

MEP 291 METAL FORMING

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 Chapter-7 | Metal-Casting

Ch.7 Metal-Casting

- **Casting:** is a solidification process in which molten metal is poured into a mold and then allowed to cool (Fig. 10.8).
- **Most** metals shrink during solidification except for gray cast iron and some aluminum alloys they expand during solidification.

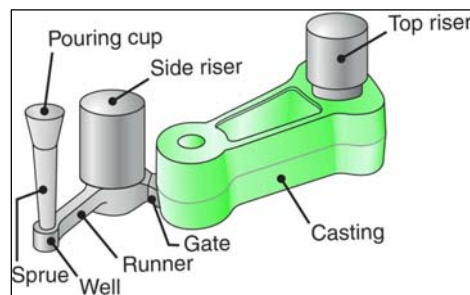


FIGURE 10.8 Schematic illustration of a typical riser-gated casting. Risers serve as reservoirs, supplying molten metal to the casting as it shrinks during solidification.

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- **The casting process involves the following:**
 - (a) Pouring molten metal into a mold shaped after that part to be produced.
 - (b) Allowing the molten metal to solidify.
 - (c) Removing the part.



FIGURE 10.16 Aluminum piston for an internal combustion engine: (a) as cast and (b) after machining. The part on the left is as cast, including risers, sprue, and well, as well as a machining allowance; the part on the right is the piston after machining.
Source: After S. Paolucci.

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Ch.7 Metal-Casting

- **Characteristics of casting:**
 - (1) Can produce complex shapes.
 - (2) Extremely large parts can be produced in one piece.
 - (3) Utilize materials that are difficult or too costly to process.
 - (4) Economically competitive with other manufacturing processes.

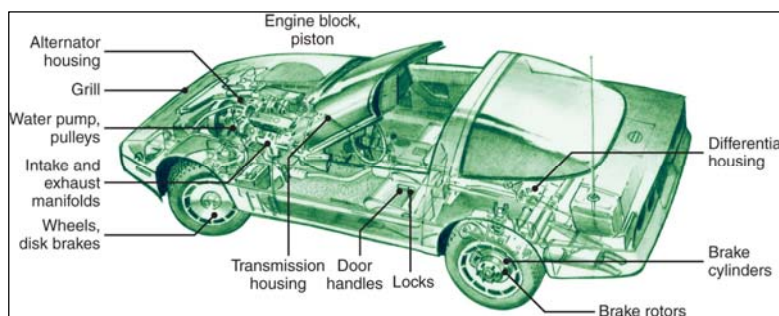


FIGURE II.2 Cast parts in a typical automobile.

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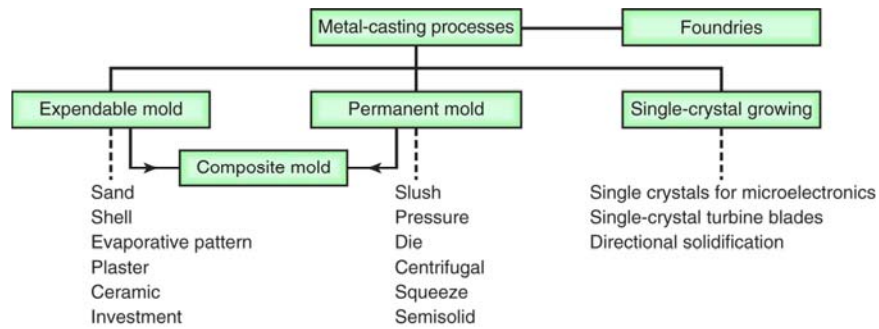


FIGURE II.3 Outline of metal-casting processes described in Part II.

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Ch.7 Metal-Casting (Fluid Flow)

Bernoulli's Theorem (conservation of energy):

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

Where,

f = Frictional loss in the liquid

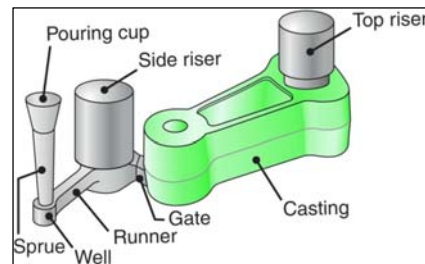
g = The gravitational constant (9.81 m/s^2 , 32.2 ft/s^2)

h = The elevation above a certain reference level

p = The pressure at that elevation

v = The velocity of the liquid at that elevation

FIGURE 10.8 Schematic illustration of a typical riser-gated casting. Risers serve as reservoirs, supplying molten metal to the casting as it shrinks during solidification.



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Ch.7 Metal-Casting (Fluid Flow)

Mass Continuity (The flow rate must be maintained everywhere in the system):

$$Q = A_1v_1 = A_2v_2$$

Where,

Q = The volume rate of flow (m^3/s)

A = The cross sectional area of the liquid stream

v = The average velocity of the liquid in that cross section

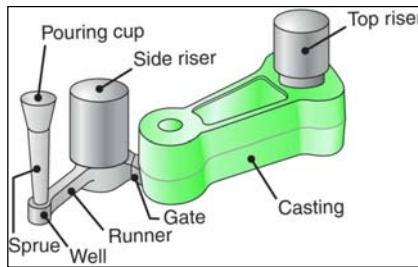


FIGURE 10.8 Schematic illustration of a typical riser-gated casting. Risers serve as reservoirs, supplying molten metal to the casting as it shrinks during solidification.

Ch.7 Metal-Casting (Fluid Flow)

- **Aspiration:** a process where the air is sucked (entrapped) in the liquid.
- **A tapered sprue** is used to prevent the molten metal from separation from the sprue wall.

Sprue Design (pressure at the top = pressure at the bottom/no frictional losses):

$$\frac{A_1}{A_2} = \sqrt{\frac{h_2}{h_1}}$$

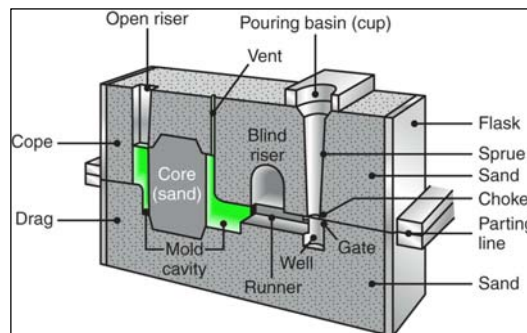


FIGURE 11.3 Schematic illustration of a sand mold, showing various features.

Ch.7 Metal-Casting (Fluid Flow)

Velocity of the molten metal leaving the gate:

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

Where,

h = The distance from the sprue base to the liquid metal height

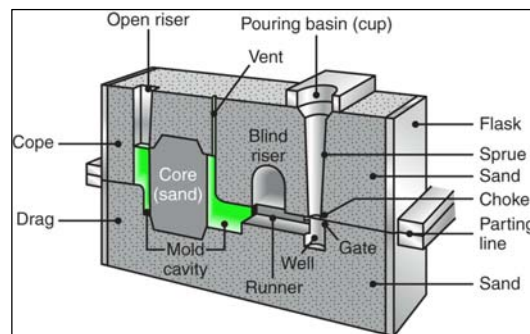


FIGURE 11.3
Schematic illustration of a sand mold, showing various features.

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Ch.7 Metal-Casting (Fluid Flow)

Reynolds Number (Re):

$$Re = \frac{vD\rho}{\eta}$$

Where,

v = The velocity of the liquid

D = The diameter of the channel

ρ = The density of the liquid

η = The viscosity of the liquid

If $Re < 2000$ laminar flow

If $20,000 > Re > 2000$ a mixture of laminar & turbulent flow

If $Re > 20,000$ turbulent flow

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Ch.7 Metal-Casting (Solidification Time)

Solidification Time:

$$\text{Solidification time} = C \left(\frac{\text{Volume}}{\text{Surface area}} \right)^n$$

Where,

$$n = 2$$

C = A constant that reflects the mold material, the metal properties, and the temperature

Example-1 (Solidification Time)

Three metal pieces being cast have the same volume ($v=1\text{m}^3$), but different shapes: One is sphere, one a cube, and the other a cylinder with its height equal to its diameter. Which piece will Solidify the fastest, and which one the slowest? Assume that $n=2$.

Solution:

$$v=1 \text{ m}^3$$

$$n=2$$

Example-1

Surface area of sphere:

$$V = \left(\frac{4}{3}\right) \pi r^3 \rightarrow 1 = \frac{4}{3} \pi r^3 \rightarrow r^3 = \frac{1}{\frac{4}{3} \pi} \rightarrow r = \sqrt[3]{\frac{3}{4\pi}}$$

$$r = \sqrt[3]{\frac{3}{4\pi}} = 0.62m$$

$$A = 4\pi r^2 = 4\pi (0.62)^2 = 4.84m^2$$

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Example-1

Surface area of cube:

$$V = a^3 \rightarrow 1 = a^3 \rightarrow a = \sqrt[3]{1} \rightarrow a = 1$$

$$A = 6a^2 = 6(1)^2 = 6m^2$$

Surface area of cylinder:

$$V = \pi r^2 h [h = 2r \text{ "height=diameter"}]$$

$$V = 2\pi r^3 \rightarrow r = \sqrt[3]{\frac{1}{2\pi}} = 0.54m$$

$$A = 2\pi r^2 + 2\pi r h = 2\pi r^2 + 4\pi r^2 = 6\pi r^2 = 6\pi (0.54)^2 = 5.5m^2$$

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Example-1

Solidification time of sphere:

$$t_{sphere} = C \left(\frac{V}{A} \right)^2$$

$$t_{sphere} = \left(C \text{ min}/m^2 \right) \left(\frac{1m^3}{4.8m^2} \right)^2 = 0.043C \text{ min}$$

Solidification time of cube:

$$t_{cube} = C \left(\frac{V}{A} \right)^2$$

$$t_{cube} = \left(C \text{ min}/m^2 \right) \left(\frac{1m^3}{6m^2} \right)^2 = 0.028C \text{ min}$$

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Example-1

Solidification time of cylinder:

$$t_{cylinder} = C \left(\frac{V}{A} \right)^2$$

$$t_{cylinder} = \left(C \text{ min}/m^2 \right) \left(\frac{1m^3}{5.5m^2} \right)^2 = 0.033C \text{ min}$$

- In conclusion, The cube-shaped piece will solidify first, and the sphere-shaped piece will solidify last.

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Example-2

Pure aluminum has a density of 2700 kg/m^3 and a viscosity of 0.0015 Ns/m^2 is poured into a sand mold. The metal level in the pouring basin is 10 in. above the metal level in the mold, and the runner is circular with a 0.4 in. diameter. What is the velocity and rate of the flow of the metal into the mold? Is the flow turbulent or laminar? Assume that $v_1 = 0$ and the pressure does not change and there are no friction.

Solution:

$$\Delta h = 10 \text{ in}$$

$$\rho = 2700 \text{ kg/m}^3$$

$$\eta = 0.0015 \text{ Ns/m}^2$$

$$D = 0.4 \text{ in}$$

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Example-2

Velocity & the rate of the flow :

$$h_1 + \frac{P_1}{\rho g} + \frac{v_1^2}{2g} = h_2 + \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + f'$$

$$h_1 = h_2 + \frac{v_2^2}{2g} \Rightarrow v_2 = \sqrt{2g(h_1 - h_2)} \rightarrow v_2 = \sqrt{2g \Delta h}$$

$$v_2 = \sqrt{2(32.2 \text{ ft/s}^2)(12 \text{ in/ft})(10 \text{ in})} = 87.9 \text{ in/s}$$

$$Q = v_2 A$$

$$A_{\text{circle}} = \frac{\pi}{4} D^2 = \frac{\pi}{4} (0.4)^2 = 0.126 \text{ in}^2$$

$$Q = v_2 A = (87.9 \text{ in/s})(0.126 \text{ in}^2) = 11 \text{ in}^3/\text{s}$$

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Example-2

Re number:

$$v_2 = 87.9 \frac{\text{in}}{\text{s}} \times \frac{1\text{ft}}{12\text{in}} \times \frac{1\text{m}}{3.28\text{ft}} = 2.23 \text{m/s}$$

$$D = 0.4\text{in} \times \frac{1\text{ft}}{12\text{in}} \times \frac{1\text{m}}{3.28\text{ft}} = 0.01016\text{m}, \left[N = \frac{\text{kg} \cdot \text{m}}{\text{s}^2} \right]$$

$$\text{Re} = \frac{vD\rho}{\eta} = \frac{(2.23\text{m/s})(0.01016\text{m})(2700\text{kg/m}^3)}{0.0015\text{Ns/m}^2} = 40,782$$

- Re > 20,000 therefore the flow is turbulence.