MME 345

Lecture **B:13**

The Design of Gating System

2. Introduction to the gating system

Ref:

[1] P. Beeley, Foundry Technology, Butterworth-Heinemann, 2001
[2] J. Campbell, Castings, Butterworth-Heinemann, 2001
[3] Heine, Loper, Rosenthal, Principles of Metal Casting, Tata McGraw-Hill, 1976

Topics to discuss....

1. Introduction
2. Functions of gating systems
3. Elements of gating systems
4. Types of gating systems
5. Controlling factors in gating system
6. Surface tension controlled filling in gating systems

1. Introduction

- Getting the liquid metal out of crucible and into the mould cavity is a critical step.
- The series of funnels, pipes and channels used to guide liquid metal from the ladle into the mould cavity is known as the **gating system** or the **running system.**
- Recent work observing the liquid metal as it travel through the filing system indicates that most of the damage is done to castings by poor filling system design.
- Leaving its design to chance or even to the patternmaker is a risk not to be recommended.

- Most castings are made by pouring the liquid metal into the opening of the running system using the action of gravity to effect the filling action of the mould

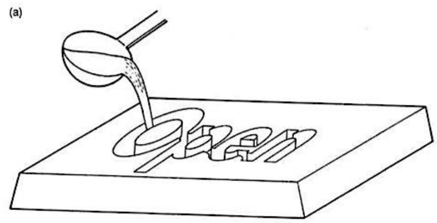
  thus gravity sand casting and gravity die-casting are important casting processes at the present time
- Gravity castings have, however, gained a poor reputation for reliability and quality, simply because their running systems have in general been badly designed

  surface turbulence had led to porosity and cracks, and unreliability in leak-tightness and mechanical properties
- Most of the running systems available are empirical, based on transparent model work

  real-time video radiography of mould filling and simulation software make the life easier now-a-days

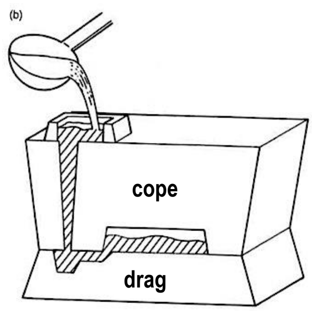
An invaluable design rule: "If in doubt, visualise water"

An open mould



- cope not required (e.g., wall plaque or plate which don't need a well-formed back surface)
- liquid metal poured directly into the mould cavity
- skill of foundrymen important
- other viscous and poorly fluid materials cast in this way includes: hydraulic cements and concrete

A closed mould
(Partially Sectioned)



- filling the mould represents the greatest of challenges
- about 15% investment castings are scrapped due to having random inclusions, random porosity, and misrun – the standard legacy of turbulent system
- this 15% may rise to 85-95% for heavy castings (never 100% !!) and may reduce to 5% for small castings (never 0 % !!)
- design of running system is crucial
- only a carefully worked out running system will give filling with low surface turbulence, and therefore reproducible every time.

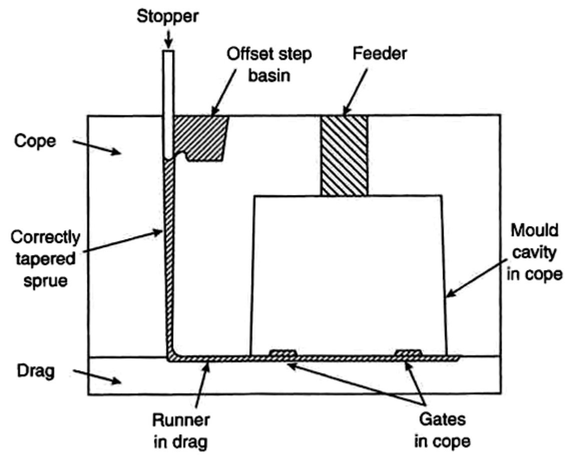
2. Function of Gating Systems

- In a good running system, the pouring speed and pouring temperature are under the control of the running system, not the pourer.

- The functions of a good running system are:

1. Economy of size
2. The filling of mould at the required speed
   for most castings, this roughly equals 0.5 m/s
3. The delivery of only liquid metal into the mould cavity
   no other phases such as slag, oxide, sand, air or other gases
4. The elimination of surface turbulence
   preferably at an early state in the running system; should gather the fragmented stream due to the long fall through the sprue together again
5. Establish proper temperature gradient
6. Ease of removal

3. Elements of a Gating System

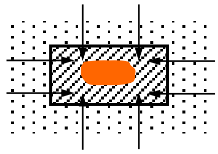


basic components of a simple gating system for a horizontally parted mould

Additional features:

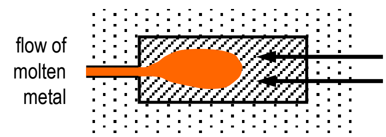
- Core
- Riser or feeder
- Skim core, strainer, delay screen, sprue plug
- Filter, dross trap

Progressive vs. directional solidification



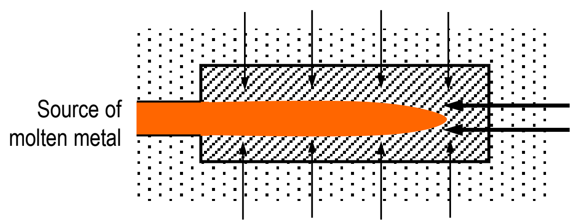
progressive solidification

solidification begins from the mould wall more or less evenly towards the centre, creating an isolated area of molten metal in the casting.



directional solidification

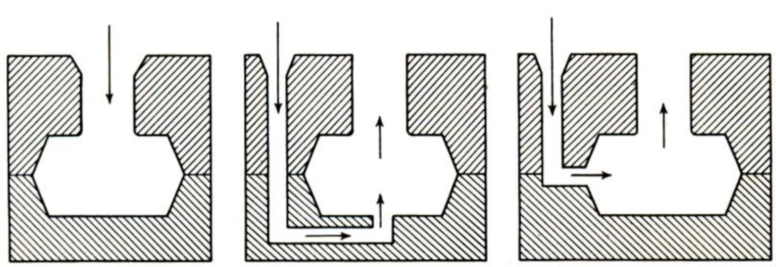
solidification begins in the section of the mould furthest from the supply of new molten metal (the feeder) and moves uniformly in the direction of that supply



combination of progressive and directional solidifications

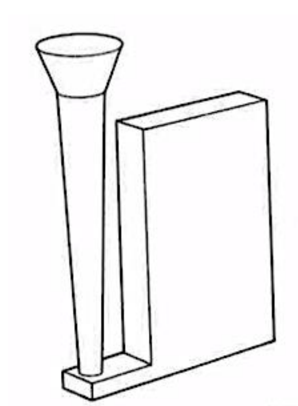
4. Types of Gating Systems

Top pouring vs. Bottom pouring systems

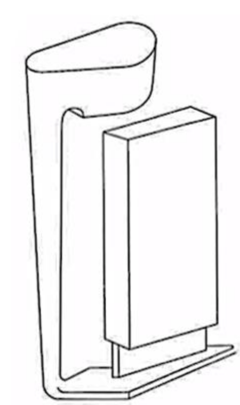


(a) Top pouring system, (b) Bottom pouring system, (c) Side pouring system

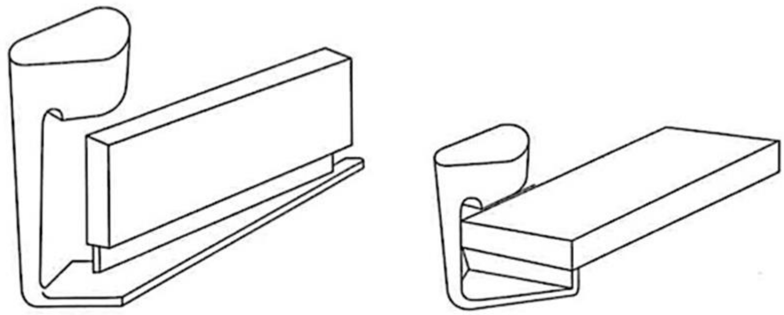
Top pouring	Bottom pouring
Faster pouring rate, less fluidity requirement	Filling against gravity, slow pouring rate; more fluid liquid preferred
Severe splashing and mould erosion	Elimination of splashing and mould erosion
Oxidation of liquid metal resulted	Quiet entry to mould cavity; less turbulence, less oxide formation
Favourable temperature gradient	Unfavourable temperature gradient



a poor bottom-gated filling system because of direct entry of high velocity liquid into the mould cavity

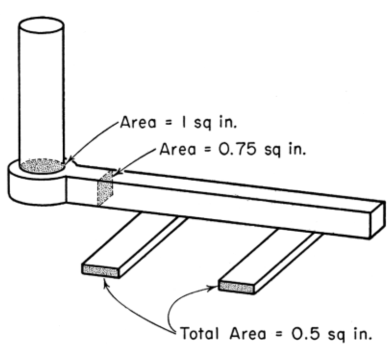


an improved version of the previous bottom-gated filling system

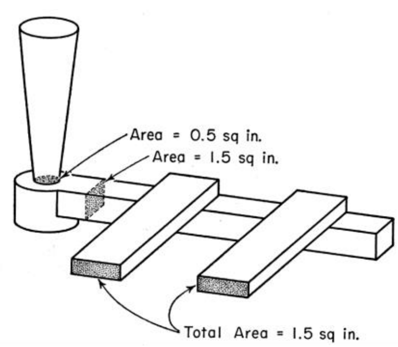


further improvements of the previous bottom-gated filling system by height reduction

Pressurized vs. Unpressurized systems

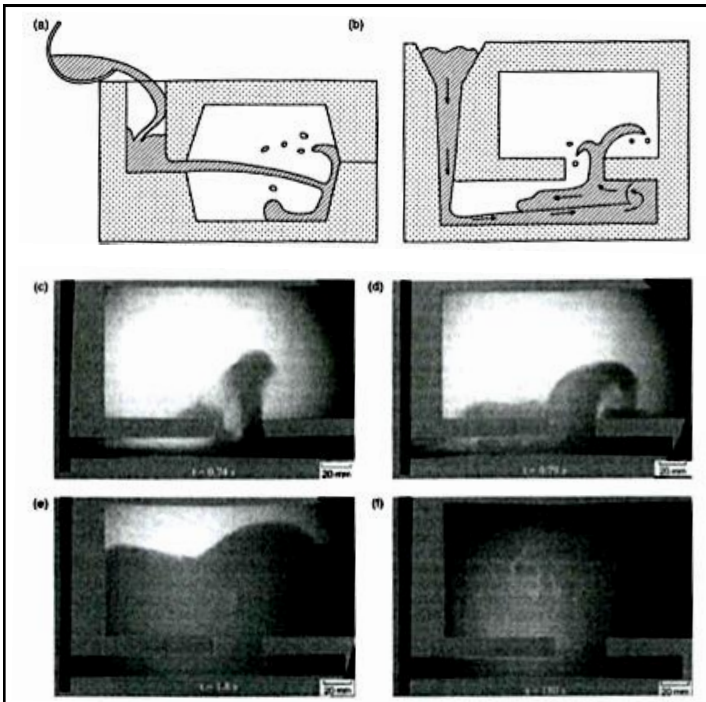


pressurised system



unpressurised system

Pressurised system	Unpressurised system
Gate is used as choke	Sprue base is used as choke
Velocity increases as the liquid flows from sprue to runner to gate	Velocity decreases as liquid flows from sprue to runner to gate
Turbulence resulted	Turbulence minimised
Gating system is kept full due to back pressure	Careful design is required to keep gating system full
Velocity in each of multiple gates (of equal area) is equal	Obtaining equal flow in multiple gates is difficult
Volume of gating system is smaller producing high casting yield	High volume of gating system producing low casting yield



The mould filling of

(a) pressurized system, showing the jetting of liquid into the mould cavity

(b) unpressurized system, showing the fast underjet, and the rolling back wave in the oversized runner

(c) – (e) x-ray video frames of filling of an aluminium alloy using unpressurized system

(f) the final casting showing sub-surface bubble and internal cracks

Naturally pressurized system

- No localized choke
- The whole of the length of the filling system should experience its walls in permanent contact and gently pressurized by the liquid metal
- Thus, effectively the whole length of the running system should be designed to act like a choke; a kind of continuous choke principle, and an uniformly pressurized systems
- So, the new design concept is based on designing the flow channels in the mould so as to follow the natural form that the flowing metal wishes to take

Naturally pressurized system is part-way between the pressurized and unpressurized system

Example of gating ratio
(sprue bottom area : runner area : gate area)

Pressurized system:	**1.0 : 0.8 : 0.6**
	1.0 : 1.0 : 0.8
Unpressurized system:	**1.0 : 2.0 : 4.0**
	1.0 : 4.0 : 4.0
Natural system:	**1.0 : 1.2 : 1.4**
Slightly pressurized system:	**1.0 : 1.1 : 1.2**
	1.0 : 1.1 : 1.2

Problems of naturally pressurized system

- No built-in mechanism for any significant reduction in velocity of the stream
- The high velocity at the base of the sprue is maintained (with only minor reduction) into the mould
- Thus the benefits of complete filling of the running system to exclude air are lost on entering the mould cavity

- The naturally pressurized approach requires completely separate mechanisms to reduce the velocity of the melt through the ingates
- The options include:
  - **[1] The use of filters**
  - **[2] the provision of specially designed runner extension systems such as flow-offs**
  - **[3] a surge control system**
  - **[4] the use of a vertical fan gate at the end of the runner**
  - **[5] the use of vortices to absorb energy while avoiding significant surface turbulence**

5. Controlling Factors in Gating Systems

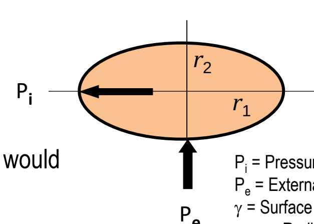
1. Type of gating system
   (top / bottom pouring, pressurised / unpressurised system)
2. Pouring temperature (fluidity of metal)
3. Type of pouring equipment
   (ladle / pouring cup / pouring basin)
4. Rate of pouring
5. Size and type of runner and sprue
6. Size, number and location of ingates

6. Surface Tension-Controlled Filling in Gating System

- If the section thickness is small (< 2 mm), the liquid may not be able to enter the mould at all !!
  - this is an effect due to surface tension
  - if the surface is sharply curved or a reduction in filling pressure is resulted, the surface tension resistance may reverse the liquid flow, causing it to empty out of the mould

- For thin-section castings

$$P_i - P_e = \gamma (1/r_1 + 1/r_2)$$



P_i = Pressure inside liquid metal
P_e = External pressure in the mould
γ = Surface tension of liquid
r_1, r_2 = Radii of curvature

- For circular mould or narrow plate, filling would be possible only

$$P_i - P_e > 2\gamma/r$$

- If the mould is wetted by the liquid
  - γ/r term will be negative.
  - surface tension will assist the metal to enter the mould

- For non-wetted circular moulds:

$$P_i - P_e > 2\gamma/r$$

$$(P_a + h\rho g) - (P_a + P_m) > 2\gamma/r$$

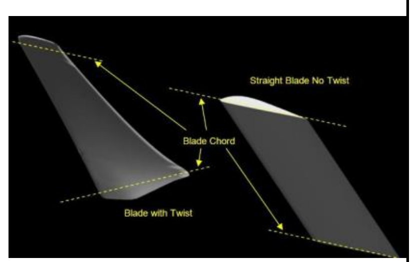
$$h\rho g - P_m > 2\gamma/r$$

P_a = Atmospheric pressure
P_m = mould gas pressure
$h\rho g$ = liquid head pressure

- ❖ **Venting the mould – good or bad for mould filling?**
- ❖ **Role of atmospheric pressure?**
- ❖ **Use of vacuum casting?**

- For vacuum-assisted filling (not vacuum casting):

$$h\rho g + P_a > 2\gamma/r$$



$g = 10\ m/s^2$
$\rho = 2500\ kg/m^3$ (for Al castings)
$\gamma = 1.0\ N/m$
$P_a = 100\ kPa$

Example:

$2\gamma/r$ = 2 kPa for 1-mm section **(0.5 mm radius)**

$2\gamma/r$ = 10 kPa for 0.1 mm radius **(trailing edge of turbine blade wheels)**

Sprue height, h = 100 mm; $h\rho g = 2.5\ kPa$

- ▶ **the 1 mm section would just fill**
- ▶ **but the trailing edge has no chance of filling**

For vacuum-assisted filling ➔ $(h\rho g + P_a) = 103.5\ kPa$

To summarise:

- For thin castings (sections < 1-2 mm):
  - surface tension has a strong influence
  - filling is only possible due to external influence (centrifugal force, application of pressure and vacuum etc.)

- Metal head required forcing the liquid into small sections:

$$h\rho g = 2\gamma/r \; ; \quad h = 2\gamma/\rho g r$$

  - if the section is halved, head will be doubled
  - if the density is doubled, head will be doubled again

- For high enough external pressure, liquid metal can fill small radii to reproduce finer details (very good surface finish and definition).

For high-pressure die casting

- P = 1 MPa (10 atm) would reproduce a radius of 0.001 mm
- but generally pressure in the range of 100 MPa (1000 atm) is used, which can force the liquid metal into radii of 10^{-8} m (dimension of atom !!)

For centrifugal casting

- casting velocity of 10 m/s would produce about 10 g (or, 100 m/s^2) acceleration and a better finer details of a factor 11 can be achieved
- but in industrial centrifugal castings, 50-100 g are normally used

Why do industrial production processes use such a high value of pressure or centrifugal force?

Surface finish

- For sufficiently high metal head pressure,
  - surface tension no longer able to resist metal penetration
  - castings with rough surface are resulted

To resist metal penetration:

1. Use finer sand to make mould/core.
   - permeability must be taken into consideration
2. Application of mould wash

Next Class

MME **345**, Lecture **B:14**

The Design of Gating System

3. Theoretical considerations in gating design