

Summary of the Feeding Rules

Rule 1: The heat transfer requirement.

Rule 2: The volume requirement.

Rule 3: The feed path requirement.

Rule No. 0: Do not feed

ZEROTH RULE: Do not feed, unless absolutely necessary !!

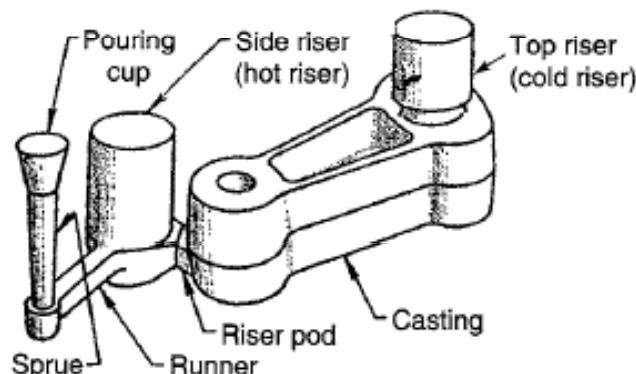
- gives economic benefits
- applies particularly to thin castings

Riser design

Also follow blackboard discussions

Riser design

- A riser is designed to feed the solidification shrinkage in a part.
- From the standpoint of heat transfer, an ideal riser will be spherical in shape because it has the smallest surface area for a fixed volume of metal. This will slow down the cooling of the riser, thus allowing a smaller riser to be used for feeding of the shrinkage. Spherical risers may, however, be somewhat difficult to use in sand molds because they present some challenges in retrieving the spherical riser pattern from a completed sand mold. A more practical and widely used type of riser shape is a cylinder.
- It should be evident that a riser should take longer to solidify than the casting that it is designed to feed; as a rule of thumb, a riser should take about 20% more time to solidify than the casting.
- Two types of risers are commonly used: a hot (or live) riser and a cold (or dead) riser (Figure). When a casting is gated through the riser, the latter is called a hot riser because it receives the hottest (last incoming) metal. A cold riser is positioned on a noncritical surface of the part, from where it can be readily cut off after casting with minimum damage to the part surface. In actual practice, hot risers are preferred to cold risers for their obvious advantage in promoting directional solidification and ease of feeding the solidification shrinkage. However, for reasons of economy of mold size, cold risers may be used (with the mold size increasing vertically rather than sideways).



Riser design considerations

1. Riser shape
2. Riser size as a function of casting shape
3. Location of risers
4. Grouping of castings
5. Riser connections to the casting
6. Use of chills
7. Use of insulators and exothermic compounds
8. Special conditions arising from joining sections

Lecture 8

ME 361A

Riser design

Also follow blackboard discussions

Thus, the use of a large riser volume (to ensure large solidification time) is uneconomical. So, a riser should be designed with the minimum possible volume while maintaining a cooling rate slower than that of the casting.

It may be noted that a casting with a high surface area/volume ratio requires a riser larger than that determined by considering only the cooling rate. This is shown clearly by the example that follows.

Let us consider a steel plate of dimensions $25 \text{ cm} \times 25 \text{ cm} \times 0.25 \text{ cm}$. The casting then has the A/V ratio as

$$\left(\frac{A}{V}\right)_c = \frac{2 \times 625 + 4(25 \times 0.25)}{25 \times 25 \times 0.25} \text{ cm}^{-1} = 8.16 \text{ cm}^{-1}.$$

A cubical riser with sides 1.25 cm has the A/V ratio as

$$\left(\frac{A}{V}\right)_r = \frac{6 \times 1.25 \times 1.25}{1.25 \times 1.25 \times 1.25} = 4.8 \text{ cm}^{-1}.$$

Thus, the riser is assured to have a much slower cooling rate (more solidification time) than that of the casting. The volume shrinkage of steel during solidification is 3%. So, the minimum volume of the riser necessary is

$$0.03 \times \frac{625}{4} \text{ cm}^3 = 4.69 \text{ cm}^3.$$

The riser we have considered has the volume 1.95 cm^3 only. Therefore, a much larger riser is required.

For a given shape of the riser, the dimensions of the riser should, however, be chosen so as to give a minimum A/V ratio, and the minimum volume should be ensured from the shrinkage consideration. It must be remembered that a liquid metal flows from the riser into the mould only during the early part of the solidification process. This necessitates the minimum volume of the riser to be approximately three times that dictated by the shrinkage consideration alone.

EXAMPLE 2.9 Determine the dimensions of a cylindrical riser to be used for casting as aluminium cube of sides 15 cm. The volume shrinkage of aluminium during solidification is 6.5%.

SOLUTION First of all, let us determine the diameter/height ratio of the most compact cylinder so that, for a given volume, the surface area is minimum. With the diameter and the height of the cylinder as d and h respectively, the surface area of the cylinder is

$$A = \pi dh + 2\frac{\pi}{4}d^2$$

and the volume of the cylinder is

$$V = \frac{\pi}{4}d^2h \quad \text{or} \quad h = \frac{4V}{\pi d^2}.$$

Hence,

$$A = \pi d \frac{4V}{\pi d^2} + 2\frac{\pi}{4}d^2 = \frac{4V}{d} + \frac{\pi}{2}d^2.$$

For A to be minimum,

$$\frac{\partial A}{\partial d} = 0 \quad \text{or} \quad -\frac{4V}{d^2} + \pi d = 0 \quad \text{or} \quad d^3 = \frac{4V}{\pi}.$$

Again,

$$\frac{4V}{\pi} = d^2h = d^3$$

or

$$h = d^1 \quad (\text{when } \frac{A}{V} = \frac{6}{d}).$$

Now, the minimum volume necessary for the riser is $V_r = 3 \times 0.065V_c$, where V_c is the volume of the casting and is equal to 3375 cm^3 . So, $V_r = 658.2 \text{ cm}^3$. Thus, the diameter of the riser (d), which is also equal to the height of the riser, can be written as

$$h = \left(\frac{4V_r}{\pi}\right)^{1/3} = 9.43 \text{ cm}.$$

Now,

$$\left(\frac{A}{V}\right)_t = \frac{6}{d} = \frac{6}{h} = \frac{6}{9.43} \text{ cm}^{-1} = 0.636 \text{ cm}^{-1},$$

$$\left(\frac{A}{V}\right)_c = \frac{6 \times 15 \times 15}{15^3} \text{ cm}^{-1} = 0.4 \text{ cm}^{-1} \quad [\text{this is less than } \left(\frac{A}{V}\right)_t].$$

So, the riser will not have a longer solidification time. The dimensions of the riser can be recalculated as follows. For

$$\left(\frac{A}{V}\right)_t \leq \left(\frac{A}{V}\right)_c,$$

we need

$$\frac{6}{d} \leq 0.4 \text{ cm}^{-1} \quad \text{or} \quad d \geq 15 \text{ cm}.$$

With the minimum value of d , $V_r = (\pi/4)d^2h = (\pi/4)d^3 = 2650 \text{ cm}^3$. This volume is much more than the minimum V_r necessary. Let us now consider the top riser when the optimum cylindrical shape is obtained with $h = d/2$ and again $(A/V)_r = 6/d$. However, with a large top riser, the cube loses its top surface for the purpose of heat dissipation. Hence,

$$\left(\frac{A}{V}\right)_c = \frac{5 \times 15 \times 15}{15^3} \text{ cm}^{-1} = \frac{1}{3} \text{ cm}^{-1}.$$

To have

$$\left(\frac{A}{V}\right)_r \leq \left(\frac{A}{V}\right)_c \quad \text{or} \quad \frac{6}{d} \leq \frac{1}{3} \text{ cm}^{-1},$$

d should be greater than or equal to 18 cm. So, the riser volume with minimum diameter is given as

$$V_r = \frac{\pi}{4}d^2h = \frac{\pi}{4}18^2 \times 9 \text{ cm}^3 = 2289 \text{ cm}^3$$

which is greater than the minimum V_r necessary. Though we see that with a top riser there is a little saving of material as compared with the side riser, we have to use, however, a deeper mould with the top riser. Thus, in this case, the side riser may be chosen.

Some other aspects must be considered in riser design

- The riser must be tall enough to develop sufficient hydrostatic pressure for metal to flow into the shrinkage cavity in the part.
- Metals and alloys such as steels are called "skin-forming" because a solidified layer of metal forms on all the surfaces, including the top surface of an open riser, very early during cooling. This solid skin can prevent the atmospheric pressure from acting on the liquid metal in the riser and obstruct metal flow into the shrinkage void developing in the casting. This problem is overcome by using "pressure-risering" in which the solid skin on top of the riser is physically punctured with the help of a core rod to allow atmospheric pressure to aid the flow of metal.

Riser Size Estimation Using Chvorinov's Rule

Foundrymen's rule-of-thumb - the solidification time of the riser should be about 25% greater than that of the casting, i.e., $t_R \sim 1.25 t_c$, where R and c refer to the riser and casting, respectively.

$$\left(\frac{V}{SA}\right)_r^2 = 1.25 \left(\frac{V}{SA}\right)_c^2 \quad (2-29)$$

where the subscripts “r” and “c” again denote the riser and casting, respectively (note that the mold constant B will be same for the riser and the casting). This equation provides a method to design risers. The following example illustrates the use of this method. Consider a 2 in. \times 4 in. \times 6 in. rectangular plate-shaped casting that is connected to a cylindrical side riser ($H/D = 1.5$) through a small neck. Here $V_{\text{cast}} = 2 \times 4 \times 6 = 48 \text{ in}^3$, $SA_{\text{cast}} = 48 + 24 + 16 = 88 \text{ in}^2$, and

$$V_{\text{Riser}} = \pi \left(\frac{D}{2}\right)^2 H = \frac{\pi(D)^2 H}{4} = \frac{\pi(D)^2(1.5D)}{4} = \frac{1.5}{4} \pi D^3$$

$$SA_{\text{Riser}} = 2\pi \left(\frac{D}{2}\right) H = 2\pi \left(\frac{D}{2}\right)^2 = \pi D(1.5D) + \frac{\pi D^2}{2} = 2\pi D^2$$

On substituting these expressions for volumes and areas in

$$\left(\frac{V}{SA}\right)_r^2 = 1.25 \left(\frac{V}{SA}\right)_c^2$$

we obtain after simplification the result that $D = 3.25 \text{ in.}$, and therefore $H = 1.5 \times 3.25 = 4.88 \text{ in.}$

If, in the previous example, the riser were placed directly on top of one of the large rectangular faces of the plate casting, with the area of the circular base of the riser being common to both the riser and the casting, then the base area must be subtracted from the heat-dissipating surfaces of both the riser and the casting. This is because the circular base of the riser forms an adiabatic surface across which there is not heat transfer. The common area of the riser base is $= 0.25\pi(D)^2$, and the corrected areas will be $SA'_{\text{cast}} = 88 - 0.25\pi D^2$, and $SA'_{\text{Riser}} = 2\pi(0.5D)^2 + \pi DH - 0.25\pi D^2$. If, as before, we assume that ($H/D = 1.5$), then, $V_{\text{Riser}} = 0.25\pi D^2 H = 0.375\pi D^3$. The new surface area of the riser is $SA_{\text{Riser}} = \pi DH + \pi(0.5D)^2 = 1.75\pi D^2$. Substituting these expressions for corrected areas of the casting and the riser in the expression

$$\left(\frac{V}{SA}\right)_r^2 = 1.25 \left(\frac{V}{SA}\right)_c^2$$

yields the following cubic equation in D : $D^3 - 112.14D + 319.27 = 0$. This equation can be solved numerically (for example, by using the Newton-Raphson method) to yield $D = 3.11 \text{ in.}$, 8.65 in. and a negative (unrealistic) root. Note that both the positive roots are viable, but better casting yield will be achieved by using the smaller diameter riser. Let $D = 3.11 \text{ in.}$ and, therefore, $H = 1.5D = 1.5 \times 3.11 = 4.67 \text{ in.}$

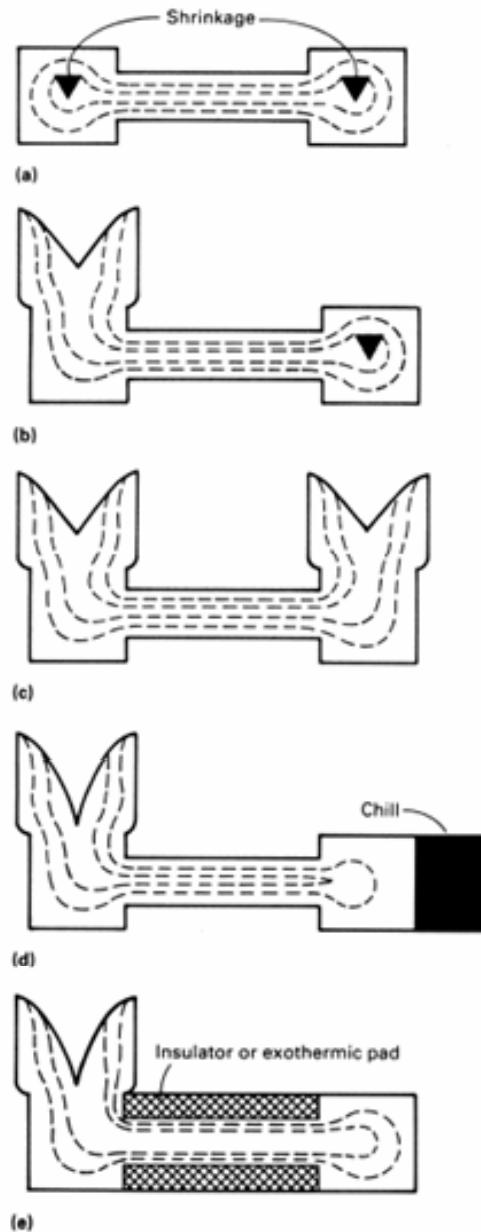


Fig. 16 Risering of isolated heavy sections joined by a thinner section to minimize shrinkage and number of risers. (a) Workpiece with no risers. (b) Riser added to one side. (c) Risers located on both ends. (d) Chill applied to one end and riser to other end. (e) Riser used on one end and insulator or exothermic pad on opposite end

Internal chills

The use of internal chills is somewhat more critical than external chills for the following reasons:

1. The chill may not fuse with the casting, thereby establishing points of weakness.
2. Cleanliness of the chill is more important since it will be completely surrounded by metal, and any gas that is created cannot readily escape.
3. The chill may alter the mechanical properties of the casting where it is used.
4. The composition of the chill must be compatible with the metal being poured. Thus a cast-iron internal chill would not be used for a steel or a nonferrous casting. Usually, the chill should have approximately the same composition of the metal in which it is to be used.

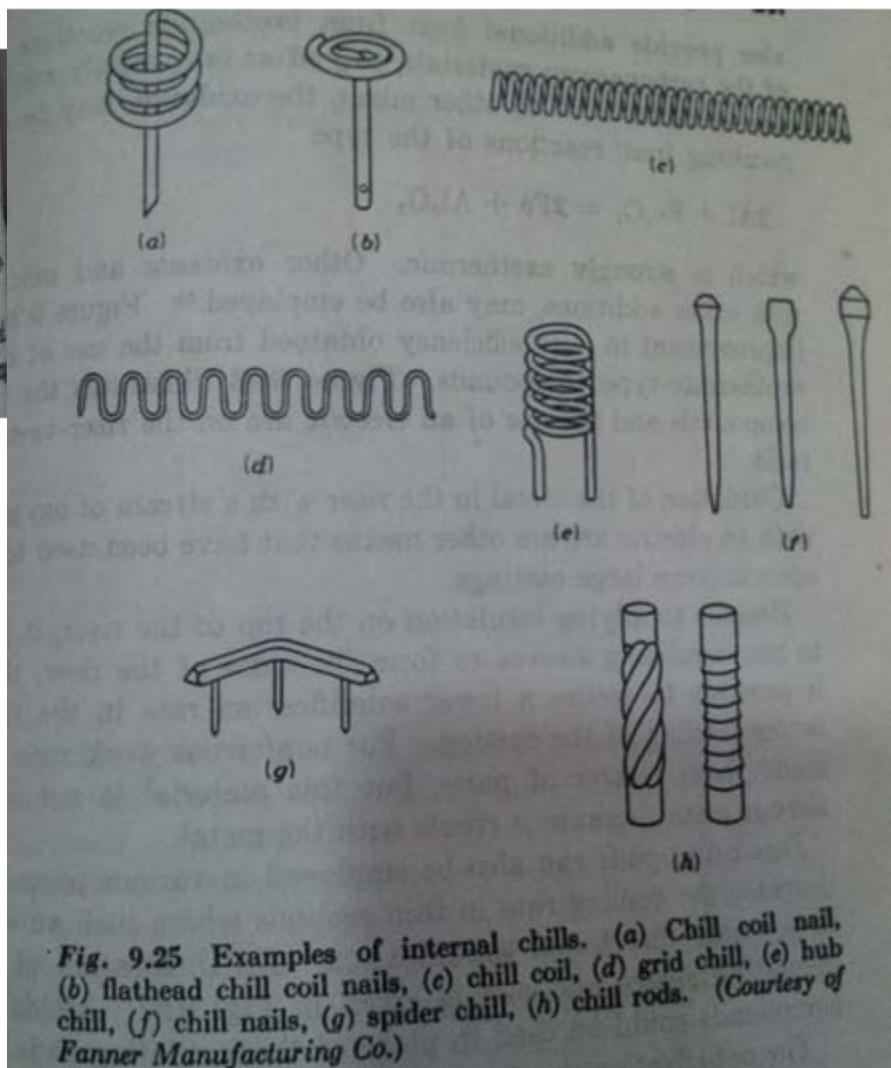


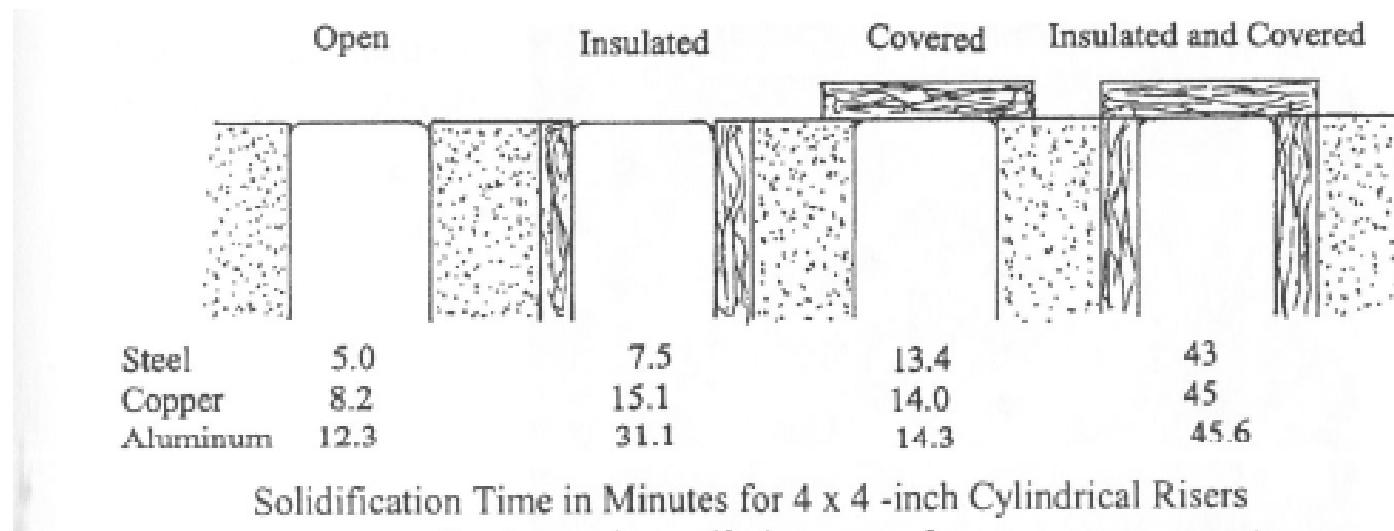
Fig. 9.25 Examples of internal chills. (a) Chill coil nail, (b) flathead chill coil nails, (c) chill coil, (d) grid chill, (e) hub chill, (f) chill nails, (g) spider chill, (h) chill rods. (Courtesy of Fanner Manufacturing Co.)

Heat loss from risers

Use of insulating and exothermic compounds

Artificial means to avoid freezing of the top of the riser so that the molten metal beneath can be exposed to the atmospheric pressure.

- Insulating effect by addition of powdered graphite/ charcoal, refractory compounds.
- Exothermic compounds to supply heat by an exothermic chemical reaction and to keep the riser top hot



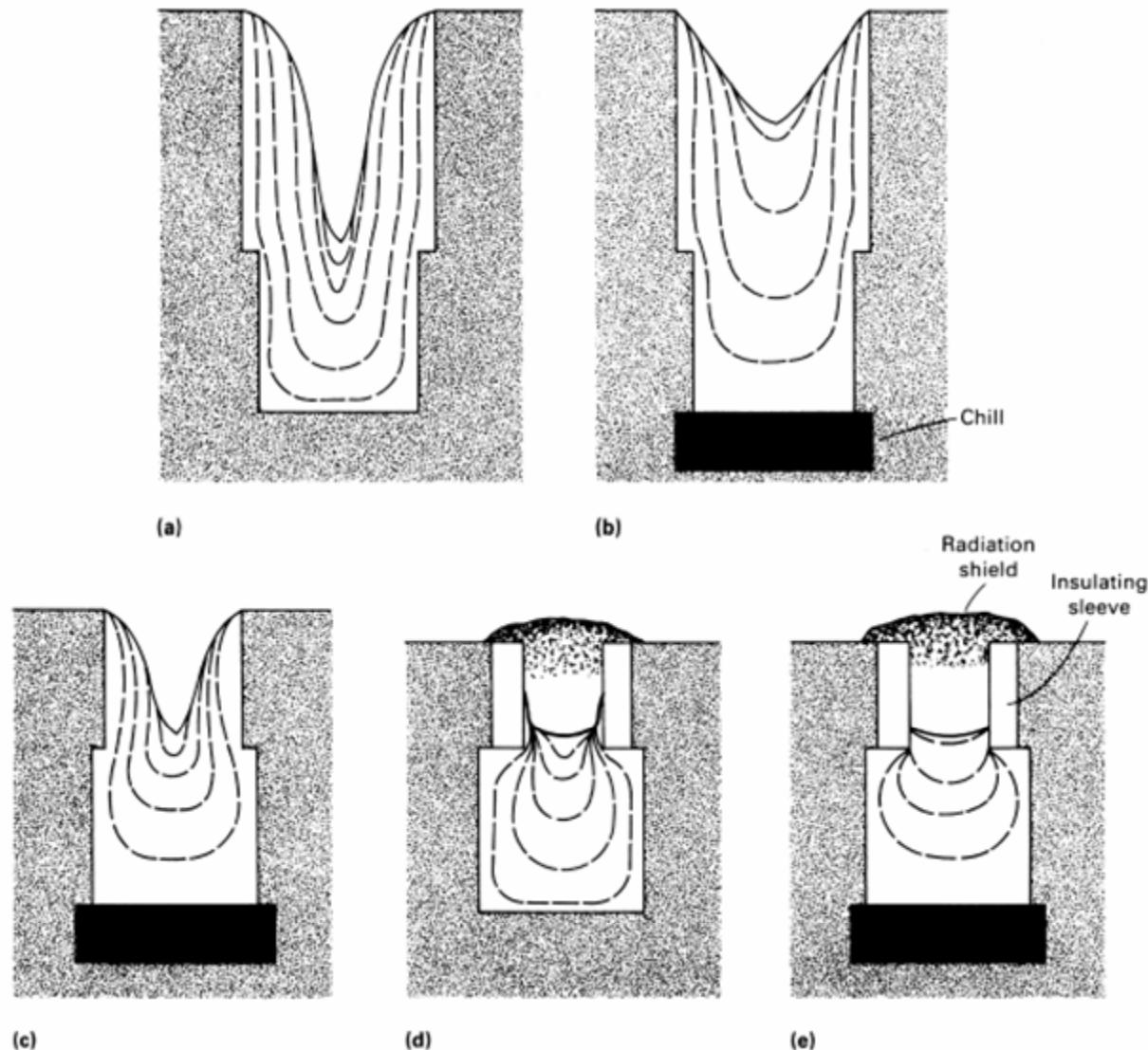


Fig. 3 Methods of controlling shrinkage in an iron cube to reduce riser size. (a) Open-top riser. (b) Open-top riser plus chill. (c) Small open-top riser plus chill. (d) Insulated riser. (e) Insulated riser plus chill

Factors in Riser Size

The thermal properties of feeding systems can be readily incorporated into the modulus method of riser calculation discussed previously (Ref 32). Cylindrical risers are the most common because this shape has a high modulus for a given volume of metal and because this shape is easy to mold. The modulus of a cylindrical riser, M_r , is given by:

$$M_r = \frac{V_r}{A_r} = \frac{\pi R^2 H}{2\pi R H + \pi R^2} = \frac{RH}{2H + R}$$
$$= \frac{DH}{4H + D} \quad (\text{Eq } 5)$$

where R is the riser radius, D is the riser diameter, and H is the riser height.

Riser insulation in the form of a sleeve and hot topping may be regarded as effectively decreasing the surface area of the riser. The effect of the sidewall (sleeve) insulation may be represented by a factor x and that of a hot topping by a factor y , both relative to sand (where $x = 1$ for sand). The factors x and y have been termed apparent surface alteration factors (ASAF). The effective modulus M_r of a cylindrical riser incorporating feeding systems on both the sidewall and top is given by:

$$M_r = \frac{DH}{4Hx + Dy} \quad (\text{Eq } 6)$$

The ASAF values of insulating and exothermic feeding system materials vary and generally range from 0.50 to 0.90. The smaller the ASAF value, the more efficient the insulation. For example, if $x = 0.65$ and $y = 0.7$, then for a cylindrical riser with a height-to-diameter ratio of 1 to 1 (where $H = D$):

$$M_r = \frac{D^2}{4D(0.65) + D(0.7)} = \frac{D^2}{3.3D} \quad (\text{Eq } 7)$$
$$= 0.303D$$

This should be compared with the modulus of a similar 1 to 1 sand-lined riser, which is $0.2D$.

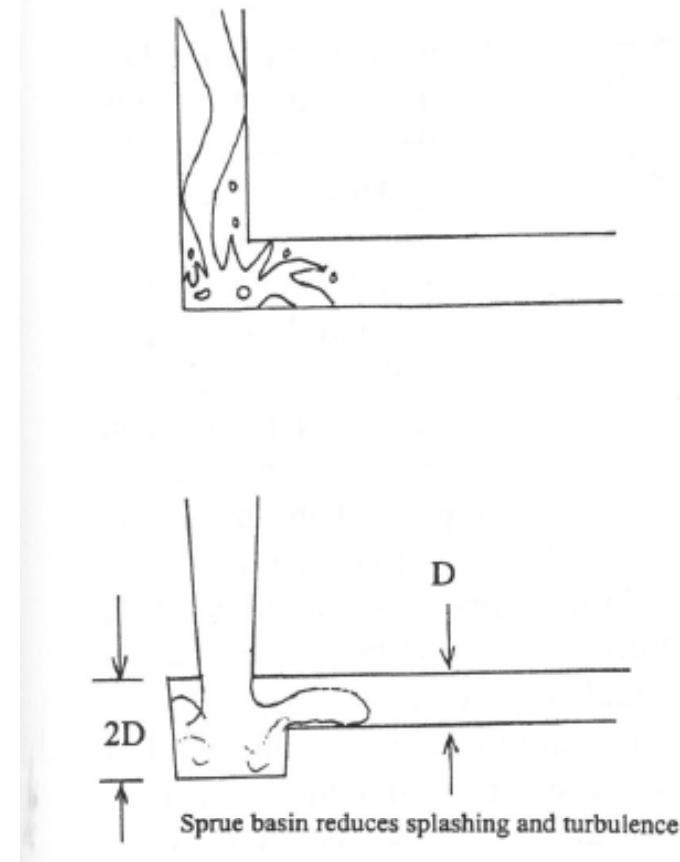
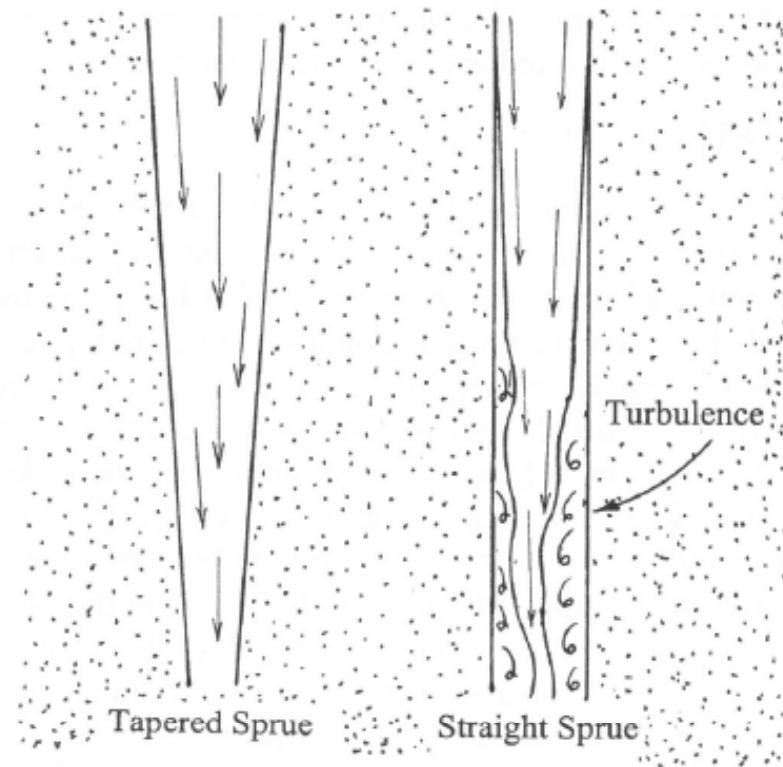
Runner and gates

Runners and gates should be designed to obtain the following characteristics:

1. Absence of sharp corners or changes of section that may lead to turbulence or gas entrapment
2. Proper relation between cross-sectional areas of the several gates, between gates and runners, and between the runners and the sprue
3. Proper location of the gates to ensure adequate feeding of low-velocity metal into the mold cavity

SPRUES:

Sprues should be tapered with the small end being down.



Sprue basin or sprue well

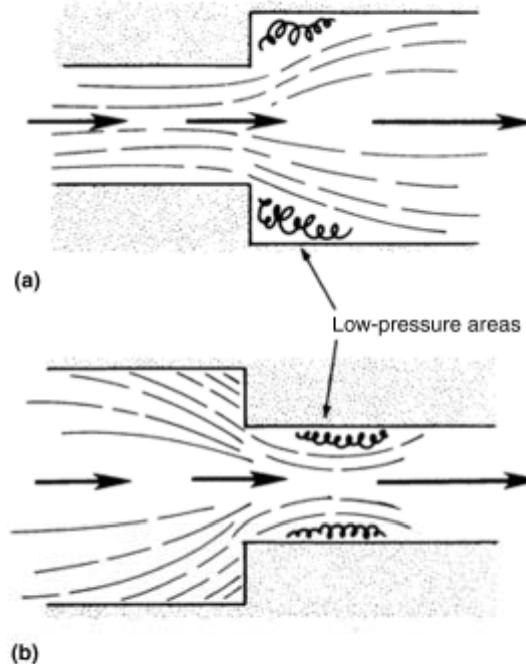


Fig. 6 Schematic showing the formation of low-pressure areas due to abrupt changes in the section of a flow channel. (a) Sudden enlargement of channel. (b) Sudden reduction of the channel

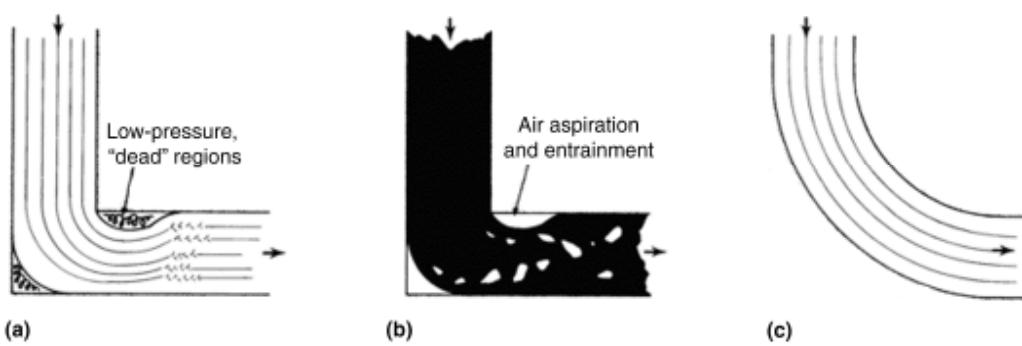
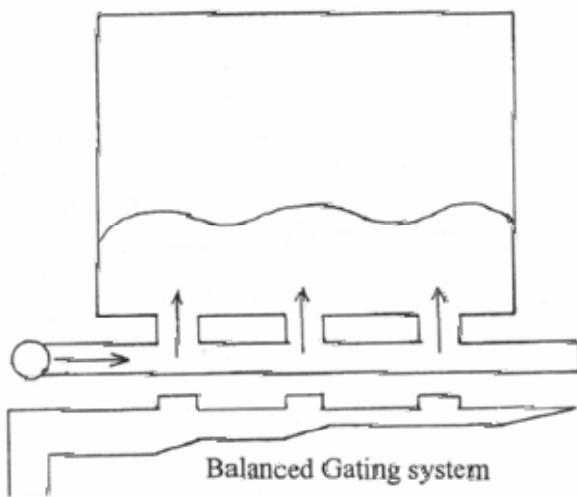
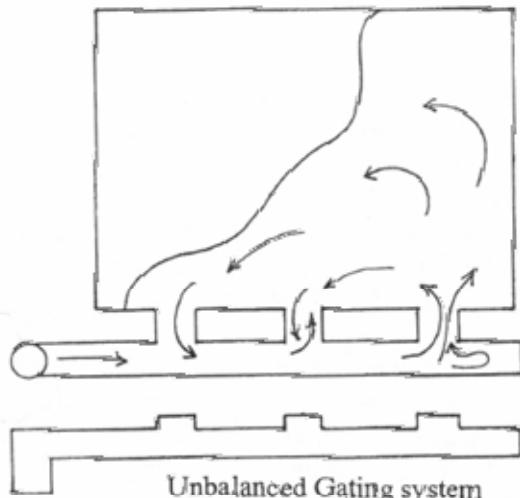


Fig. 7 Schematic illustrating fluid flow around right-angle and curved bends in a gating system. (a) Turbulence resulting from a sharp corner. (b) Metal damage resulting from a sharp corner. (c) Streamlined corner that minimizes turbulence and metal damage

Tapered runners



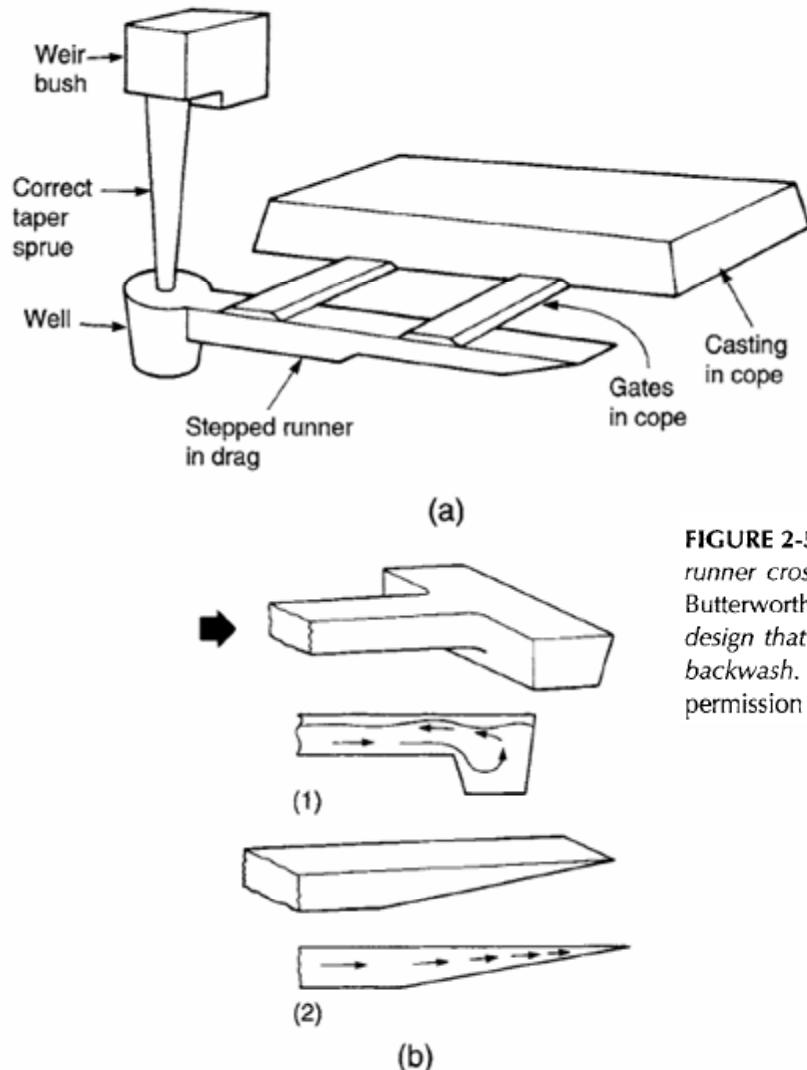


FIGURE 2-5 (a) Diagram showing a stepped runner that is used with multiple gates. Keeping the runner cross-section constant would cause uneven flow from the gates. (J. Campbell, Castings, Butterworth-Heinemann, Boston, 1999, p. 33) (b) Design of the runner extension: (1) incorrect design that causes backwash and impurities in the casting, and (2) correct design that prevents backwash. (J. Campbell, Castings, Butterworth-Heinemann, Boston, 1999, p. 54). Reprinted with permission from Elsevier.

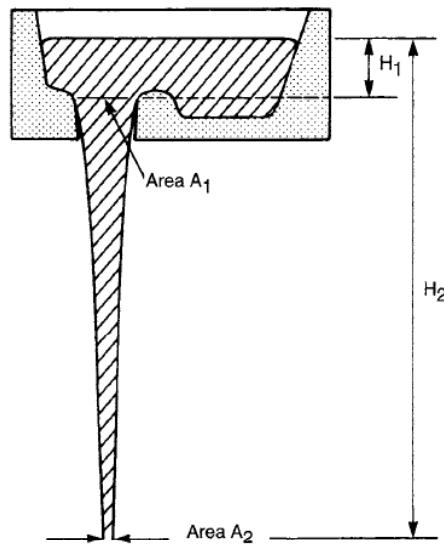
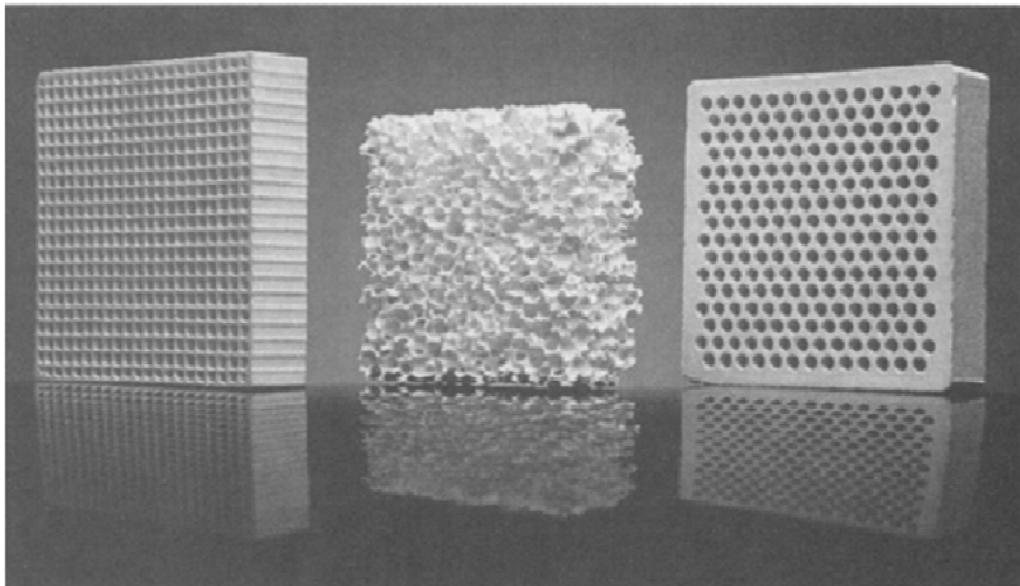
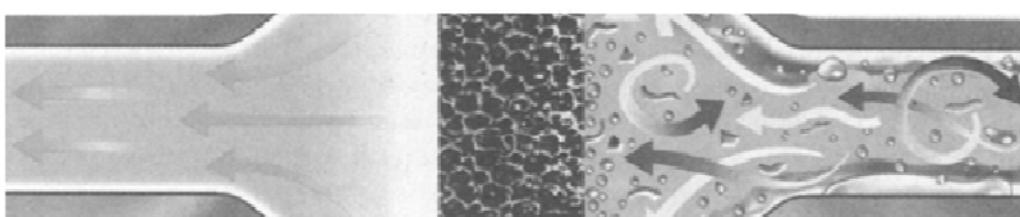


FIGURE 2-3 A tapered sprue with the metal head H_1 in the pouring basin, and the total metal head, H_2 . The cross-sectional areas at the top and the bottom of the sprue are A_1 and A_2 . Note that the fluid mass crossing the areas A_1 and A_2 per unit time is constant. As the metal velocity at A_1 is $\sqrt{2gH_1}$, and the velocity at A_2 is $\sqrt{2gH_2}$, the product $A_1 \cdot \sqrt{2gH_1}$ must equal $A_2 \cdot \sqrt{2gH_2}$. This yields the fundamental relationship $A_1 \cdot \sqrt{H_1} = A_2 \cdot \sqrt{H_2}$. (J. Campbell, Castings, Butterworth-Heinemann, Boston, 1999, p. 38). Reprinted with permission from Elsevier.

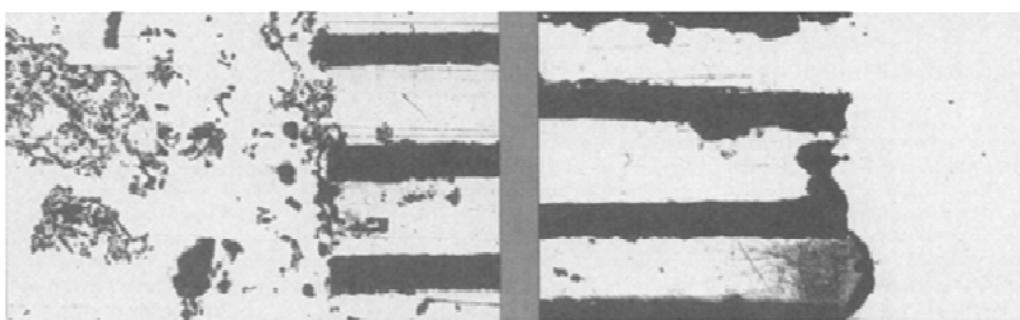


(c)

FIGURE 2-5 continued (c) Examples of ceramic filters and honeycomb used to trap impurities in the gating system of a sand mold. (M. Sahoo et al., Modern Castings, May 1995, p. 42). Reprinted with permission from Modern Casting, Schaumburg, IL (www.moderncastings.com). (d) Diagram showing the effect of filter on flow pattern. (B. Braun, Modern Castings, March 2004, American Foundry Society, Des Plaines, IL, p. 2). (e) Photograph showing entrapment of impurity particles at the entrance to a filter. (M. Sahoo et al., Modern Castings, May 1995, p. 42). Reprinted with permission from Modern Casting, Schaumburg, IL (www.moderncastings.com).



(d)



(e)

Gating systems for castings

- Traditionally gating systems have been designed on the basis of two fundamental laws, **the law of continuity and Bernoulli's theorem**.
- A simple analytical equation for the law of continuity can be derived from the conservation of mass, assuming a system with **incompressible walls**.

$$dm/dt = \rho_1 \cdot A_1 \cdot V_1 = \rho_2 \cdot A_2 \cdot V_2$$

$$Q = \rho_1 \cdot A_1 \cdot V_1 = \rho_2 \cdot A_2 \cdot V_2 = ct.$$

Bernoulli's theorem

$$h + P / \rho g + V^2 / (2g) + E_f = ct.$$

where h is the metallostatic head, P is the external pressure (atmospheric, metallostatic, applied pressure), and E_f is the friction energy due to frictional losses

Casting design improvements

21

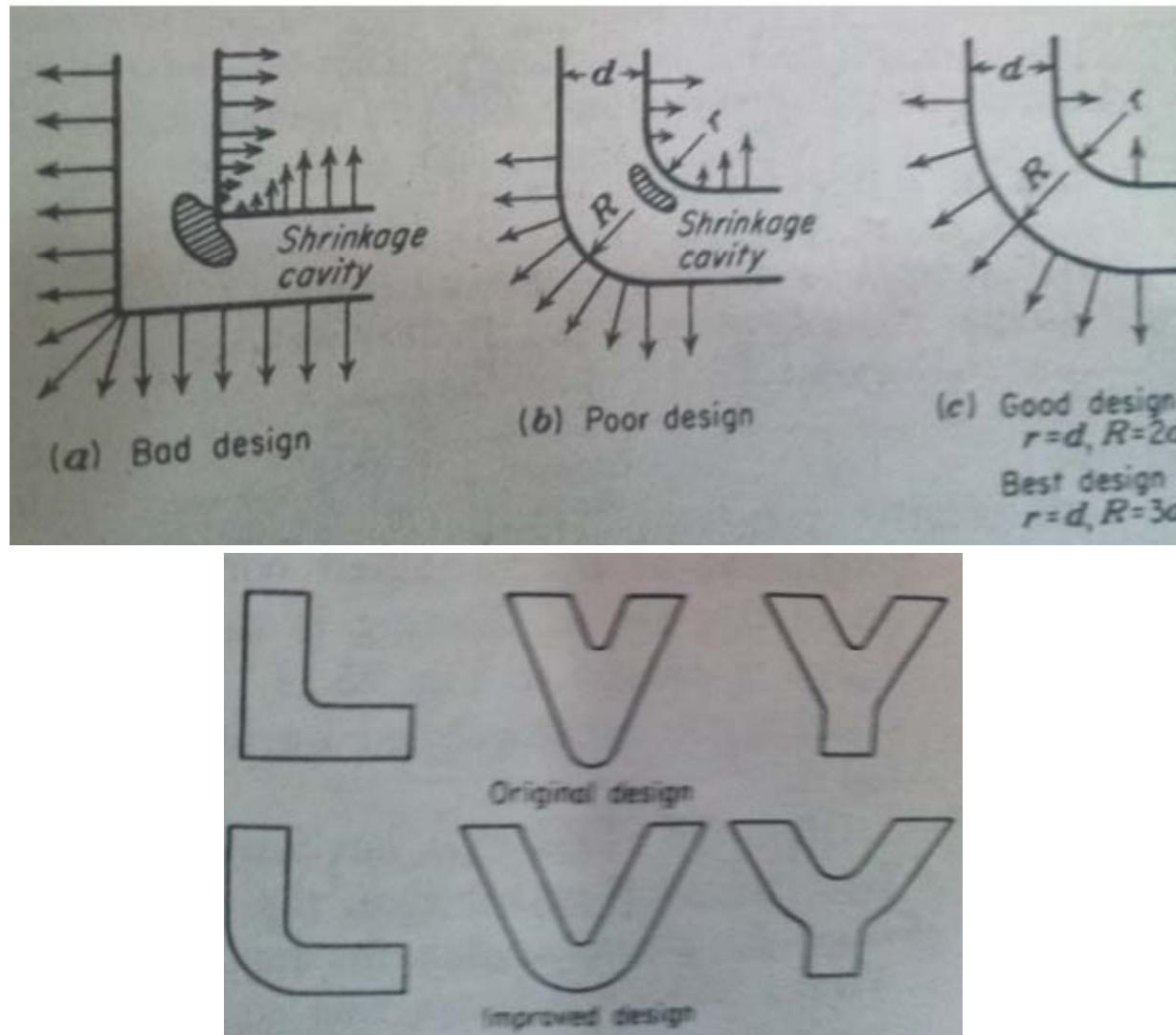


Fig. 25.11 Minimizing hot spots on joining members of a casting.
(Courtesy of Steel Founders' Society of America.)

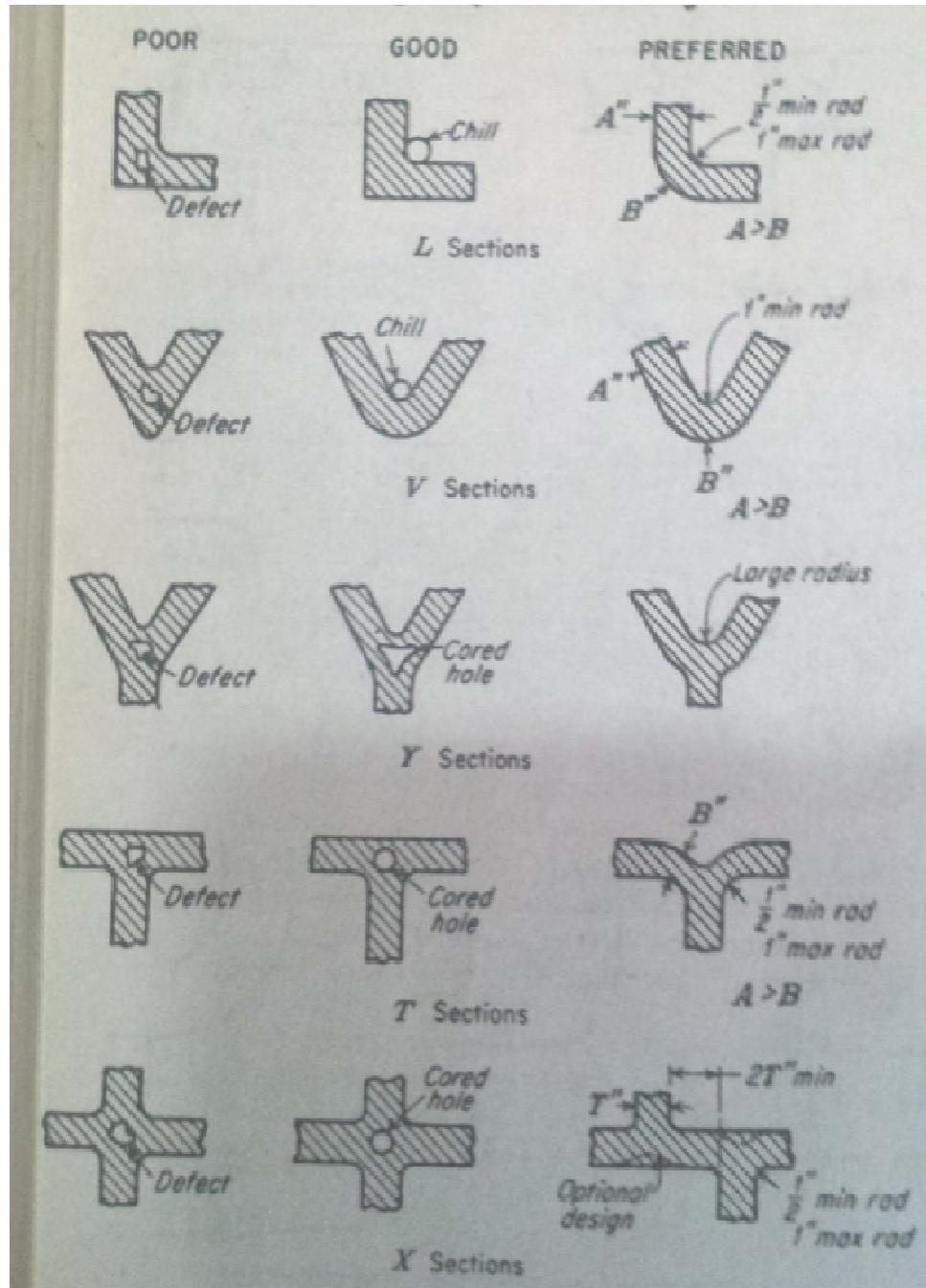


Fig. 25.12 Methods of treating joining members of castings to avoid hot-spot troubles. (From R. W. Bolz.¹³)

Some innovative ideas

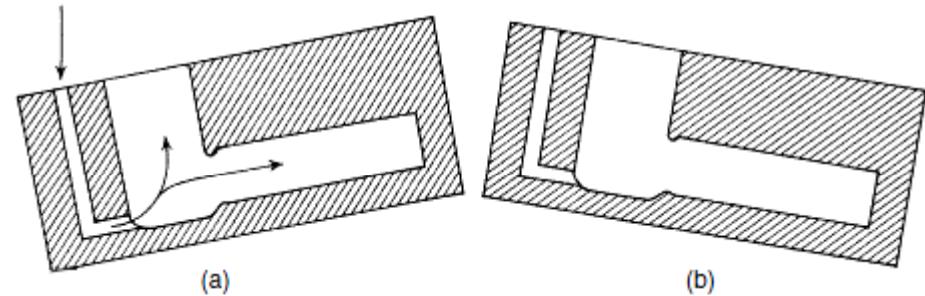
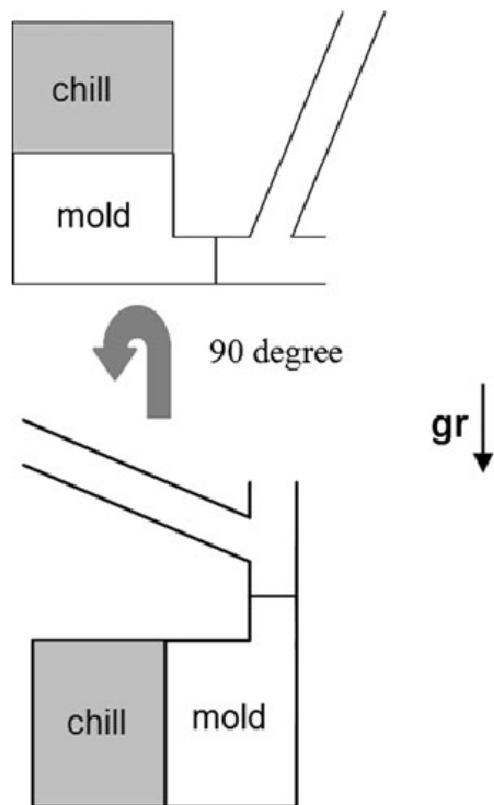


Figure 3.11 Partial mould reversal. Positions (a) for pouring, (b) for feeding

Fig. 4—Schematic of the mold rollover arrangement.

Inspection of casting

Nondestructive inspection techniques are essential for creating a confidence when using a cast product. In this section, we shall briefly outline some of these techniques for testing the various kinds of defects.

Visual Inspection

Common defects such as rough surfaces (fused sand), obvious shifts, 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.

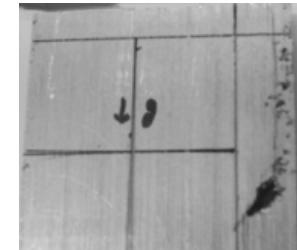
Pressure Test

The pressure test is conducted on a casting to be used as a pressure vessel. In this, 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.

Magnetic Particle Inspection

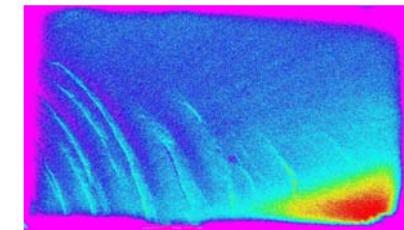
The magnetic particle test is conducted to check for very small voids and cracks at or just below the surface of a casting of a ferromagnetic material.

The test involves inducing a magnetic field through the section under inspection. Once done, the powdered ferromagnetic material is spread out onto the surface. The presence of voids or cracks in the section results in an abrupt change in the permeability of the surface; this, in turn, causes a leakage in the magnetic field. The powdered particles offer a low resistance path to the leakage. Thus, the particles accumulate on the disrupted magnetic field, outlining the boundary of a discontinuity.



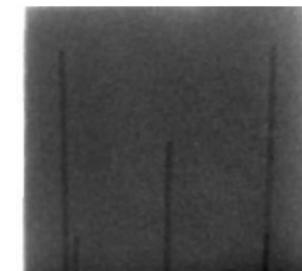
Dye-Penetrant Inspection

The dye-penetrant method is used to detect invisible surface defects in a nonmagnetic casting. The casting is brushed with, sprayed with, or dipped into a dye containing a fluorescent material. The surface to be inspected is then wiped, dried, and viewed in darkness. The discontinuities in the surface will then be readily discernible.



Radiographic Examination

The radiographic method is expensive and is used only for subsurface exploration. In this, both X- and γ -rays are used. With γ -rays, more than one film can be exposed simultaneously; however, X-ray pictures are more distinct. Various defects, e.g., voids, nonmetallic inclusions, porosity, cracks, and tears, can be detected by this method. On the exposed film, the defects, being less dense, appear darker in contrast to the surrounding.



Ultrasonic Inspection

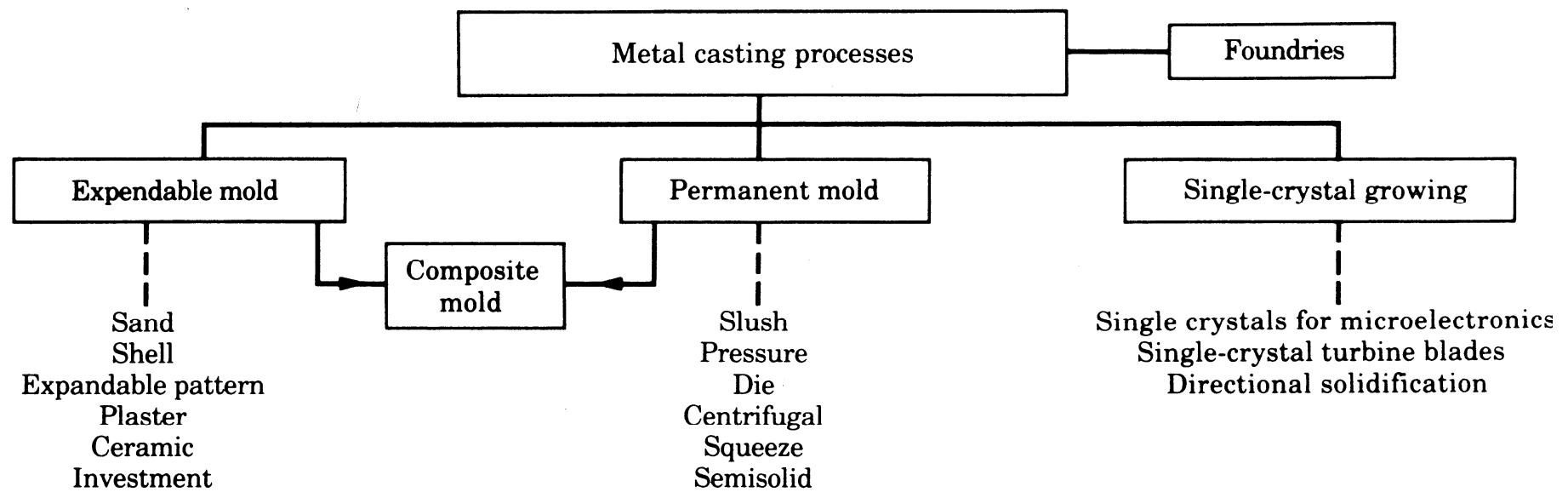
In the ultrasonic method, an oscillator is used to send an ultrasonic signal through the casting. Such a signal is readily transmitted through a homogeneous medium. However, on encountering a discontinuity, the signal is reflected back. This reflected signal is then detected by an ultrasonic detector. The time interval between sending the signal and receiving its reflection determines the location of the discontinuity. The method is not very suitable for a material with a high damping capacity (e.g., cast iron) because in such a case the signal gets considerably weakened over some distance.

Lecture 9

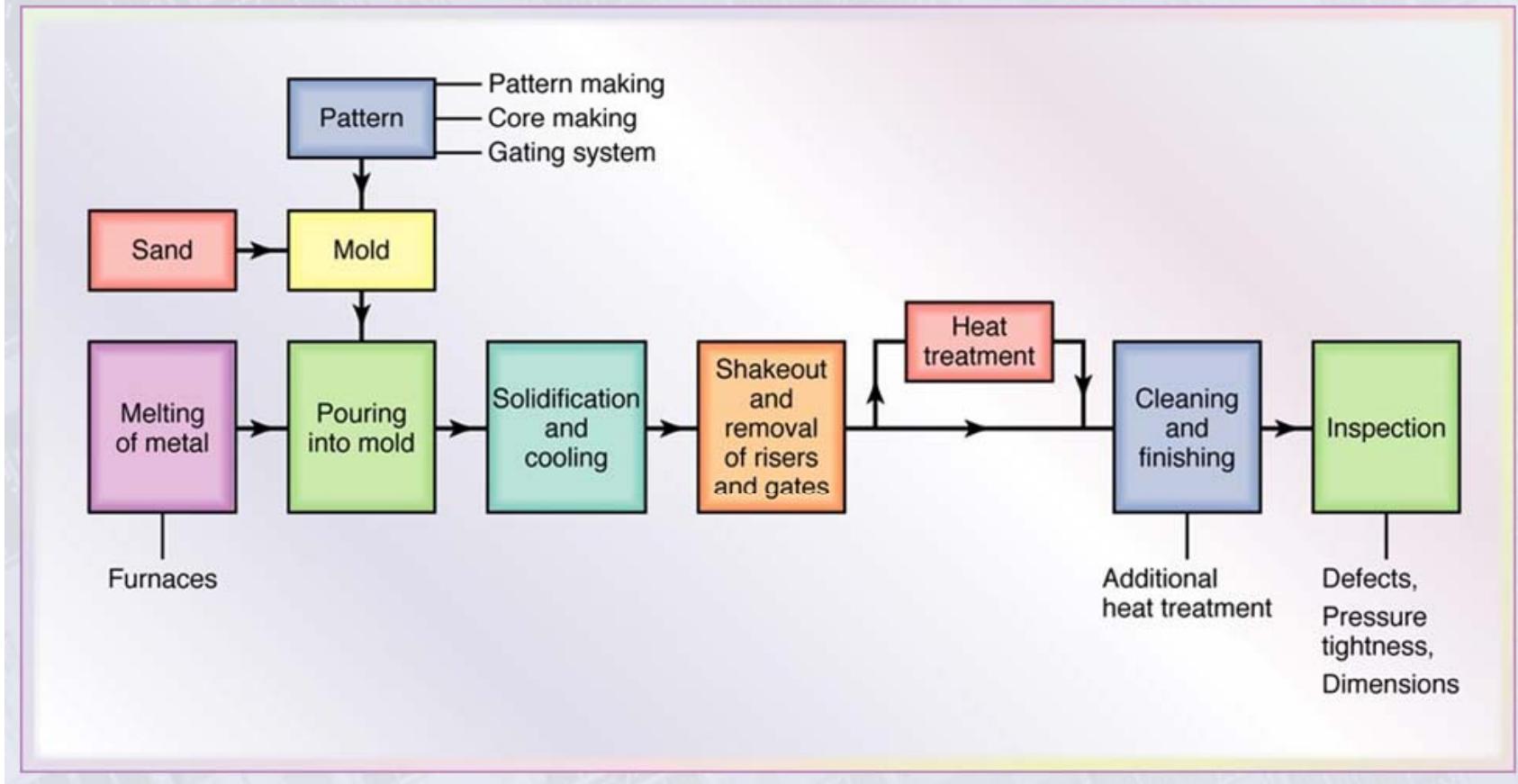
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Various Casting Processes- case studies
(critical assessment)

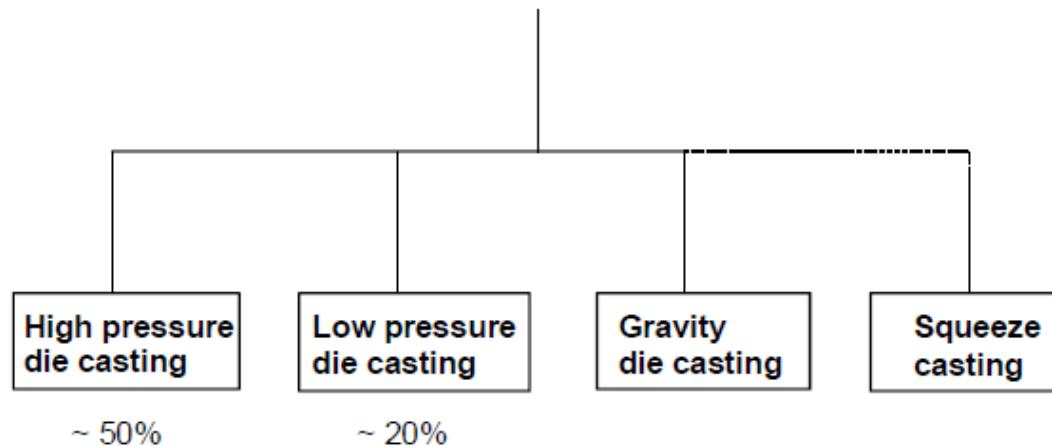
Common casting processes



Production Steps in Sand-Casting



Die casting processes



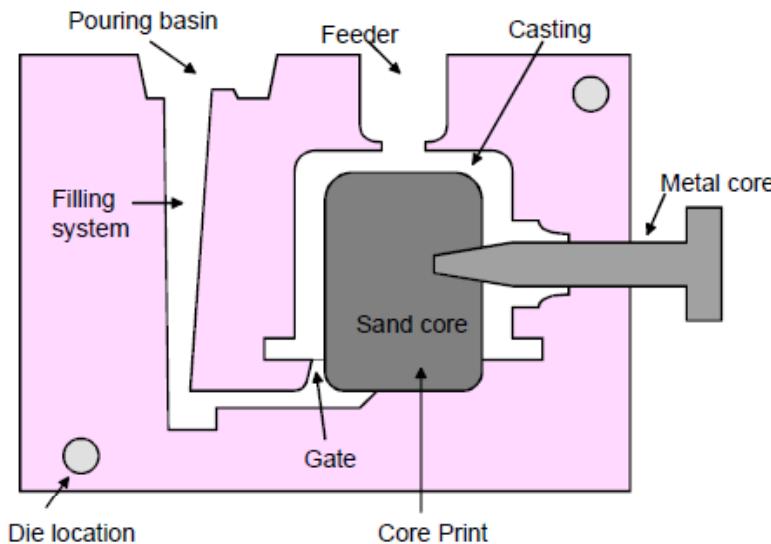
Advantages:

- reusable dies
- ease of automation
- high productivity
- high accuracy
- good surface finish

Problems:

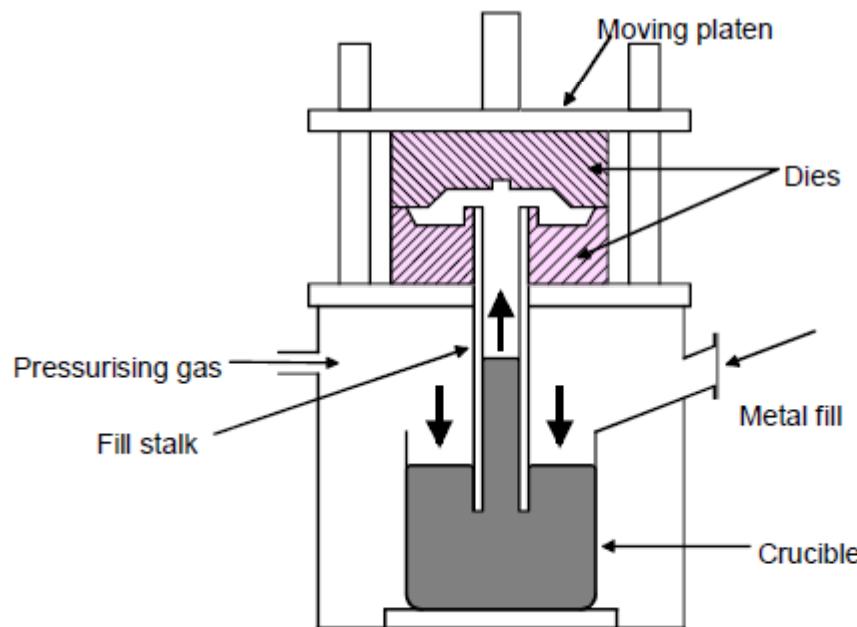
- expensive dies
- limited sizes and shapes
- expensive machines
- limited life of dies as a result of thermal fatigue

Gravity die casting



Gravity die casting is the simplest die-casting process. It enables castings to be produced with only a very modest capital investment. However, it can also be automated with either horizontally or vertically-parted dies. Good quality castings can be produced if sufficient care is taken to design running and gating systems which minimize surface turbulence in the metal as it flows into the die.

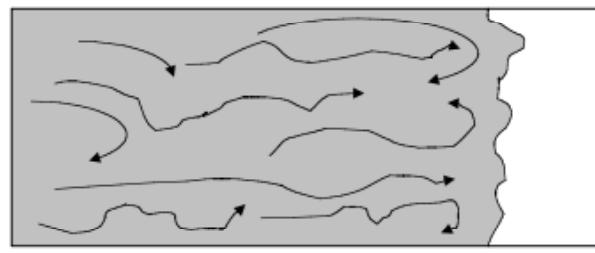
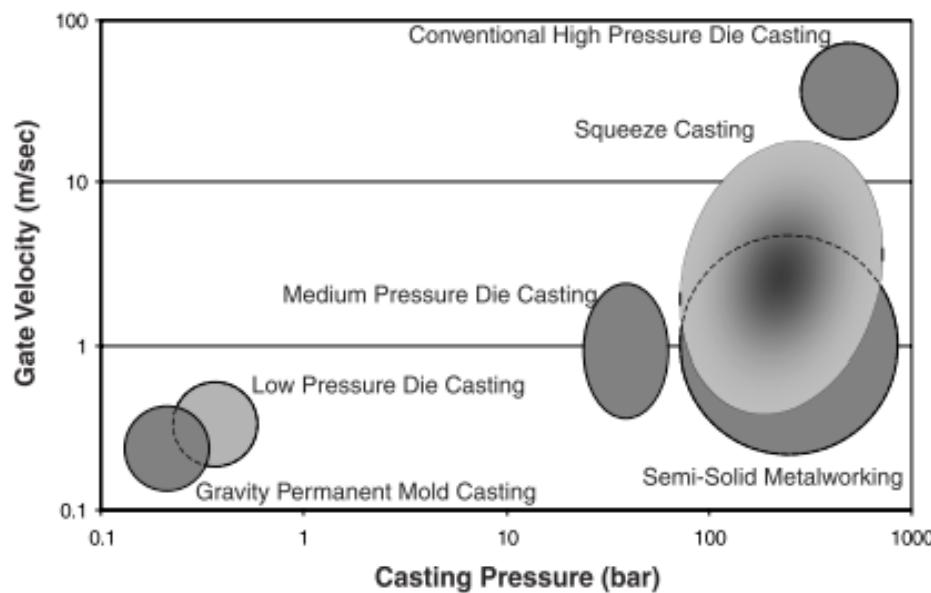
Low pressure die casting



Low pressure die casting differs in two significant ways. Firstly, the machine is vertically oriented which gives a horizontal die-parting line. The molten metal is held in a sealed vessel which is then pressurized by gas (usually air) so that metal is displaced "up-hill" into the die cavity. In theory, this should be beneficial since it should lead to the controlled filling of the mould. This process is mainly used for producing automotive wheels.

High integrity die casting processes

- High pressure die casting
- Vacuum die casting
- Squeeze casting
- Semi-solid metal working



Direction of Metal Flow

Figure 2.3 Graphical illustration of planar flow.

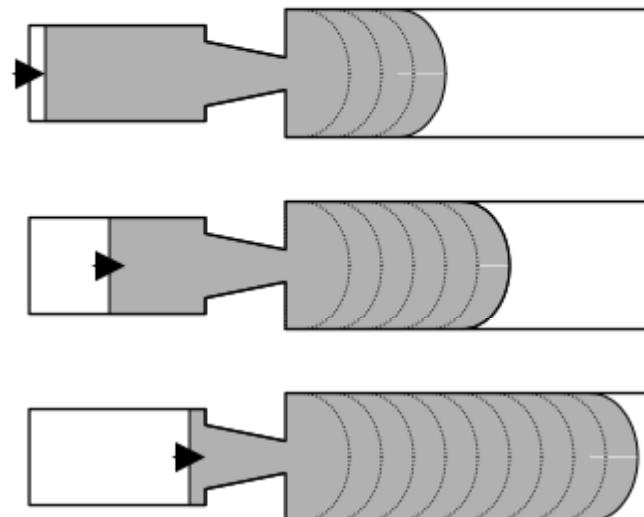


Figure 2.4 Graphical illustration showing the progression of a die cavity filling with a planar metal front.

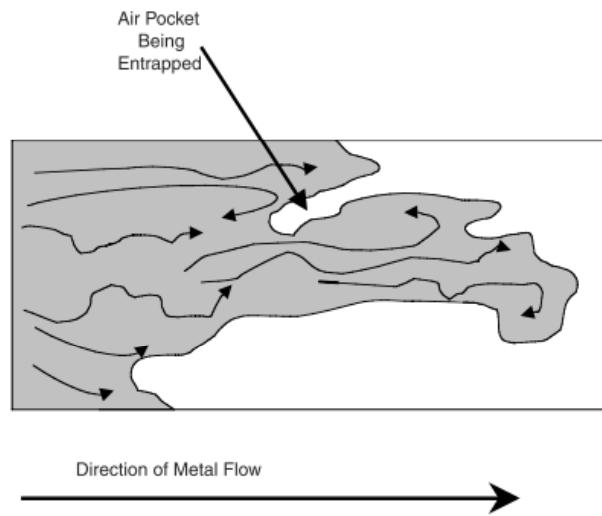


Figure 2.5 Graphical illustration showing nonplanar flow.

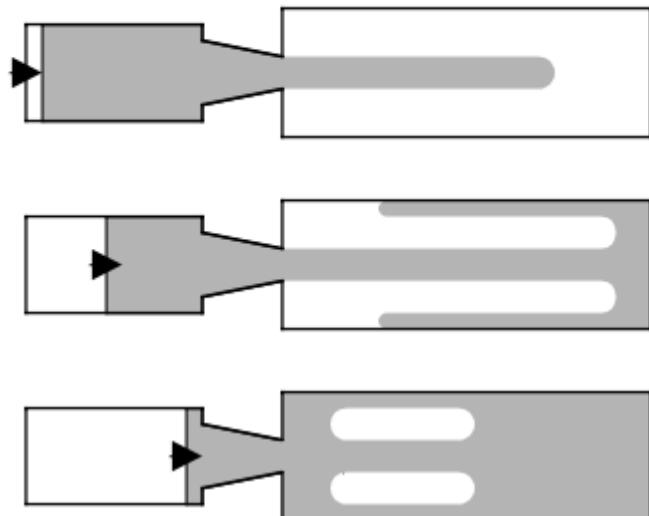


Figure 2.6 Graphical illustration showing the progression of a die cavity filling with a nonplanar metal front.

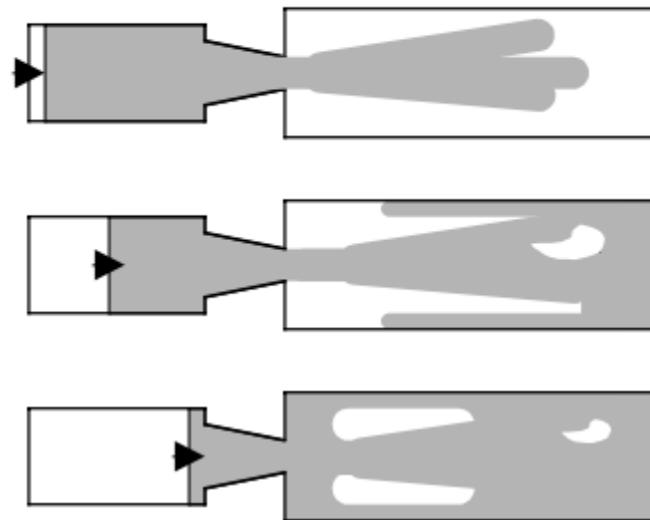
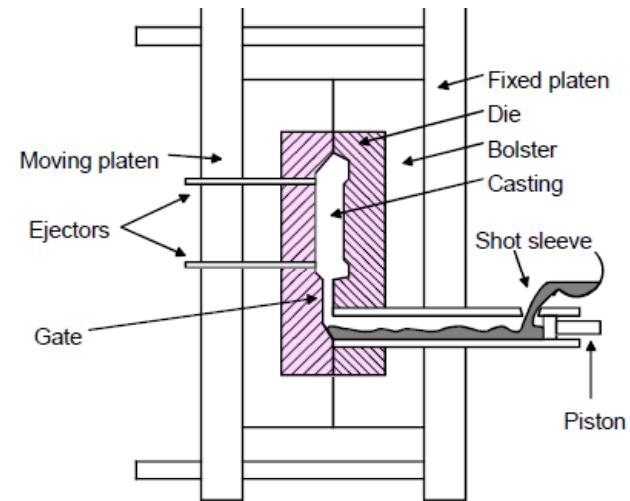


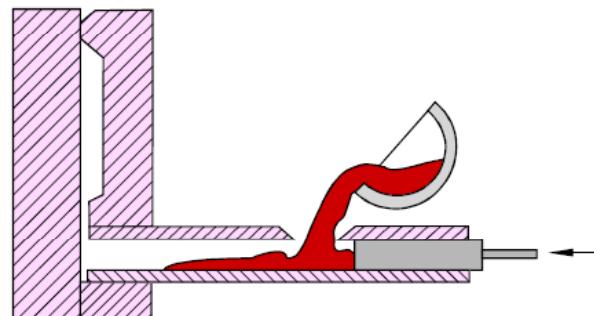
Figure 2.7 Graphical illustration showing the progression of nonplanar fill.

High pressure die casting

High pressure die casting is carried out using a large, expensive piece of equipment shown schematically in **Figure**. It consists of two vertical platens on which bolsters are located which hold the die halves. One platen is fixed and the other can move so that the die can be opened and closed. A measured amount of metal is poured into the shot sleeve and then introduced into the mould cavity using a hydraulically driven piston. Once the metal has solidified, the die is opened and the casting removed.



High Pressure Die Casting



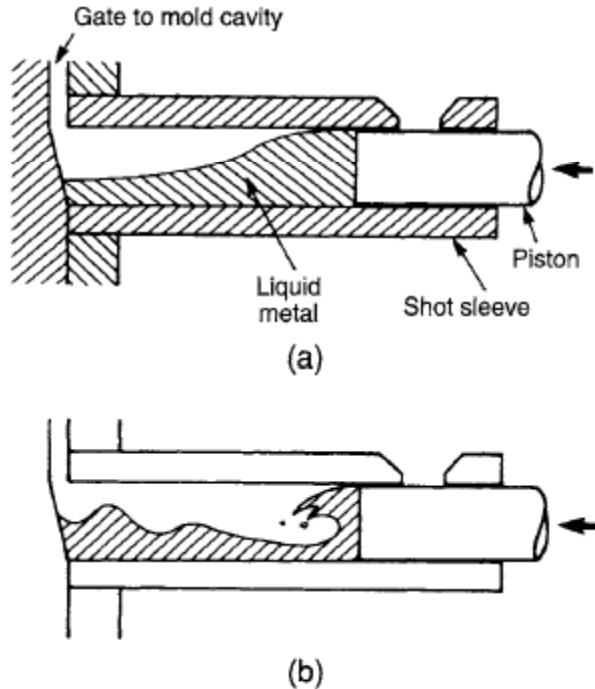


FIGURE 2-20 (a) Laminar flow of metal in controlled pressurization, and (b) turbulent flow in uncontrolled pressurization, which results in porosity in the cast part. (J. Campbell, *Castings*, Butterworth-Heinemann, Boston, 1999, p. 64). Reprinted with permission from Elsevier.

- In conventional high pressure and vacuum die casting, high gate velocities result in atomized metal flow within the die cavity, as shown in Figures 2.8 and 2.9
- Entrapped gas is unavoidable

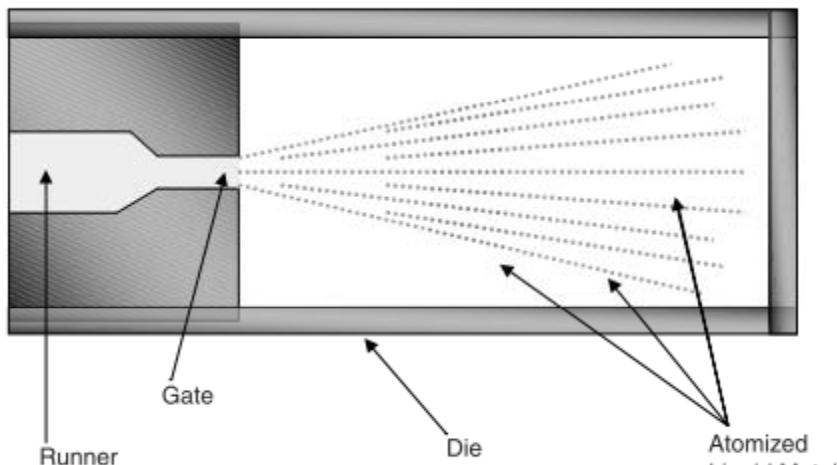


Figure 2.8 Illustration showing atomized flow typical in conventional die casting.

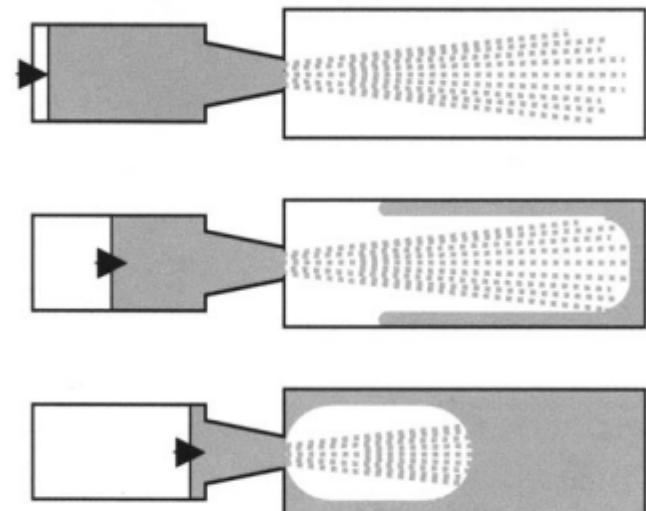


Figure 2.9 Graphical illustration of die fill with atomized metal flow in conventional die casting.

Vacuum die casting

- Entrapped gas is a major source of porosity in conventional die castings. Vacuum die casting is characterized by the use of a controlled vacuum to extract gases from the die cavities, runner system, and shot sleeve during processing. Vacuum die casting builds upon conventional die casting practices by minimizing the effects of a major contributor to porosity.

$$\nu = \nu_{\text{Entrained}} + \nu_{\text{Lube}} + \nu_{\text{Soluble gas}} + \nu_{\text{shrinkage}}$$

$$\nu = \nu_{\text{entrapped}} + \nu_{\text{shrinkage}}$$

- The vacuum die casting process minimizes gas entrapment by removing gases from the cavity generated by two of these mechanisms (1st two). Both air in the die cavity and gases generated by the decomposition of lubricants can be removed using the vacuum die casting process.
- In conventional die casting, gases are typically vented from the die.
- However, the amount of gas that must vent from the dies is much greater than that of just the die cavity. All gases in the runner system must be vented as well as any volume of the shot sleeve not filled with metal.

MANAGING GASES IN THE DIE

During processing, the vacuum should be applied to the die as long as possible to extract as much gas as possible. Care must be taken to locate the vacuum shut-off valve at the last location to fill in the die. If the vacuum shut-off valve is placed at the furthest point from the gate, the valve may close early in the fill process.

Gas porosity can also originate from gases dissolved in the liquid metal. Due to the short cycle times and the speed of solidification in both conventional and vacuum die casting, this form of porosity rarely occurs.

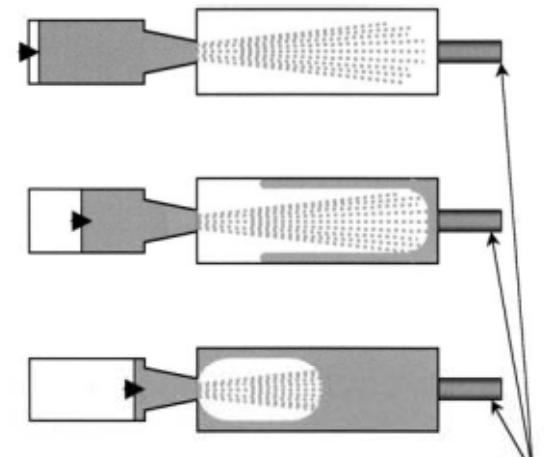
Dissolved gases do not have enough time to coalesce and form porosity.

Subsequent heat treating, however, can create conditions for such porosity to form into blisters.

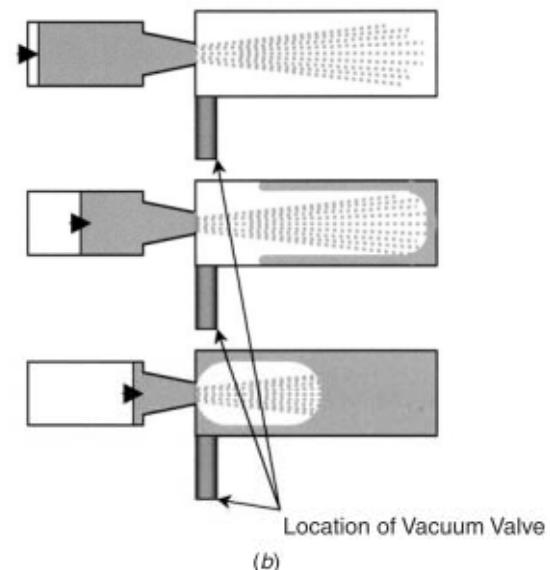
This source of porosity can be minimized by following good melting and holding practices.

MANAGING SHRINKAGE IN THE DIE

As with all die casting processes, high metal intensification pressures are maintained throughout solidification to minimize solidification shrinkage as excellent feeding is caused by high pressure



(a)



(b)

Figure 3.1 Graphical illustration showing the progression of a die cavity filling with (a) improper vacuum valve placement and (b) proper vacuum valve placement.

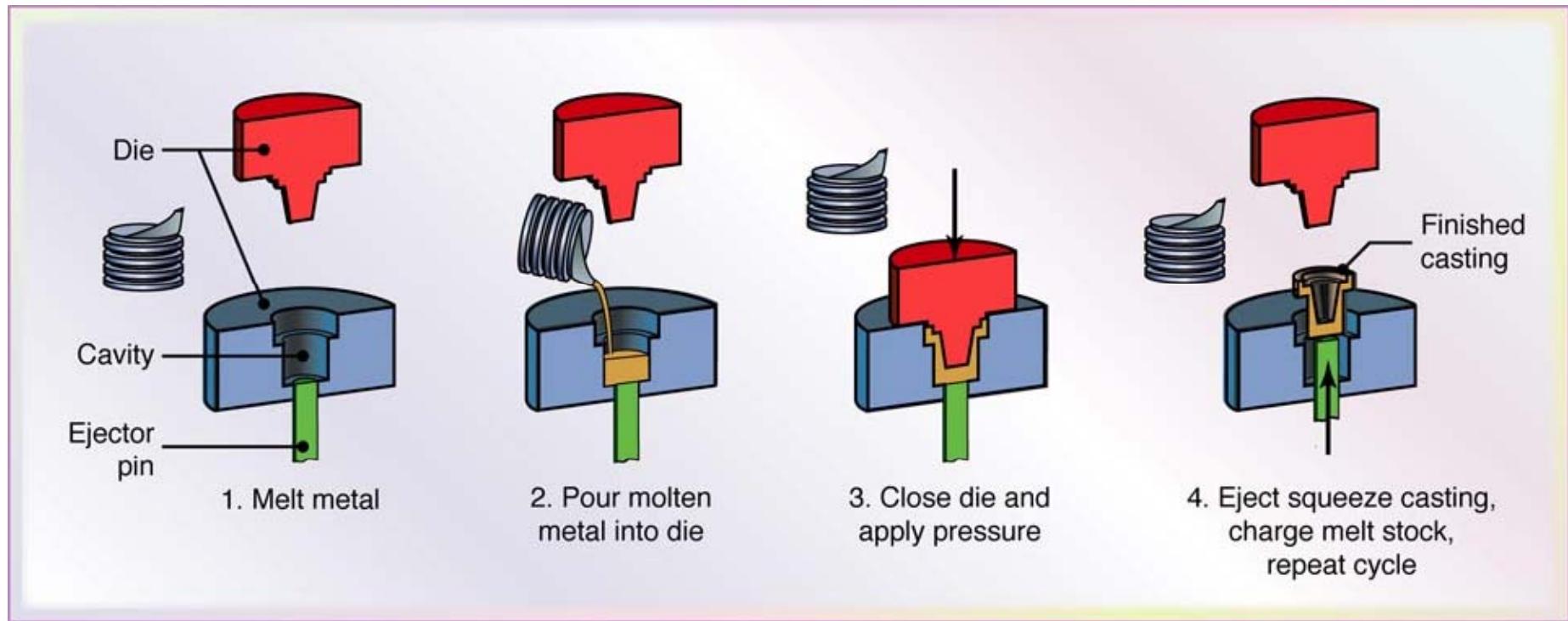
Lecture 10

ME 361A

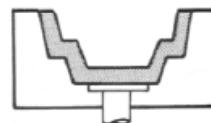
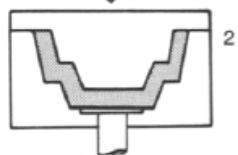
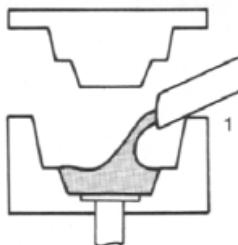
Various Casting Processes...contd.

Critical assessment

Squeeze Casting



Sequence of operations in the squeeze-casting process. This process combines the advantages of casting and forging.



Squeeze casting is analogous to forging and involves introduction of a measured quantity of metal in a die, followed by die closure and pressurization with a hydraulic press.

Squeeze casting, or liquid metal forging, differs from die casting in two fundamental ways:

- (1) a metered quantity of metal is gravity-poured (not injected) in a preheated metal die, and
 - (2) the metal is pressurized during solidification (60 - 250 MPa).
- The problem of turbulence during die filling is minimized as the metal is poured rather than injected, and high pressures during solidification eliminate all porosity, thereby yielding defect-free premium quality castings.
 - The process is a high-precision, net-shape casting process that yields excellent finish and high strength parts.
 - Ceramic fiber-reinforced aluminum alloy pistons, Ni-base hard crusher wheel inserts, steel missile components, and cast iron mortar shells are some of the parts cast using squeeze casting.
 - Wrought alloys can be used because the application of pressure eliminates the need for good fluidity.
 - Because the external pressure eliminates the air gap that would normally form at the casting-die interface, the thermal contact is perfect and cooling is rapid.
 - The application of a large hydrostatic pressure to a solidifying metal could lower its melting point. This leads to faster solidification. The above two reasons causes less time for grain growth and thus grain refinement. But not as much as in high pressure die casting.

Different metals will experience different levels of melting point depression. For example, it has been estimated that a pressure of 151 MPa will lower the melting point of pure tin by about 4.3 °C

Squeeze Casting Process

- The forging ([Wrought](#)) alloys, which generally have poor fluidities which normally precludes the casting route, can be cast by this process. This is a unique advantage enjoyed by Squeeze Casting.
- For this reason, it is sometimes known as Squeeze Forming, to emphasize its similarity to forging processes.



Applications

Advantages:

- variety of materials
- close tolerances
- good mechanical properties

Problems:

- special machines



Cannon TCS squeeze casting machine

SQUEEZE CASTING

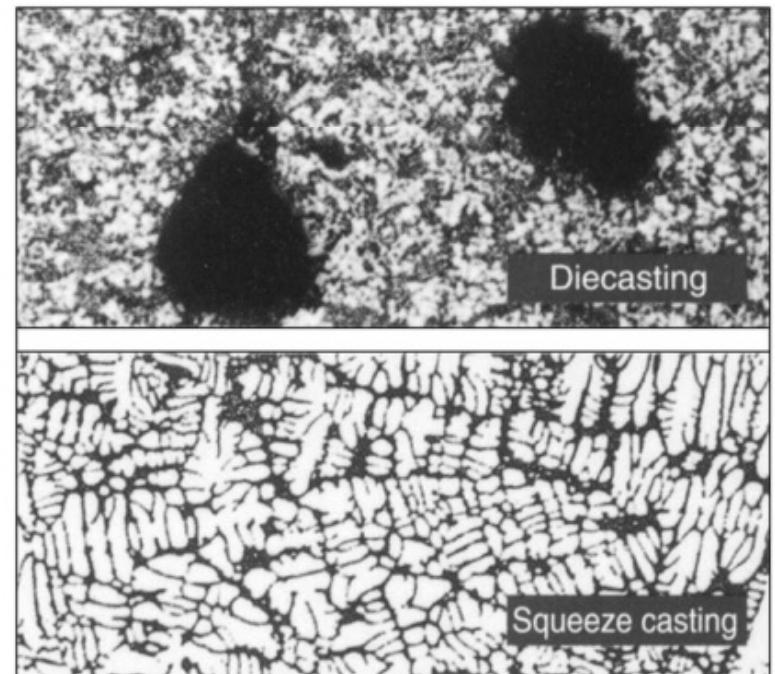
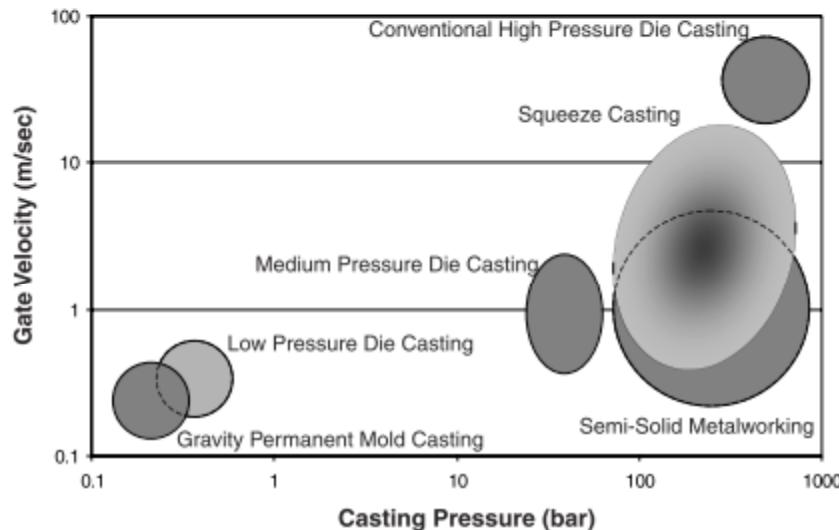


Figure 4.3 Microstructural comparisons between conventional die casting and squeeze casting. (Courtesy of UBE Machinery, Inc.)

Squeeze casting utilizes two strategies:

1. eliminating or reducing the amount of entrapped gases and
 2. eliminating or reducing the amount of solidification shrinkage
- Squeeze casting is characterized by the use of a large gate area (in comparison to conventional die casting) and planar filling of the metal front within the die cavity.
 - Squeeze casting works to minimize both solidification shrinkage and gas entrapment.
 - Planar filling allows gases to escape from the die, as vents remain open throughout metal injection.

MANAGING GASES IN THE DIE

- Porosity is attributed to physical gas entrapment during die filling, to the gasification of decomposing lubricants, and to gas dissolved in the liquid alloy, which evolves during solidification.
- The nature of the squeeze casting process minimizes gas entrapment in comparison to conventional die casting. By utilizing larger gate cross-sectional areas and slower shot speeds, atomized fill is avoided. Planar fill can be achieved during squeeze casting.
- Gas porosity can also originate from gases dissolved in the liquid metal. Although not a major factor in conventional die casting due to the extremely high cycle times, the longer solidification durations associated with squeeze casting may allow dissolved gases to precipitate and form porosity. This source of porosity can be controlled using good melting and holding practices.

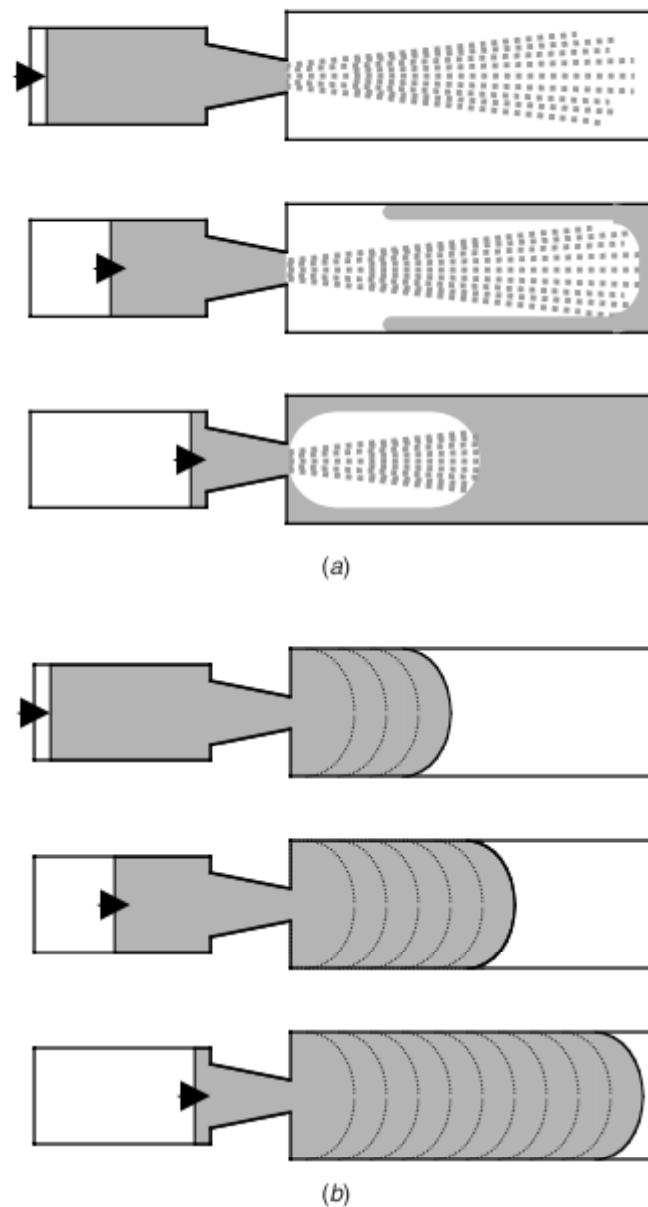


Figure 4.4 Graphical illustration showing the progression of a die cavity filling with (a) atomized filling and (b) a planar metal front.

MANAGING SHRINKAGE

- High metal intensification pressures are maintained throughout solidification in conventional and vacuum die casting.
- Unfortunately, the small gates typically used in conventional die casting freeze quickly. Once solidified, the gates are a barrier that inhibits further pressurization within the die.
- Due to increased gate areas in comparison to conventional and vacuum die casting, gates typically remain open throughout much of component solidification when using the squeeze casting process. Pressurized metal is fed to the die cavities, reducing solidification shrinkage and minimizing the effect of this porosity-forming mechanism.

Lecture 11

ME 361A

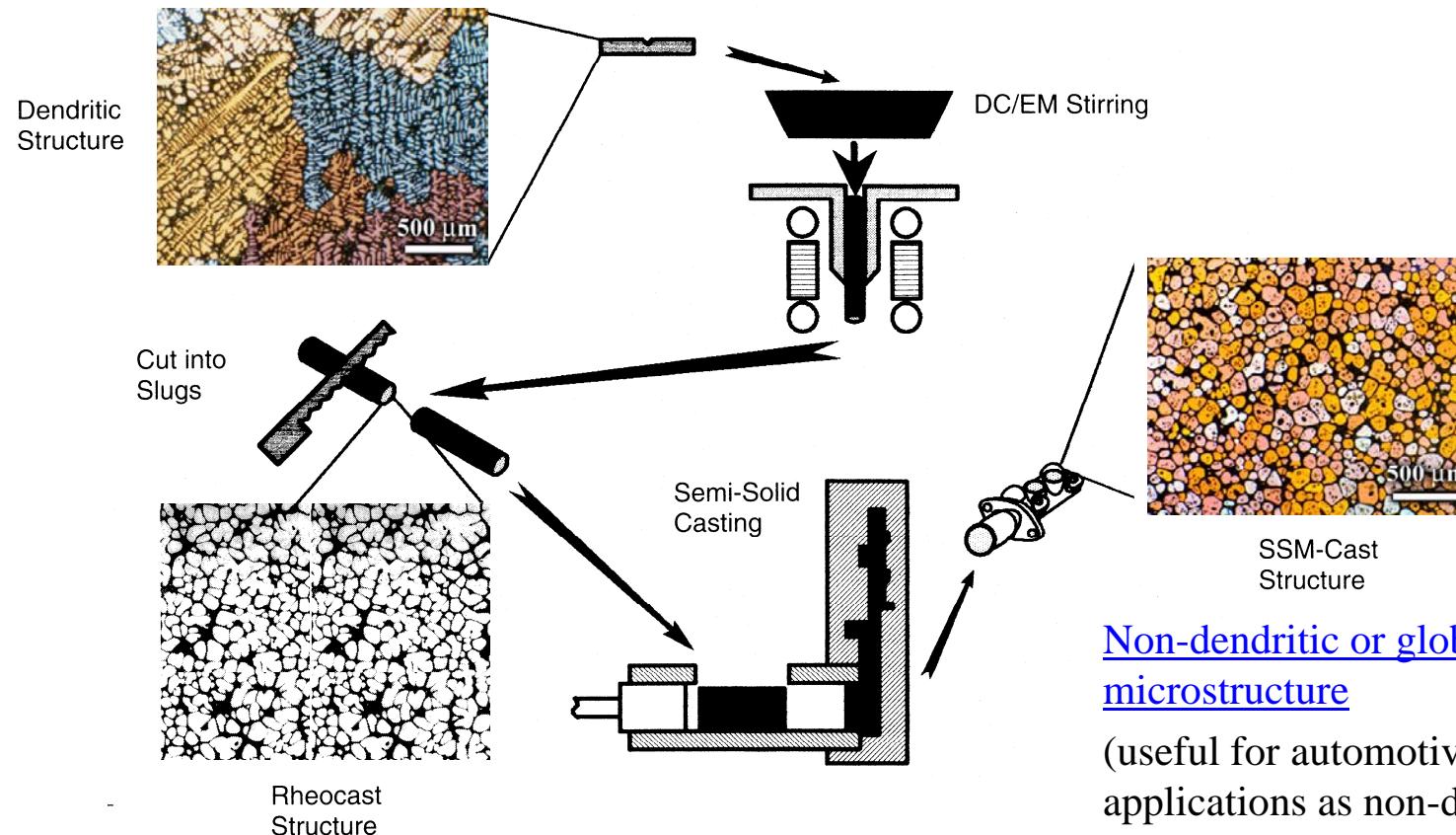
Various Casting Processes...contd.

Critical assessment

High integrity casting processes

- High pressure die casting
- Vacuum die casting
- Squeeze casting
- Semi-solid metal working

Semi-solid casting new process

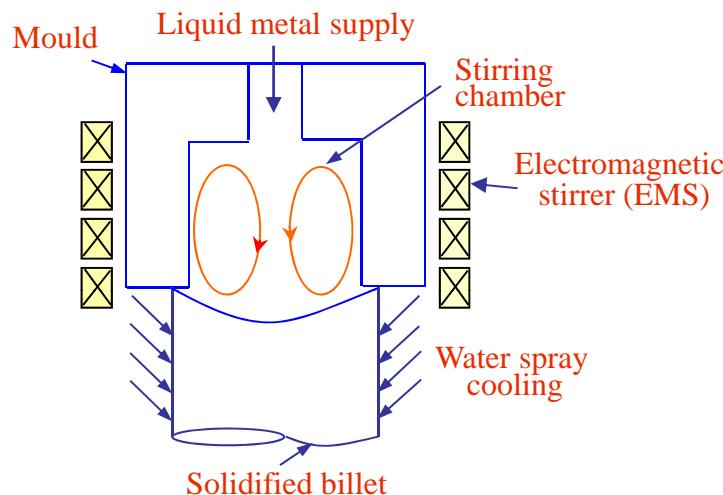


Non-dendritic or globular
microstructure

Non-dendritic or globular
microstructure

(useful for automotive applications as non-dendritic globular microstructure provides uniform and isotropic mechanical properties)

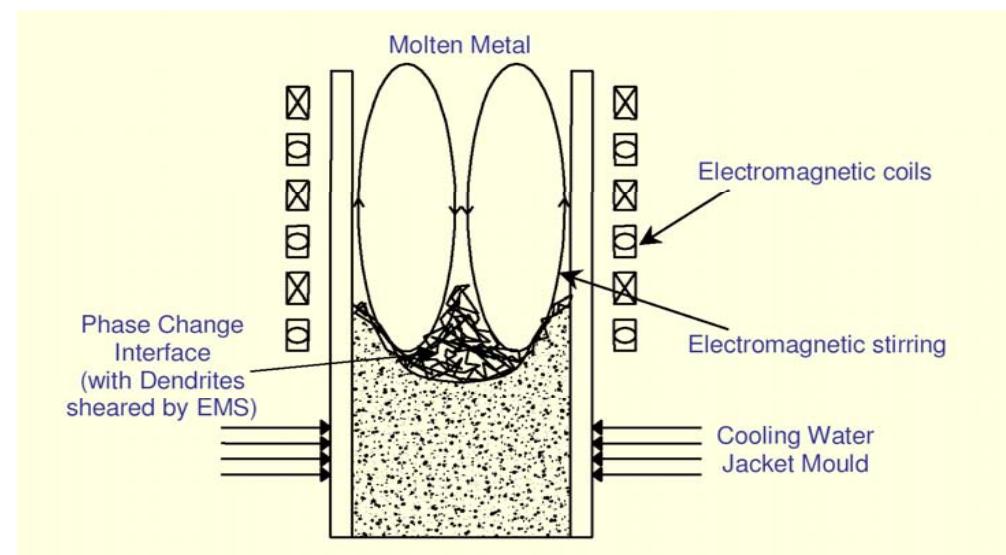
Electromagnetic stirring for producing non-dendritic billets (semi-solid casting)



DC Casting with
electromagnetic stirring (EMS)

Vigorous stirring, by an electromagnetic field, creates the necessary fragmentation action for detachment of dendrites from the solidifying front

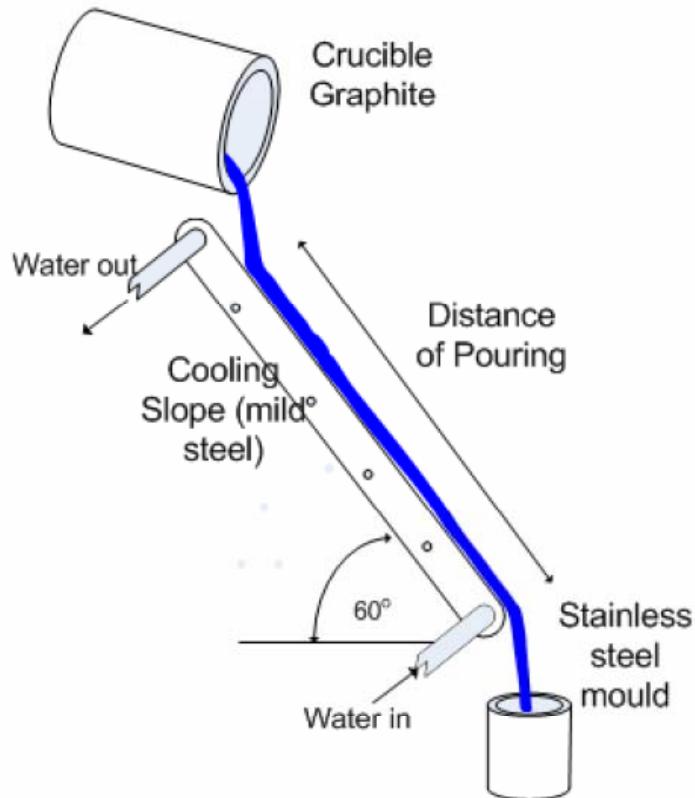
Fragmentation and heat removal can be controlled in a non-intrusive manner



Electromagnetic casting process

- Now, ultrasonic stirring is also in use
- Compared to these non-intrusive stirring techniques, mechanical stirring is usually not used as it needs a intrusive mean for causing stirring. This can cause melt contamination

Cooling slope method for semi-solid slurry on demand



Advantages:

No need of expensive electromagnetic stirrers to produce semi-solid slurry

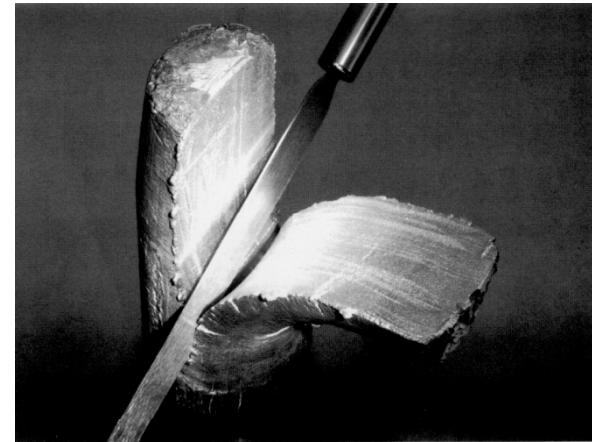
Parameters:

- Slope angle
- Pouring distance
- Poring temperature

Semi-solid casting

Advantages:

- low temperature
- laminar flow
- shrinkage reduction
- good surface finish
- high accuracy



Problems:

- special alloys
- high cost

SEMI-SOLID METALWORKING

Semi-solid metalworking extends the capabilities of conventional die casting by

1. reducing the amount of entrapped gases,
2. reducing the amount of solidification shrinkage, and
3. modifying the microstructure of the alloy.

MANAGING GASES

- Gas porosity is attributed to physical gas entrapment during die filling, to the gasification of decomposing lubricants, and to gas dissolved in the liquid alloy, which evolves during solidification.
- Semi-solid metalworking exhibits planar metal flow due to the highly viscous behavior of semi-solid metal combined with larger gate cross-sectional areas and slower shot speeds in comparison to conventional die casting.
- Planar metal flow allows vents to remain open throughout much of cavity fill. Slower shot speeds also allow more gases to escape from the die before compression of the gases occurs.

MANAGING SHRINKAGE

- As with all die cast processes, high metal intensification pressures are maintained throughout solidification, pressurized metal is fed to the die cavities, reducing solidification shrinkage.
- When utilizing semi-solid metalworking, a reduction in solidification shrinkage porosity is realized as a result of injecting metal that is already partially solid into the die.
- Also, the amount of heat, which must be removed to complete solidification, is reduced for the same reason. This allows cycle times to be shortened in comparison to high pressure die casting. So feeding is needed for shorter time.
- Due to larger gate areas in comparison to conventional and vacuum die casting, gates typically remain open throughout much of component solidification, resulting in easy feeding from the gates.

MICROSTRUCTURES IN SEMI-SOLID METALWORKING

Unlike products manufactured using traditional casting methods, the microstructure of products manufactured using semi-solid metal working is not dendritic. During processing, the dendritic structure is broken up and evolves into a spheroidal structure. The mechanical properties of the spheroidal microstructure is superior to those found in castings with dendritic microstructures.

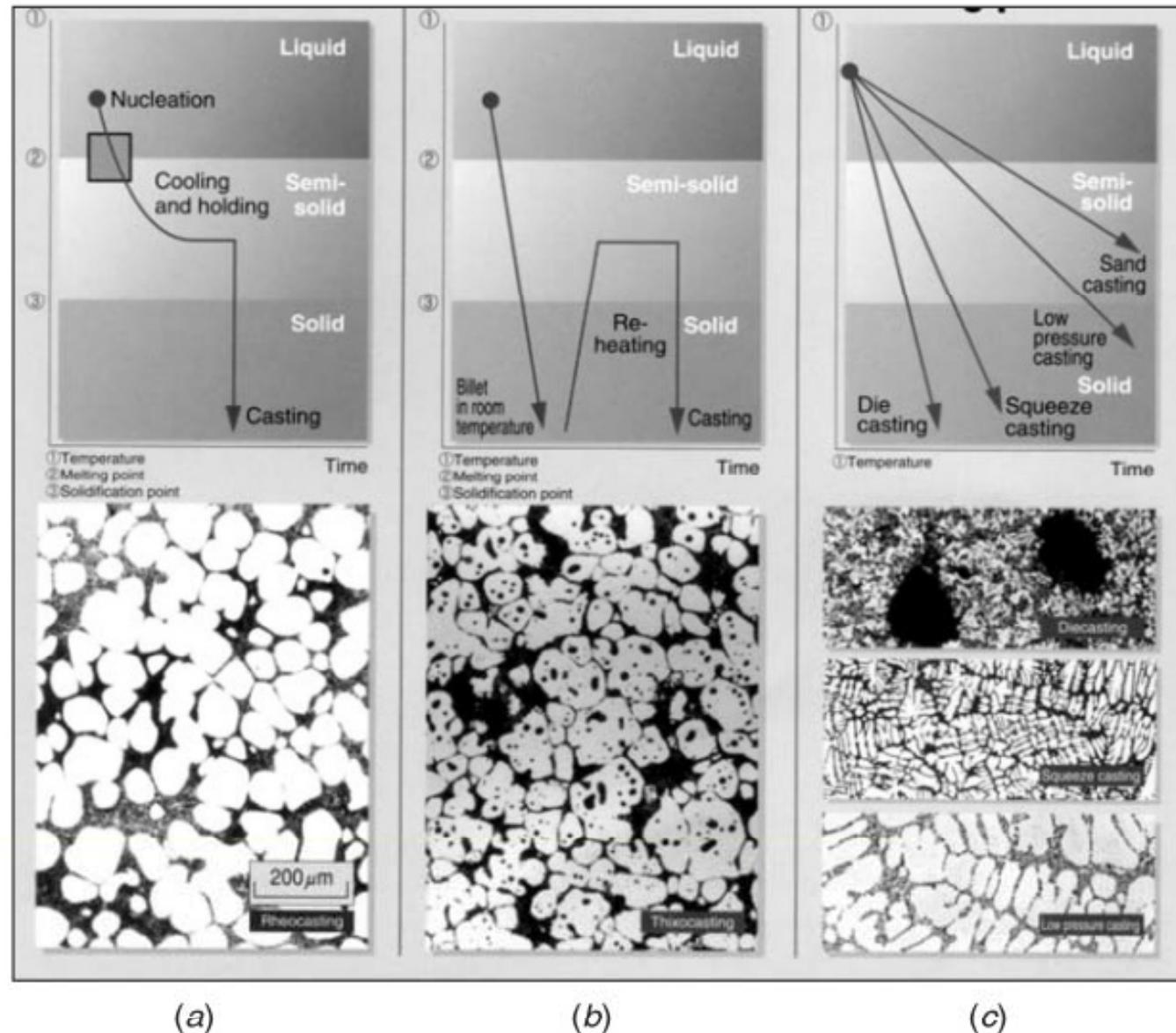


Figure 5.3 Process comparison between (a) direct semi-solid metalworking, (b) indirect semi-solid metalworking, and (c) conventional casting processes.

DEFECTS UNIQUE TO SQUEEZE CASTING AND SEMI-SOLID METALWORKING

Contaminant Veins

- Contaminant veins are unique defects that result from the planar filling phenomenon of squeeze casting and semi-solid metalworking processes.
- When filling the die, the metal front remains relatively intact and picks up contaminants such as die lubricants, die steel corrosion products, and other impurities.
- This contamination is intensified by oxidation at the metal front. The result is a contaminant vein composed of metal oxides and other impurities trapped within the casting. Most often contaminant veins are located at the last location of fill within a die.

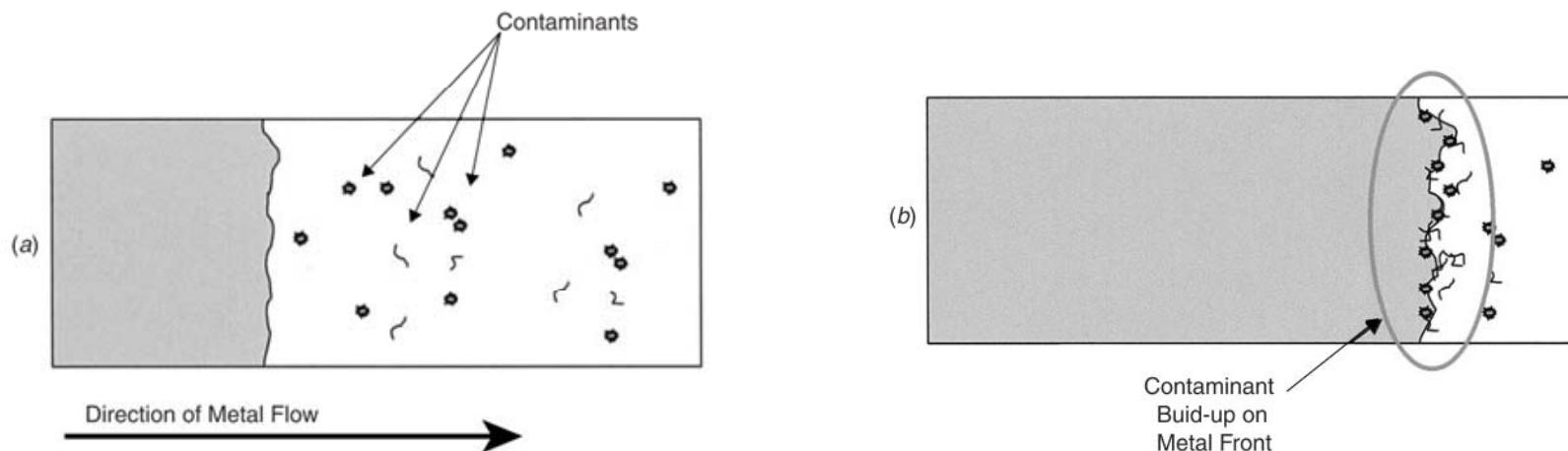
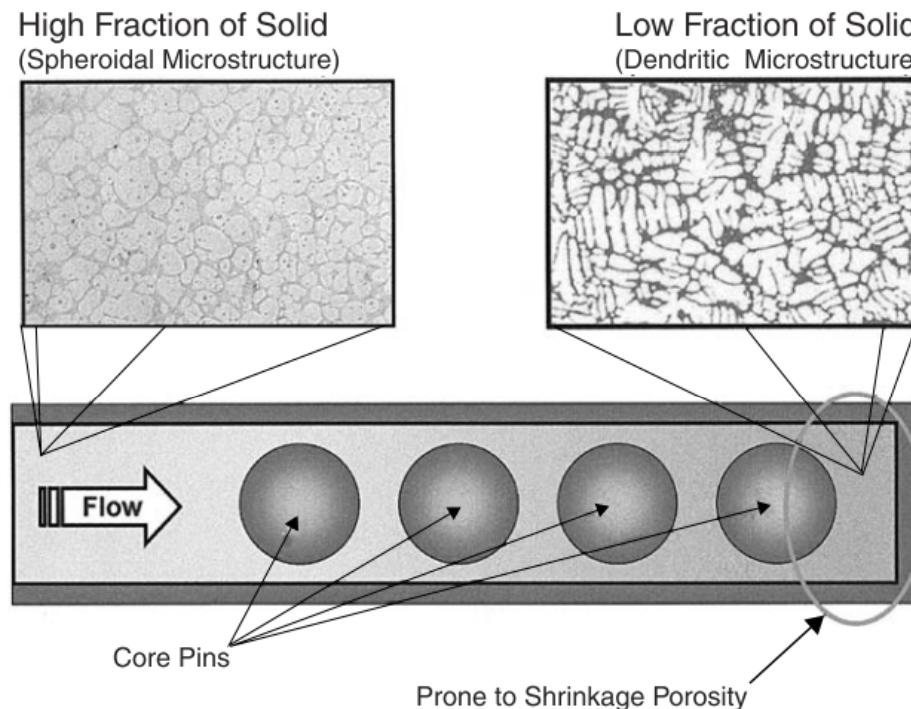


Figure 11.1 Contaminant veins form as (a) a clean planar fill front collects contaminants and (b) the metal progresses through the die cavity.

Phase Separation

Unique to semi-solid metalworking processes. The metal injected into the die cavity during semi-solid processing is partially solid and partially liquid. This two-phase mixture does not necessarily remain homogeneous. The liquid phase flows easily and in some cases will leave its solid counterpart behind, resulting in phase separation. Cases of phase separation have been observed when the metal fill front must travel a significant distance within the die cavity while flowing around multiple cores. The cores choke the passage of the solid phase. The resulting product has nonuniform material properties as the microstructure of the metal near the gate is highly spheroidal while the microstructure of the metal at the last location to fill is dendritic. Solidification shrinkage also becomes a problem in the dendritic region.



Variation in the mechanical properties caused by phase separation can be a serious issue in structural members. The dendritic region of the component has inferior mechanical properties in comparison to the bulk material. Moreover, porosity caused by solidification shrinkage can act as a stress concentrator, increasing the chances of failure.