

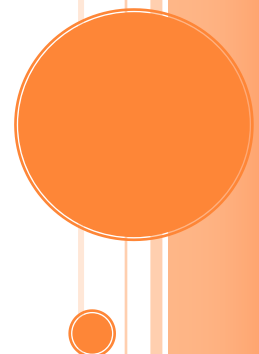
SAND CASTING DESIGN RULES

Santosh Reddy Sama, Guha P Manogharan

Sand casting is the most popular casting process employed in industry because of its great geometric freedom capability and for its cost effectiveness. In this article, we provide design rules for optimal sand casting performance.

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06-Feb-17



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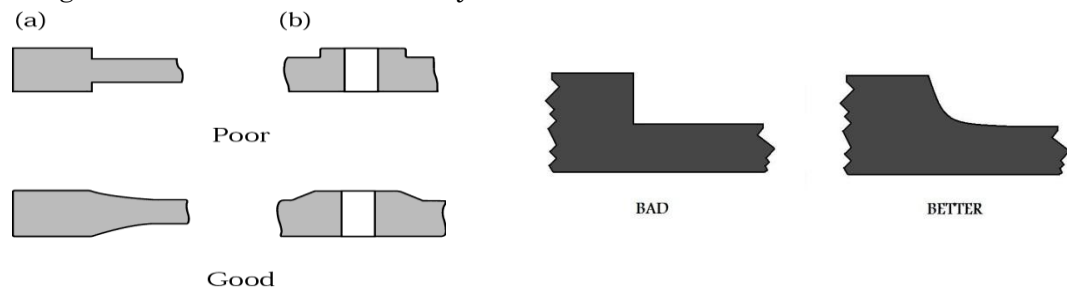
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It must be emphasized that this article was highly inspired by a brochure “Casting Design and Performance” by ASM International.

The design of a successful casting requires an integrated approach that considers both functional and process requirements simultaneously. This article discusses the basic design considerations of the part and the entire casting process.

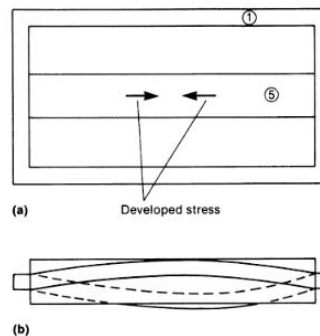
Basic part design:

1. Avoid using sharp corners and angles as they act as stress raisers and may cause cracking and tearing during solidification. Therefore, section changes in castings should be blended smoothly into each other.



Design modifications to avoid defects in castings
(Sharp corners are avoided to reduce stress concentrations)

2. Extensive horizontal flat surfaces should be avoided as they may warp during cooling because of temperature gradients. They also develop poor surface finish.
3. Do not interpose thin sections between thick sections.
4. Avoid isolated thick section.



The effects of design on distortion of castings. (a) Top view of casting; numbers indicate moduli of the two sections. (b) Distortion caused by solidification stresses

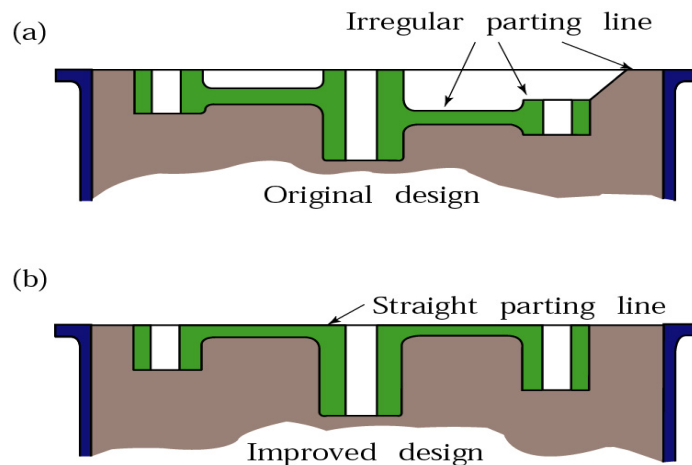
Basic mold design:

- **Part orientation in the casting**

Orientation of the part should be such that the large portion of the casting is relatively low and the height of the casting is minimized.

- **Parting line design**

1. Parting line should be along a flat plane rather than be contoured. Irregular parting lines should be prevented until and unless it is unavoidable.

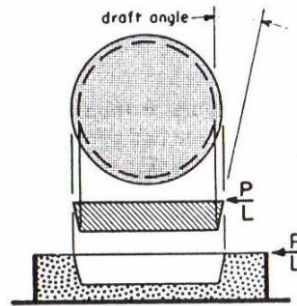


Designing for a straight parting line to reduce pattern and casting costs. (a) Irregular parting line is a costly design. (b) Straight parting line is less expensive.

2. For less dense material (like Al alloys), parting line should be placed as low as possible
3. For denser metals (like steels), mid-height location is recommended.
4. Parting line greatly influences the total cost of the casting process. It has effects on the total required number of cores, gating system and weight of the final casting.
5. Critical dimensions should not cross parting lines in molds.

- **Pattern design**

1. A small draft ($\sim 0.5^\circ$ to 2°) should be provided to enable removal of the pattern without damaging the mold.



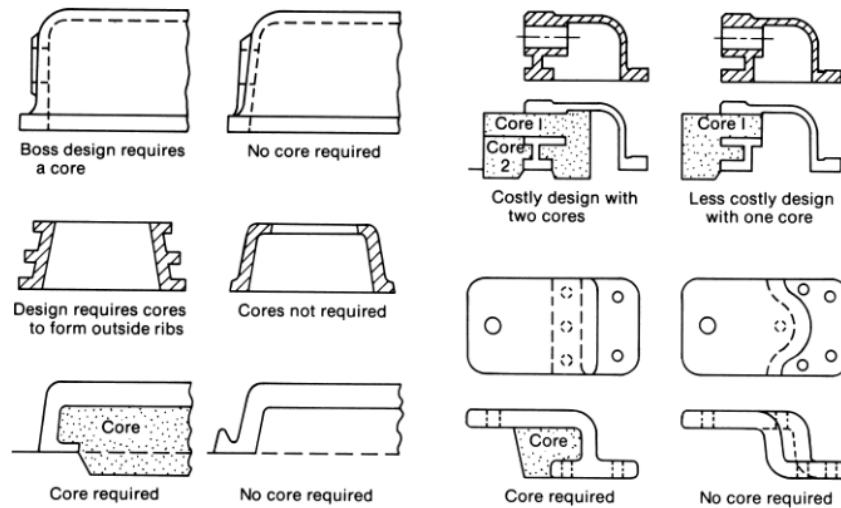
Thin disc whose edges have been drafted

2. Pattern should also take into account the following allowances and should be fabricated accordingly:
 - a. Patternmaker's shrinkage because of solid-solid contraction (~1% to 2%).
 - b. Machining allowance (~2mm to 5mm for small castings and to more than 25mm for large castings).

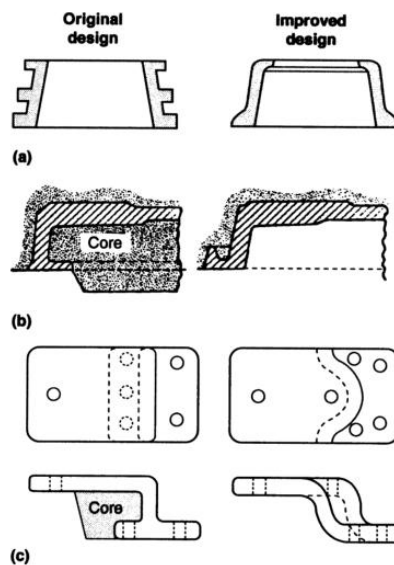
Typical patternmaker's shrinkage of various metals[23]		
Metal	Percentage	in/ft
Aluminum	1.0–1.3	$\frac{1}{8}$ – $\frac{5}{32}$
Brass	1.5	$\frac{3}{16}$
Magnesium	1.0–1.3	$\frac{1}{8}$ – $\frac{5}{32}$
Cast iron	0.8–1.0	$\frac{1}{10}$ – $\frac{1}{8}$
Steel	1.5–2.0	$\frac{3}{16}$ – $\frac{1}{4}$

- **Core design**

1. An important rule in economical casting design is to eliminate as many design features requiring cores as possible. Cores that are only absolutely necessary for producing the desired shape should be used if design is to be directed toward lower cost castings.
2. Core consolidation is one such method where we reduce the total number of cores by integrating several cores and designing them as a single one.



Restrictions to pattern removal and some potential solutions

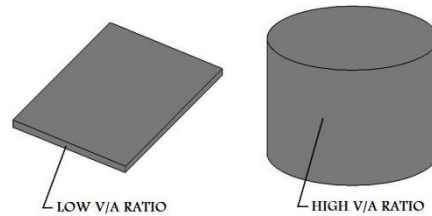


Redesign of castings to eliminate cores. (a) Casting redesigned to eliminate outside cores. (b) implication of a base plate design to eliminate a core. (c) Redesign of a bracket to eliminate a core and to decrease stress problems.

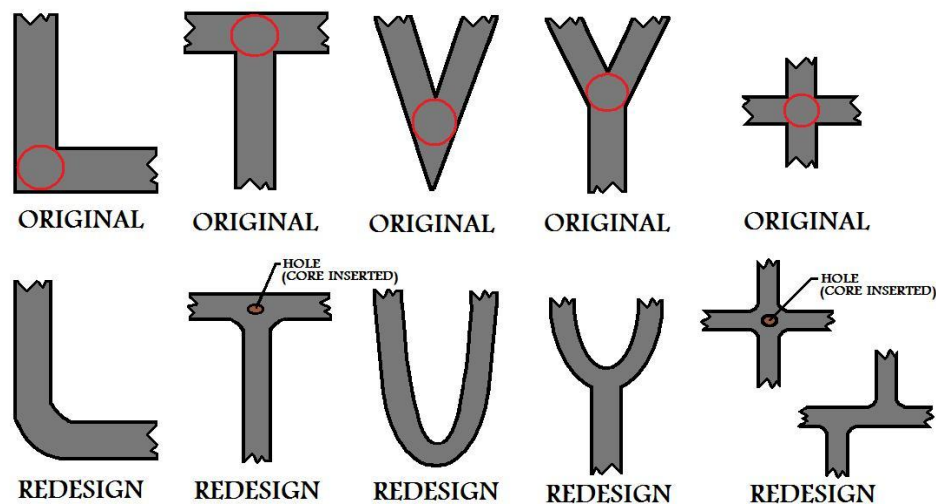
Solidification characteristics:

1. Almost all molten alloys, with some important exceptions, undergo shrinkage during solidification.
2. The basic objective of good casting design is to concentrate this liquid-solid contraction to the last portion(s) of the casting to solidify.

3. We use Chvorinov's rule as the basic technique to study solidification process and the rule states that the time of solidification is directly proportional to the square of the volume-to-area ratio of the casting (or casting section). This section modulus approach is an approximate analysis scheme to provide valuable insights into the solidification times and, therefore, the propensity for defect formation during solidification.

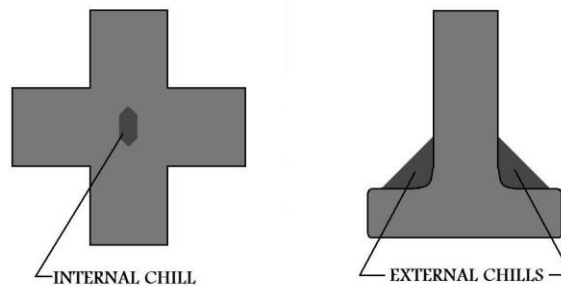


4. According to this rule, solidification progresses from the parts that have least section modulus to the locations where section modulus is high. Objective is to design such that casting sections should freeze progressively, so that the contraction results in a sound part.
5. This is generally done by adding reservoirs of molten metal called risers/feeders that feed liquid metals to the last portion of the casting to solidify. Risers are designed to have the highest casting modulus.
6. The portion where the casting modulus is very high in the casting will freeze slowly and will have properties that defer from adjacent locations. These locations are called hotspots and our aim is to eliminate all the hot-spots to the maximum extent possible.
7. Elimination of hotspots can be possibly achieved by:
- Adding cores to the thickest section
 - Feeding molten metal through risers
 - Redesigning the junction



8. Accelerating the solidification of a section of the casting that will need to solidify at a faster rate to eliminate hotspots can be attained by inserting

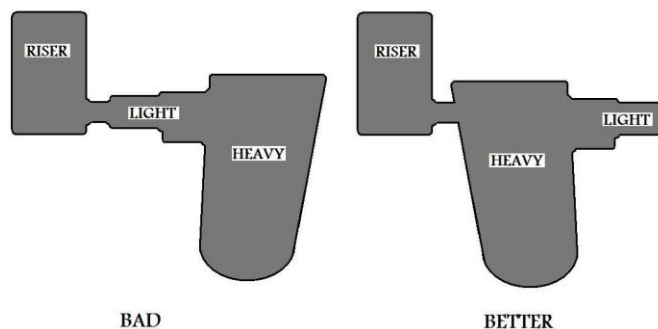
chills inside the mold cavity before pouring. Chills are of two types. Internal chills are directly fused into the casting and External chills help to remove heat from the casting faster than the surrounding material.



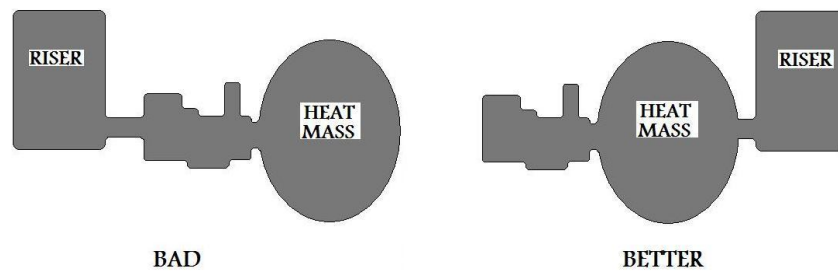
Types of Chills: Internal Chills and External Chills

Riser design:

1. Risers help to feed liquid metal into the last portion of the casting. Proper placement of the risers on castings changes the way in which both the casting and riser(s) solidify such that the riser is the last to solidify.
2. When designed correctly, a casting that's free of shrinkage will be produced because all the shrinkage for the entire mass of both casting and riser will be concentrated in the riser.
3. Riser location:
 - a. Solidification should proceed directionally from those parts of the casting farthest from the riser, through the intermediate portions of the casting, and finally into the riser itself, where the final solidification will occur.
 - b. Risers should be placed to achieve the maximum pressure differential and, when possible, should be open to the mold surface. Blind or enclosed risers must be adequately vented.
 - c. Top riser is typically more efficient than the side riser
 - d. For a side riser, it is recommended to gate through the casting for maximum effectiveness.
 - e. Flow of material is very important to the manufacturing process. Do not feed a heavy section through a lighter one.



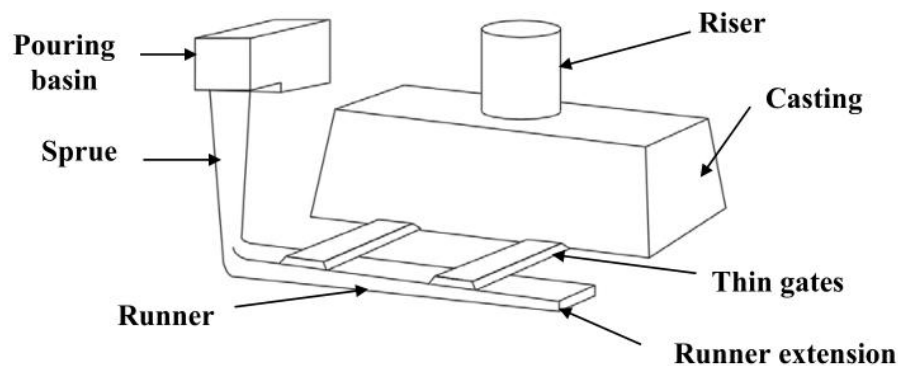
- f. Avoid large masses in locations distant to risers



4. Shape of riser:
 - a. A cylindrical shape has a good volume-to-area ratio and is easily moldable and hence is recommended.
 - b. Side riser should be provided with a hemispherical bottom to prevent premature freezing of the riser/casting junction.
5. Size of riser:
 - a. Top risers: Riser height should be at least equal to the riser diameter.
 - b. Side risers: Riser height as 1.5 times the riser diameter is often used.
6. Number and size of risers should be minimized to increase mold yield and to reduce production costs. Various methods can be used to establish this criterion:
 - a. Chilling the casting: Reducing the solidification time
 - b. Insulating the riser: Extending its solidification time.
7. Insulating the riser greatly reduce cooling in the risers from the steep temperature gradient between the liquid metal of the casting, and the room temperature air.

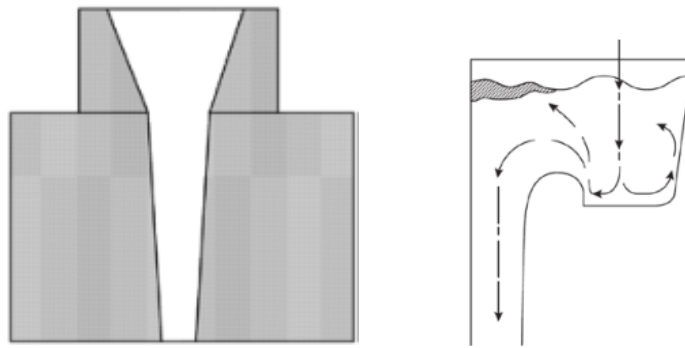
Gating system design:

1. A gating system refers to all passageways through which the molten metal passes to enter the mold cavity. The basic components of a simple gating system are pouring basin, sprue, runner, gates.



Schematic of a traditional gating system layout

2. General gating system design rules:
 - a. A gating system should fill the mold cavity completely before freezing.
 - b. Minimizing turbulence plays an important role in the quality of the casting. A turbulence metal flow tends to form dross in the mold. Avoid sudden or right angle changes in flow direction.
 - c. A proper thermal gradient should be maintained so that the casting is cooled without any shrinkage cavities or distortions.
 - d. System design should be economical to maximize the yield and should be easy to implement and remove after casting solidification.
3. Pouring basin design:
 - a. Pouring basin is the first part of the gating system to handle the molten metal and maintain pressure head over sprue. A good design of pouring basin eliminates the slag entering the down sprue.



a) Conical pouring basin and b) Offset step basin

- b. Conical basin: Conical pouring cups are the most popular cups almost everywhere in the foundry industry.

Advantages:

1. Easy to make
2. Inexpensive

Drawbacks:

1. Molten metal enters at high, unchecked velocity and this result in undesired turbulence.
2. Contaminants that enter along with the melt and not filtered and are necessarily taken directly down the sprue.
3. Extremely susceptible to vortex formation and air entrapment.

- c. The offset step basin: This design brings the horizontal jet across the top of a sprue to a stop.

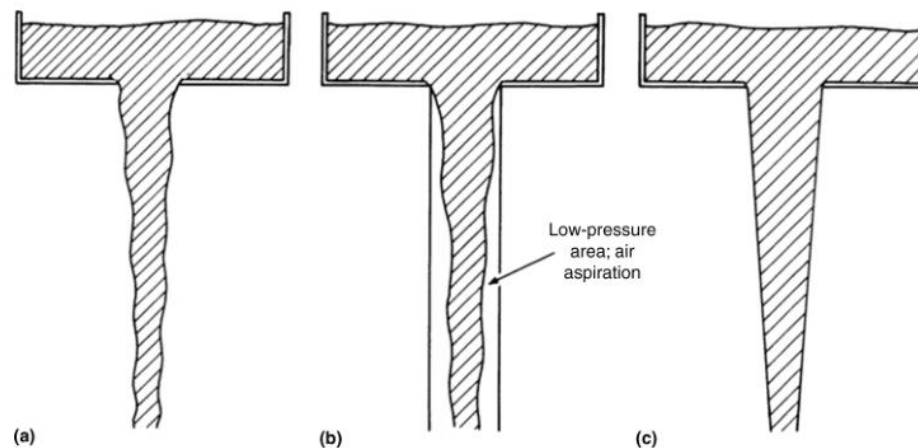
Advantages:

1. The offset blind end of the basin is important in bringing the vertical downward velocity to a stop.

2. Velocity of the melt that enters the sprue is checked and unwanted components like slag, dross can be separated.

Drawbacks:

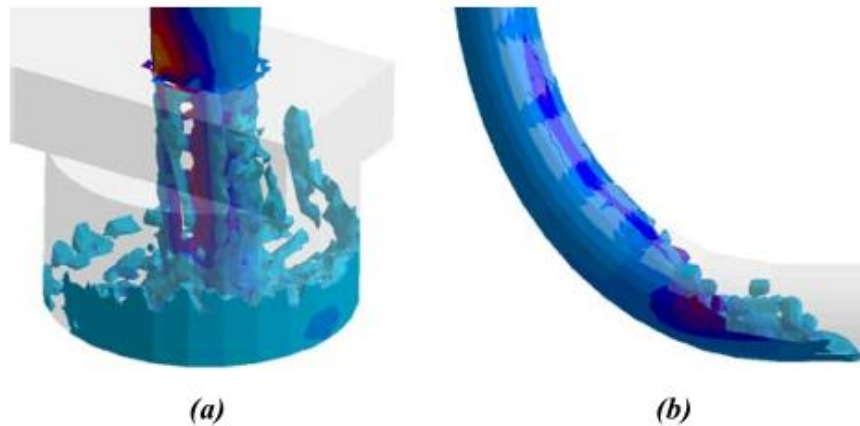
1. Expensive
 2. Difficult to keep the down runner full from the beginning to the end of the pouring with this type of pouring basin.
4. Sprue design: Sprue aids in getting the melt down to the lowest level of the mold while introducing a minimum of defects despite the high velocity of the stream.
 - a. Sprue should be designed as narrow as possible so that the metal has minimal opportunity to break and entrain its surface during the fall.
 - b. To reduce air entrapment and oxide formation, sprues should be tapered so as to mimic the taper that the falling stream adopts naturally as a result of its acceleration due to gravity.



Schematic showing the advantages of a tapered sprue over a straight-sided sprue. (a) Natural flow of a free-falling liquid. (b) Air aspiration induced by liquid flow in a straight-sided sprue. (c) Liquid flow in a tapered sprue

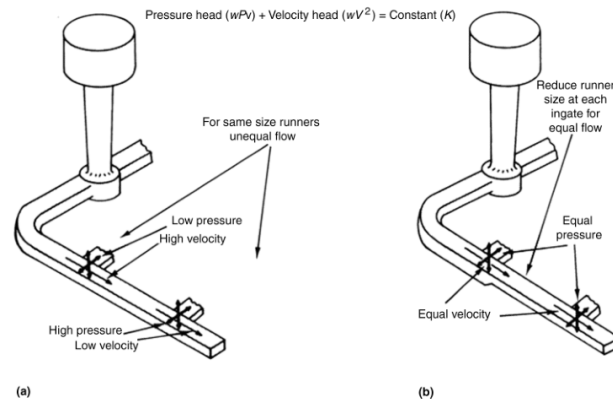
- c. Sprue base: Sprue base is the junction where the falling liquid emerges from the exit of the sprue and executes a right- angle turn along the runner. Sprue base design considerations:
 - i. Bottom well: It is one of the widely used designs for a sprue base. Though the fundamental idea of this bottom well has been to take in the first metal stream falling from the sprue and comfort it so that calm and non-turbulent melt flow throughout the horizontal runner, in reality, the well has been an opportunity for the melt to churn, entraining quantities of oxide and bubble defects.
 - ii. Turn: For a narrow turn without a well the velocity of the metal in the runner had the benefit of additional friction from

the wall, giving a small (approximately 20 %) but useful reduction in metal speed.



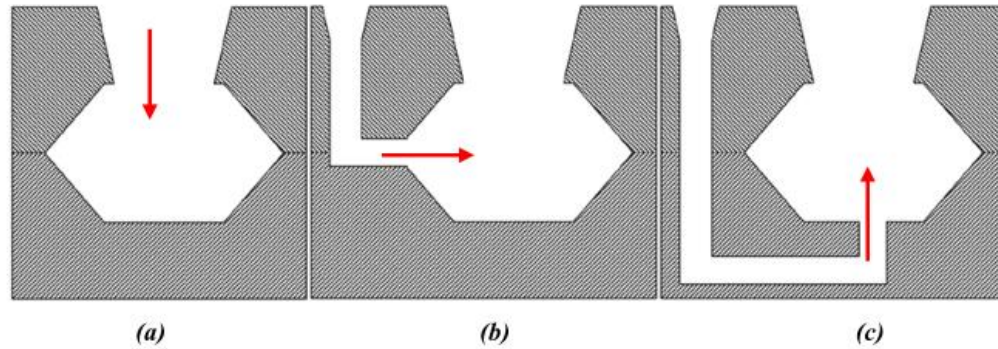
Common types of sprue/runner junctions: a) A sprue well, b) Turn

5. Runner design: Runner is the part that distributes the melt horizontally around the mold, reaching distant parts of the mold cavity quickly to reduce heat loss problems.
 - a. The cross section area of a runner need to be enlarged compared to the sprue exit to provide sufficient friction and hence to slow down the melt. Care must be taken to not expend this area too much. Else, the runner will be incompletely filled resulting in surface turbulence and surface oxidation.
 - b. Taper sections as liberally as possible toward risers to help control directional solidification.
 - c. Runner extension: The first metal entering the gating system will generally be the most heavily damaged by contact with the mold medium and with air as it flows. To avoid having this metal enter the casting cavity, momentum effects can be used to carry it past the ingates into the runner extension. The ingates will then fill with the cleaner, less damaged metal that follows the initial molten metal stream. Slowing down the melt before entering the mold cavity is another function of runner extensions.
 - d. Equalizing flow through ingates: For systems with multiple ingates, flow conditions are equalized through each gate by decreasing runner cross sectional area after each ingate. By stepping down the runner after the first ingate, metal velocities and pressures at the two ingates can be equalized. This can be achieved by gradually tapering the runner to a smaller cross section along its length, but patternmaking limitations usually make it simpler to incorporate actual steps in the runner.



Applying Bernoulli's theorem to flow from a runner at two ingates for a filled system and comparing velocity and pressure at the ingates for two runner configurations

6. Gates design: A gate is a channel which connects runner with the mold cavity and through which molten metal flows to fill the mold cavity.
 - a. Size of gates: A small gate is used for a casting which solidifies slowly and vice-versa.
 - b. Location of gates: Gates should be located such that the mold cavity is filled uniformly and in a way that gives beneficial heat distribution in the casting after mold filling.
 - c. Shape of gates: The best cross-section for gates is a trapezoidal one that smoothly passes into a rectangular section at the junction of the cavity. Gates should not have any sharp edges.
 - d. To increase the ease of removal of gates from the cast part after solidification, the gates at the junction to the cavity are much reduced in thickness.
 - e. Proper relation between cross-sectional areas of the several gates, between gates and runners, and between the runners and the sprue.
 - i. Develop enlargement in the gating system to dissipate momentum effects.
 - f. According to the position in the mold, gating may be classified as:
 - i. *Top gating*: Top gating system isn't recommended as it results in a lot of erosive effect when melt stream impinges the bottom of the mold cavity and the associated splashing gives an opportunity for oxidation.
 - ii. *Parting line gating*: This practice offers the best compromise between moulding convenience and the ideal gating arrangement.
 - iii. *Bottom gating*: Bottom gating is highly recommended because the metal enters quietly and steadily through the mold, splashing and metal/mould impingement re nearly eliminated.



Methods of gating: (a) Top gating, (b) Side gating and (c) bottom gating

7. Gating ratio classification: Gating ratio is defined as the relative cross sectional areas of the sprue, runner gate and expressed particularly in the order- Sprue: Runner: Gate. Common unpressurized gating ratios are 1:2:2, 1:2:4, and 1:4:4. A typical pressurized gating ratio is 4:8:3.
 - a. *Unpressurized System*: This system has the advantage of reducing metal velocity in the gating system as it approaches and enters the casting. This is because lower velocities help encourage laminar flow.
 - b. *Pressurized system*: These systems have advantage of less size and weight, thus increasing mold yield. Mold or core erosion can happen because of high velocity and therefore is disadvantageous.

Mold filling (Pouring rules):

1. Pouring rate should be optimum.
 - a. Too slow: Flowing metal stream freezes
 - b. Too fast: Erosion and turbulence
2. Establish non-turbulent metal flow
3. Systematically fill the mold cavity with metal of minimally degraded quality.
4. Keep the sprue continuously filled during pouring.

References:

- [1] Lampman, S. "Casting Design and Performance." ASM International (2009).
- [2] Kotas, Petr. Integrated modeling of process, structures and performance in cast parts. Technical University of Denmark (DTU), 2011.
- [3] Guleypoglu, S. "Casting Process Design Guidelines." TRANSACTIONS-AMERICAN FOUNDRYMENS SOCIETY (1998): 869-876.