Chapter 6

Casting Process

INTRODUCTION

Manufacture of a machine part by heating a metal or alloy above its melting point and pouring the liquid metal/alloy in a cavity approximately of same shape and size as the machine part is called casting process. After the liquid metal cools and solidifies, it acquires the shape and size of the cavity and resembles the finished product required. The department of the workshop, where castings are made is called foundry.

The manufacture of a casting requires:

(*a*) Preparation of a pattern,

(*b*) Preparation of a mould with the help of the pattern,

(*c*) Melting of metal or alloy in a furnace,

(*d*) Pouring of molten metal into mould cavity,

(*e*) Breaking the mould to retrieve the casting,

(*f*) Cleaning the casting and cutting off risers, runners etc., (this operation is called 'fettling'), and

(*g*) Inspection of casting.

Castings are made in a large number of metals and alloys, both ferrrous and non-ferrous. Grey cast iron components are very common; steel castings are stronger and are used for components subject to higher stresses. Bronze and brass castings are used on ships and in marine environment, where ferrous items will be subjected to heavy corrosion. Aluminium and aluminium-magnesium castings are used in automobiles. Stainless steel castings are used for making cutlery items.

Casting is an economical way of producing components of required shape either in small lots or in larger lots. However, castings are less strong as compared to wrought components produced by processes such as forging etc. However castings offer the possibility of having slightly improved properties in certain part of the casting by techniques such as use of chill etc. In casting process, very little metal is wasted.

PATTERNS

Patterns are replicas of the casting required. It is similar in shape and size to the final product, but not exactly. Usually, the mould is prepared in wet sand, to which some binder is added to hold sand particles together. The pattern is then withdrawn from inside the sand mould in such a manner that the impression/cavity made in the mould is not damaged or broken in anyway. Finally molten metal is poured into this cavity and allowed to solidify and cool down to room temperature.

PATTERN ALLOWANCES

Since most metals shrink in volume, when solidifying from liquid state and again on cooling, it is obvious, that the pattern should be made slightly larger than the size of finished casting. This difference in size of the pattern is called shrinkage allowance. For cast iron, this allowance is 1% and for aluminium, it is about 1.6%.

On many occasions, castings produced in the foundry shop are machined subsequently. The object of machining is to get exact sizes and better surface finish on the component. If such is the case, a layer of 1.5–2.5 mm thick material has to be provided all round the casting. This is done by making the pattern suitably bigger than the casting. This increase in size of pattern is called "machining allowance".

Another important allowance provided on patterns is called draft allowance. It facilitates withdrawal of pattern from the mould. It is provided on vertical surfaces. The idea is to give an inclination of 2–3 degrees to vertical surfaces, so that while lifting the pattern, the upper surface is wider and withdrawing the pattern with draft provided will not damage the sand mould. On inner vertical surfaces, draft is provided in such a way that top surface is narrower and bottom portion of pattern is wider.

Apart from the above allowances, some other allowances are sometimes given to compensate for inherent distortion or bending of castings. Sharp corners and bends are also radiusized while making a pattern.

Patterns are usually made of good quality wood. Wood is easy to work, acquires good smooth surface and properly seasoned wood retains its size. It is also relatively cheap and abundant. However, if a very large number of castings are required, metal patterns may be used. Usually, they are made of aluminium-magnesium alloys.

TYPES OF PATTERNS

(*i*) **Solid or single piece pattern:** Such patterns are made in one piece and are suitable only for very simple castings. There is no provision for runners and risers etc. Moulding can be done either in the foundry floor (called pit moulding) or in a moulding box. There is no difficulty in withdrawing the pattern from the mould as the broadest portion of the pattern is at the top. As an example, if a cylindrical pin with a circular head has to be cast, a one piece pattern shown in Fig. 6.1 will be adequate.

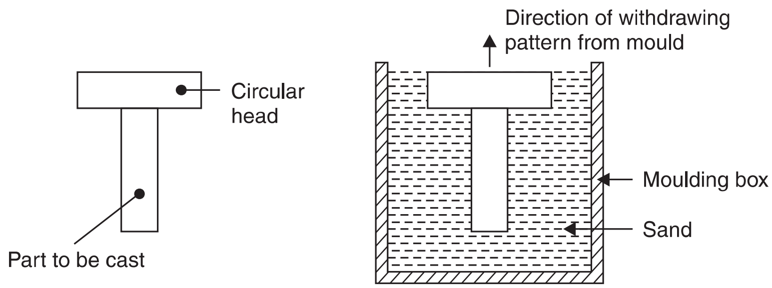

Fig. 6.1

(*ii*) **Split pattern:** It is not practical to have one piece pattern for parts of complicated shapes, because it would not be possible to withdraw the pattern from the mould. For example, if a circular head was added to the bottom of the pin shown in Fig. 6.1, it would make it necessary to go in for a split pattern as shown in Fig. 6.2.

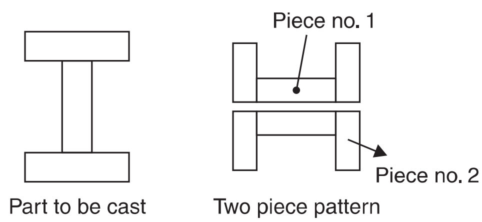

Fig. 6.2

One-half of the impression in the mould will be made by using piece no. 1 in one moulding box and the other half of the impression will be made by using piece no. 2 in a second moulding box. After withdrawing the pattern halves from the respective moulding boxes, the two boxes will be assembled and clamped together, so that the complete impression is available for pouring the metal.

The two pattern halves are provided with locating dowels, so that one-half may sit on the other half in the exact position required with no mismatch. Also two tapped holes are provided on the flat mating surface of each part. These tapped holes are used to provide a grip to lift the pattern halves from the sand without damaging the mould-impression.

The line along which the pattern is divided into halves is called "parting line" and it usually follows the broadest cross-section of the casting. Deciding where the parting line should be is a matter of considerable skill and experience.

Some of the more complicated castings may require pattern to be split in three or even more pieces.

(*iii*) **Loose piece pattern:** In some cases, the casting may have small projections or overhanging portions. These projections make it difficult to withdraw the pattern from the mould. Therefore these projections are made as loose pieces. They are loosely attached to the main part of the pattern and the mould is made in the usual way.

When the main pattern is withdrawn from the mould, the loose pieces slip off and remain behind in the mould. After removing the main body of the pattern, the loose pieces are taken out by first moving them laterally and then lifting them through the space vacated by the main pattern. The method is illustrated in Fig. 6.3.

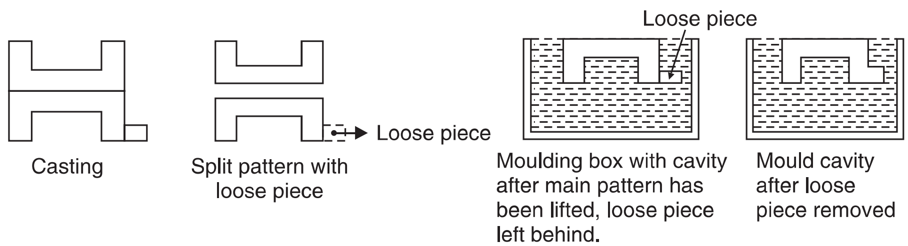

Fig. 6.3

(*iv*) **Match plate pattern:** Match plate is a metal plate, usually made of aluminium. The two halves of the split pattern are mounted on this match plate one on either side. While fixing them to the match plate, care is taken so that there is no mismatch. These patterns are used in conjunction with mechanically operated moulding machines. Bottom side of match plate pattern is used for making the bottom half of the mould impression in one moulding box (known as the drag). The upper side of the match plate pattern is used for making the mould impression in another moulding box. Finally, the two moulding boxes are kept on top of each other, the bottom box is known as the drag, whereas the top one is called the cope.

(*v*) **Gated patterns:** Sometimes alongwith the pattern for the casting, another portion is added so that when the impression is made in the moulding box, the cavity contains a shallow channel along with the main cavity for the object to be cast. This channel will be used for feeding molten metal into the main cavity and is known as the "gate". Such patterns where provision for gating has been made are called gated patterns. It removes the necessity of making a gate separately.

(*vi*) Other pattern types include skeleton pattern, sweep pattern and segmental pattern etc. In these patterns, the full pattern is not made and the mould is completed with an improvised pattern. This is done to reduce the cost of pattern making. This procedure is resorted to, if only one or two moulds are to be made.

MOULDING SAND AND ITS PROPERTIES

In foundries, sand is used for making moulds. Natural sand found on the bed and banks of rivers provides an abundant source, although high quality silica sand is also mined. Sand is chemically SiO_2^- silicon dioxide in granular form. Ordinary river sand contains a contain percentage of clay, moisture, non-metallic impurities and traces of magnesium and calcium salts besides silica grains. This sand, after suitable treatment, is used for mould making. A good, well prepared moulding sand should have the following properties:

(*i*) Refractoriness *i.e.,* it should be able to with stand high temperatures.

(*ii*) Permeability *i.e.*, ability to allow gases, water vapour and air to pass through it.

(*iii*) Green sand strength *i.e.*, when a mould is made with moist sand, it should have sufficient strength, otherwise mould will break.

(*iv*) Good flowability *i.e.,* when it is packed around a pattern in a moulding box, it should be able to fill all nooks and corners, otherwise the impression of pattern in mould would not be sharp and clear.

(*v*) Good collapsibility *i.e.,* it should collapse easily after the casting has cooled down and has been extracted after breaking the mould. It is particularly important in case of core making.

(*vi*) Cohesiveness *i.e.,* ability of sand grains to stick together. Without cohesiveness, the moulds will lack strength.

(*vii*) Adhesiveness *i.e.,* ability of sand to stick to other bodies. If the moulding sand does not stick to the walls of moulding box, the whole mould will slip through the box.

Properties like permeability, cohesiveness and green strength are dependent upon size and shape of sand grains, as also upon the binding material and moisture content present in sand. Clay is a natural binder. Chemical binders like bentonite are sometimes added if clay content in natural sand is not enough.

Standard tests have been devised by foundry men to determine properties of sand. Generally fresh moulding sand prepared in the foundry has the following composition:

Silica	75% (approx.)
Clay	10–15%
Bentonite	2–5% (as required)
Coal dust	5–10%
Moisture	6–8%

Core sand has oil as the main binding material. A core gets surrounded by molten metal which causes the oil to vaporise. This increases collapsibility of sand and makes it easy to remove sand from the holes in the casting.

MOULD MAKING TECHNIQUE

Mould making is a very skilled operation. We shall describe, step by step, the procedure for making a mould for a split pattern.

Step 1: Place bottom half of the split pattern on a flat moulding board, with the parting surface face downwards. Sprinkle some parting sand on the pattern and the moulding board. Parting sand is silica sand without any clay or binding material. Then place a moulding box to enclose the pattern.

Step 2: Spread facing sand to cover all parts of the pattern up to a depth of 20–25 mm. Facing sand is freshly prepared moulding sand. Fill up the remaining space left in the moulding box with backing sand. Backing sand is prepared by reconditioning the previously used foundry sand which is always available on the foundry floor. Use of backing sand reduces the requirement of facing sand, which is quite costly.

Step 3: Next, the sand in the moulding box is rammed with a special tool. Ramming means pressing the sand down by giving it gentle blows. Sand should be packed in the moulding box tightly but not too tightly. If as a result of ramming, the level of sand goes down in the box, more sand should be filled in and rammed. Then with a trowel, level the sand lying on the top of the mould box. Next take a venting tool (it is a long thick needle), make venting holes in the sand taking care that they are not so deep as to touch the pattern. This moulding box will form the lower box, and is called “drag”.

Step 4: Now turn over the moulding box gently and let it rest on some loose sand after levelling the foundry floor. Place the top half of split pattern in correct relative position on the flat surface of the bottom half of the pattern. Place another empty moulding box on the top of first moulding box (*i.e.*, drag) and clamp them temporarily. Sprinkle some parting sand upon the exposed surface of the top half of pattern and the surrounding sand. Cover the pattern in 20–25 mm deep facing sand. Place two taper pins at suitable places, where runner and riser are to be located. Full up the box with backing sand, pack in sand with ramming tool, level sand and make venting holes. Remove taper pins and make room on foundry floor, next to the drag box, for keeping the “cope” as the top box is called Unclamp the moulding boxes, lift ‘cope’ and place it down on its back. Now the flat parting surface of both parts of the split pattern can be seen one in each box.

Step 5: In order to lift the patterns from cope and the drag, locate the tepped holes on the flat surface and screw in a lifting rod in these holes. This provides a handle with which the patterns can be easily lifted up vertically. However first the patterns are loosened a bit by rapping these handles gently before lifting them. This minimises the damage to sand moulds.

Step 6: After removing wooden pattern halves, the mould cavities may be repaired in case any corners etc., have been damaged. This is a delicate operation. Also, if any sand has fallen into the mould cavity, it is carefully lifted or blown away by a stream of air.

Step 7: In case, any cores are used to make holes in the casting, this is time for placing the cores in the mould cavity. Of course, the cores are supported properly by means of core prints or other devices like chaplets etc. Lack of adequate support for cores may result in their displacement from correct position when the liquid metal is poured in.

Step 8: Before closing of the mould boxes, graphite powder is sprinkled on the mould surface in both boxes. In the drag box, a gate is cut below the location of the runner (in the cope box). The molten metal poured in the runner will flow through the gate into the mould cavity.

In case, the moulds have been dried, instead of graphite powder, a mould wash containing suspension of graphite in water is lightly spread over the mould surface.

After all these operations are complete, the cope box is again placed on the drag and clamped securely. Now the mould is ready for pouring molten metal. Molten metal is poured until it shows up in the riser. It ensures that mould cavities are full of metal and that it will not run short. A complete mould ready for pouring is shown in Fig. 6.4. Sand moulds are of three kinds:

(*a*) **Green sand mould:** In such moulds, pouring of molten metal is done, when the sand is still moist.

(*b*) **Skin dry moulds:** Such moulds are superficially dried by moving a flame over mould cavity so that mould dries only up to a depth of few mm.

(*c*) **Dry moulds:** After preparing such moulds, they are dried by keeping the mould for 24–36 hours in an owen whose temperature is maintained at 130–150°C. Dry sand moulds are stronger and cannot give rise to any moisture related defects in the casting. Mould wash improves the surface finish of castings.

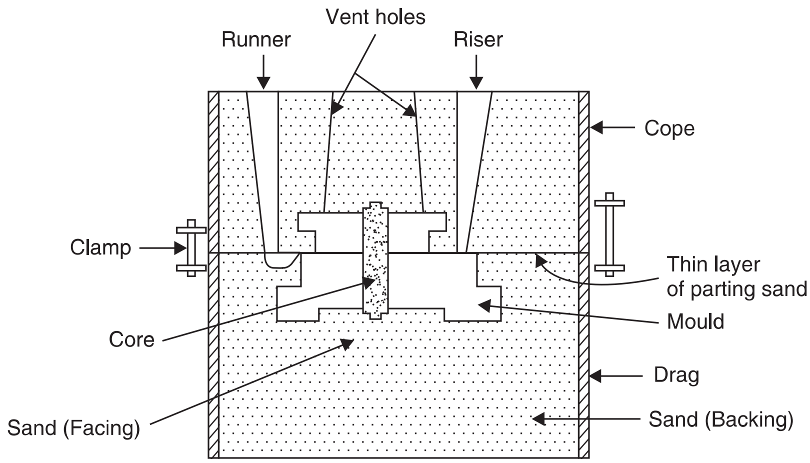

Fig. 6.4 A mould ready for pouring

CORES

Whenever a hole, recess, undercut or internal cavity is required in a casting, a core, which is usually made up of a refractory material like sand is inserted at the required location in the mould cavity before finally closing the mould.

A core, being surrounded on all sides by molten metal, should be able to withstand high temperature. It should also be adequately supported otherwise due to buoyancy of molten metal, it will get displaced. When the molten metal around the core solidifies and shrinks, the core should give way, otherwise the casting may crack (hot tear). Cores, as explained previously, should be made of oil sand and dried in owens before use.

Cores are made with the help of core boxes. Core boxes are made of wood and have a cavity cut in them, which is the shape and size of the core. The sand in mixed and filled in the core boxes. It is then rammed. A core box is made in two halves, each half contains half impression of core. Sometimes a core may need reinforcements to hold it together. The reinforcements are in the shape of wire or nails, which can be extracted from the hole in the casting along with core sand.

CORE PRINTS

A core must be supported in the mould cavity. Wherever possible, this is done by providing core prints. Core prints are extensions of the core which rest in similar extensions of the mould cavity so that core remains supported in the mould cavity without the core falling to the bottom of the cavity. For example, if the pin with collars shown in Fig. 6.5 had a central hole, the hole could be produced by inserting a core in mould cavity as shown in Fig. 6.5.

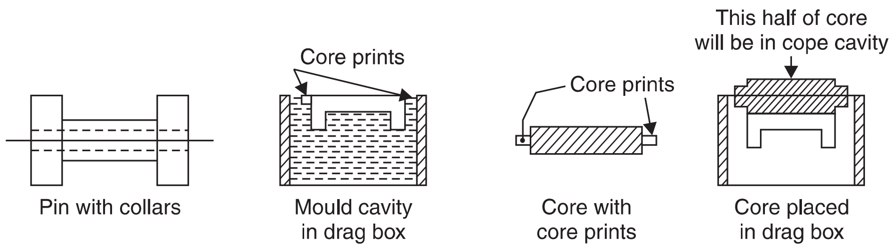

Fig. 6.5

Another device to support cores is "chaplets". These are clips made of thin sheets of the same metal as the casting. These clips are used to support the weight of cores. When the molten metal is poured, chaplets melt and merge into the molten metal.

GATES, RUNNERS AND RISERS

The passage provided in the mould through which molten metal will flow into the mould cavity is known as the gating system. It is provided by scooping out sand in the drag box to cut necessary channels.

The top of the runner hole in the cope is widened into a pouring basin. The molten metal then flows down through the runner into a well from where it enters the gating system and into the mould cavity. At a suitable location in the mould cavity the riser hole is connected.

Without a gate, the metal would have fallen straight into the mould cavity damaging it. Besides, the gating system is so designed as to trap impurities from entering into mould cavity.The function of the riser is two fold. Firstly, it provides a visible indicator that the mould cavity is full. Secondly and more importantly, the molten metal in the riser provides a reservoir to feed the shrinkage caused as the casting progressively solidifies and cools. It is desirable that the metal in the riser remains molten as long as possible. This is done by providing a ''hot-top".

Sometimes, the riser does not open out to the top surface of the cope box, it is then called a blind riser. In that case, its sole function is to feed the shinkage associated with solidification of molten metal.

The various terms associated with gating system will be clear by studying the gating system shown in Fig. 6.6.

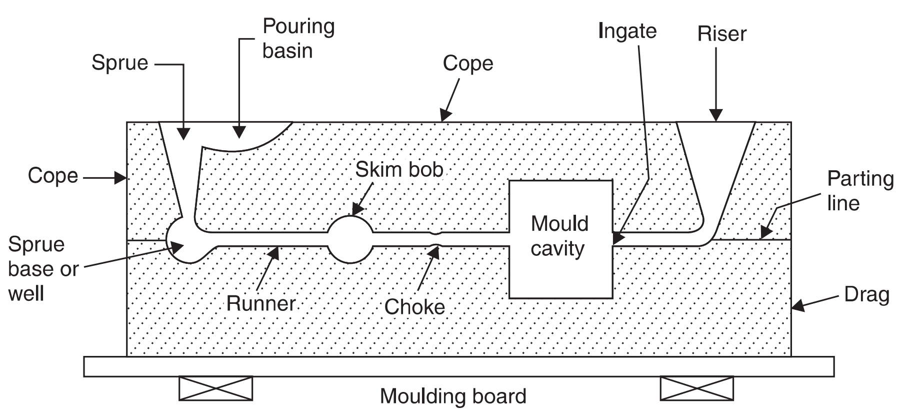

Fig. 6.6 Gating system

CUPOLA

For casting, metal has to be heated above its melting point. The heating is done in a furnace. Depending upon the fuel used, the furnaces may be classified as electric, oil fired or coal fired etc. Where metal free from any impurities is required, electric furnaces are used. In oil fired and coal fired furnaces, the flame plays upon the hot metal and the molten metal picks up impurities by coming in contact with flames. Electric furnaces are costly and equally costly to operate.

Usually, for non-ferrous metals and alloys, oil fired crucible furnaces are used. The metal is placed in large graphite crucibles and heated on the outside surface of crucibles, so that flames donot come in actual contact with metal.

CONSTRUCTION

For melting cast iron, a cupola furnace is used. It is one of the most economical and convenient ways of providing a supply of molten cast iron. Cupola uses coke as fuel. Coke is produced by heating ordinary steam coal in an inert atmosphere. It gives more intense heat than coal.

Cupola consists of a long cylindrical steel shell with its interior lined with refractory fire-bricks. It is erected vertically up and rests on short pillars about 0.85 metres above the ground level. The bottom of the cupola is provided with steel doors which are also lined with fire resistant material and covered with a layer of good quality sand.

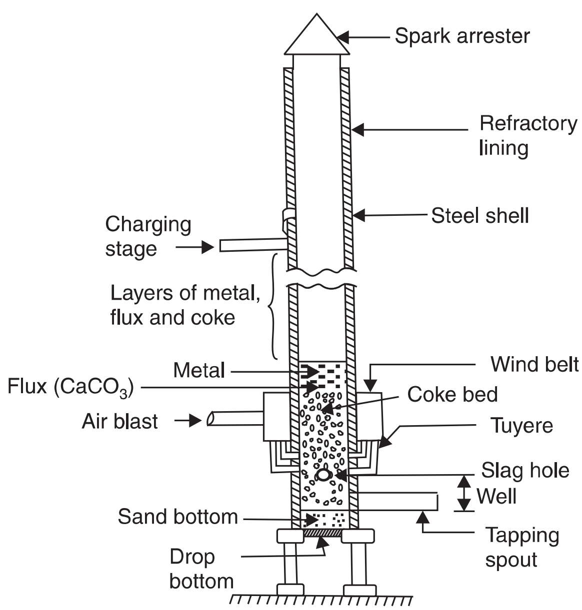

Fig. 6.7 Cupola

At a suitable height, near the top of this steel shell, an opening is cut, which is used for charging fuel and raw materials into the furnace. A wind box, connected to a motorised blower is provided at a height of one meter or so above the bottom closing doors. From this wind box, small air passages are provided into the cupola shell for supply of air to aid combustion of fuel. These air passages are called tuyeres. At the bottom, above the door, a tapping spout is provided to tap molten metal and about 350 mm above the tapping hole another hole called the slag hole is provided at the back of the cupola, through which liquid slag can be forced out under air pressure.

The cylindrical space provided between the tap hole and the slag hole is called the molten metal well in which the molten metal accumulates between two-taps. All these features are depicted in Fig. 6.7.

OPERATION OF CUPOLA

In the cupola the first operation is to repair the lining of the door and area around it and then closing the hinged doors. Doors are jammed shut, so that there is no possibility of their opening while the cupola is in operation. Then fire is lighted at the bottom with the help of some wood and kerosene oil rags. When the fire is burning strongly, coke is added from the top charging door until the height of coke bed reaches about half a metre above tuyeres. After that tuyeres are opened partially, air blower is switched on and alternate layers of metal, flux (in the form of limestone pieces) and coke are charged from the top. These alternate layers settle down on coke bed. When the cupola is filled up to the level of charging door, the tuyeres are opened fully and the heating of charge begins. The coke near the tuyeres start burning and the coke bed becomes intensely hot. The metal in lower layers near the coke bed starts melting. Lime stone breaks down to CaO and CO_2. The calcium oxide reacts with impurities like silica and other oxides forming slag ($CaSiO_3$). Slag is lighter and floats upon the molten metal layer. Ultimately, when enough metal has melted, the slag is blown out by opening the slag hole. The metal is then tapped by puncturing the tap hole with a long steel rod with one end shaped like a cone. The molten metal will start flowing into the metal chute and is collected into ladles (refractory lined steel buckets to which long handles are welded) and taken away for pouring into moulds. The tap hole is then closed by plugging it with a lump of fire clay.

The properties of cast iron improve with addition of small amounts of ferro manganese and ferro silicon. Since most of the manganese and silicon already present in scrap cast iron, pig iron and a little bit of thin steel scrap, which forms the metallic charge dropped into cupola, is oxidised and lost, addition of ferro manganese and ferro silicon has to be done to the molten metal in the ladles before pouring.

After the day's work is over, extra coke is charged into the cupola along with last charge. After all the metal has melted, the air blower is switched off and the bottom door of cupola is opened. Whatever unburnt coke etc., is left, is allowed to fall to the ground beneath the cupola door. This is necessary otherwise the left over coke, slag and metal etc., may join up in one mass, then its removal will become extremely difficult. The size of a cupola is denoted by its internal diameter.

CASTING DEFECTS

Some of the common defects in the castings are described below:

1. **Blow-holes:** They appear as small holes in the casting. They may be open to surface or they may be below the surface of the casting. They are caused due to entrapped bubbles of gases. They may

be caused by excessively hard ramming, improper venting, excessive moisture or lack of permeability in the sand.

2. **Shrinkage cavity:** Sometimes due to faulty design of casting consisting of very thick and thin sections, a shrinkage cavity may be caused at the junction of such sections. Shrinkage cavity is totally internal. It is illustrated in Fig. 6.8.

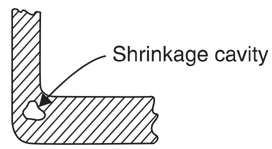

Fig. 6.8

It is caused due to shrinkage of molten metal. Remedy is to use either a chill or relocation of risers.

3. **Misrun:** This denotes incomplete filling of mould cavity. It may be caused by bleeding of molten metal at the parting of cope and drag, inadequate metal supply or improper design of gating.

4. **Cold shut:** A cold shut is formed within a casting, when molten metal from two different streams meets without complete fusion. Low pouring temperature may be the primary cause of this defect.

5. **Mismatch:** This defect takes place when the mould impression in the cope and drag do not sit exactly on one another but are shifted a little bit. This happens due to mismatch of the split pattern (dowel pin may have become loose) or due to defective clamping of cope and drag boxes.

6. **Drop:** This happens when a portion of the mould sand falls into the molten metal. Loose sand inadequately rammed or lack of binder may cause this defect.

7. **Scab:** This defect occurs when a portion of the face of a mould lifts or breaks down and the recess is filled up by molten metal.

8. **Hot tear:** These cracks are caused in thin long sections of the casting, if the part of the casting cannot shrink freely on cooling due to intervening sand being too tightly packed, offers resistance to such shrinking. The tear or crack usually takes place when the part is red hot and has not developed full strength, hence the defect is called “hot tear”. Reason may be excessively tight ramming of sand.

9. Other defects include scars, blisters, sponginess (due to a mass of pin holes at one location) and slag inclusions etc.

DIE CASTING

A sand mould is usable for production of only one casting. It cannot be used twice. Die is essentially a metal mould and can be used again and again. A die is usally made in two portions. One portion is fixed and the other is movable. Together, they contain the mould cavity in all its details. After clamping or locking the two halves of the dies together molten metal is introduced into the dies. If the molten metal is fed by gravity into the dies, the process is known as gravity die casting process. On the otherhand, if the metal is forced into the dies under pressure (*e.g.*, a piston in a cylinder pushes the material through cylinder nozzle), the process is called “pressure die casting”.

The material of which the dies are made, should have a melting point much higher than the melting point of casting material. A great number of die castings are made of alloys of zinc, tin and lead, and of alloys of aluminium, magnesium and copper. Hence dies are made out of medium carbon low alloy steels. The dies are usually water or air blast cooled.

Since most materials contract on cooling, extraction of castings from dies becomes important otherwise they will get entangled in the die as they cool. Therefore, in the design of dies, some arrangement for extraction of casting is incorporated.

STEPS IN DIE CASTING

1. Close and lock the two halves of a die after coating the mould cavity surfaces with a mould wash, if specified:
2. Inject the molten metal under pressure into the die.
3. Maintain the pressure until metal solidifies.
4. Open die halves.
5. Eject the casting along with runner, riser etc.
6. The above cycle is repeated.

Two pressure die casting methods are used:

1. **Hot chamber process:** This uses pressures up to 35 MPa and is used for zinc, tin, lead, and their alloys. In this process the chamber, in which molten metal is stored before being pressure injected into the die, is kept heated.
2. **Cold chamber process:** In this process, pressures as high as 150 MPa are used. The storing chamber is not heated. This process is used mainly for metals and alloys having relatively higher melting point *e.g.,* aluminium, magnesium and their alloys.

Advantages and disadvantages of die casting:

1. It is used for mass production of castings of small and medium size. *e.g.,* pistons of motorcycle and scooter engines, valve bodies, carburettor housings etc.
2. The initial cost of manufacturing a die is very high. It is a disadvantage.
3. This process produces high quality, defect free castings.
4. The castings produced by this process are of good surface finish and have good dimensional control and may not require much machining. All castings produced are identical.
5. Large size castings cannot be produced by this process. It is a disadvantage.
6. Castings with very complex shapes or with many cores are difficult to produce by die casting.
7. In case of mass production, castings can be produced cheaply.
8. The process does not require use of sand and requires much less space as compared to a conventional foundry using sand moulds.

QUESTIONS

1. What is a pattern? Name the various allowances associated with patterns and why are they provided?
2. Describe, stepwise, the procedure of making a mould with a two piece split pattern.
3. What are the requisite properties in a good foundry sand?
4. Make properly labelled sketch of a cupola and write a brief account of its operation.
5. Enumerate some common casting defects and explain the reasons which cause these defects.