Chapter Two – Casting Processes

Introduction:

Casting process is the process by which a component is made when pouring a molten metal in a formed die or cavity. The process used for making a casting depends on:

1. The quantity to be produced.
2. The metal to be casted.
3. Form (geometry) of the part.

The casting properties are depended on:

1. Viscosity.
2. Surface tension.
3. Oxide film formation.
4. Fluidity (measure of the capability of a metal to flow into and to fill the mold before freezing. It defines to the great extend the quality of the casting).

Types of Casting Processes:

1. Sand Casting Mold (expendable).
2. Permanent Casting Mold.

A large number of components are made by casting due to (advantages of casting):

1. Casting can produce very complex geometry parts with internal cavities and hollow sections.
2. It can be used to make small (few thousands grams) to very large size parts (thousands of kilograms).
3. It is economical, with very little wastage: the extra metal in each casting is re-melted and re-used.
4. Cast metal is isotropic – it has the same physical/mechanical properties along any direction.

5. Variety of metals can be used in the casting.

Common Examples for Castings:

Door handles, locks, the outer casing or housing for motors, pumps, wheels of many cars, etc…

Casting is also heavily used in the toy industry to make parts, e.g., toy cars, planes, and so on.

Disadvantages of Casting:

1. Limitation in mechanical properties, porosity.
2. Dimensional accuracy, surface finish.
3. Safely hazard.
4. Environmental problems.
5. Internal defects.

Solidification and Pouring Time:

- **Solidification time is a function of the size and shape:**

$$TST \propto \frac{1}{(surface\ area)^n}$$

$$TST = C_m \left(\frac{volume\ of\ casting}{surface\ area\ of\ casting} \right)^n$$

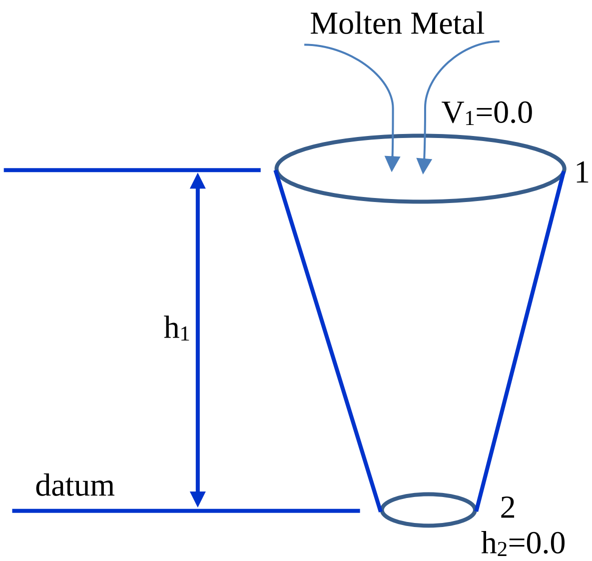
n: constant usually equal to 2.

TST: total solidification time, sec, min.

C_m: (mold constant) experimentally determined value that depends on mold material, thermal properties of casting metal, and pouring temperature relative to melting point. For example: C_m=0.2 min/mm^2.

- **Pouring Time:**
  From Bernoulli's theorem at any two points in a flowing fluid:

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = h_2 + \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + h_f$$



Where;

h: head,

p: static pressure,

ρ: density,

v: flow velocity,

g: gravity,

h_f: friction losses

assume h_f=0.0 and same static pressure p_1=p_2 then:

$$\boldsymbol{v_2 = \sqrt{2gh_1}}$$

From continuity law:

$$Q = v_1 A_1 = v_2 A_2$$

Mold Filling Time (MFT) = V/Q

V: volume of casting (mold cavity volume)

Q: volume flow rate of metal

A: cross-sectional area of molten metal.

Example (1):

3 pieces of castings have the same volume but with different shapes. One is a sphere, one is a cube and the other is a cylinder with height equal to diameter. Which piece will solidify the fastest and which one the slowest?

Solution:

We assume $V=1.0\ unit^3$, calculate the areas

1. Sphere

$V_{sphere}= (4/3)\ \pi\ r^3$, $A_{sphere}=4\ \pi\ r^2$ (surface area)

$\therefore\ A_{sphere}=4.84\ unit^2$

2. Cube

$V_{cube}=a^3 \Longrightarrow a=1$

$A_{cube}=6a^2=6\ unit^2$ (surface area)

3. Cylinder

$V_{cylinder}=\pi\ r^2\ h= \pi\ r^2\ (2r)$

$A_{cylinder}=2\ \pi\ r^2 + 2\ \pi\ r\ h =2\ \pi\ r^2 + 2\ \pi\ r\ (2r)= 6\ \pi\ r^2 = 5.54\ unit^2$ (surface area)

$\therefore\ TST_{sphere}= C_m\ (1/4.84)^2 = 0.043\ C_m$

$\therefore\ TST_{cube}= C_m\ (1/6)^2 = 0.028\ C_m$

$\therefore\ TST_{cylinder}= C_m\ (1/5.54)^2 = 0.033\ C_m$

Hence:

Cube casting will solidify the fastest

Sphere casting will solidify the slowest

Example (2):

A mold sprue is 20 cm long, and the cross-sectional area at its base is 2.5 cm2. The sprue feeds a horizontal runner leading into a mold cavity whose volume is 1560 cm3. 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 molten metal at the sprue base is given by

$$v_2 = \sqrt{2gh_1}$$

$$v_2 = \sqrt{2(981)(20)} = 198 \cdot 1\ cm/s$$

(b) The volume flow rate is given by

$$Q = v_1 A_1 = v_2 A_2 = (2 \cdot 5)(198 \cdot 1) = 495 \cdot 3\ cm^3/s$$

(c) Time required to fill the mold cavity is given by

Mold Filling Time (MFT) = V/Q = 1560/495.3 = 3.2 s

Heating the Metal:

The heat energy required to heat the metal to a molten temperature sufficient for casting is the sum of :
(1) the heat to raise the temperature to the melting point,
(2) the heat of fusion to convert it from solid to liquid, and
(3) the heat to raise the molten metal to the desired temperature for pouring.

This is given by:

$$H = \rho V\{C_s(T_m - T_o) + H_f + C_l(T_p - T_m)\}$$

Where;

H: total heat required to raise the temperature of the metal to the pouring temperature, J (Btu);
ρ: density, g/cm^3 (lbm/ in^3);
C_s: weight specific heat for the solid metal, J/g ºC (Btu/lbm ºF);
T_m: melting temperature of the metal, ºC (ºF);

T_o: starting temperature—usually ambient, ºC (ºF);
H_f: heat of fusion, J/g (Btu/lbm);
C_l: weight specific heat of the liquid metal, J/g ºC (Btu/lbm ºF);
T_p: pouring temperature, ºC (ºF);
V: volume of metal being heated, cm^3 (in^3).

Example (3):

One cubic meter of a certain eutectic alloy is heated in a crucible from room temperature to 100 ºC above its melting point for casting. The alloy's density=7.5 g/cm^3, melting point=800 ºC, specific heat=0.33 J/g ºC in the solid state and 0.29 J/g ºC in the liquid state; and heat of fusion=160 J/g. How much heat energy must be added to accomplish the heating, assuming no losses? Take ambient temperature in the foundry equal to 25 ºC and assume density of the liquid and solid states of the metal are the same.

Solution:

Note that $1m^3=10^6$ cm^3 then

$$H = (7.5)(10^6)\{0.33(800-25)+160+0.29(900-800)\} = 3336(10^6)\ J$$

Casting Technology:

General steps of casting operation:

1. Mold preparation
2. Metal heating
3. Pouring
4. Cooling until solidify
5. Further processing

Types of Casting Processes:

According to type of mold used, casting processes divide into:

1. Expendable-mold casting

It is characterized with the following features:

(a) The mold after process must be destroyed in order to remove the casting.

(b) The mold materials: sand, plaster and similar materials like binders.

(c) More intricate geometries can be produced by this type.

2. Permanent-mold casting

It is characterized with the following features:

(a) The mold can be used many times to produce many castings.

(b) The mold is made of metal or, less commonly, a ceramic refractory material (durable materials).

(c) Geometries produced by this type are limited in complexity.

(d) Some of permanent mold processes have certain economic advantages in high production operations.

Expendable-Mold Casting:

(A) Sand-Casting Molds:

They divide into closed-molds and open-molds as shown in Figure (2-1).

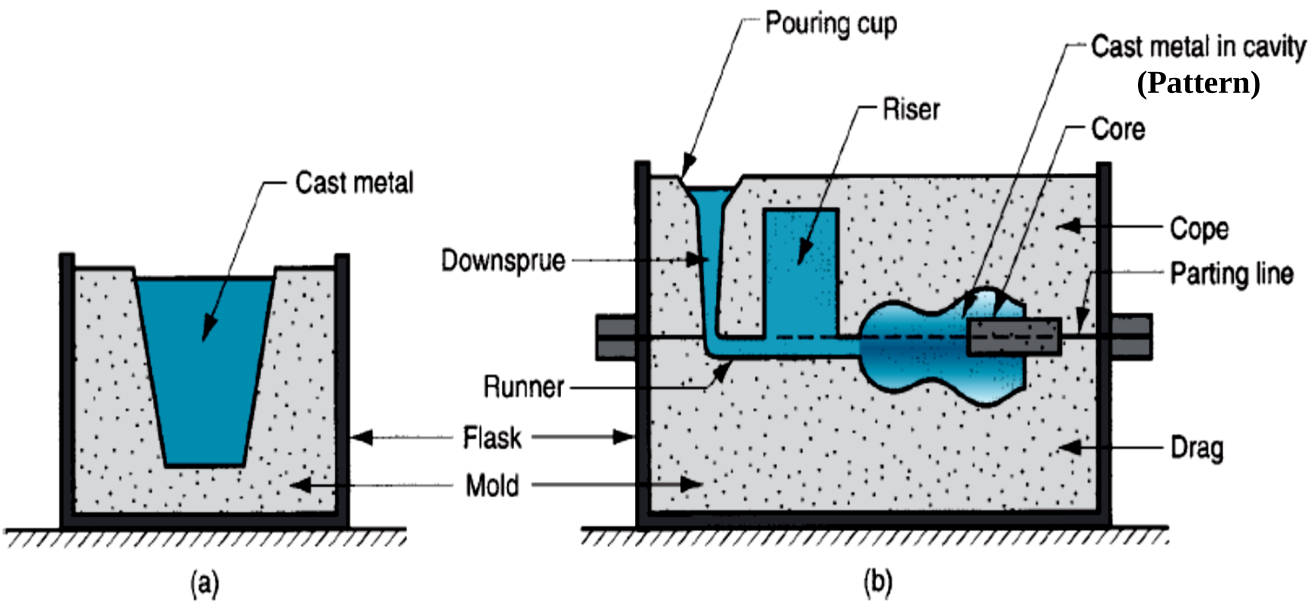


Figure (2-1) Sand casting molds; (a) open mold, (b) closed mold

Open Mold: simply a container in the shape of the desired geometry.

Closed Mold: in which the mold shape is more intricate and requires a gating system (passageway) leading into the mold cavity. This type of mold consists of the following items:

(a) Mold: includes cope (upper half) and drag (bottom half).
(b) Flask: contains the cope and drag.
(c) Parting Line: boundary line at which the cope and drag are met.
(d) Pattern:
- Forms the mold cavity which is created by packing the sand around the pattern.
- The mold cavity defines the external surfaces of the cast part.
- The mold sand is moist and contains a binder to keep its shape.

- The pattern is made of wood, metal, plastic, or other material and has the shape of the part to be cast.
- The pattern is usually made oversized to allow for shrinkage of the metal as it solidifies and cools.

(e) Gating System:

- It includes the following parts: pouring cup, downsprue and runner.
- It is a channel or network of channels through which the molten metal flows into cavity.
- At top of the downsprue, there is a pouring cup to minimize splash and turbulence.
- The pouring cup is a simple cone-shaped funnel. Some pouring cups are designed in the shape of a bowl, with an open channel leading to the downsprue.

(f) Riser:

- It is liquid metal reservoir to compensate for shrinkage during solidification.
- It is designed to freeze after solidify the main casting.
- In sand casting, the natural porosity of the sand mold permits the air and gases to escape through the walls of the cavity in order to fill the mold cavity completely.

(g) Core:

- It is placed inside the mold cavity to define the interior geometry of the part.
- In sand casting, cores are generally made of sand, although other materials can be used, such as metals, plaster, and ceramics.

Riser Design:

The riser must remain molten until after the casting solidifies. Chvorinov's rule can be used to compute the size of a riser that will satisfy this requirement. The following example illustrates the calculation.

Example (4):

A cylindrical riser must be designed for a sand-casting mold. The casting itself is a steel rectangular plate with dimensions 7.5cm X 12.5cm X 2.0 cm. Previous observations have indicated that the total solidification time (TST) for this casting=1.6 min. The cylinder for the riser will have a diameter-to-height ratio (D/h)=1.0. Determine the dimensions of the riser so that its TST=2.0 min. Take n=2.0

Solution:

1- calculate the C_m mold constant for the casting (plate) from the below equation:

$$TST = C_m \left(\frac{volume\ of\ casting}{surface\ area\ of\ casting}\right)^n$$

Volume of casting (plate) = 7.5x12.5x 2 =187.5 cm^3
Surface area of casting (plate) = 2(7.5x12.5 + 7.5x2 + 12.5x2) = 267.5 cm^2

TST = 1.6 min for casting (plate)

Then:

C_m = TST / (volume of casting / surface area of casting)^2 = 1.6 / (187.5/267.5)^2

C_m = 3.26 min/cm^2

2- calculate the dimensions of riser:

Volume of riser = (π D^2 h) /4

Surface area of riser = (π D h) + 2(π D^2/4)

We have D/h=1, then D=h. Substituting D for h in volume and surface area of riser, we get:

Volume of riser = (π D^3) /4

Surface area of riser = (π D^2) + 2(π D^2/4) = 1.5 π D^2

We have TST=2min for the riser, then:

TST = C_m (Volume of riser / Surface area of riser)^2

$$2 = 3 \cdot 26 \left(\frac{\frac{\pi D^3}{4}}{1 \cdot 5 \pi D^2} \right)^2 = 3 \cdot 26 \left(\frac{D}{6} \right)^2 = 0 \cdot 09056 D^2$$

$\therefore \boldsymbol{D = 4 \cdot 7\ cm}$

$\therefore \boldsymbol{h = D = 4 \cdot 7\ cm}$

Shrinkage:

The shrinkage phenomena is occurred during cooling and freezing of the metal casting as stated in figure (2-2).

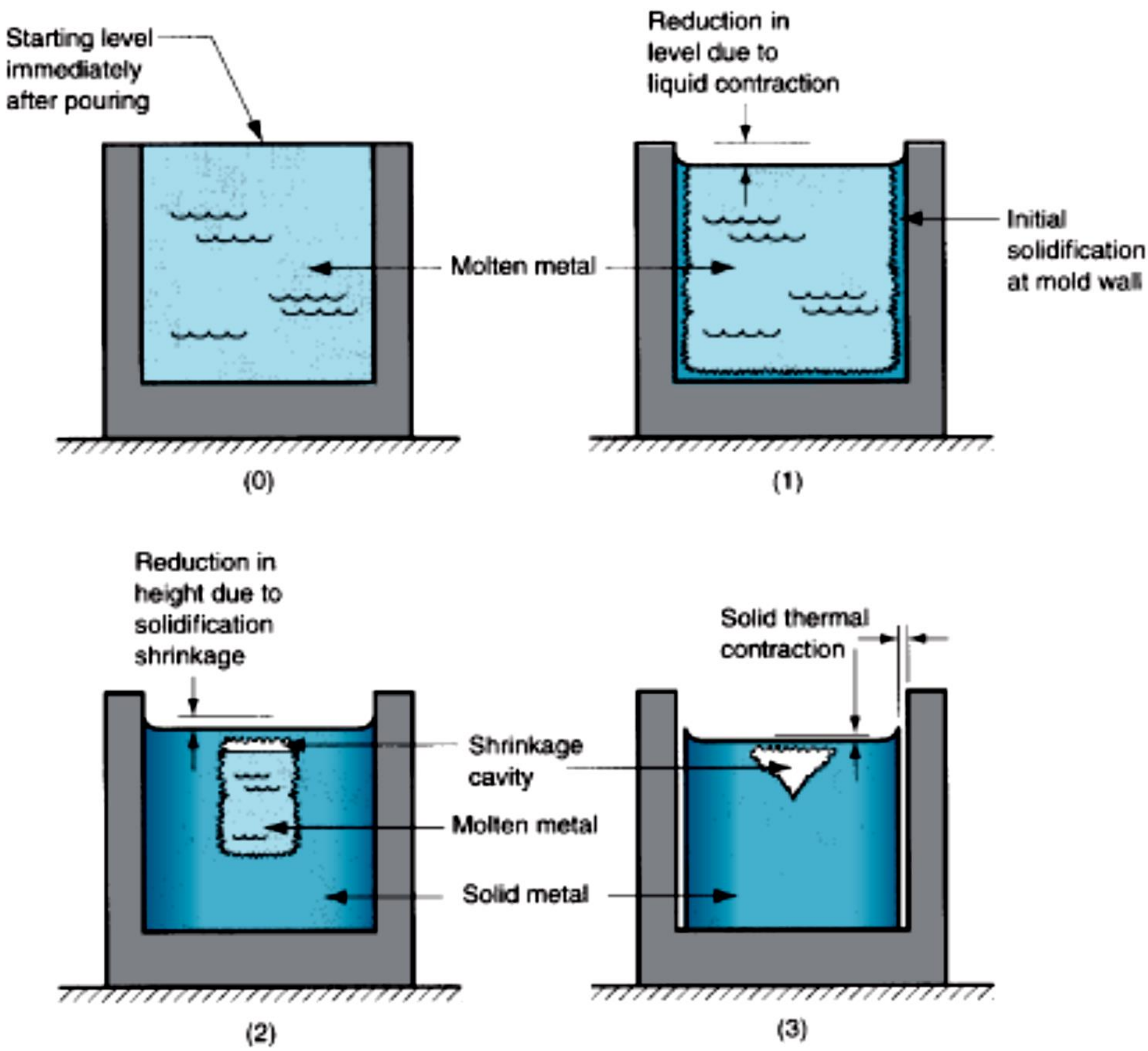


Figure (2-2) shrinkage steps of the molten metal during solidification and cooling

(0) Starting level of molten metal immediately after pouring;
(1) Reduction in level caused by liquid contraction during cooling;
(2) Reduction in height and formation of shrinkage cavity caused by solidification shrinkage (contraction during the phase change from liquid to solid);
(3) Further reduction in height and diameter due to thermal contraction during cooling to room temperature of the solid metal.

Directional Solidification:

In order to minimize the damaging effects of shrinkage, it is desirable for the regions of the casting most distant from the liquid metal supply to freeze first and for solidification to progress from these remote regions toward the riser.

The directional solidification is achieved by the following ways:

1- Calculate TST for the casting, casting's orientation inside the mold, riser system design.
2- Use the chills (chills: internal or external heat sinks that cause rapid freezing in certain regions of the casting).

Internal chills: are small metal parts placed inside the cavity before pouring so that the molten metal will solidify first around these parts. The internal chill should have a chemical composition similar to casting.

External chills: are metal inserts in the walls of the mold cavity that can remove heat from the molten metal more rapidly than the surrounding sand in order to promote solidification.

Figure (2-3) illustrates using of the external chills.

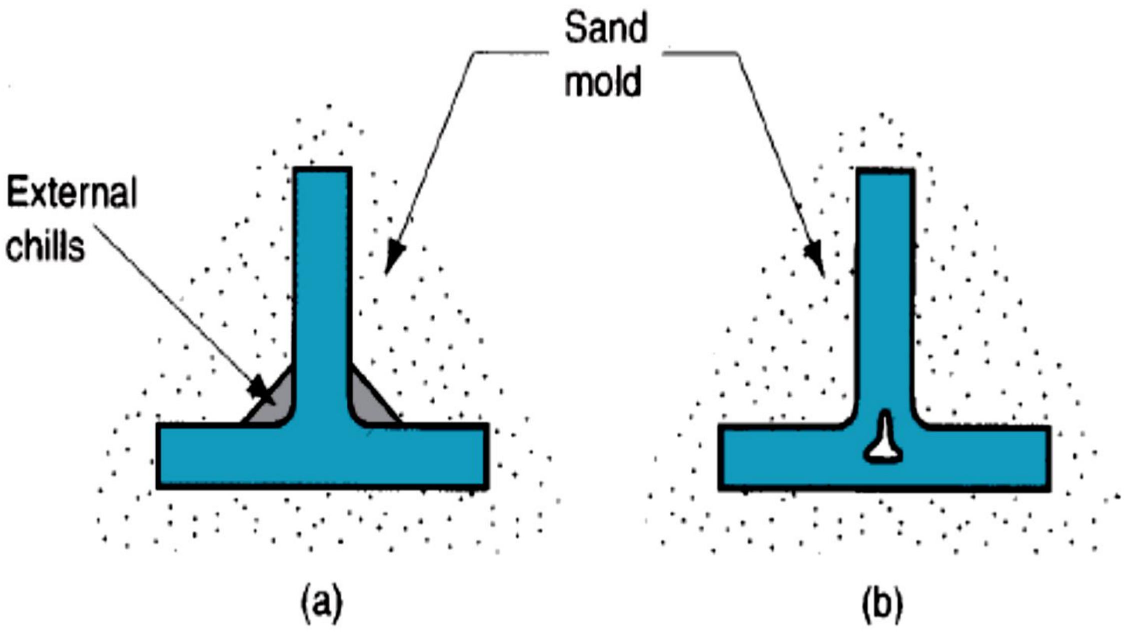


Figure (2-3) (a) External chill and (b) No chills used.