the surface to form ahard shell



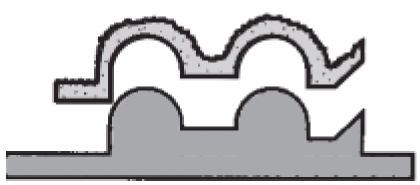
(3)

(3) box is repositioned so that loose, uncured particles drop away



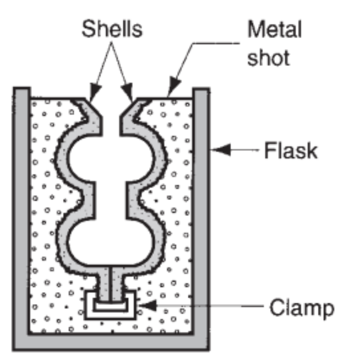
(4)

(4) sand shell is heated inoven for several minutes to complete curing



(5)

(5) shell mold is stripped from the pattern

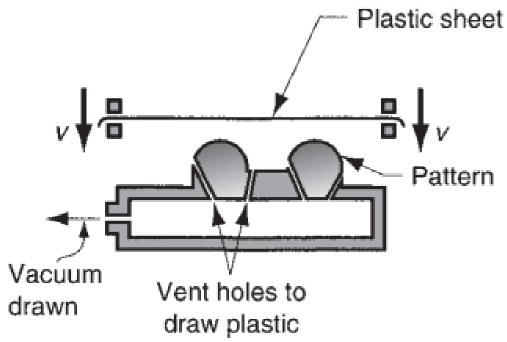


(6)

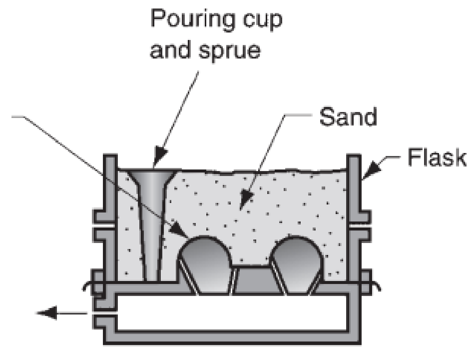
(6) two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is accomplished

Vacuum Molding

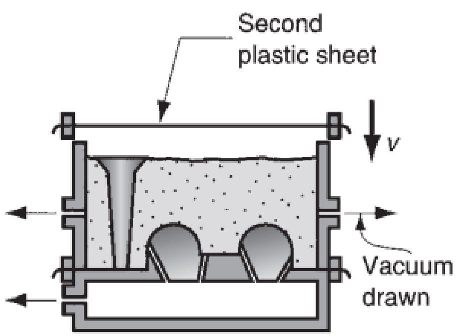
Vacuum molding, also called the V-process, was developed in Japan around 1970. It uses a sand mold held together by vacuum pressure rather than by a chemical binder. Accordingly, the term vacuum in this process refers to the making of the mold rather than the casting operation itself. The steps of the process are explained in Figure 11.6. Because **no binders are used**, the sand is **readily recovered in vacuum molding**. Also, the sand does not require extensive mechanical reconditioning normally done whenbinders are used in the molding sand. Since **no water is mixed with the sand, moisturerelated defects are absent** from the product. Disadvantages of the V-process are that it is relatively slow and not readily adaptable to mechanization.



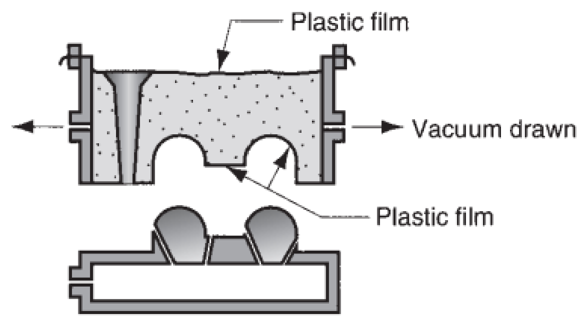
a thin sheet of preheated plastic is drawn over a match-plate or cope-and-drag pattern by vacuum—the pattern has small vent holes to facilitate vacuum forming



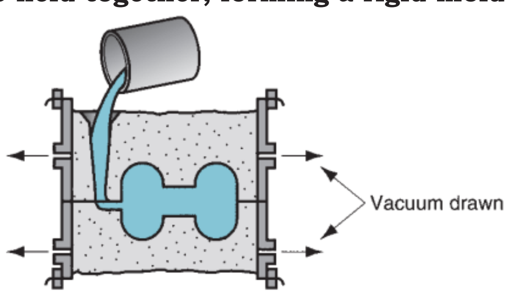
A specially designed flask is placed over the pattern plate and filled with sand, and a sprue and pouring cup are formed in the sand



another thin plastic sheet is placed over the flask, and a vacuum is drawn that causes the sand grains to be held together, forming a rigid mold



the vacuum on the mold pattern is released to permit the pattern to be stripped from the mold

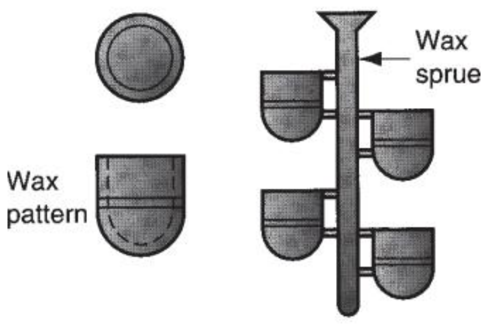


this mold is assembled with its matchinghalf to form the cope and drag, and with vacuum maintained on both halves, pouring is accomplished. The plastic sheet quickly burns away on contacting the molten metal. After solidification, nearly all of the sand can be recovered for reuse.

Investment Casting

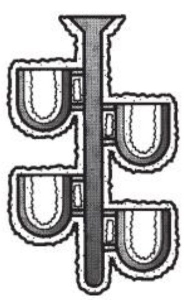
In investment casting, a pattern made of wax is coated with a refractory material to make the mold, after which the wax is melted away prior to pouring the molten metal. The term investment comes from one of the less familiar definitions of the word invest, which is “to cover completely,” thisreferring to the **coating of the refractory materialaround the wax pattern**. It is a precision casting process, because it is capable of making castings of high accuracy and intricate detail. The process dates back to ancient Egypt (Historical Note 11.1) and is also known as the lost-wax process, because the wax pattern is lost from the mold prior to castingSteps in investment casting are described in Figure 11.8. Since the wax pattern is melted off after the refractory mold is made, a separate pattern must be made for every casting. Pattern production is usually accomplished by a molding operation—pouring or injecting the hot wax into a master die that has been designed with proper allowances for shrinkage of both wax and subsequent metal casting. In cases where the part geometry is complicated, several separate wax pieces must be joined to make the pattern. In high production operations, several patterns are attached to a sprue, also made of wax, to form a pattern tree; this is the geometry that will be cast out of metal. The video clip on casting contains a segment on investment casting.

Coating with refractory (step 3) is usually accomplished by dipping the pattern tree into a **slurry of very fine grained silica or other refractory (almost in powder form) mixed with plaster to bond the mold into sha**pe. The small grain size of the refractory material provides a smooth surface and captures the intricate details of the wax pattern. The final mold (step 4) is accomplished by repeatedly dipping the tree into the refractory slurry or by gently packing the refractory around the tree in a container. The mold is allowed to air dry for about 8 hours to harden the binder.

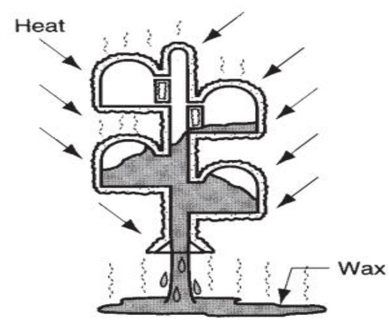


(1) wax patterns are produced; (2) several patterns are attached to a sprue to form a pattern tree

(3) the pattern tree is coated with a thin layer of refractory material

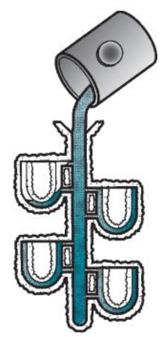


(4) the full mold is formed by covering the coated tree with sufficient refractory material to make it rigid



5) the mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity

(6) the mold is preheated to a high temperature, which ensures that all contaminants are eliminated from the mold; it also permits the liquid metal to flow more easily into the detailed cavity; the molten metal is poured; it solidifies



(7) the mold is broken away from the finished casting. Parts are separated from the sprue.

The Basic Permanent-Mold Process

Permanent-mold casting uses a metal mold constructed of two sections that are designed for easy, precise opening and closing. These molds are commonly made of steel or cast iron. The cavity, with gating system included, is machined into the two halves to provide accurate dimensions and good surface finish. Metals commonly cast in permanent molds include aluminum, magnesium, copper-base alloys, and cast iron. However, cast iron requires a high pouring temperature, 1250C to 1500C (2282F–2732F), which takes a heavy toll on mold life. The very high pouring temperatures of steel make permanent molds unsuitable for this metal, unless the mold is made of refractory material.

Steps in the basic permanent-mold casting process are described in Figure 11.10. In preparation for casting, the mold is first preheated and one or more coatings are sprayed on the cavity. 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. After pouring, as soon as the metal solidifies, the mold is opened and the casting is removed. Unlike expendable molds, permanent molds do not collapse, so the mold must be opened before appreciable cooling contraction occurs in order to prevent cracks from developing in the casting.

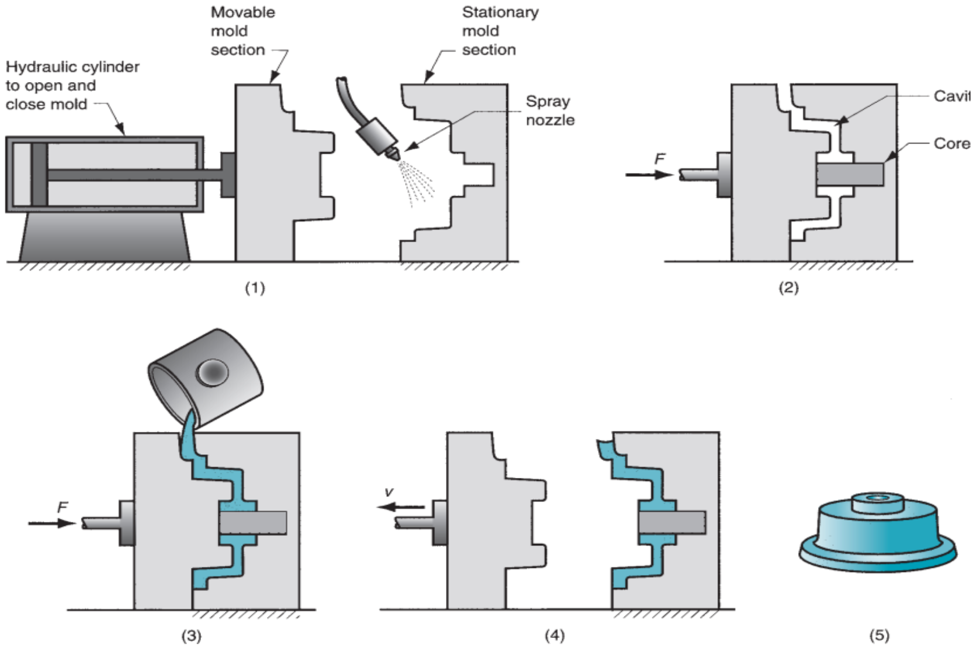


FIGURE 11.10 Steps in permanent-mold casting: (1) mold is preheated and coated; (2) cores (if used) are inserted, and mold is closed; (3) molten metal is poured into the mold; and (4) mold is opened. Finished part is shown in (5)

Die casting

Die casting is a manufacturing process that can produce geometrically complex metal parts through the use of reusable molds, called dies. The die casting process involves the use of a furnace, metal, die casting machine, and die. The metal, typically a non-ferrous alloy such as aluminum or zinc, is melted in the furnace and then injected into the dies in the die casting machine. There are two main types of die casting machines - hot chamber machines (used for alloys with low melting temperatures, such as zinc) and cold chamber machines (used for alloys with high melting temperatures, such as aluminum).

The process cycle for die casting consists of five main stages, which are explained below. The total cycle time is very short, typically between 2 seconds and 1 minute.

Clamping - The first step is the preparation and clamping of the two halves of the die. Each die half is first cleaned from the previous injection and then lubricated to facilitate the ejection of the next part. Lubrication may not be required after each cycle, but after 2 or 3 cycles, depending upon the material. After lubrication, the two die halves, which are attached inside the die casting machine, are closed and securely clamped together.

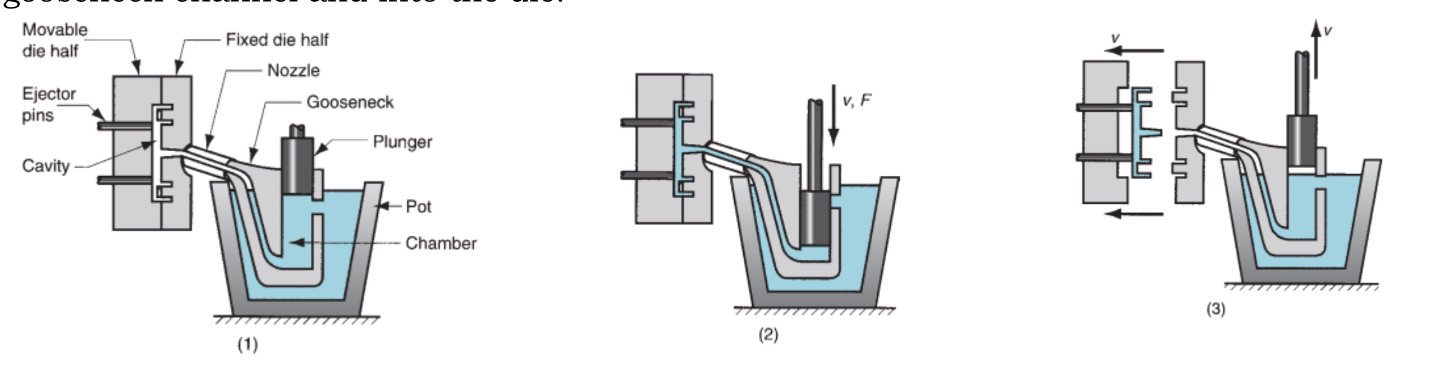
Injection - The molten metal, which is maintained at a set temperature in the furnace, is next transferred into a chamber where it can be injected into the die. The method of transferring the molten metal is dependent upon the type of die casting machine, whether a hot chamber or cold chamber machine is being used. The molten metal is injected at high pressures into the die. This pressure holds the molten metal in the dies during solidification. The injection time is the time required for the molten metal to fill all of the channels and cavities in the die. This time is very short, typically less than 0.1 seconds, in order to prevent early solidification of any one part of the metal.

Cooling - The molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity. When the entire cavity is filled and the molten metal solidifies, the final shape of the casting is formed. The die cannot be opened until the cooling time has elapsed and the casting is solidified.

Ejection - After the predetermined cooling time has passed, the die halves can be opened and an ejection mechanism can push the casting out of the die cavity. Once the casting is ejected, the die can be clamped shut for the next injection.

Trimming - The excess material, along with any flash that has occurred, must be trimmed from the casting either manually via cutting or sawing, or using a trimming press.

Hot chamber die casting machine - Hot chamber machines are used for alloys with low melting temperatures, such as zinc, tin, and lead. The temperatures required to melt other alloys would damage the pump, which is in direct contact with the molten metal. The metal is contained in an open holding pot which is placed into a furnace, where it is melted to the necessary temperature. The molten metal then flows into a shot chamber through an inlet and a plunger, powered by hydraulic pressure, forces the molten metal through a gooseneck channel and into the die.

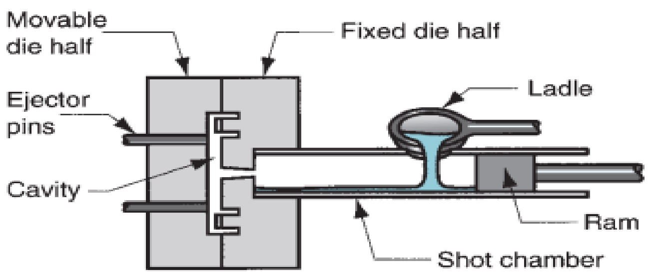


with die closed and plunger withdrawn, molten metal flows into the chamber

plunger forces metal in chamber to flow into die, maintaining pressure during cooling and solidification

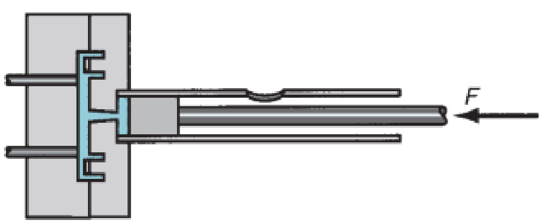
plunger is withdrawn, die is opened, and solidified part is ejected

Cold chamber die casting machine - Cold chamber machines are used for alloys with high melting temperatures that cannot be cast in hot chamber machines because they would damage the pumping system. Such alloys include aluminum, brass, and magnesium. The molten metal is still contained in an open holding pot which is placed into a furnace, where it is melted to the necessary temperature. However, this holding pot is kept separate from the die casting machine and the molten metal is ladled from the pot for each casting, rather than being pumped. The metal is poured from the ladle into the shot chamber through a pouring hole. The injection system in a cold chamber machine functions similarly to that of a hot chamber machine, however it is usually oriented horizontally and does not include a gooseneck channel. A plunger, powered by hydraulic pressure, forces the molten metal through the shot chamber and into the injection sleeve in the die.



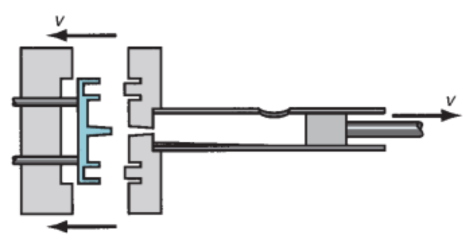
(1)

With die closed and ram withdrawn, molten metal is poured into the chamber



Ram forces metal to flow into die, maintaining pressure during cooling and solidification

(2)



Ram is withdrawn, die is opened, and part is ejected.

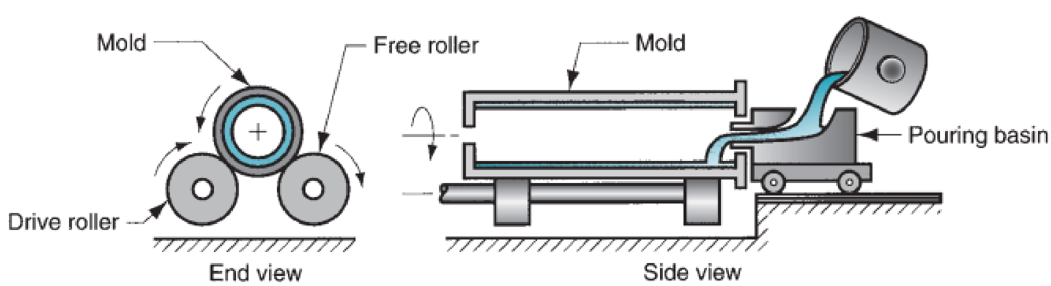
(3)

Centrifugal casting

In true centrifugal casting, molten metal is poured into a rotating mold to produce a tubular part. Examples of parts made by this process include pipes, tubes, bushings, and rings.

Molten metal is poured into a horizontal rotating mold at one end. In some operations, mold rotation commences after pouring has occurred rather than beforehand.

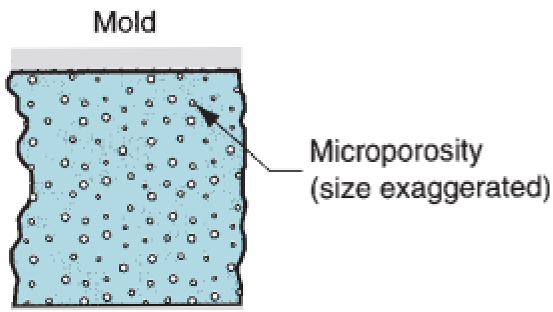
The high-speed rotation results in centrifugal forces that cause the metal to take the shape of the mold cavity. Thus, the outside shape of the casting can be round, octagonal, hexagonal, and so on. However, the inside shape of the casting is (theoretically) perfectly round, due to the radially symmetric forces at work. Orientation of the axis of mold rotation can be either horizontal or vertical, the former being more common.

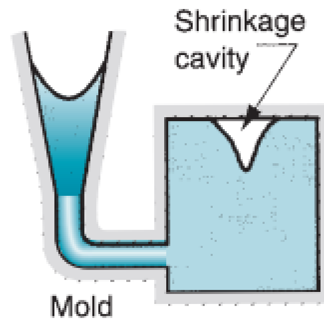


Defects in the casting

A) Gas Defects:

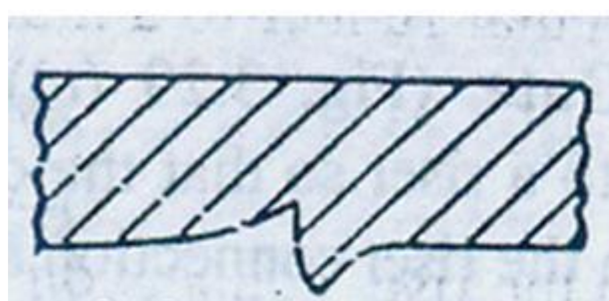
1. ***Sand blow*** is a defect consisting of a balloon-shaped gas cavity caused by release of mold gases during pouring. It occurs at or below the casting surface near the top of the casting. Low permeability, poor venting, and high moisture content of the sand mold are the usual causes.
2. ***Microporosity*** Consists of a network of small voids caused by localized solidification shrinkage of the final molten metal. The defect is usually associated with alloys.
3. ***Shrinkage cavity*** These are caused by liquid shrinkage occurring during solidification of the casting. To compensate this proper feeding of liquid metal is required also proper casting design is required.





B) Moulding Material Defects

1. ***Sand Inclusion*** During poring molten metal the sand erosion taking place will remove sand particles from the mould. These sand particles moving along with molten matel and present in the casting. It can be avoided by selecting proper moulding sand and using appropriate moulding method. Also by altering the gating system it can be avoided.
2. ***Sand Fusion*** This is caused by fusion of sand grains with molten metal. It is caused due to lower refractoriness or pouring temperature is too high.
3. ***Rat Tail*** Under the influence of heat, the sand expands, thereby moving the mould walls backwords as a result casting surface may have marked small tail like elements.

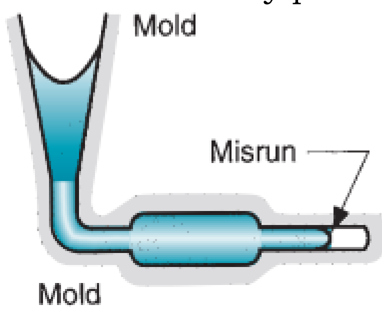


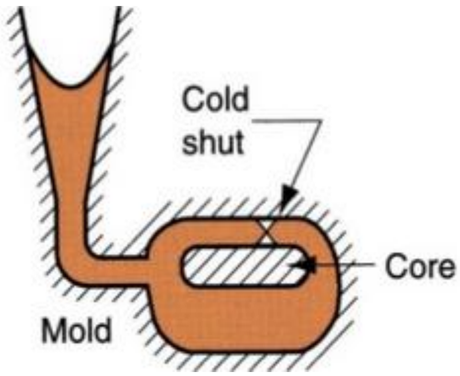
Rat tail

C) Pouring Metal Defects

1. ***Slag inclusion*** Any impurities present into the molten metal if they are not separated properly.

2. ***Misrun*** Non availability of molten metal in the projection of casting cavity. It happen because, solidification starts before complete filling of casting cavity. It can be eliminated by reducing pouring time.
3. ***Cold Shut*** Discontinuity present in the solidified molten metal is called cold shut.





Inspection of Casting

1. Visual Inspection

Common defects such as surface roughness, obvious shifts, the omission of cores and surface cracks can be detected by a visual inspection of the casting. Cracks may also be detected by hitting the casting with a mallet and listening to the quality of the tone produced.

2. Hydrostatic Pressure Test

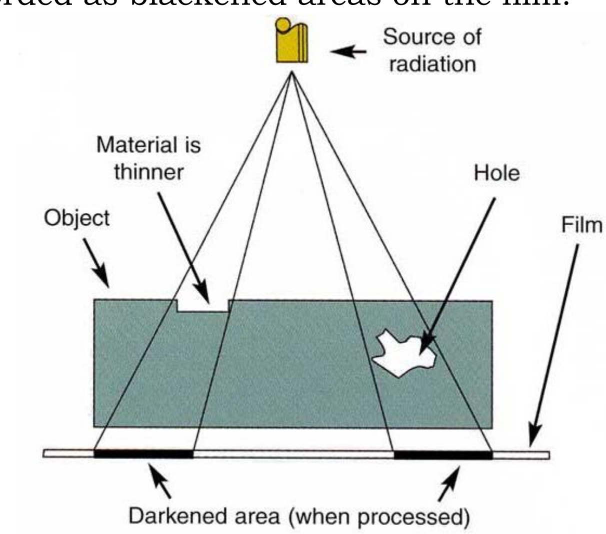
The Hydrostatic pressure test is conducted on a casting to be used as a pressure vessel.

In this test, first, all the flanges and ports are blocked.

Then the casting is filled with water, oil or compressed air, Thereafter, the casting is submerged in a soap solution when any leak will be evident by the bubbles that come out.

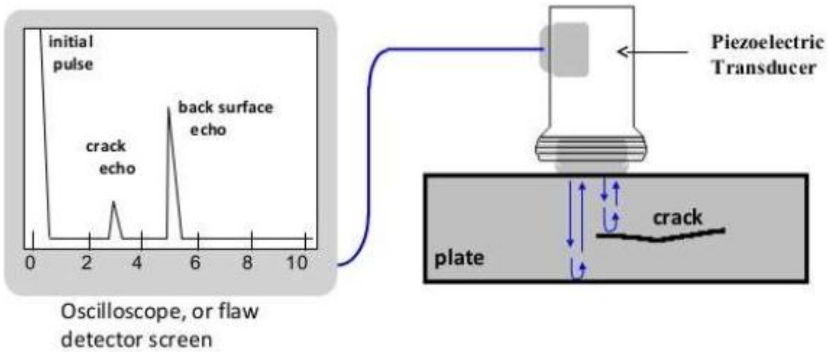
3. Radiographic Examination

Radient energy from X-Ray tube is passed through the section of the casting, and intensity of the emergent rays are recorded on a film held on a opposite surface. Defects in the form of voids or cracks are recorded as blackened areas on the film.



4. Ultrasonic Inspection

In the Ultrasonic method, **an oscillator** is used to send an ultrasonic signal through the casting. Ultrasonic signal is readily transmitted through a homogeneous medium. However, on encountering a discontinuity, the signal is reflected back. This reflected signal is then detected by an **ultrasonic detector**. The time interval between sending the signal and receiving its reflection determines the location of the discontinuity.



5. Coin Testing

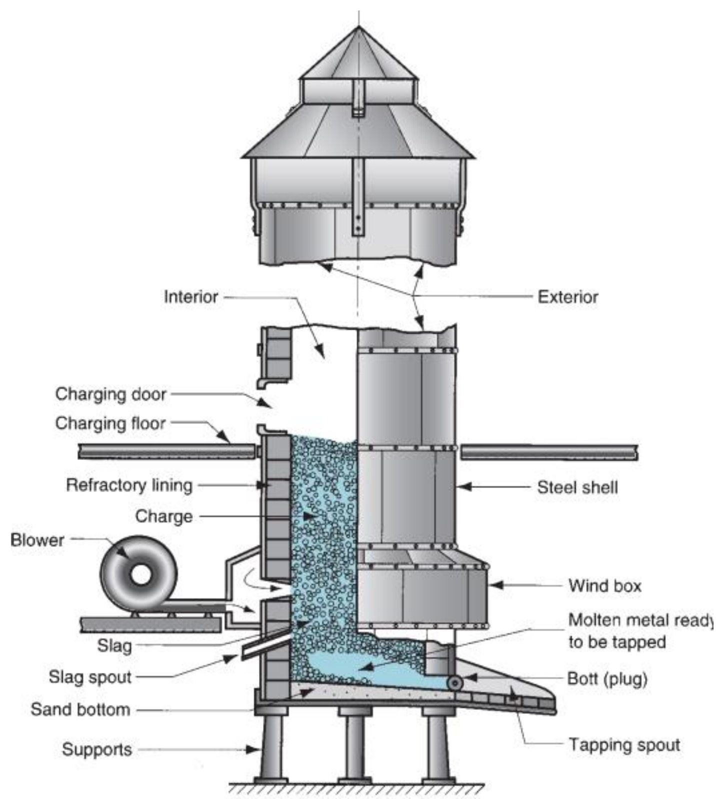
By hitting with a coin on to the component and by hearing the sound coming from the casing, the presence of the defect can be estimated. But it needs well experienced inspector

FURNACES

A) Cupolas

A cupola is a vertical cylindrical furnace equipped with a tapping spout near its base. Cupolas are used only for melting cast irons.

1. It consists of a large shell of steel plate lined with refractory.
2. The "charge," consisting of iron, coke, flux, and possible alloying elements, is loaded through a charging door located less than halfway up the height of the cupola.
3. The iron is usually a mixture of pig iron and scrap (including risers, runners, and sprues left over from previous castings).
4. Coke is the fuel used to heat the furnace.
5. Forced air is introduced through openings near the bottom of the shell for combustion of the coke.
6. The flux is a basic compound such as limestone that reacts with coke ash and other impurities to form slag. The slag serves to cover the melt, protecting it from reaction with the environment inside the cupola and reducing heat loss.
7. As the mixture is heated and melting of the iron occurs, the furnace is periodically tapped to provide liquid metal for the pour.



The cupola is the only method of melting which is continuous in its operation.

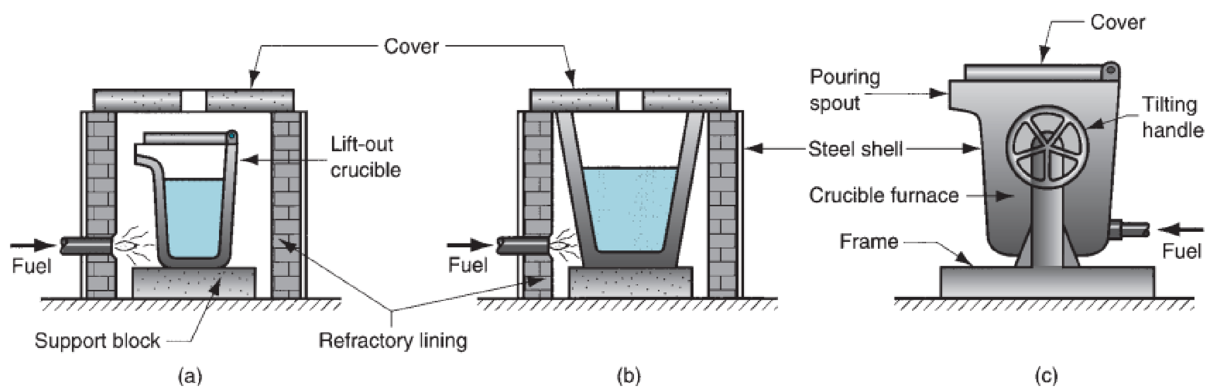
B) Crucible Furnaces Crucible furnaces are one of the oldest and simplest types of melting unit used in the foundry. The furnaces uses a refractory crucible(a ceramic or metal container) which contains the metal charge. The charge is heated via conduction of heat through the walls of the crucible. The heating fuel is typically coke, oil or gas. 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.

Crucible furnaces are typically classified according to the method of removing the metal from the crucible:

Tilting-pot furnace, in which the molten metal is transferred to the mould or ladle by mechanically tilting the crucible and furnace body.

Lift-out crucible, in which the crucible and molten metal are removed from the furnace body for direct pouring into the mould.

Stationary pot, in which the metal is ladled from the crucible to the mould.



C) Electric-Arc Furnaces In this furnace type, the charge is melted by heat generated from an electric arc. Various configurations are available, with two or three electrodes. Power consumption is high, but electric-arc furnaces can be designed for high melting capacity (23,000–45,000 kg/hr or 25–50 tons/hr), and they are used primarily for casting steel.