Permanent Mold Casting Process

Permanent mold casting is used for casting parts with complex shape and narrow size tolerances. As can be understood from the name, in this method a metal die made of two or more parts is used. The metallic die named as permanent mold is repeatedly used to produce a large number of the same cast parts.

The liquid metal is filled with the effect of gravity into the mold. Simple cores can be made of metal and complex shaped cores can be made of sand mixture or plaster. When non-metal cores are used, the method is called semi-permanent die casting. The production speed is higher than sand mold casting and lower lower than the high pressure die casting.

The number of pieces to be cast must be high enough to cover or meet the high cost of the mold. Although there is no maximum size limitation, the method is more suitable for casting small parts. All alloys are not suitable for casting with this methode. The production of some shapes by this method is not possible, either due to the location of the parting line or the difficulty in removing the cast part from the mold.

The main metals that can be cast into the metal mold are aluminum, magnesium, copper, zinc based alloys and hypereutectic gray cast iron.

Up to 13 -14 kg parts can be produced by this methode

This metode is not suitable for steel castings due to the high melting temperature. For the metals which can be cast by this methode, the casting temperature, the approximate mold life and the mold operating temperature are given in the table below.

It would be useful to make an explanation for the english literature. In the American literature, pressure die casting is referred to as die casting while metal mold casting is named as permanent mold casting. However, in European literature, pressure die casting is called as pressure die casting and metal mold casting is termed as gravity die casting.

Metal	Casting Temperature (C)	Approximate Mold Life (casting cycles)	Working Temperature of the Mold (C)
Al based alloys	704-760	Up to 100.000	343-427
Cu based alloys	1038-1149	5000-20.000	121-260
Mg based alloys	649-704	20.000-100.000	149-316
Zn based alloys	388-427	100.000+	204-260
Grey cast iron	1260-1482	5.000-20.000	316-427

Permanent mold process

Permanent mold processes:

• using only metal mold for casting

• Molds are generally made of steel, CI

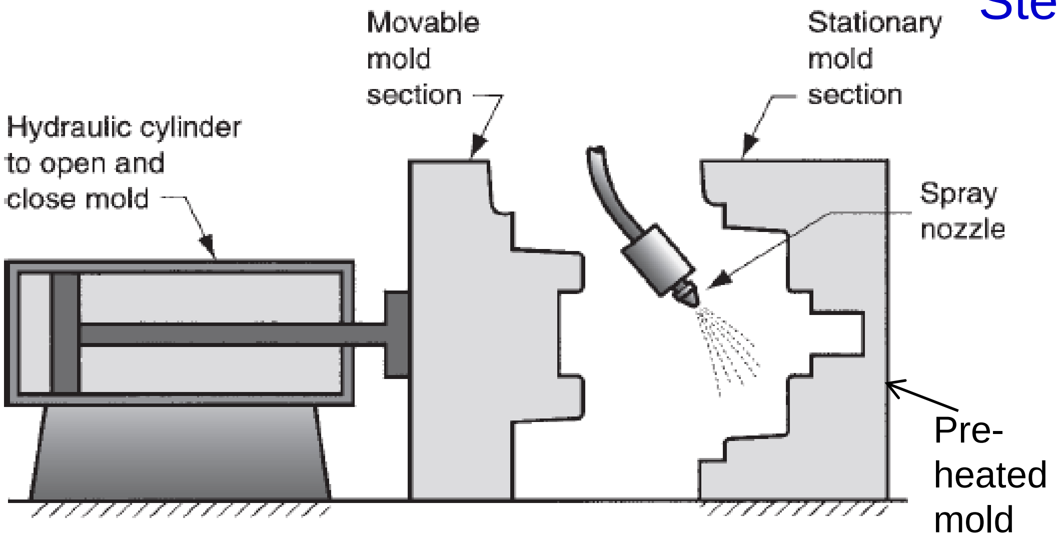
• materials that can be cast: Al, Mg, Cu based alloys, CI (affect the mold life, hence not used)

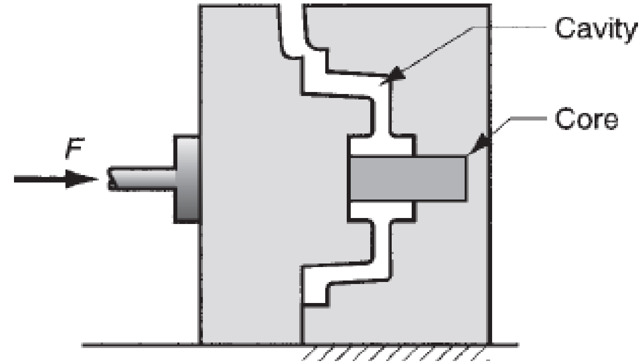
• cores are also made of metal, but if sand is used then called semi permanent-mold casting

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

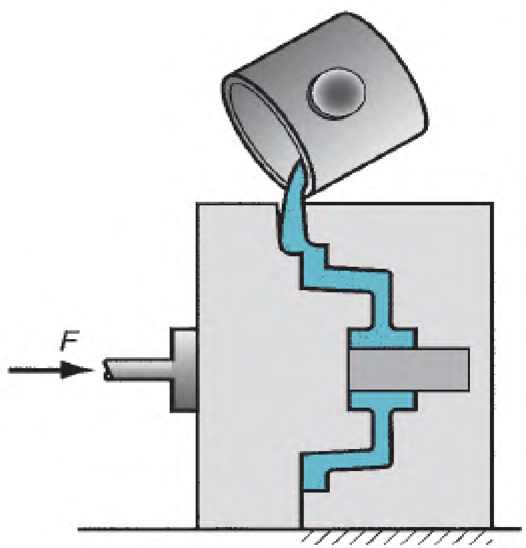
• limitations: restricted to simple part geometries, low melting point metals, mold cost is high. Best suitable for small, large number of parts

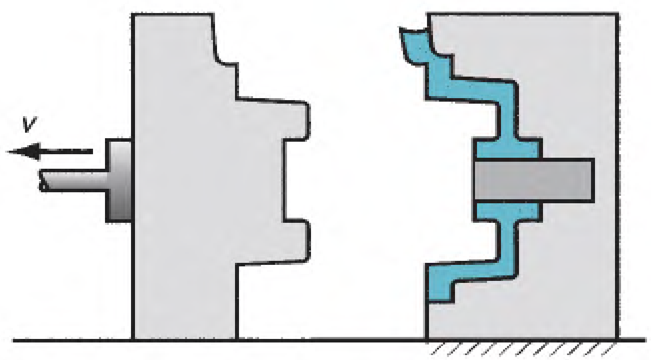
Steps in permanent mold process

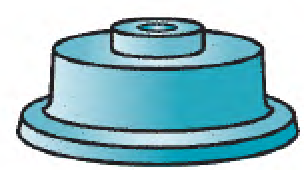




Preheating facilitates metal flow through the gating system and into the cavity.
The coatings aid heat dissipation and lubricate the mold surfaces for easier separation of the cast product





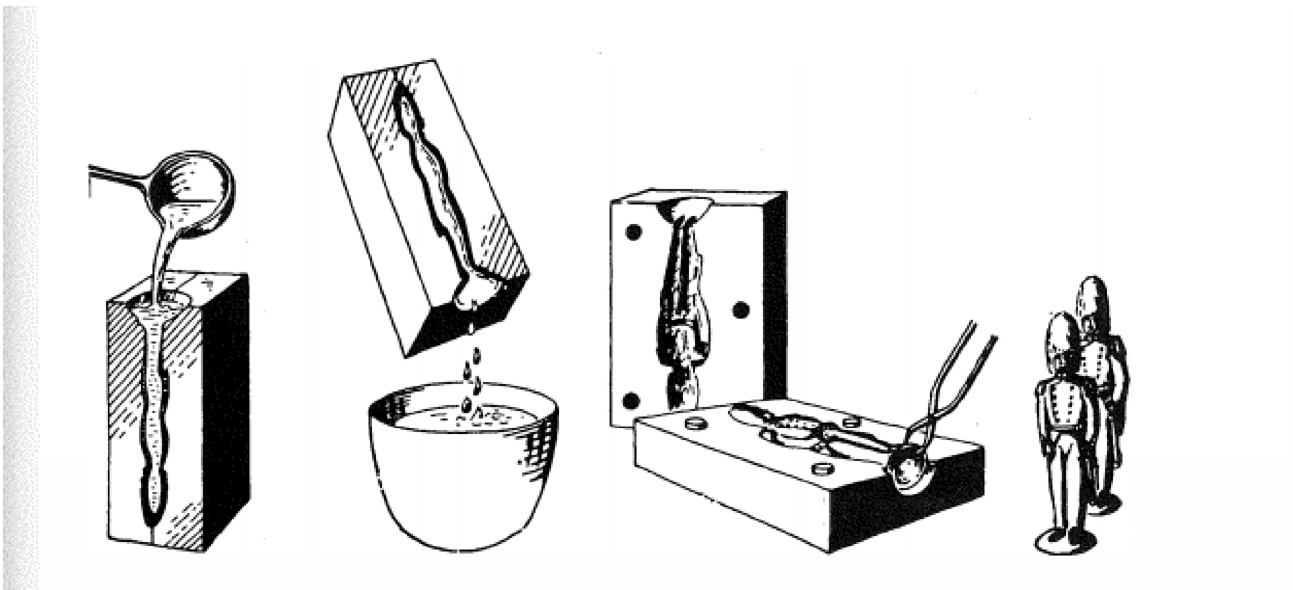


Slush Casting

Slush-molded castings are hollow castings produced without the use ofcores. Small statues, as trophies, toys, kettles and ornamental ware such as lamp bases are the principal types of castings produced by this method. Of all the metal casting processes in general commercial use, slush casting is probably the least known. The process has little competition from other methods of fabrication and its field is a restricted one.

In the slush-molding process, the molds are generally made of bronze, casting plaster molds or cast iron depending on the metal which will be poured into the mold. Some aluminum alloys are used in the slush casting process, but predominately the alloys used are zinc-base with some lead- and tin-base.
In most cases, the molds are of the conventional 2-section, split-type al-though multi part molds are used. The molds are equipped with handle sand mounted on trunnions so that they can be rotated in a vertical arc. The molds are then heated prior to being poured either by torches or by the pouring of a number of dummy castings until they are close enough to the temperature of the metal being poured as to prevent cold shuts.

The filling or gate end of the mold is arranged in a gentle arc or slope. Inpouring, that end is turned so that it is at the lowest point of the setup. As the operator pours metal with one hand into the gate from a small dip ladle, he gradually turns the mold upward with the other hand in order to permit the metal to enter the cavity slowly and gently. The thickness of the wall of the casting depends on the time interval between the filling and the inverting of the mold, as well as on the chemical and mechanical properties of the alloy and the temperature and composition of the mold. The metal is allowed to remain in the mold until the casting walls reach the desiredthickness. Then the gate end is turned down quickly to permit the remaining liquid metal to flow or slush out into the ladle. This metal is then re-turned to the furnace for subsequent pouring. The wall thickness of castings poured is controlled by mold and metal temperature, rate of filling and holding time before emptying or slushing.



The zinc alloys predominately used for slush casting are of two classes: the aluminum-zinc type and the aluminum-copper-zinc type. The aluminum-zinc alloy usually has a nominal composition of 5.5% A1 with the remainder special high grade zinc. Because this alloy is readily slush cast, producing very thin walls, its use is popular from the standpoint of initial cost.However, unless the impurity limits are closely controlled, castings made from this alloy are susceptible to subsurface network corrosion and premature failure by warping and cracking. Small variations in the aluminum content are not critical, except that they affect slightly the slushing characteristics of the alloy and consequently prevent the production of castings with thin walls. However, with the eutectic composition of 5.0% A1 it is al-most impossible to produce slush castings since one of the requirements of a slush casting alloy is that it must not have a single solidification point but must have instead an appreciable slushy range between the liquidus and solidus temperatures.

The second class of zinc alloys mentioned previously has a nominal composition of 4.75% A1 and 0.25% Cu with the remainder special highgradezinc. Alloys of this class produce castings with improved mechanical properties and also with longer service life, resulting from the protective effect of copper addition. Slush casting this type of alloy is more difficult and produces castings with thicker wall sections thus increasing the cost of the cast-ing. Because copper additions adversely affect the casting characteristics of slush casting alloys, commercial practice usually dictates against using more than the absolute minimum of copper in order to keep the wall sections as thin as practical. (Fig. 80)

The lead alloy used for slush casting is close to the antimony-lead eutectic alloy in composition. Other elements may be added to improve both the casting qualities and the grain refinement. A typical composition is 13.0%Sb, 1.0% Sn, 0.5% As, 0.1% Cu and the remainder Pb (lead). The excel-lent resistance to corrosion of this alloy does not depend on the exact com-position of the alloy. However, it is necessary to maintain close control of the composition to avoid impurities which, even in small quantities, impair solidification characteristics or casting quality.

It is important to keep the composition of the zinc-aluminum-copper alloy under close control since increases in the aluminum content above 4.75%approach the eutectic composition which is not desired. Decreases in the aluminum content make the fluidity of the alloy too low for slush casting.The copper addition must be sufficient to afford the degree of durabilitydesired, but should not exceed an amount that would affect production seriously by causing excessive weight in the castings.

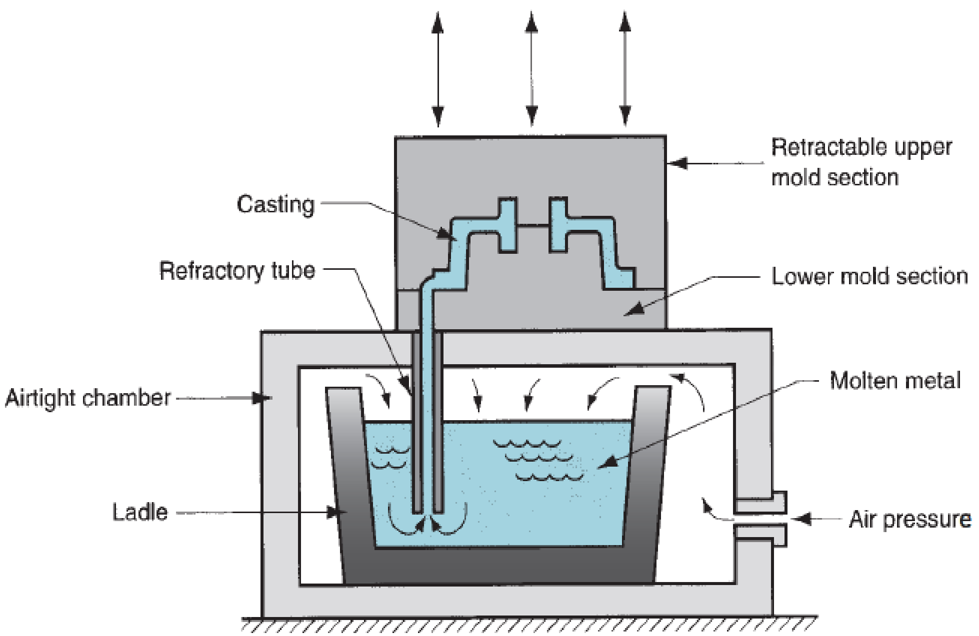
Variations of permanent mold casting

Low pressure casting:

• In the earlier casting process, metal flow in mold cavity is by gravity pull, but in low pressure casting, liquid metal is forced into the cavity under low pressure, app. 0.1 MPa, from beneath the surface so that metal flow is upward.

• advantage: molten metal is not exposed to air; gas porosity and oxidation defects are minimized

Vacuum permanent mold casting: variation of low pressure casting, but in this vacuum is used to draw the molten metal into the mold cavity.



Low pressure casting

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

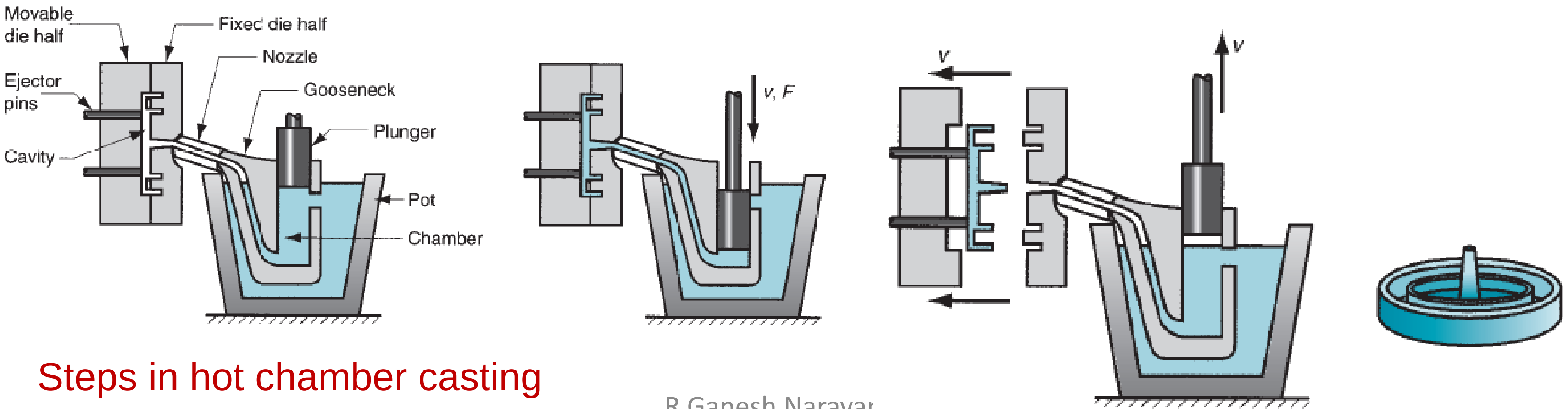
Die casting

In this process, high pressure of app. 7 to 350 MPa is used to pressurize the molten metal into die cavity. The pressure is maintained during solidification.

Category: hot chamber machines, cold chamber machines

hot chamber machines:

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

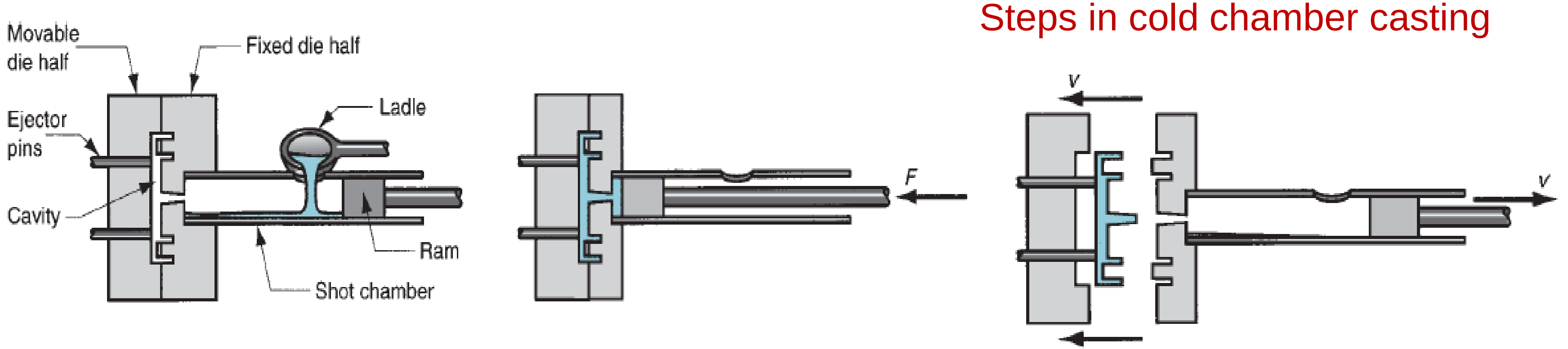


Steps in hot chamber casting

cold chamber machines:

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

Steps in cold chamber casting



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

Advantages of die casting:

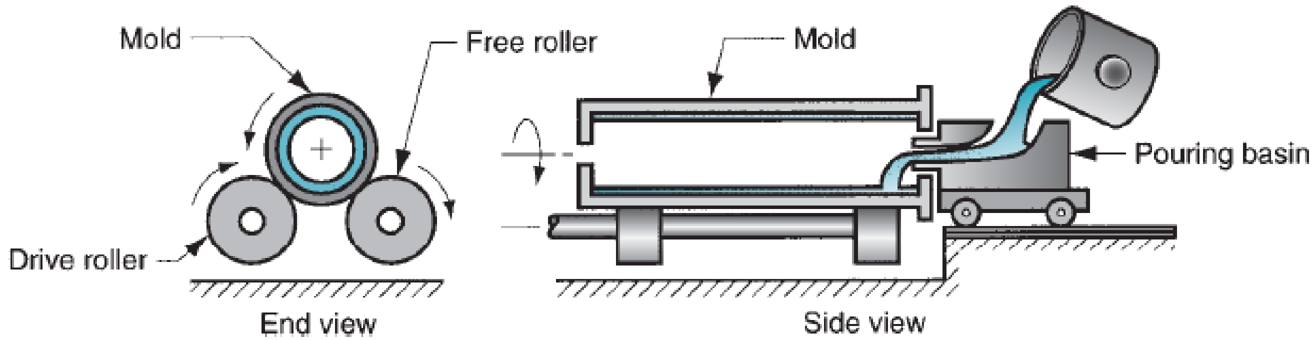
- high production rates and economical
- Close tolerances possible of the order of ±0.076 mm
- thin section with 0.5 mm can be made
- small grain size and good strength casting can be made because of rapid cooling

Centrifugal casting

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

- includes : true centrifugal casting, semicentrifugal casting

True centrifugal casting:



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

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- Orientation of the mold can be **horizontal or vertical**

For horizontal centrifugal casting:

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

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

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

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

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

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

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

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

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

Vertical centrifugal casting:

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

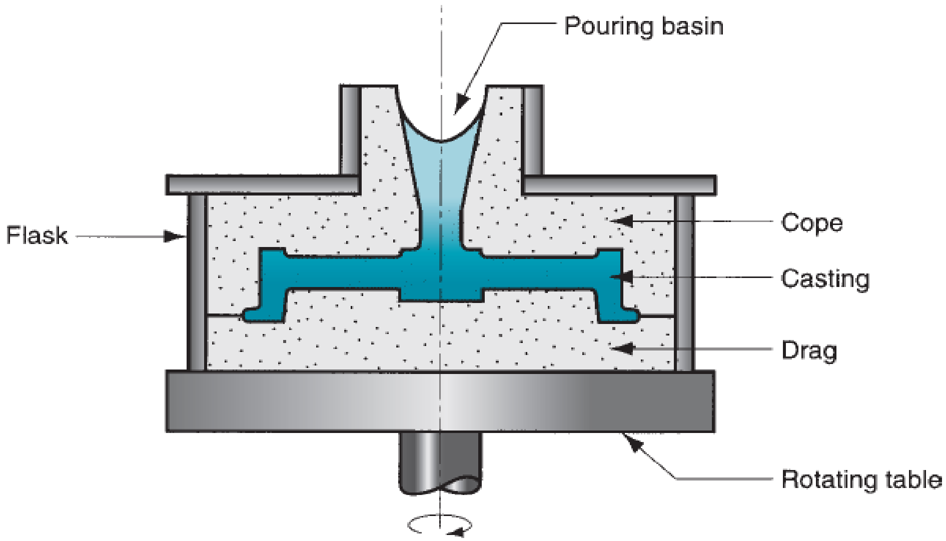
$$N = \frac{30}{\pi}\sqrt{\frac{2gL}{{R_{it}}^2 - {R_{ib}}^2}}$$

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

It is observed from the eqn. that for $R_{it} = R_{ib}$, the speed of rotation N will be infinite, which is practically impossible.

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

Semicentrifugal casting:



In this process, centrifugal force is used to produce non-tubular parts (solid), and not tubular parts. GF will be around 15 by controlling the rotation speed. Molds are provided with riser at the center.

Generally the density of metal will be more at the outer sections and not at the center of rotation. So parts in which the center region (less denser region) can be removed by machining (like wheels, pulleys) are usually produced with this method.

Continuous Casting Process

The principle of continuous casting has been known for a considerable number of years. As far back as 1846, Sir Henry Bessemer took out a patent for the production of tinfoil and sheet lead direct from the molten metal. In 1891 Sir Henry presented a paper on the manufacture of continuous heats of malleable iron and steel direct from fluid metal. It took another 60 years for Sir Henry's principle to be developed into an economic, viable process for the steel industry. The work of Junghans in the 1920s initiated the adoption of the continuous casting technique in the nonferrous field, and in the next two decades there were a considerable number of semi-continuous vertical casting machines producing billets and slabs in brass, copper and aluminum. The main interest and publicity centered around the introduction of the first continuous units for steel billets and blooms, but it was only in the mid 1950s that the continuous casting process was accepted as a proven production method for steel.

Continuous casting is one of the most revolutionary developments in the history of steelmaking. The realization has developed steadily since World War II that billets and slabs could be made continuously instead of by batches (an expensive and involved process from ingot making through all of the reheating and primary milling sequences). The first machine was installed in Germany in 1943. (Fig. 78)

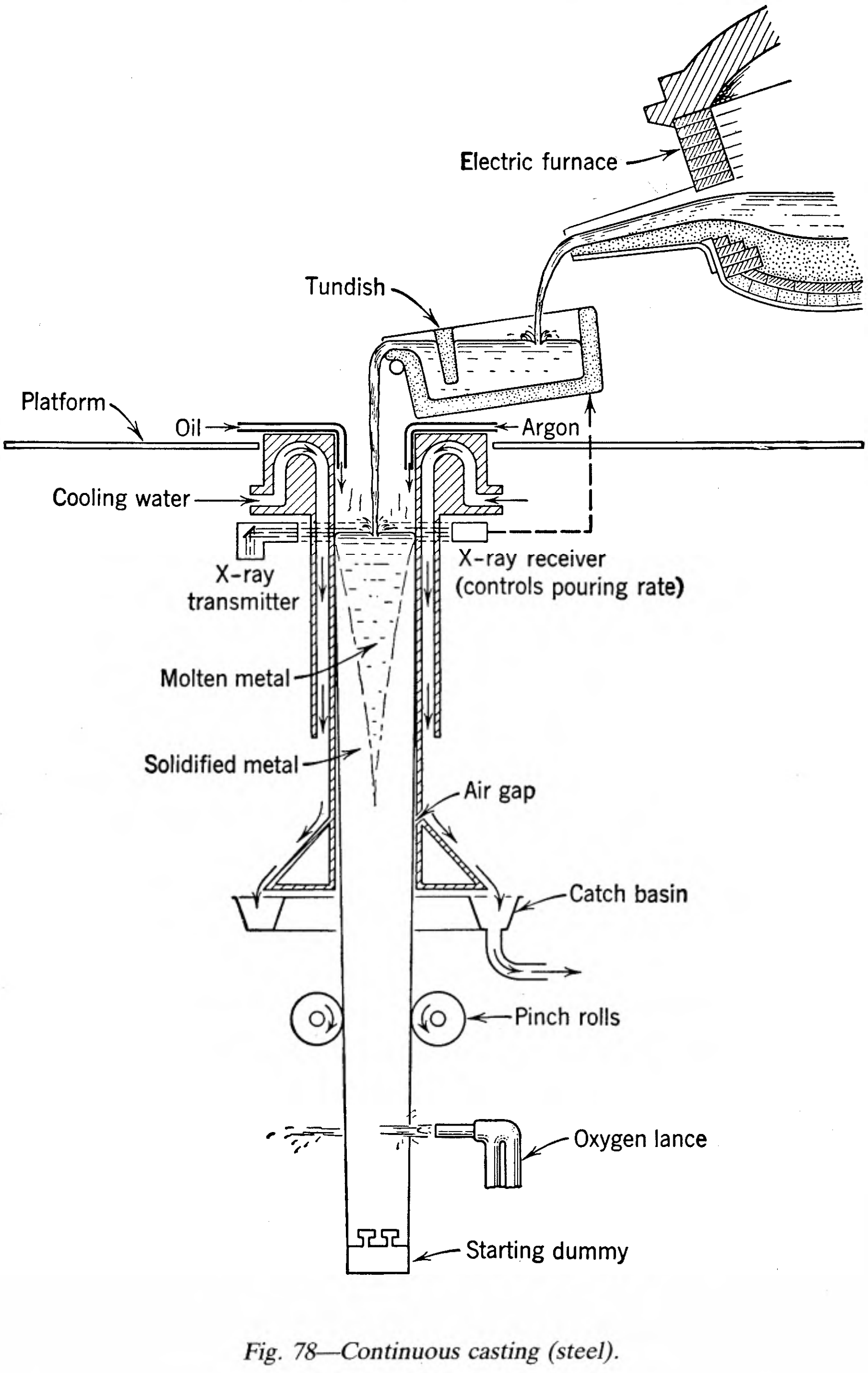


Fig. 78—Continuous casting (steel).

In the process, the molten steel is poured from a special ladle into a tundish from which it flows gently into a vertical mold, which generally is up to a meter in length, and of the cross section needed in the final casting. The mold is water cooled and is usually of thick copper and steel. At the beginning of the operation, the bottom of the mold is closed by a "dummy" and the machine starts the rolling action. The molten steel must solidify on its way down through it, and it is sprayed with water for further cooling before leaving. The billet in the lubricated mold moves downward allowing more molten metal to flow in at the top.

As it immerges, the billet has a solid, though incandescent, skin which holds the shape. The billet next moves downward between rollers and is then bent round by passing between movable rollers pushed forward to the correct extent. In this manner, it bends round until horizontal and moving over a roller track. At a predetermined stage along the horizontal track, it is cut off to form separate billets. The solidified bar, or shaped billet, is continuously drawn, up to 5 inches or more in diameter. Although the bars can be made in any length, they are usually notched and broken into convenient six foot sections

Though the process is expensive, it can be made economically competitive by making the machine with several billets running simultaneously, or having several "strands," as the technique is often referred to. This versatility guarantees a tons-per-hour increase in production. Careful control of all factors involved is necessary and because of this, a continuous casting machine produces steel of consistent quality. The continuous casting of shaped cross sections such as rounds, squares and hexagonal shapes suggests the possibility that joists, beams and girders will eventually be continuously cast, thus avoiding the need for costly mills. Continuously cast gray, ductile and high alloy irons are commercially available and are characterized by a fine grain structure.

Steel production continued to utilize the already established principle of the vertical aligned machine, using the open circuit system, where the molten metal is held in a suitably designed ladle, poured through air into a tundish situated above the mold and a controlled stream of metal from the tundish is directed vertically into a reciprocating water-cooled copper mold.

Because of the very high installation costs of the vertical machines, and because of quality problems associated with internal shrinkage and relatively poor surface finish resulting from production with this open system, relatively small progress was made during the first twenty years. Thus, by 1970 there were only 299 units in operation producing only 9.3% of the total output of steel ingots. In contrast to the first 20 years, by 1977 a total of 734 units had been installed, producing over 30% of the total steel ingots. It is estimated that during the next decade, a great majority of all of the ingots will be produced by this method. The bulk of the machines being installed at present have a capacity of between 25 and 250 tons per hour mainly for the production of plain carbon steels.

While no paper concerning continuous casting would be complete without reference to steel production, the continuous casting of cast iron and nonferrous metals has been responsible for the major new developments in this process. Although continuous casting of phosphorus bronze and cast iron (two materials which cannot be satisfactorily forged or rolled but have to be used essentially in the as-cast form) covers a relatively limited field of application, this small section of the industry was responsible for the introduction of a very significant new development. It concerned the introduction of the *closed* system where a metal cooler with a graphite die insert was attached directly to the holding furnace, the graphite die insert protruding into the molten metal. This closed circuit system had the obvious advantages of eliminating oxidation of the metal between the holding furnace and the cooler, thus providing a superior surface finish. It had the additional advantage of the hydrostatic pressure of the metal in the holding furnace resulting in a sounder and more homogeneous structure of metal leaving the die. The idea of a closed system utilizing vertical alignment was pursued actively in the U.K. while the first production unit combining the closed system with horizontal alignment was also introduced in the U.K. The companies pursuing these developments were primarily interested in the production of cast iron and therefore had the opportunity for a direct comparison of the merits of the vertical and horizontal alignment units. The success of the horizontal machine, owing to its greater safety, reliability and lower cost was so apparent that shortly afterwards production on the vertical machine was abandoned and all operations were concentrated in the foundry using the horizontal machine. Although the closed circuit machines operating in a vertical plane for production of nonferrous bars and tubes were widely adopted by various nonferrous foundries, the principle of the horizontal machine was actively pursued by two engineer foundrymen, Wertli of Switzerland and H.A. Krall of Germany. Both the Wertli machine and Krall's machine (the latter sold under the name of Technica Guss) gained a worldwide reputation in the nonferrous industry while Technica Guss proved also to be very successful in the cast iron field. The impact of the closed system horizontal machine in the nonferrous and cast iron fields is best illustrated by the fact that at present there are more than 150 of these machines operating throughout the world—approximately 1/3 in cast iron and 2/3 in the nonferrous fields.

As far as cast iron is concerned, the field of continuous casting application is far more limited since the material cannot be subsequently rolled or forged. However, as in the case of steel and nonferrous metals, continuously cast gray iron has numerous advantages over conventional castings, such as:

1. Complete absence of defects normally associated with sand castings e.g. surface defects, blow holes, shrinkage and sand inclusions.
2. Homogeneous and close grain structure giving excellent machinability, good wear resistance and ability to withstand hydraulic or pneumatic pressures.
3. Availability of a very comprehensive range of bar material stock, thus eliminating delays in deliveries, preparation of patterns, etc.

In general engineering, most cast iron bars are used for comparatively simple applications when straightforward turning or drilling are the only requirements. Examples of this are gears, valve guides, seals, spindles, bushes, rollers and pulleys. Continuously cast iron bar in long lengths is ideal for long production runs where automatic bar turning machines can be used with considerable savings. Both the glass and textile industries consume substantial quantities of bar in either round or special shaped form, but the biggest outlets at the moment are to be found in the hydraulic, pneumatic and machine tool industries. There is little doubt that the continuous casting process will continue to play an ever increasing part in the cast metal industry and that the demand for these types of machines will continue to grow.