

II/IV B.Tech. – Mechanical Engineering

Name of the subject : PRODUCTION TECHNOLOGY

UNIT-1: Metal casting: part - 1

INTRODUCTION

Casting is a process in which molten metal flows by gravity or other force into a mold where it solidifies in the shape of the mold cavity. The term casting is also applied to the part that is made by this process.

Casting includes both the casting of ingots and the casting of shapes. The term ingot is usually associated with the primary metals industries; it describes a large casting that is simple in shape and intended for subsequent reshaping by processes such as rolling or forging.

Shape casting involves the production of more complex geometries that are much closer to the final desired shape of the part or product.

Advantages:

A variety of shape casting methods are available, thus making it one of the most versatile of all manufacturing processes. Among its capabilities and **advantages** are the following:

1. Casting can be used to create complex part geometries, including both external and internal shapes.
2. Some casting processes are capable of producing parts to net shape. No further manufacturing operations are required to achieve the required geometry and dimensions of the parts. Other casting processes are near net shape, for which some additional shape processing is required (usually machining) in order to achieve accurate dimensions and details.
3. Casting can be used to produce very large parts. Castings weighing more than 200 tons can be made.
4. The casting process can be performed on any metal that can be heated to the liquid state.
5. Some casting methods are quite suited to mass production.

There are also **disadvantages** associated with casting. These include limitations on mechanical properties, porosity, poor dimensional accuracy and surface finish for some casting processes, safety hazards to humans when processing hot molten metals, and environmental problems.

Parts made by casting processes range in size from small components weighing only a few grams up to very large products weighing tons. The list of parts (**Applications**) includes dental crowns,

jewelry, statues, wood-burning stoves, engine blocks and heads for automotive vehicles, machine frames, railway wheels, frying pans, pipes, and pump housings.

All varieties of metals can be cast, ferrous and nonferrous. Casting can also be used on other materials such as polymers and ceramics.

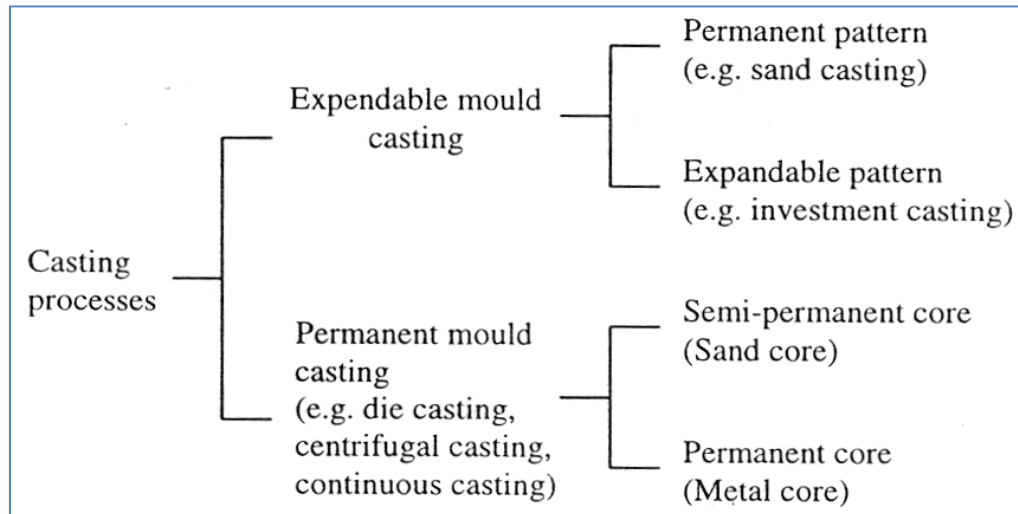


Fig. 1.1 Classification of Casting Processes

SAND CASTING PROCESS.

Definition: *Sand casting*, also known as sand-mold casting, consists of pouring molten metal into a sand mold, allowing the metal to solidify, and then breaking up the mold to remove the casting. The casting must then be cleaned and inspected, and heat treatment is sometimes required to improve metallurgical properties.

Sand casting is the most widely used casting process, accounting for a significant majority of the total tonnage cast. Nearly all casting alloys can be sand cast like metals with high melting temperatures, such as steels, nickels, and titanium. Its versatility permits the casting of parts ranging in size from small to very large and in production quantities from one to millions.

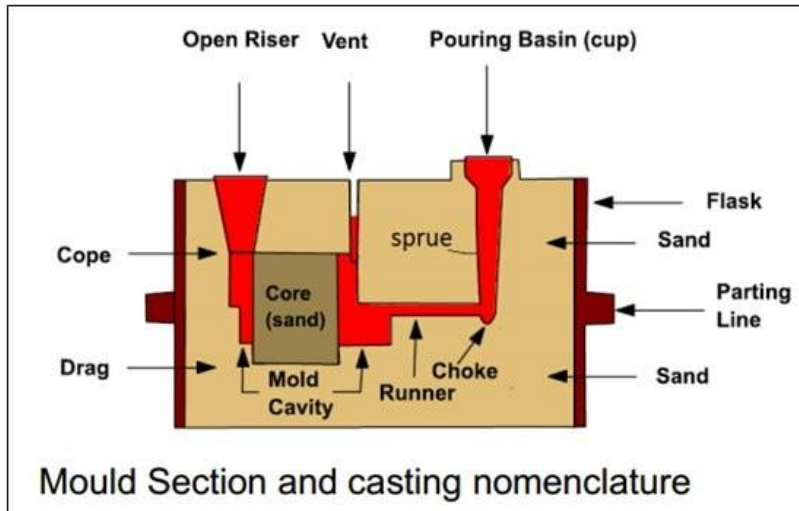


Fig.1.2 Terminology used in sand moulding.

Important casting terms (Refer Fig.1.2)

Flask: A metal or wood frame, without fixed top or bottom, in which the mould is formed. Depending upon the position of the flask in the moulding structure, it is referred to by various names such as drag – lower moulding flask, cope – upper moulding flask, cheek – intermediate moulding flask used in three piece moulding.

Pattern: It is the replica of the final object to be made. The mould cavity is made with the help of pattern.

Parting line: This is the dividing line between the two moulding flasks that makes up the mould.

Moulding sand: Sand, which binds strongly without losing its permeability to air or gases. It is a mixture of silica sand, clay, and moisture in appropriate proportions.

Facing sand: The small amount of carbonaceous material sprinkled on the inner surface of the mould cavity to give a better surface finish to the castings.

Core: A separate part of the mould, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.

Pouring basin: A small funnel shaped cavity at the top of the mould into which the molten metal is poured.

Sprue: The passage through which the molten metal, from the pouring basin, reaches the mould cavity. In many cases it controls the flow of metal into the mould.

Runner: The channel through which the molten metal is carried from the sprue to the gate.

Gate: A channel through which the molten metal enters the mould cavity.

Chaplets: Chaplets are used to support the cores inside the mould cavity to take care of its own weight and overcome the metallostatic force.

Riser: A column of molten metal placed in the mould to feed the castings as it shrinks and solidifies. Also known as “feed head”.

Vent: Small opening in the mould to facilitate escape of air and gases.

The production sequence of a sand casting is outlined in Figure 2.

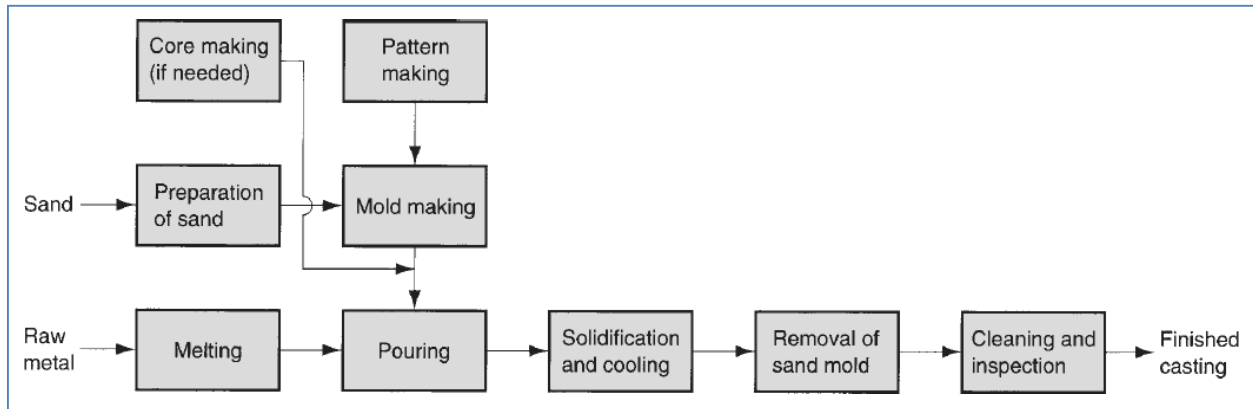


Fig.1.3 Steps in the production sequence in sand casting.

The steps include not only the casting operation but also pattern making and mold making.

The cavity in the sand mold is formed by packing sand around a **pattern** (an approximate duplicate of the part to be cast), and then removing the pattern by separating the mold into two halves. The mold also contains the gating and riser system. In addition, if the casting is to have internal surfaces (e.g., hollow parts or parts with holes), a **core** must be included in the mold. Since the mold is sacrificed to remove the casting, a new sand mold must be made for each part that is produced.

Advantages

- Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized.
- Possible to cast practically any material: ferrous or non-ferrous.
- The necessary tools required for casting moulds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process.
- There are certain parts (like turbine blades) made from metals and alloys that can only be processed this way. Turbine blades: Fully casting + last machining.
- Size and weight of the product is not a limitation for the casting process.

Limitations

- Dimensional accuracy and surface finish of the castings made by sand casting processes are a limitation to this technique.
- Many new casting processes have been developed which can take into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting

process, investment casting process, vacuum-sealed moulding process, and shell moulding process.

- Metal casting is a labour intensive process.
- Automation is expensive.

Steps in making sand castings

The six basic steps in making sand castings are, (i) Pattern making, (ii) Core making, (iii) Moulding, (iv) Melting and pouring, (v) Cleaning.

Pattern making - Pattern: Replica of the part to be cast and is used to prepare the mould cavity. It is the physical model of the casting used to make the mould. Pattern is made of wood plastic or metal.

The mould is made by packing some readily formed aggregate material, such as moulding sand, surrounding the pattern. When the pattern is withdrawn, its imprint provides the mould cavity. This cavity is filled with metal to become the casting.

If the casting is to be hollow, additional patterns called ‘cores’, are used to form these cavities.

Core making

Cores are placed into a mould cavity to form the interior surfaces of castings. Thus the void space is filled with molten metal and eventually becomes the casting.

Moulding

Moulding is nothing but the mould preparation activities for receiving molten metal.

Moulding usually involves:

- (i) preparing the consolidated sand mould around a pattern held within a supporting metal frame,
- (ii) Removing the pattern to leave the mould cavity with cores.

Mould cavity is the primary cavity.

The mould cavity contains the liquid metal and it acts as a negative of the desired product.

The mould also contains secondary cavities for pouring and channeling the liquid material in to the primary cavity and will act a reservoir, if required.

Melting and Pouring

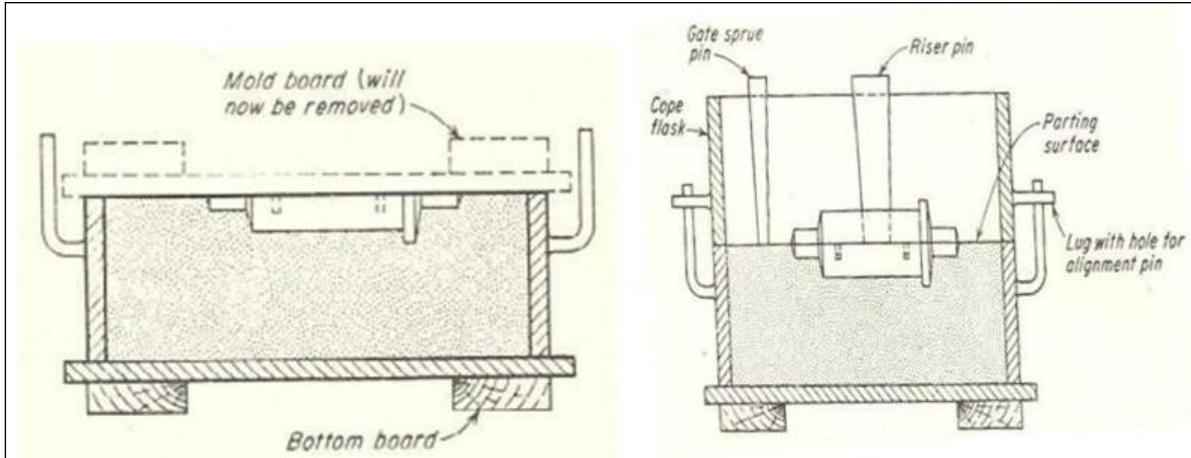
The preparation of molten metal for casting is referred to simply as melting. The molten metal is transferred to the pouring area where the moulds are filled.

Cleaning

Cleaning involves removal of sand, scale, and excess metal from the casting. Burned-on sand and scale are removed to improve the surface appearance of the casting. Excess metal, in the form of fins, wires, parting line fins, and gates, is removed. Inspection of the casting for defects and general quality is performed.

Making a simple sand mould

- 1) The drag flask is placed on the board
- 2) Dry facing sand is sprinkled over the board
- 3) Drag half of the pattern is located on the mould board. Dry facing sand will provide a non-sticky layer.
- 4) Molding sand is then poured in to cover the pattern with the fingers and then the drag is filled completely
- 5) Sand is then tightly packed in the drag by means of hand rammers. Peen hammers (used first close to drag pattern) and butt hammers (used for surface ramming) are used.
- 6) The ramming must be proper i.e. it must neither be too hard or soft. Too soft ramming will generate weak mould and imprint of the pattern will not be good. Too hard ramming will not allow gases/air to escape and hence bubbles are created in casting resulting in defects called 'blows'. Moreover, the making of runners and gates will be difficult.
- 7) After the ramming is finished, the excess sand is leveled/removed with a straight bar known as strike rod.
- 8) Vent holes are made in the drag to the full depth of the flask as well as to the pattern to facilitate the removal of gases during pouring and solidification. Done by vent rod.
- 9) The finished drag flask is now made upside down exposing the pattern.
- 10) Cope half of the pattern is then placed on the drag pattern using locating pins. The cope flask is also located with the help of pins. The dry parting sand is sprinkled all over the drag surface and on the pattern.
- 11) A sprue pin for making the sprue passage is located at some distance from the pattern edge. Riser pin is placed at an appropriate place.
- 12) Filling, ramming and venting of the cope is done in the same manner.



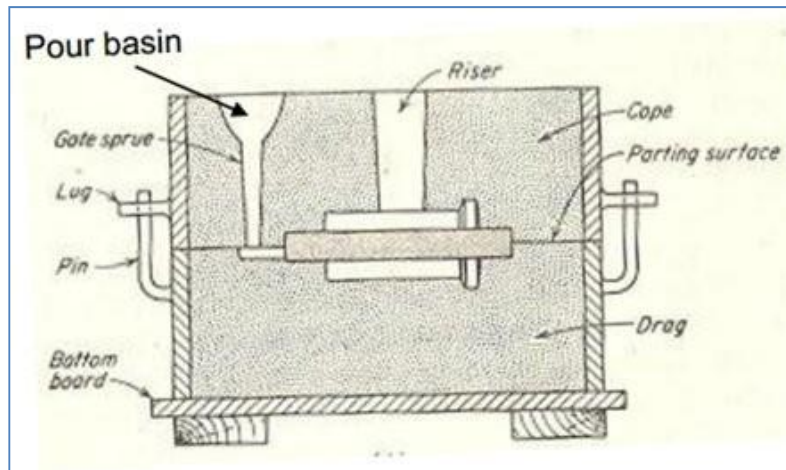
13) The sprue and riser are removed and a pouring basin is made at the top to pour the liquid metal.

14) Pattern from the cope and drag is removed.

15) Runners and gates are made by cutting the parting surface with a gate cutter. A gate cutter is a piece of sheet metal bent to the desired radius.

16) The core for making a central hole is now placed into the mould cavity in the drag. Rests in core prints.

17) Mould is now assembled and ready for pouring.



13) The sprue and riser are removed and a pouring basin is made at the top to pour the liquid metal.

14) Pattern from the cope and drag is removed.

15) Runners and gates are made by cutting the parting surface with a gate cutter. A gate cutter is a piece of sheet metal bent to the desired radius.

16) The core for making a central hole is now placed into the mould cavity in the drag. Rests in core prints.

17) Mould is now assembled and ready for pouring. Pour

PATTERNS AND CORES

A pattern is the replica of the final object to be produced by casting with some modifications in shape and dimensions. The modifications include pattern allowances core prints and handling aids for moving the casting.

Sand casting requires a *pattern* - a full-sized model of the part, enlarged to account for shrinkage and machining allowances in the final casting. **Materials used to make patterns** include wood, plastics, and metals. Wood is a common pattern material because it is easily shaped. Its disadvantages are that it tends to warp, and it is abraded by the sand being compacted around it, thus limiting the number of times it can be reused. Metal patterns are more expensive to make, but they last much longer. Plastics represent a compromise between wood and metal. Selection of the appropriate pattern material depends to a large extent on the total quantity of castings to be made.

Types of pattern

There are various types of patterns, as illustrated in Figure 3.

a) Solid or single piece pattern: The simplest is made of one piece, called a solid pattern-same geometry as the casting, adjusted in size for shrinkage and machining. Although it is the easiest pattern to fabricate, it is not the easiest to use in making the sand mold. Determining the location of the parting line for a solid pattern can be a problem, and incorporating the gating system and sprue depend on the judgment and skill of the foundry worker. So, solid patterns are generally limited to very low production quantities.

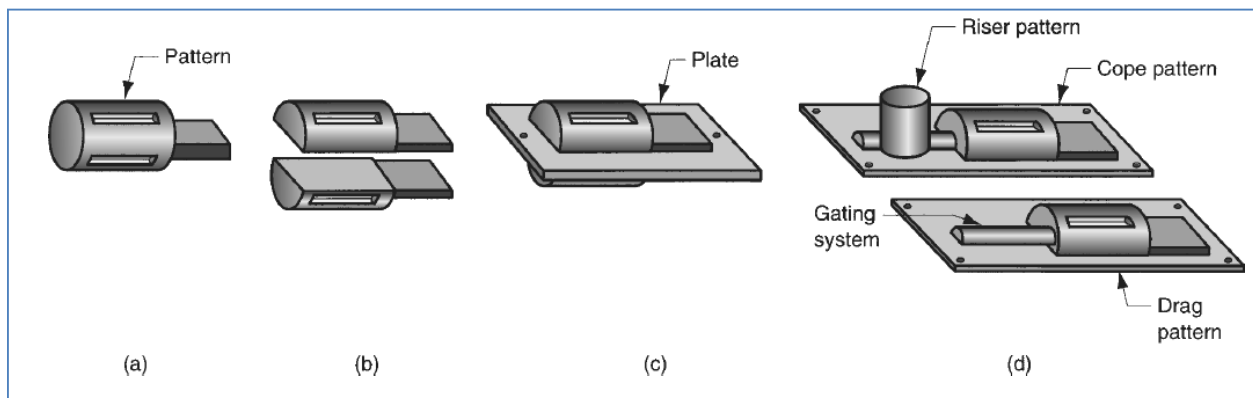


Fig.1.4 Types of patterns used in sand casting: (a) solid pattern, (b) split pattern, (c) match-plate pattern, and (d) cope-and-drag pattern.

b) Split patterns: It consist of two pieces, dividing the part along a plane coinciding with the parting line of the mold. Split patterns are appropriate for complex part geometries and moderate production quantities. The parting line of the mold is predetermined by the two pattern halves, rather than by operator judgment.

c) match-plate patterns: In match-plate patterns, the two pieces of the split pattern are attached to opposite sides of a wood or metal plate. Holes in the plate allow the top and bottom (cope and drag) sections of the mold to be aligned accurately.

d) Cope-and-drag patterns: These are similar to match-plate patterns except that split pattern halves are attached to separate plates, so that the cope and drag sections of the mold can be fabricated independently, instead of using the same tooling for both. Part (d) of the figure 2 includes the gating and riser system in the cope-and-drag patterns. It is also called gated pattern. For higher production quantities, match-plate patterns or cope-and-drag patterns are used.

Skeleton Pattern: This consists of frame of wood representing the interior and exterior forms. Strickles (like strike off bars) are used to remove excess sand which is purposely rammed with extra thickness than required for desired mold surfaces.

CORE: Patterns define the external shape of the cast part. If the casting is to have internal surfaces, a core is required. A core is a full-scale model of the interior surfaces (holes or pockets) of the part. It is inserted into the mold cavity prior to pouring, so that the molten metal will flow and solidify between the mold cavity and the core to form the casting's external and internal surfaces. The core is usually made of core sand (different from moulding sand), compacted into the desired shape. As with the pattern, the actual size of the core must include allowances for shrinkage and machining.

Chaplets: These are the metallic supports used to hold and position the core in the mold cavity during pouring. Chaplets are made of a metal with a higher melting temperature than the casting metal. For example, steel chaplets would be used for cast iron castings. On pouring and solidification, the chaplets become bonded into the casting. A possible arrangement of a core in a mold using chaplets is shown in Figure 3. The portion of the chaplet protruding from the casting is subsequently cut off.

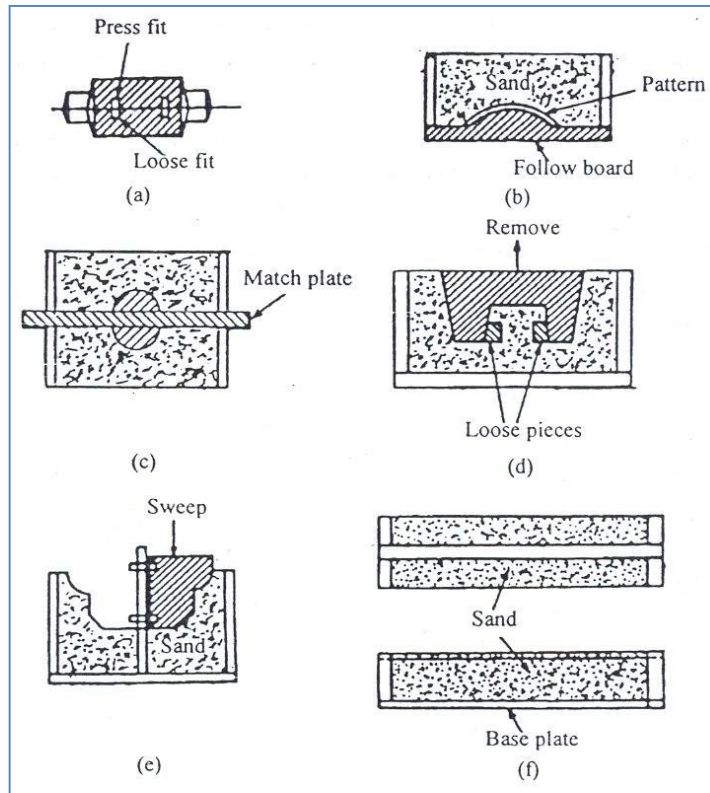
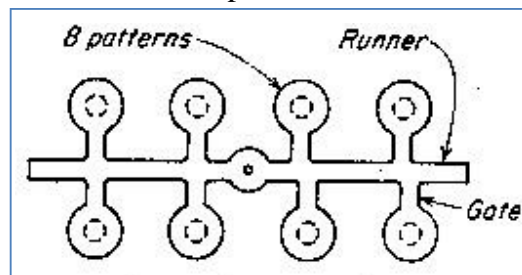
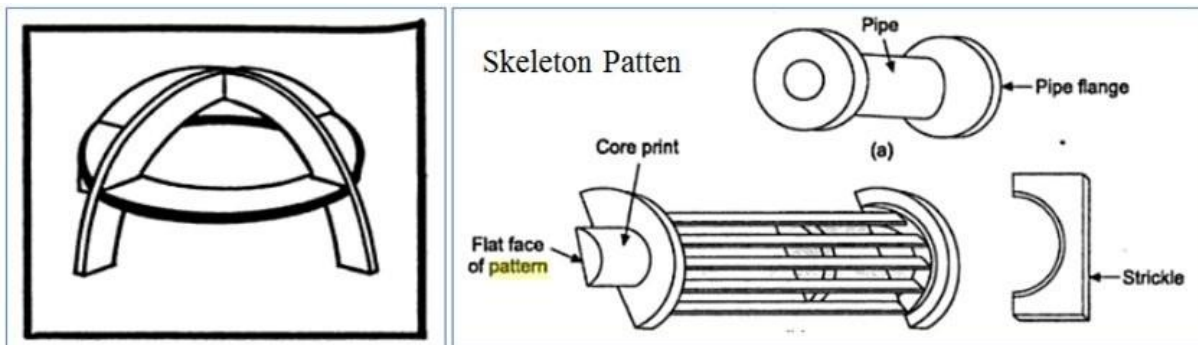


Fig.1.5 a) Split piece, b) Follow board, Match plate, d) Loose piece, e) Sweep, f) Skeleton pattern.



g) Gated pattern for making eight small patterns.



h) Skeleton Pattern

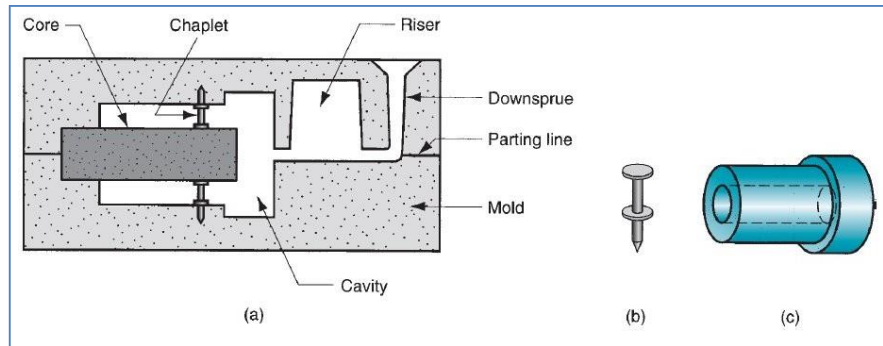


Fig.1.6 (a) Core held in place in the mold cavity by chaplets, (b) possible chaplet design, and (c) Casting with internal cavity.

Pattern allowances

The pattern and the part to be made are not same. They differ in the following aspects.

1. A pattern is always made larger than the final part to be made. The excess dimension is known as Pattern allowance. Pattern allowance => shrinkage allowance, machining allowance
2. Shrinkage allowance: will take care of contractions of a casting which occurs as the metal cools to room temperature.

Liquid Shrinkage: Reduction in volume when the metal changes from liquid state to solid state. Riser which feed the liquid metal to the casting is provided in the mould to compensate for this.

Solid Shrinkage: Reduction in volume caused when metal loses temperature in solid state. Shrinkage allowance is provided on the patterns to account for this. Shrink rule is used to compensate solid shrinkage depending on the material contraction rate.

Cast iron: One foot (=12 inches) on the 1/8-in-per-foot shrink rule actually measures 12-1/8 inches. So, 4 inch will be 4-1/24 inch for considering shrinkage allowance.

The shrinkage allowance depends on the coefficient of thermal expansion of the material (α). A simple relation indicates that higher the value of α , more is the shrinkage allowance.

For a dimension 'l', shrinkage allowance is $\alpha l (T_f - T_0)$. Here T_f is the freezing temperature and T_0 is the room temperature.

Patterns are made by using shrink rules which take into account the shrinkage allowance (1' will be 1' 3/16'' in a shrink rule for brass)

Cast iron	0.8–1.0%	($\frac{1}{10}$ – $\frac{1}{8}$ in./ft.)	
Steel	1.5–2.0%	($\frac{3}{16}$ – $\frac{1}{4}$ in./ft.)	
Aluminum	1.0–1.3%	($\frac{1}{8}$ – $\frac{5}{32}$ in./ft.)	
Magnesium	1.0–1.3%	($\frac{1}{8}$ – $\frac{5}{32}$ in./ft.)	
Brass	1.5%	($\frac{3}{16}$ in./ft.)	

Fig.1.7 Various allowances incorporated into a casting pattern

Machining allowance: will take care of the extra material that will be removed to obtain a finished product. In this the rough surface in the cast product will be removed. The machining allowance depends on the size of the casting, material properties, material distortion, finishing accuracy and machining method. For internal surfaces, the allowances should be negative.

Draft allowance: All the surfaces parallel to the direction in which the pattern will be removed are tapered slightly inward to facilitate safe removal of the pattern. This is called ‘draft allowance’. General usage: External surfaces; Internal surfaces, holes, pockets.

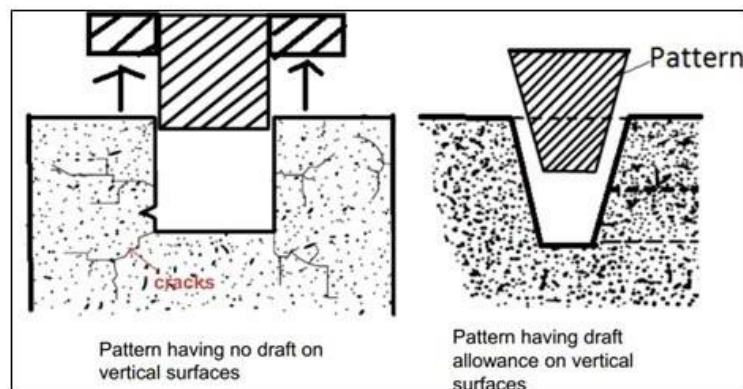


Fig. 1.8 Draft allowance

Core and core print: - Cores are used to make holes, recesses etc. in castings - So where coring is required, provision should be made to support the core inside the mould cavity. Core prints are used to serve this purpose. The core print is an added projection on the pattern and it forms a seat in the mould on which the sand core rests during pouring of the mould. The core print must be of adequate size and shape so that it can support the weight of the core during the casting operation.

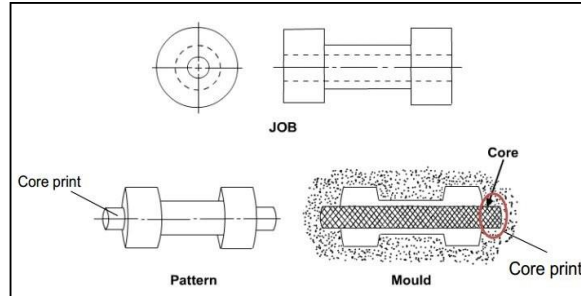


Fig.1.9 Core print and Core positioning.

Distortion allowance (camber)

Vertical edges will be curved or distorted. This is prevented by shaped pattern converge slightly (inward) so that the casting after distortion will have its sides vertical - The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different sections of the casting and hindered contraction. Prevention: - providing sufficient machining allowance to cover the distortion affect - Providing suitable allowance on the pattern, called camber or distortion allowance (inverse reflection).

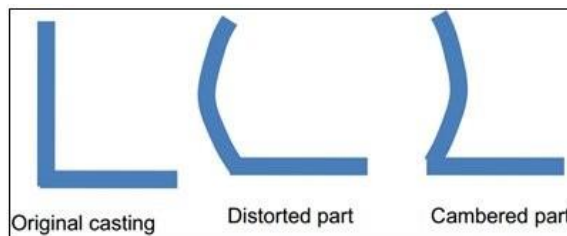


Fig.1.10 Effect of distortion

Pattern materials

For most expendable mould casting techniques a pattern is required.

Pattern material depends on number of castings to be made, metal being cast, process being used, size and shape, dimensional precision required

Wood is Cheap, easily machined but prone to warping, swelling (moisture), unstable, wears. Used for small runs. Different woods for pattern making are white pine, sugar pine. The wood should be straight grain, light, easy to work, little tendency to develop crack and warp. More durable wood is Mahogany.

Metal - more expensive but stable, accurate, durable. Typically aluminium, cast iron or steel. Either cast then machined or machined directly (e.g. NC-machining). Large runs and elevated pressure and/or temperature moulding process. When metal pattern are cast from the wooden master pattern, double shrinkage allowance must be provided on the wooden master pattern. Metal such as cast iron or aluminium are used for making metallic patterns.

Plastic - Epoxy and Polyurethane. More common now. Easy preparation, stable and durable relative to wood. Cast & machined, easily repaired, can be reinforced/backed.

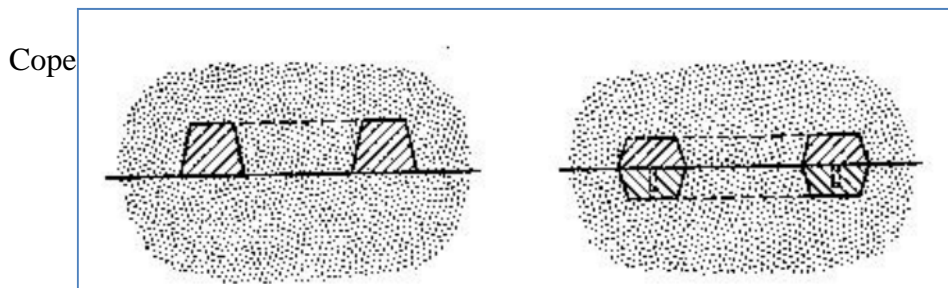
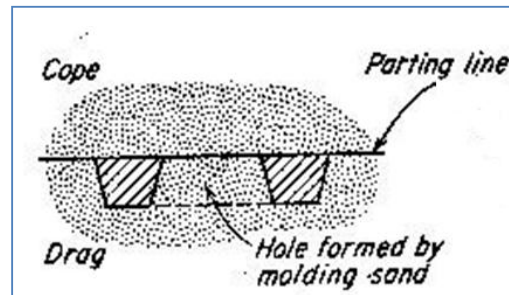
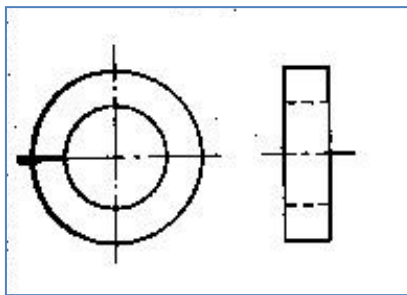
Expendable (single-use) patterns:

Wax - used for investment casting. Wax formulated for melting point, viscosity, ash residue etc. Melted out (mostly) before casting

EPS - Expanded PolyStyrene. Pre-expanded beads blown into mould, heated (steam) to completely fill mould and bond beads. Pattern is burnt out by molten metal. Carbon film possible.

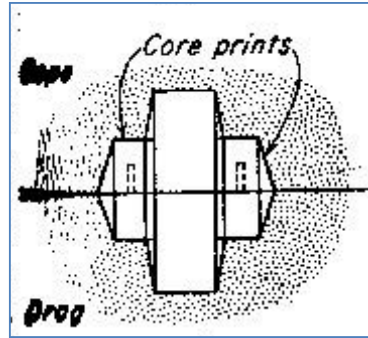
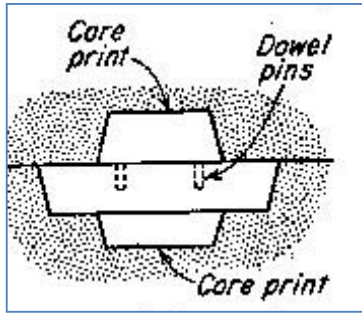
Different ways for making a casting mold

Case i)



Flat back pattern can be used for this. In this after moulding, the mold cavity is either in the drag side or in cope side or in both. The hole is formed by the molding sand. The outside edge around the flat back is the parting line and it is the starting place for draft. This is the simplest and easiest method.

Case ii)



Using a dry sand core to obtain the core and this is split pattern. The axis of the hole (and core print) is vertical in first case. The second case is same as first, except that the hole axis is horizontal.

Gating design

A good gating design should ensure proper distribution of molten metal without excessive temperature loss, turbulence, gas entrapping and slags. If the molten metal is poured very slowly, since time taken to fill the mould cavity will become longer, solidification will start even before the mould is completely filled. This can be restricted by using super-heated metal, but in this case solubility will be a problem. If the molten metal is poured very faster, it can erode the mould cavity. So gating design is important and it depends on the metal and molten metal composition. For example, aluminium can get oxidized easily. Gating design is classified mainly into two (modified: three) types: Vertical gating, bottom gating, horizontal gating.

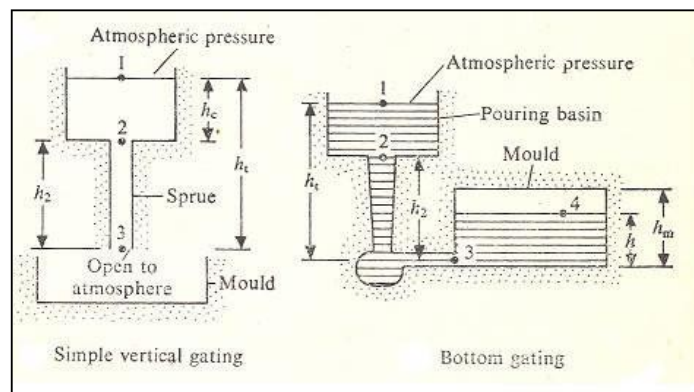


Fig. 1.11 Advantage of tapered sprue

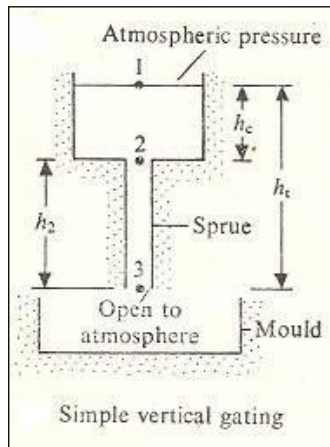
Vertical gating: the liquid metal is poured vertically, directly to fill the mould with atmospheric pressure at the base end.

Bottom gating: molten metal is poured from top, but filled from bottom to top. This minimizes oxidation and splashing while pouring.

Horizontal gating is a modification of bottom gating, in which some horizontal portions are added for good distribution of molten metal and to avoid turbulence.

Analysis of pouring and filling up mould Top

gating:



For analysis we use energy balance equation like Bernoulli's equation

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} + F_1 = h_3 + \frac{p_3}{\rho g} + \frac{v_3^2}{2g} + F_3$$

Assuming $p_1 = p_3$ and level at 1 is maintained constant, so $v_1 = 0$; frictional losses are neglected. The energy balance between point 1 and 3 gives,

$$gh_t = v_3^2 / 2 \quad v_3 = \sqrt{2gh_t}$$

Here v_3 can be referred as velocity at the sprue base or say gate, v_g

Continuity equation: Volumetric flow rate, $Q = A_1v_1 = A_3v_3$

Above two equations, v_3 and Q , say that sprue should be tapered.

As the metal flows into the sprue opening, it increases in velocity and hence the cross-sectional area of the channel must be reduced. Otherwise, as the velocity of the flowing molten metal increases toward the base of the sprue, air can be aspirated into the liquid and taken into the mould cavity. To prevent this condition, the sprue is designed with a taper, so that the volume flow rate, $Q = Av$ remains the same at the top and bottom of the sprue.

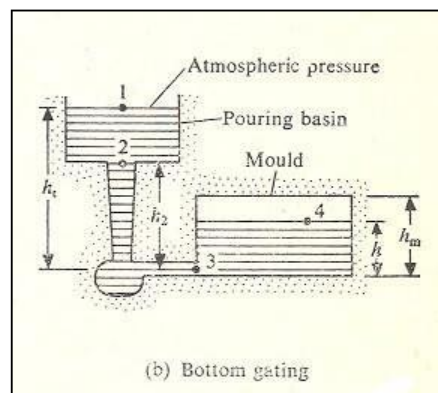
The mould filling time is given by

$$t_f = \frac{V}{Q} = \frac{V}{A_g v_3}$$

A_g = cross-sectional area of gate; V = volume of mould

Note: This is the minimum time required to fill the mould cavity. Since the analysis ignores friction losses and possible constriction of flow in the gating system; the mould filling time will be longer than what is given by the above equation.

(b) Bottom gating



$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} + F_1 = h_3 + \frac{p_3}{\rho g} + \frac{v_3^2}{2g} + F_3$$

Apply Bernoulli's eqn. between points 1 and 3 and between 3 and 4,

$$v_g = v_3 = \sqrt{2g(h_t - h)}$$

Effective head

Assuming in the mould the height moves up by " dh " in a time " dt "; A_m and A_g are mould area and gate area, then

$$A_m dh = A_g v_g dt$$

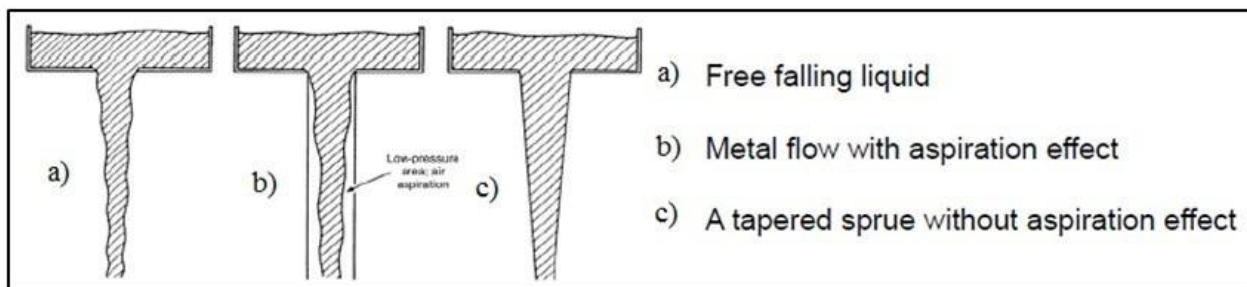
Combining above two eqns., we get

$$\frac{1}{\sqrt{2g}} \frac{dh}{\sqrt{h_t - h}} = \frac{A_g}{A_m} dt$$

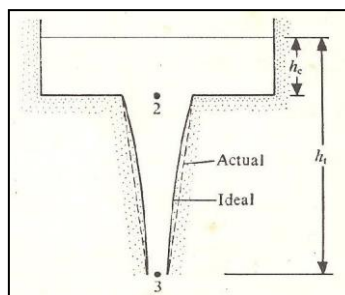
$$\frac{1}{\sqrt{2g}} \int_0^{h_m} \frac{dh}{\sqrt{h_t - h}} = \frac{A_g}{A_m} \int_0^{t_f} dt \Rightarrow t_f = \frac{A_m}{A_g} \frac{1}{\sqrt{2g}} 2(\sqrt{h_t} - \sqrt{h_t - h_m})$$

Aspiration effect

Aspiration effect: entering of gases from baking of organic compounds present in the mould into the molten metal stream. This will produce porous castings. **Pressure anywhere in the liquid stream should not become negative.**

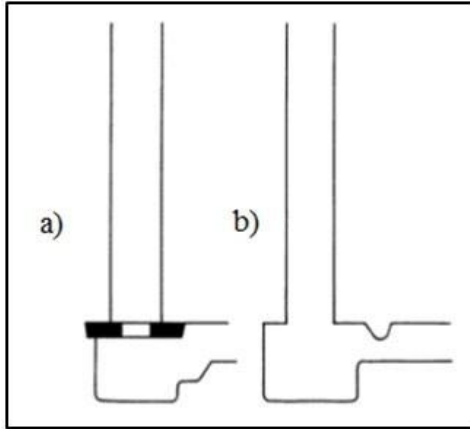


Ideal and actual profiles of sprue

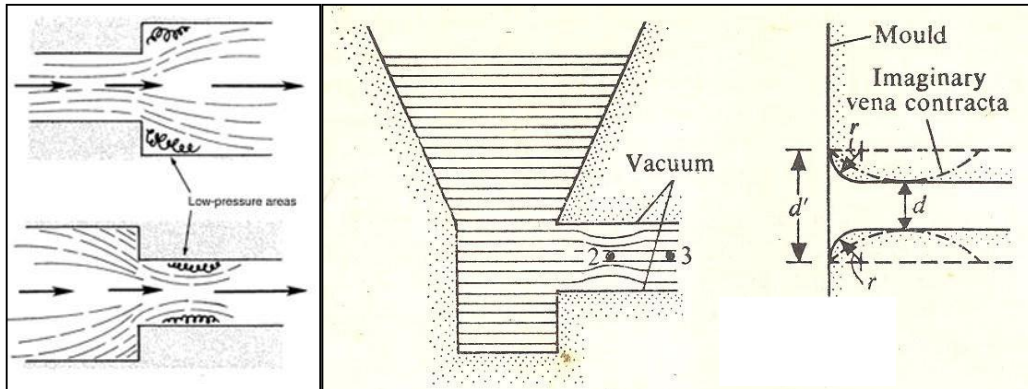


Approximating tapered sprue using choke mechanism

(a)Choke core, (b) Runner choke In many high production casting systems, tapered sprue will not be provided. Instead it is compensated by having chokes at the end of sprue or runner.

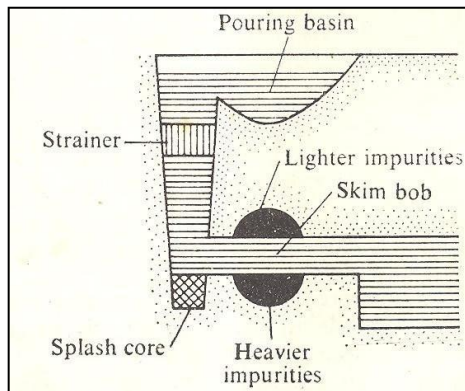


Sudden change in flow direction



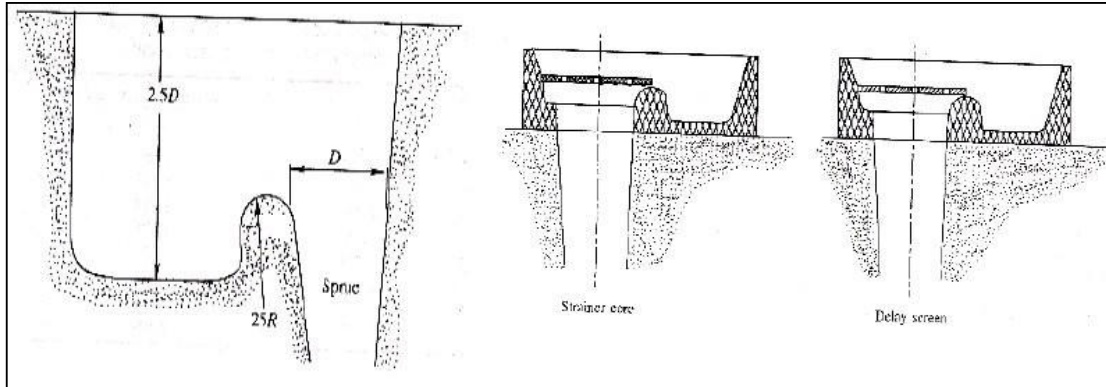
A sharp change in flow direction is avoided by designing the mould to fit vena-contracta.

Preventing impurities and turbulence in casting



The items provided in the gating system to avoid impurities and turbulence are:

Pouring basin: This reduces the eroding force of the liquid metal poured from furnace. This also maintains a constant pouring head. Experience shows that pouring basin depth of 2.5 times the sprue entrance diameter is enough for smooth metal flow.



Delay screen/Strainer core: A delay screen is a small piece of perforated screen placed on top of the sprue. This screen actually melts because of the heat from the metal and this delays the entrance of metal into the sprue, maintaining the pouring basin head. This also removes dross in the molten metal. Strainer core is a ceramic coated screen with many small holes and used for same purpose.

Splash core: provided at the end of the sprue length which reduces the eroding force of the liquid metal

Skim bob: this traps lighter and heavier impurities in the horizontal flow

Gating ratios

Gating ratio: sprue area : runner area : gate area

Non-pressurized: has choke at the bottom of the sprue base, has total runner area and gate areas higher than the sprue area. No pressure is present in the system and hence no turbulence. But chances of air aspiration is possible. Suitable for Al and Mg alloys.

In this, Gating ratio = 1 : 4 : 4

Pressurized: Here gate area is smallest, thus maintaining the back pressure throughout the gating system. This backpressure generates turbulence and thereby minimizes the air aspiration even when straight sprue is used. This is not good for light alloys, but good for ferrous castings. In this, Gating ratio = 1 : 2 : 1.

Gating ratios used in practice

	I 1 2 ' 4
z\lumini um brunze	I: fi: 6
Briss	I 1 2 8 h: 4.8
	I : I : 1
	1 . t: 1 %: 1
IJuctife irun	1.15 : 1.1 : 1
	1 . * ? : 2 , G7: 1
	* I . b : 1
I\Jalleahlcirun	1 : 2 : 9.5
	[. 5 : 1 : 2.fi
Steels	2 : 1 : 4.9
	I 1 ! 7
	1 : 2 : 1
	1 : 2 : 1,5
	: 3 : 3
	1.6 : 1.3 : 1

