Advanced Manufacturing Processes
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Module - 2
Advanced Metal Casting Processes
Lecture - 1
Metal Casting basics, Gating and Risering design

Welcome to this lecture on Advanced Manufacturing processes under module 2. I am Dr Apurbba Kumar Sharma from the Department of Mechanical and Industrial Engineering from IIT, Roorkee. Dear students, in this session we will study about metal casting process and its importance, the basic phenomena involved in metal casting process, gating and risering systems.

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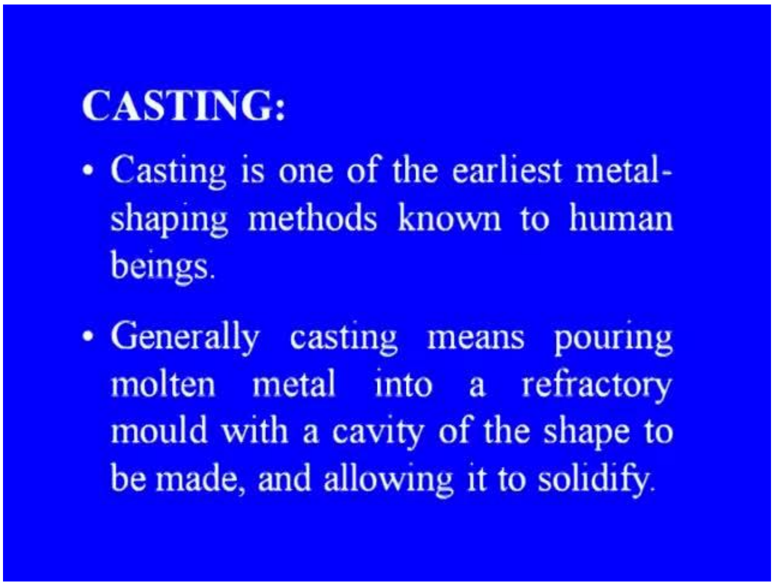

Casting is one of the earliest metal shaping methods known to human beings. Generally casting means pouring molten metal into a refractory mould with a cavity of the shape to be made, and allowing them. To solidify - on solidified the object is taken out from the mould either by breaking or by taking the mould apart, the solidified object is called casting.

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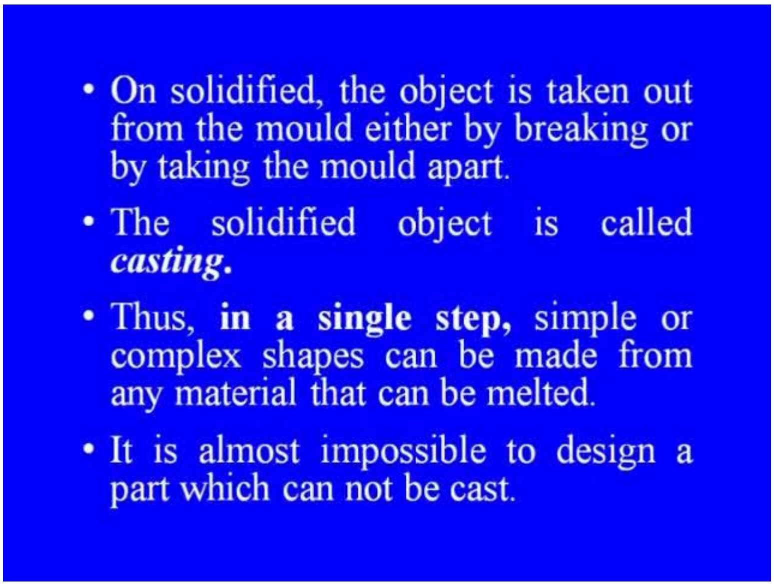

Thus in a single step, simple or complex shapes can be made from any material that can be melted. It is almost impossible to design apart, which cannot be cast. Let us see a formal definition of casting it coat.

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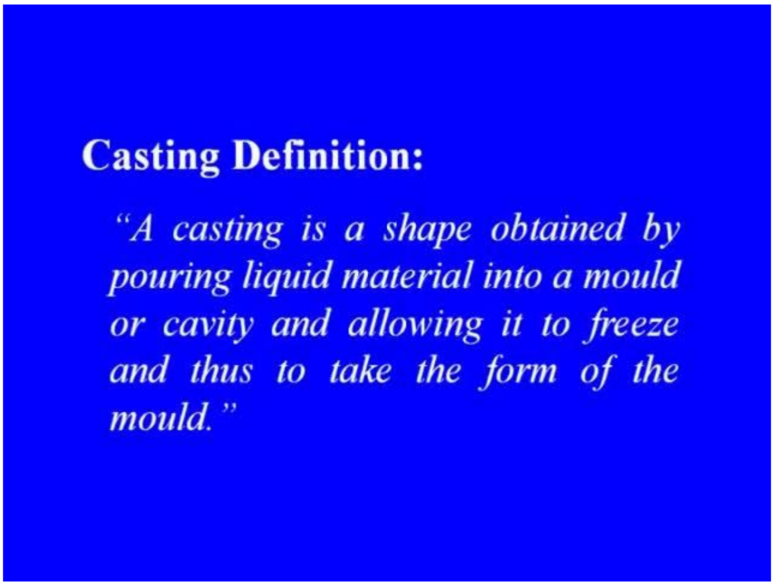

A casting is a shape obtained by pouring liquid material into a mould or cavity and allowing it to freeze and thus to take the form of the mould, and could. Let us peep into little historical background of this process. Casting was probably discovered around 3500 Before Christ in Mesopotamia. These moulds were essentially of single piece.

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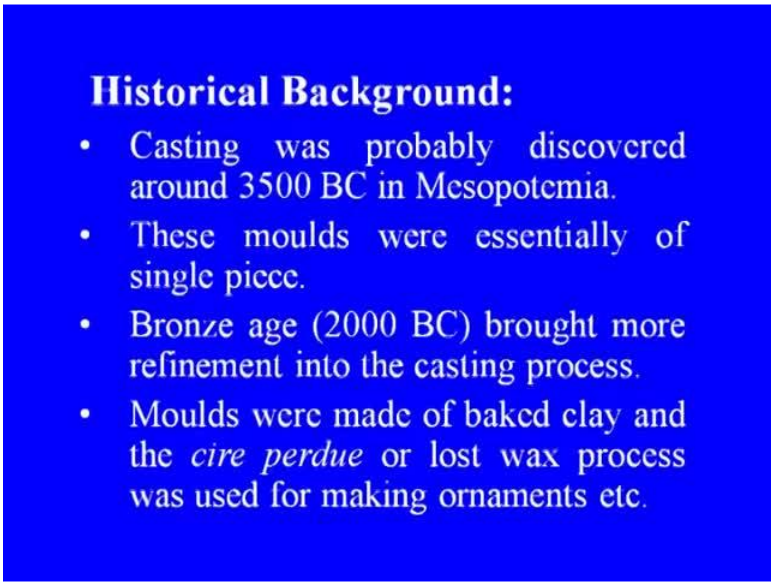

Bronze age, which is estimated at 2000 BC brought more refinement into the casting process. Moulds were made of baked clay and the cire perdue or lost wax process was used for making ornaments etcetera. The technology was greatly improved by the Chinese from around the year 1500 BC.

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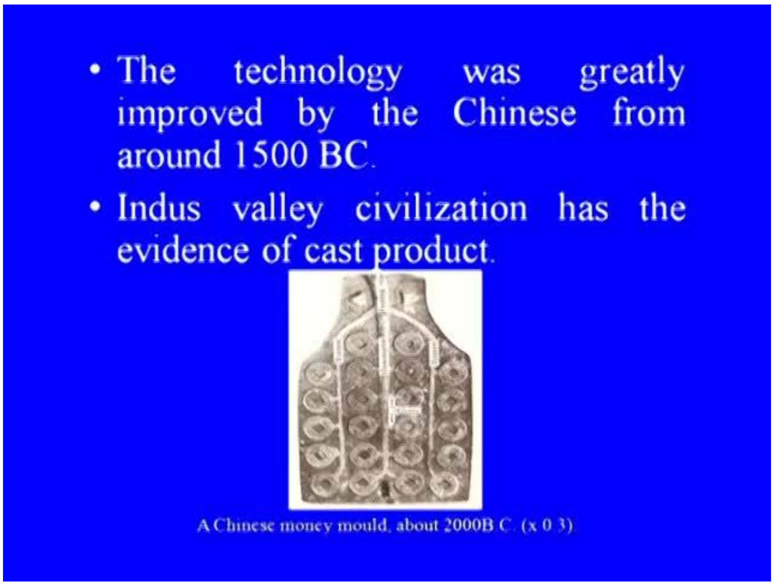

The Indus valley civilization has the evidence of cast product too. Here is the photograph of a cast mould. Now, let us see the casting problem, the casting problem can be basically divided into two areas, the design and production of the mould and number two the melting refining pouring of the liquid metal.

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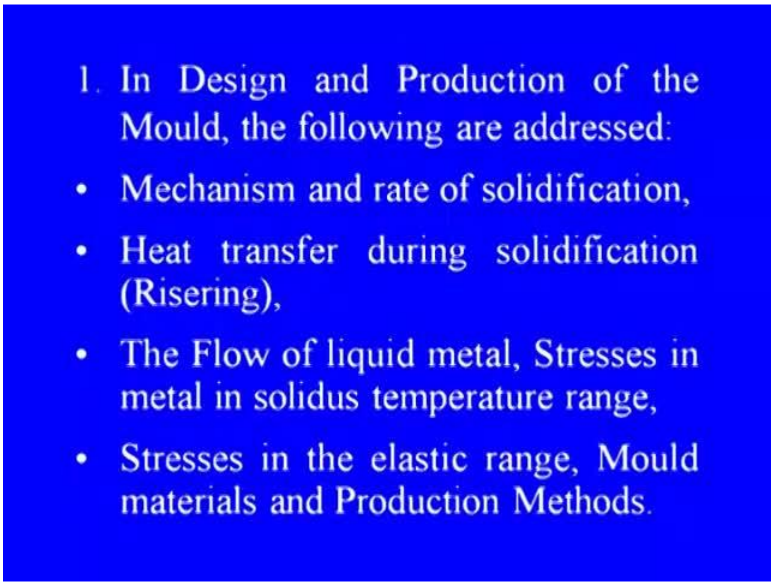

In design and production of the mould, the following are addressed. Mechanism and rate of solidification, heat transfer during solidification, the flow of liquid metal, stresses in metal in solidus temperature range, stresses in the elastic range, mould materials and production methods.

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The mechanism and rate of material solidification involves, the crystallization pattern and estimation of shrinkage in volume during solidification for calculation of the risers to be placed and proportioned properly, these factors very considerably depending upon the chemical composition of the material and thermal gradients in the mould. Thus in this process, engineering analysis tools can help significantly.

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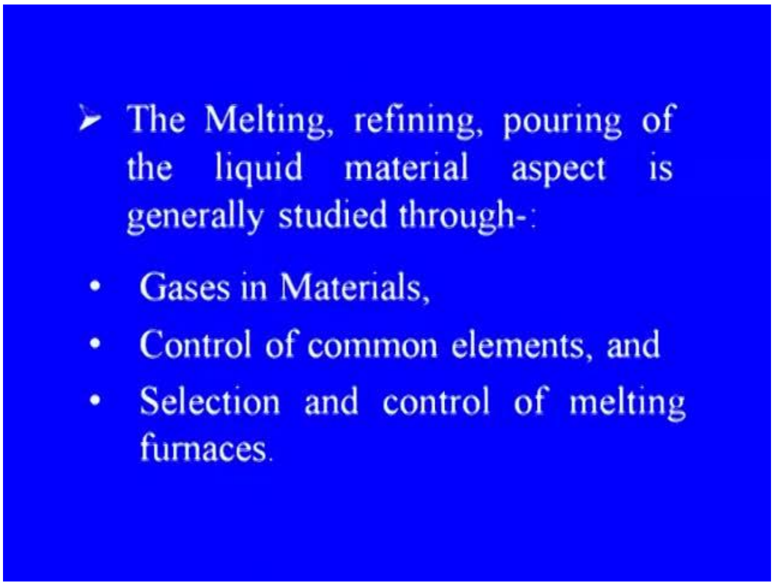

The melting refining pouring of the liquid material aspect is generally studied through number one, gases in materials, number two control of common elements and number three selection and control of melting furnaces. Now, let us look into the solidification process. The time taken for solidification of casting is relatively a very brief period in the entire production history. During this short time, the original crystal structure of the casting is formed, which is considered the backbone of the casting on which many other properties depend in this interval.

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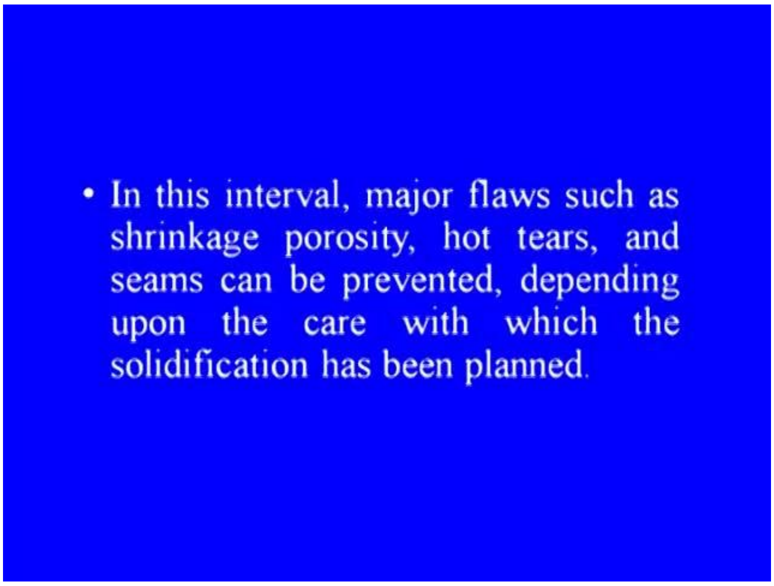

Major flaws such as shrinkage porosity, hot tears and seams can be prevented depending upon the care with which the solidification has been planned. Let us now discuss crystal nucleation process, there are two types of nucleation.

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Number one, homogeneous nucleation. Homogeneous nucleation is the formation of a new phase without the help of special nucleation sites. Number two, heterogeneous nucleation. In heterogeneous nucleation process, solidification process in which, the solid phase crystallizes on foreign nuclei. The temperature at freeze the homogeneous nucleation takes place is always below the equilibrium freezing point because it is necessary to overcome the surface tension forces, which slow down nucleus growth. The energy required to produce a nucleus of solid is the difference in free energy per unit of the volume between the liquid and the solid phases.

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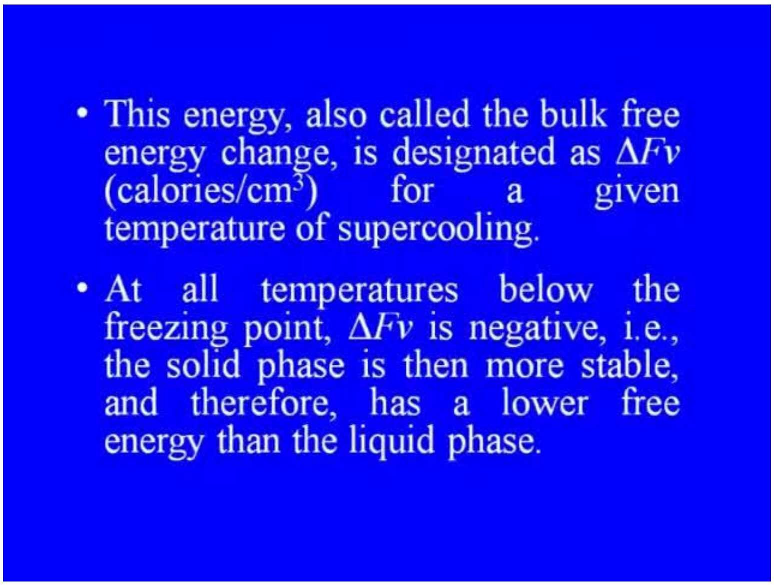

This energy also called the bulk free energy change is designated as delta F v, which is expressed in calories per square centimeter, for a given temperature of super cooling. At all temperatures below the freezing point delta F v is negative. That is the solid phase is then more stable and therefore, has a lower free energy than the liquid phase.

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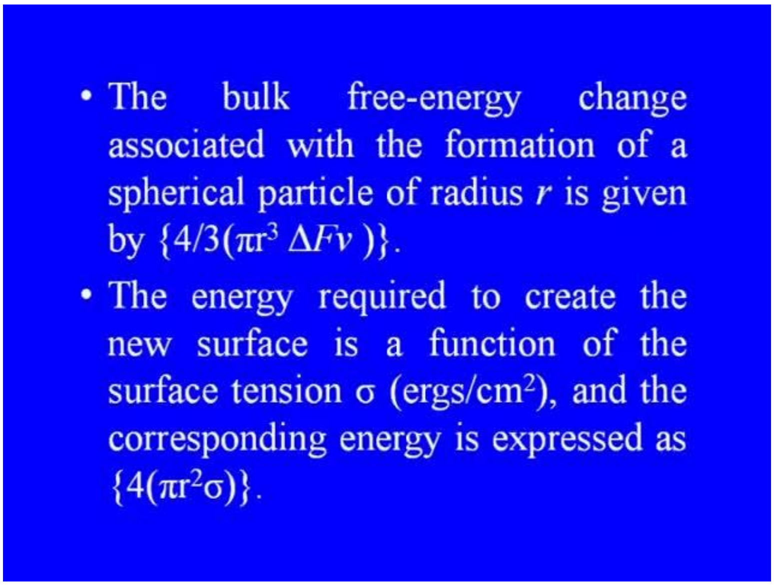

The bulk free energy change associated with the formation of a spherical particle of radius r is given by 4 upon 3 into pi r cube into delta F v. The energy required to create the new surface is a function of the surface tension sigma, which is expressed in ergs per centimeter square. The corresponding energy is expressed as 4 into pi r square into sigma, the net free energy change del F v.

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- The net free-energy change, ΔF, is then
  $\Delta F = \{4(\pi r^2 \sigma)\} + \{4/3(\pi r^3 \Delta Fv)\}$.
- Once the critical radius r* is exceeded, further growth results in a decrease of free-energy and can proceed spontaneously at the temperature of supercooling. This is shown in Figure 1.

Del F is then expressed as del F equal to 4 pi r square into sigma plus 4 upon 3 pi r cube into delta F v. Once the critical radius r star is exceeded, further growth results in a decrease of free energy and can proceed spontaneously, at the temperature of super cooling, this is shown in figure one.

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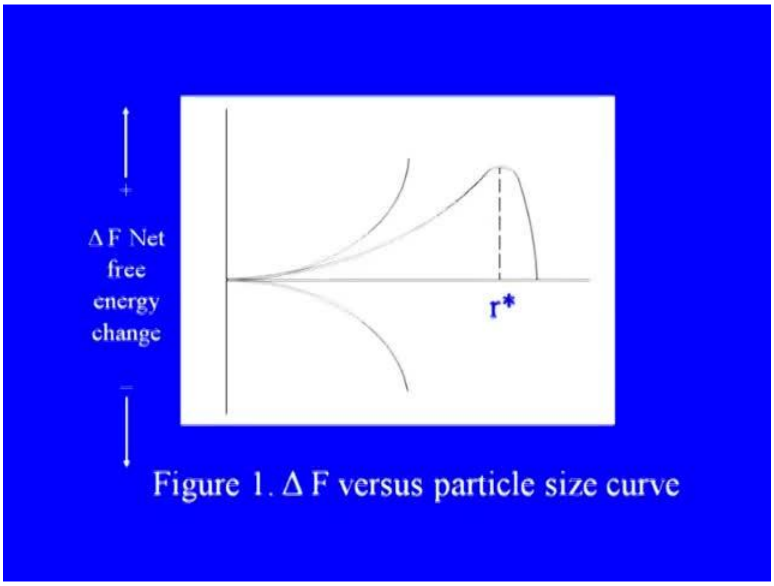

Figure 1. Δ F versus particle size curve

Here this the critical radius r star. If a particle has a radius smaller than r star, it will re dissolve because this decreasing size reduces the free energy. The size of the critical radius may be found by differentiating the above relationship with respect to r and setting the result equal to 0, which then yields r star to be equal to minus 2 sigma by delta F v.

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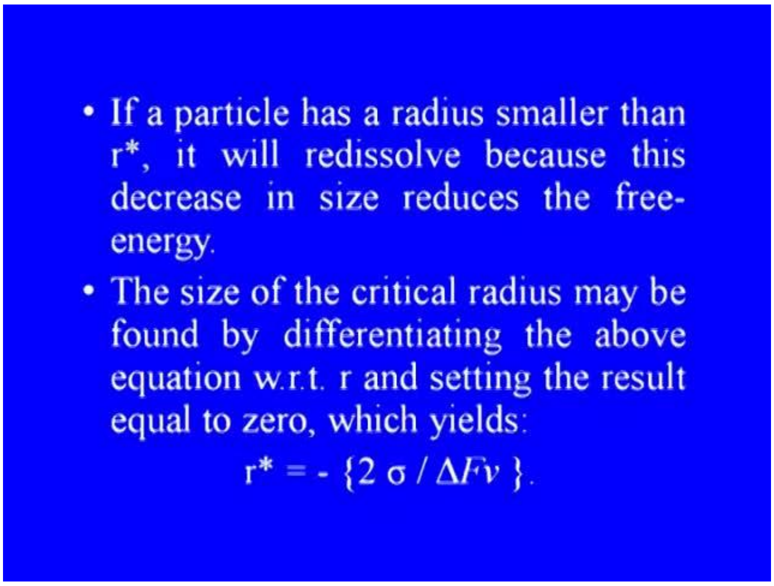

The r star relation indicates that for r star to become very small del F v must become very large in a negative sense. That is severe super cooling is needed for homogeneous nucleation. Also the term sigma does not change greatly with temperature, on the other hand delta F v increases with super cooling and therefore, causes a very small nucleus to be stable. Let us come into heterogeneous nucleation process.

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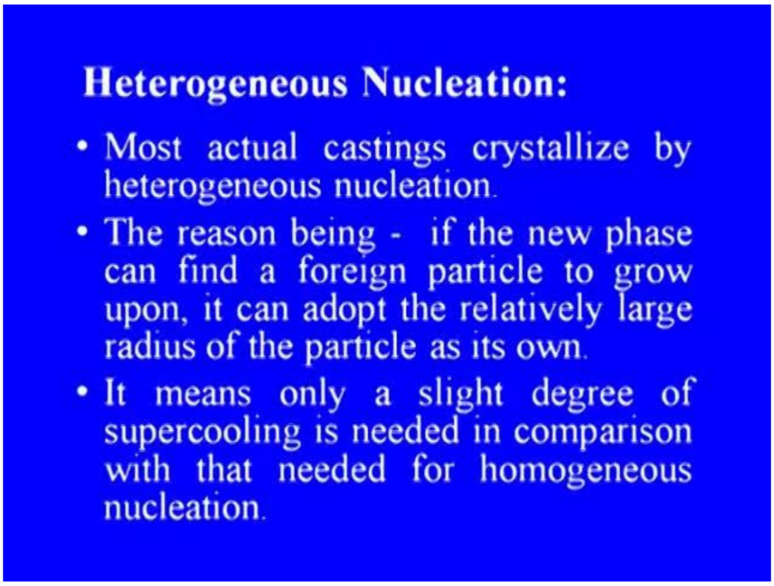

Most actual castings crystallize by heterogeneous nucleation process. The reason being, if the new phase can find a foreign particle to grow upon, it can adopt the relatively large radius of the particle as its own. It means only a slight degree of super cooling is needed in comparison with that needed for homogeneous nucleation. Quantitatively the relation depends upon the degree to which the new phase wets the foreign particle. If there is no attraction between the attempts of the foreign particle and those of the participating phase, then nucleation is not helped. The wall of a mould usually provides many heterogeneous nucleation sites, that is how the solidification process begins. Let us see an example of solidification of a pure metal.

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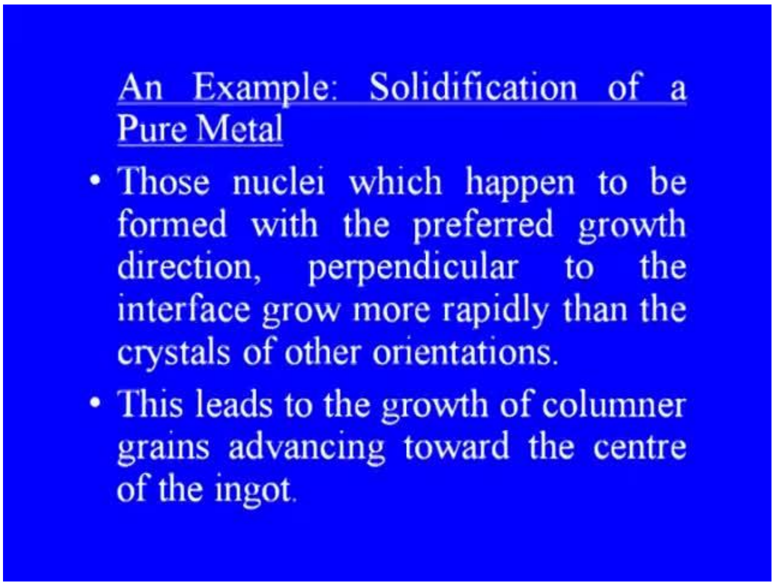

Those nuclei, which happen to be formed with the preferred growth direction perpendicular to the interface grow more rapidly than the crystals of other orientations. This leads to the growth of columner grains advancing towards the centre of the ingot. The final structure therefore, consist of a thin layer of randomly orientated grains, at the mould surface, columner grains extending to the centerline in this situation. There are no randomly oriented grains at the centre of the ingot solidification of actual castings.

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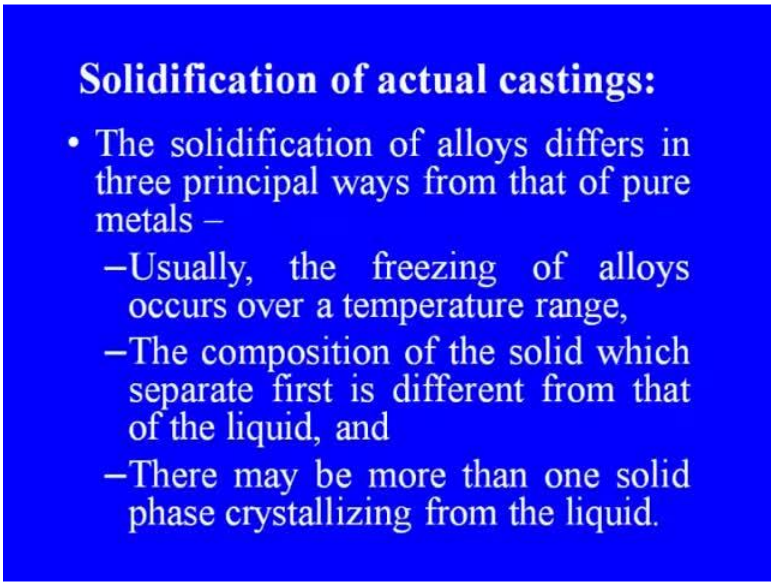

The solidification of alloys differs in three principal ways from from that of pure metals. Number one, usually the freezing of alloys occurs over a temperature range. Number two, the composition of the solid which separate first is different from that of the liquid. And number three, there may be more than one solid phase crystallizing from the liquid. Now, let us see a gating system the assembly of channels which facilitate.

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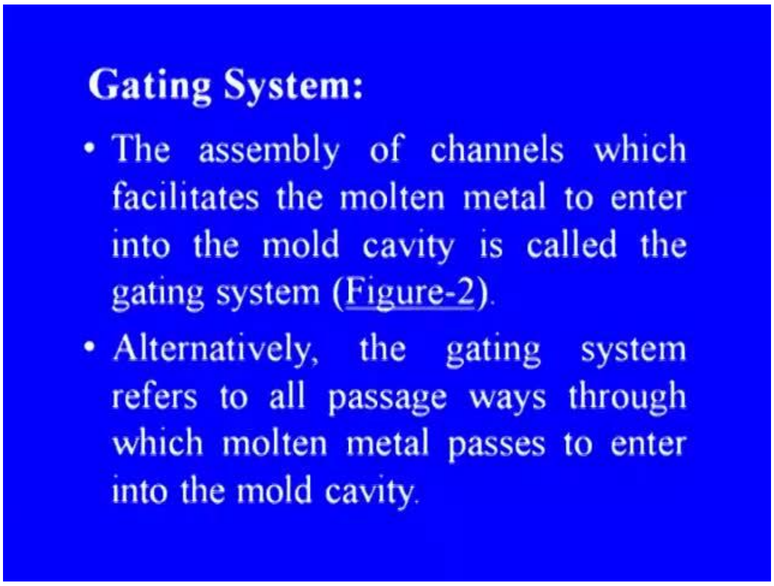

The molten metal to enter into the mold cavity is called the gating system. This is shown in the figure two. Alternatively, the gating system refer to all passage ways through which molten metal passes to enter into the mold cavity, this is a typical gating system in which, this is the pouring system, the molten metal comes through the sprue, which is constructionally tapered in shape.

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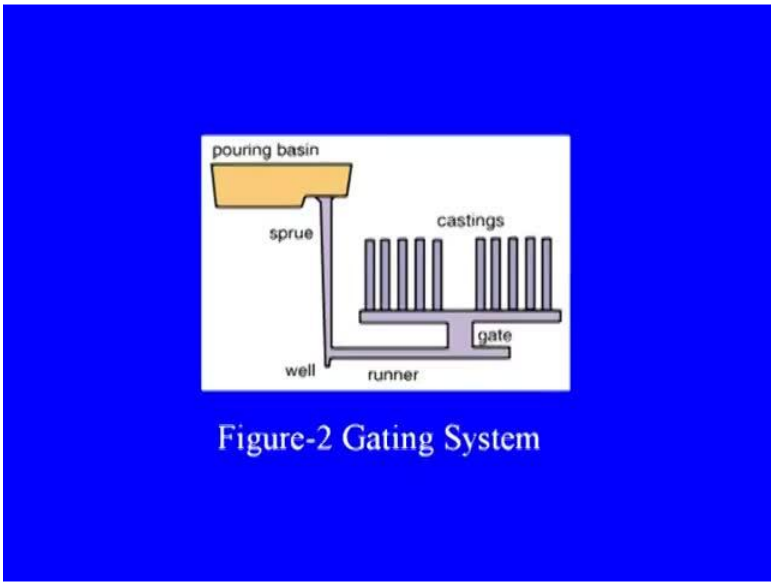

Then the liquid metal is distributed through this gating system into the various cavities. What are the goals of gating system then?

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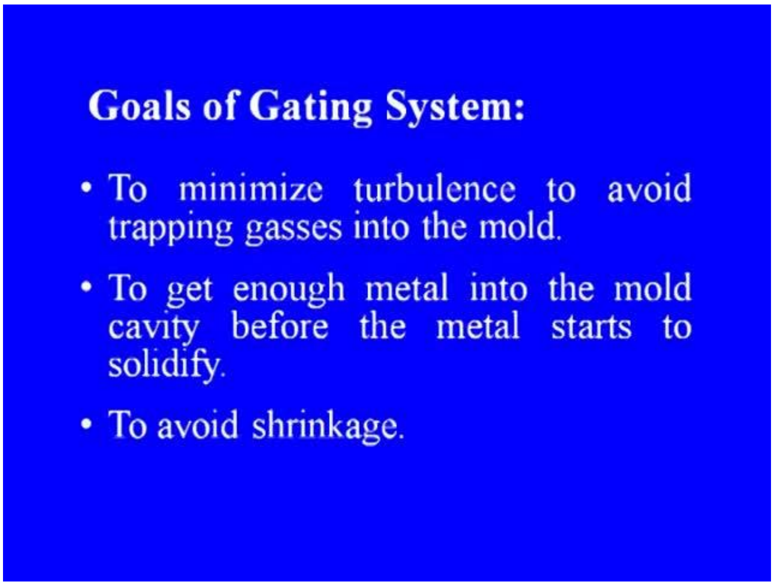

This is to minimize turbulence to avoid trapping gasses into the mold. Then to get through enough metal into the mold cavity before the metal starts to solidify. Then another goal is to avoid shrinkage to establish the best possible temperature gradient in the solidifying casting. So, that the shrink is if occurs, must be in the gating system not in the required cast product. Thereby it helps in retaining the appropriate or desired tolerances. It also incorporates or system for trapping the non metallic inclusions.

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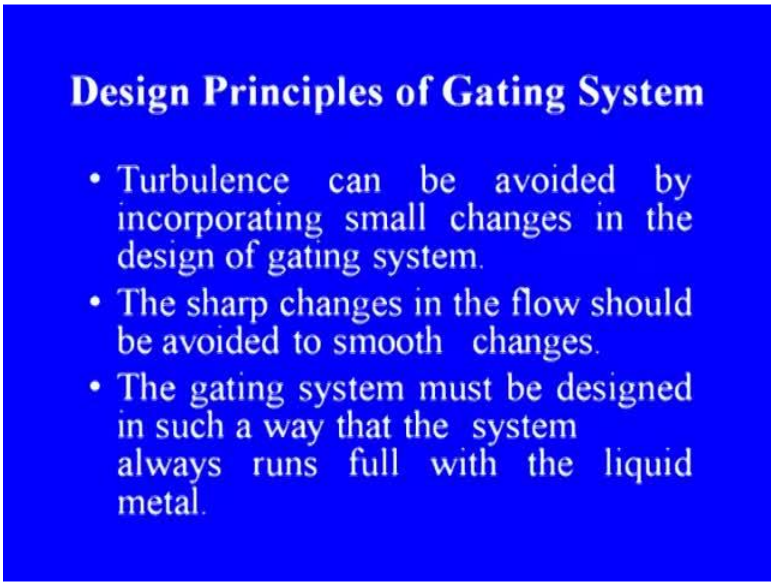

The major design principles of gating system are as follows. Turbulence can be avoided by incorporating small changes in the design of gating system. The sharp changes in the flow should be avoided to smooth changes. The gating system must be designed in such a way, that the system always runs full with the liquid metal. In gating system design sharp corner should be avoided any changes in direction or cross sectional area, should make use of rounded corners.

To avoid the aspiration, the trapped sprues are designed in the gating systems, is pure tapered to a smaller size at its bottom will create a sock, which will help keep the sprue full of molten material types of gating systems. The gating systems are of two types; pressurized gating system and un pressurized gating system.

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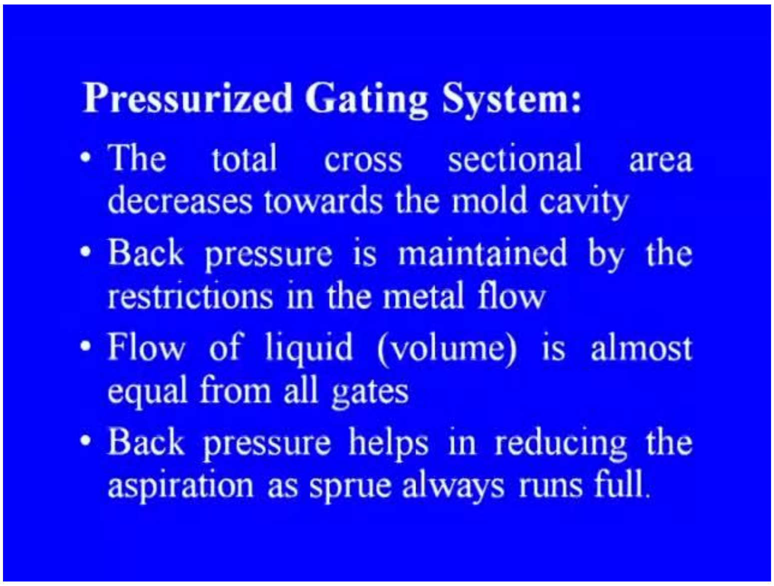

In pressurized gating system, the total cross sectional area decreases towards the mold cavity back pressure is maintained by the restrictions in the metal flow. Flow of liquid is almost equal from all gates. Back pressure, helps in reducing the aspiration as sprue always runs full, because of the restrictions the metal flows at high velocity leading to more turbulence and chances of mold erosion unpressurized gating system on the other hand.

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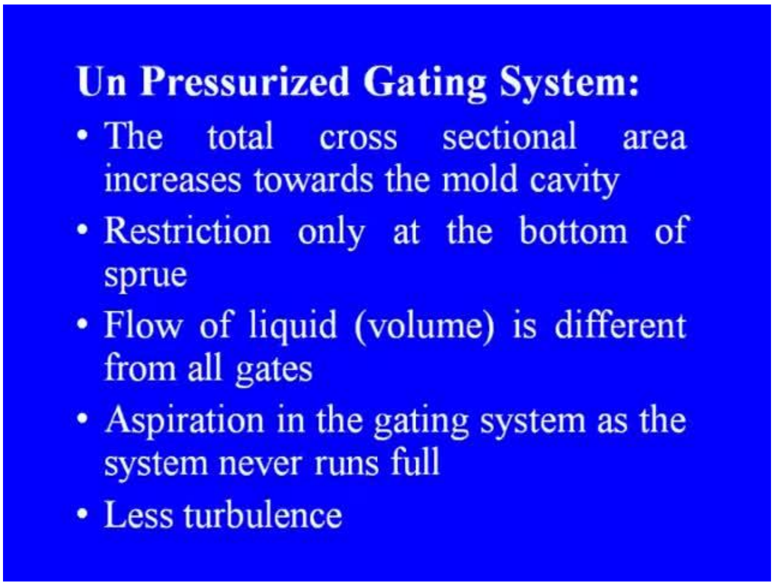

The total cross sectional area increases towards the mold cavity, restrictions only at the bottom of the sprue is given. Flow of liquid is different from all gates. Aspiration in the gating system as the system never runs full. There is less chance of turbulence. Now, let us consider the risering system. Riser is a sprue of extra metal, which flows from riser to mold cavity to compensate for shrinkage, which takes place in the casting when it starts solidifying without a riser heavier parts of the casting will have shrinkage defects, either on the surface or internally risers are known by different names as metal reservoir, feeders or headers.

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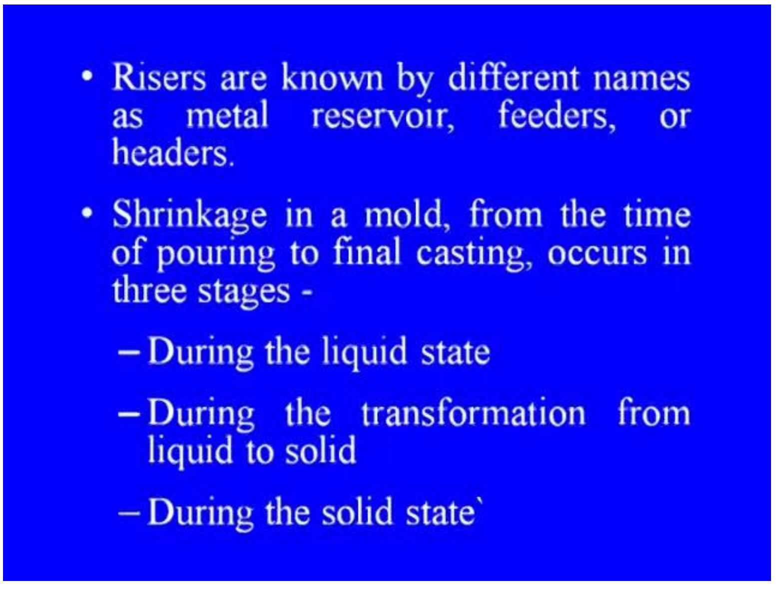

Shrinkage in a mold from the time of pouring to final casting occurs in three stages. Number one during the liquid state, number two during the transformation from liquid to solid and number three during the solid state. The first type of shrinkage is being compensated by the feeders or the great gating system. For the second type of shrinkage, risers are required. Risers are normally placed at that portion of the casting, which is last to freeze a riser must stay in liquid state, at least as long as the casting and must be able to feed the casting during this time. Now, let us see the functions of a riser.

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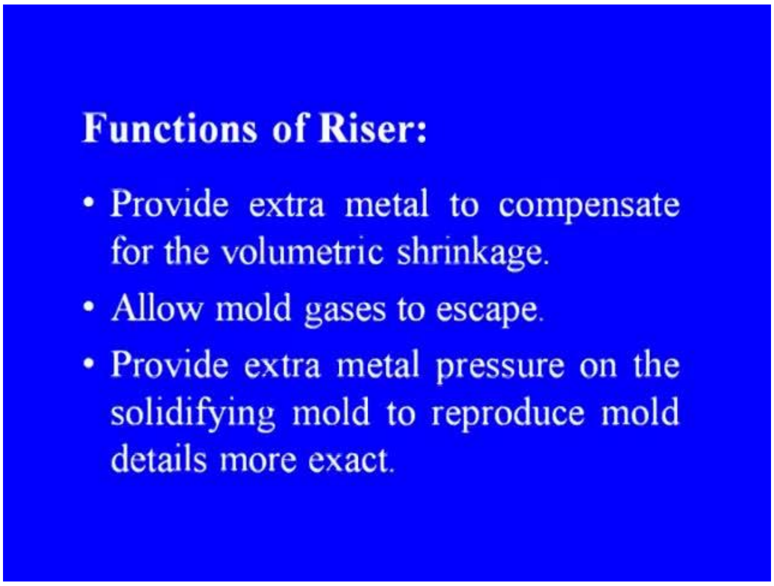

It provides extra metal to compensate for the volumetric shrinkage. Then risers allow mold gases to escape, they provide extra metal pressure on the solidifying mold to reproduce mold details more exact. Now, what are the design requirements of risers? First is the riser size for a sound casting riser must be the last to freeze the ratio of volume to surface area of the riser, must be greater than that of the casting.

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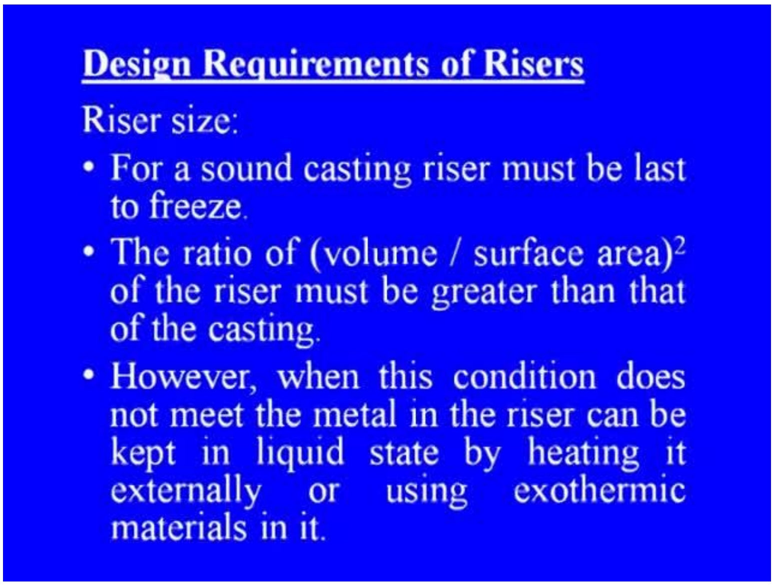

However, when this condition does not meet the metal in the riser can be kept in liquid state, by heating it externally or using exothermic materials in it. The way the riser is connected to the casting is very important, the connection called neck. So, it solidify first, so that the shrinkage cavity is located in the riser itself. The removal of the riser should be made simpler making the neck smaller.

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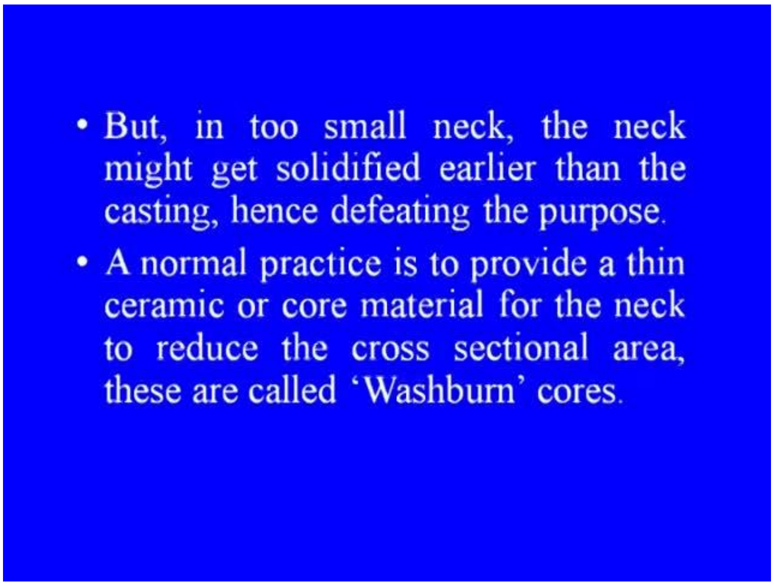

But in too small neck, the neck might get solidified earlier than the casting. Hence, defeating the whole purpose. A normal practice is, to provide a thin ceramic or core material for the neck to reduce the cross sectional area, these are called wash burn cores. Let us see few basic terminologies associated with casting technology. This will be useful throughout this module, because we will be dealing with most of the casting techniques at various point of time. Some of these are illustrated through sketches in figure two and three etcetera.

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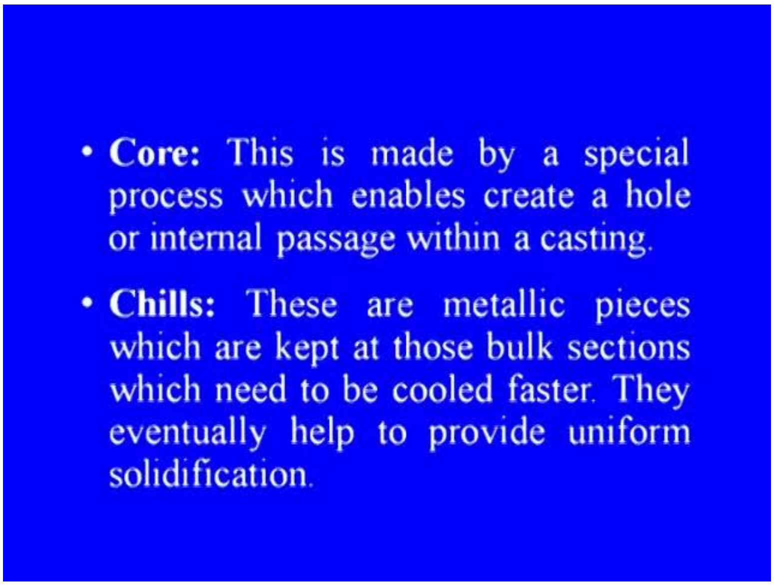

One very important terminology associated with casting is core. This is made by a special process, which enables create a hole or internal passage within a casting, which is very important, as far as the casting technology is concerned. Then chills, these are metallic pieces, which are kept at those bulk sections, which need to be cooled faster. They eventually help to provide uniform solidification, in other words or in thermodynamics terminology heat transfer terminology, rather we can call these as nothing but some kind of heat sinks like we use twins in some cases.

So, these metallic materials provide larger area, which are in contact with the heated object or in the vicinity to the heated object. So, that the rate of hit transfer can be faster, as we know rate of heat transfer is proportional to the area, area of heat transfer. Therefore, this is nothing but a technique to enhance the heat transfer area. So, what is the advantage of this? The advantage is, as the rate of heat transfer becomes faster, then the solidification can be homogeneous.

Otherwise in some cases where the section is thicker, the molten material is, the quantity of molten material is higher and therefore, it may take more time to get solidified or rather to reject the heat from the molten metal and there by getting solidified. However, with the use of chills this can be avoided or the situation can be enhanced in the form of providing higher area for heat transfer and thereby the rate of cooling becomes faster.

Therefore, consequently the entire body of the casting can get cooled at more uniform rate with that of the thin sections, which are in any way getting cooler fast.

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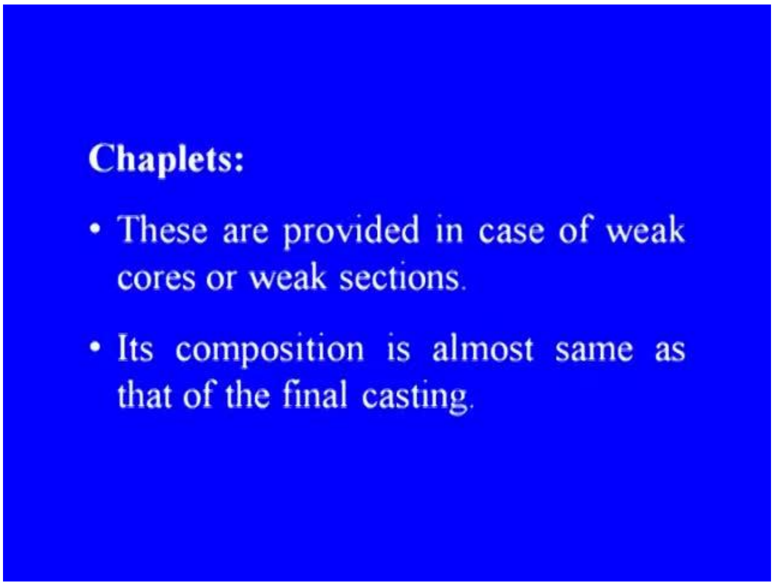

Another important term quite often used is chaplets. These are provided in case of weak cores or weak sections, as we have just now discussed. The cores are nothing but some holes or the passage provided. Therefore, by providing passage in some cases, it may so happen that the section becomes very weak, which may not be eventually possible or to withstand the load of molten metal. Therefore, these chaplets are used to strengthen this weak sections. Its composition is almost same as that of the final casting, so that the diffusion or other problems are minimized.

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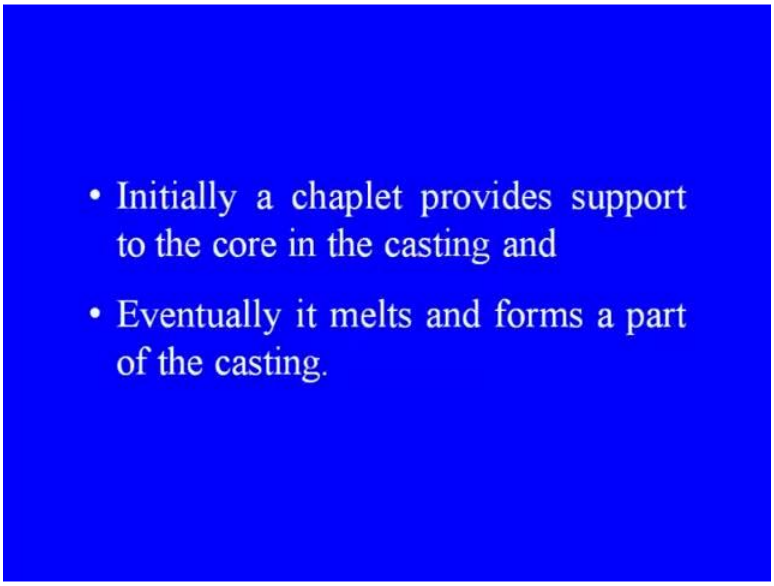

Initially a chaplet provides support to the core in the casting and eventually it melts and forms a part of casting. That is why similar composition is preferred, so that the cast product do not lose the property or the properties of the final product do not get deviated from what is designed.

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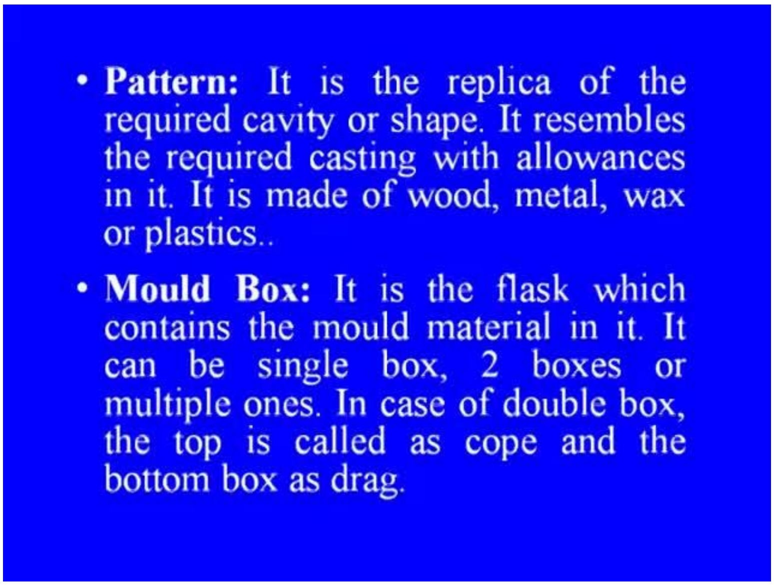

The another important one is pattern, which we will be using almost in the every session, that will be discussed in this module, that is pattern. It is the replica of the required cavity or shape. It resembles the required casting with allowances in it it is made of wood metal wax or plastics as the situation permits or as the situation could be say. For example, wax, if we use they are lost because of the coming in contact with the very high temperature molten material. On the other hand if metallic patterns are used, they can be re used for several cycles.

Then another important characteristic with this pattern is, there should be adequate allowances provided on the pattern dimension. Like some allowances may be required on account of shrinkage. As we know solid materials shrinks as it cools therefore, the molten material as it gets solidified, it volume, its volumes gets shrunk. Therefore, if we prepare a pattern with exact dimensions of what is required say 50 mm. If we produce 50 mm of pattern, then at the end of the day often solidification, we may end up with a pattern having dimension of 49 mm or 48 mm as the case may be, depending on the expansion co efficient of the material.

Therefore, this needs to be taken care of the data regarding which or readily available in hand books, that which material will undergo. How much of percentage of shrinkage? Accordingly the pattern can be made over sized to account for this shrinkage. Another important aspect in this pattern is the final finishing. Some of the patterns may need post processing, say for example, post processing due to some achieving some pre required or pre requisite surface finish.

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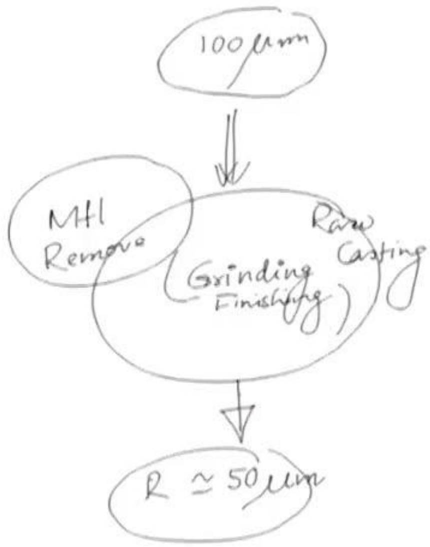

For this to achieve say from 100 micrometer to R a equal to 50 micrometer, what I need is in between some R a working or some material, I have to remove from the original cast or this is, we can say, this is raw casting casting raw casting. This process may be say grinding or some other finishing process. Now, from where this addition material will be sacrificed? This indicates that we may have to allow some additional material in the raw casting itself. That means the pattern has to made little over sized, so that it produces a bigger little. Bigger casting as required and this bigger or the additional material will be removed like this, as part of the finishing process as we have discussed here, which will ultimately give us the required dimension, this is required dimension.

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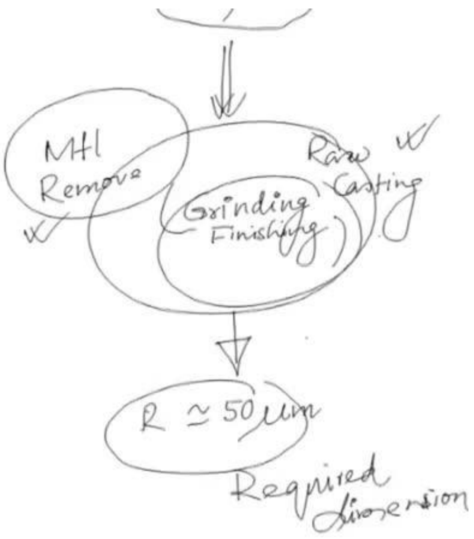

Another important term very closely associated with molding technology or casting technology is the mould box.

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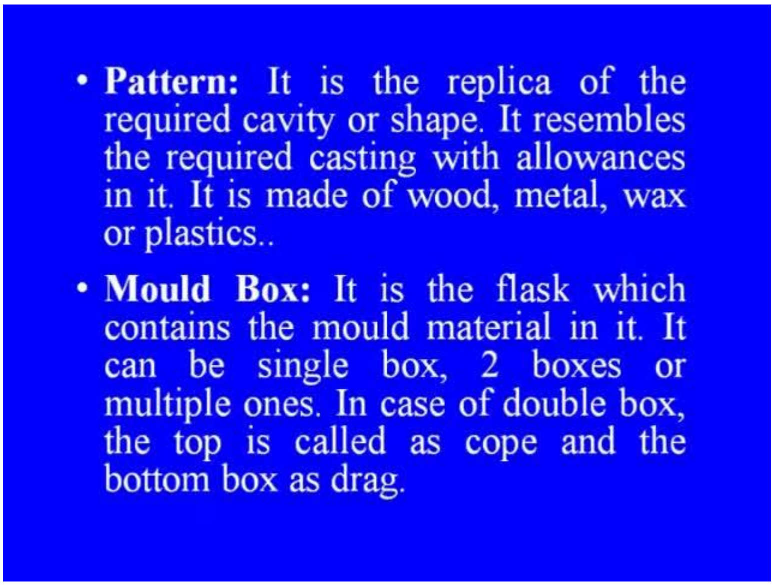

It is the flask which contains the mould material in it. It can be a single box or two boxes or a multiple box. In case of double box, the top is called as cope and the bottom box is called drag. Then molding material in most of the cases sand is the desired molding material. Since, it has high refractory property, as well as they are cheap. Sand is mixed with other ingredients as desired like to make them more flowable, etcetera or in some cases to make them more binding, binders are used and so on. Then sand molding ingredients.

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So, these are sand, clay and water, these are some of the ingredients, in some cases some other materials as binder also used like clay content etcetera can be used to give to bind, binding properties.

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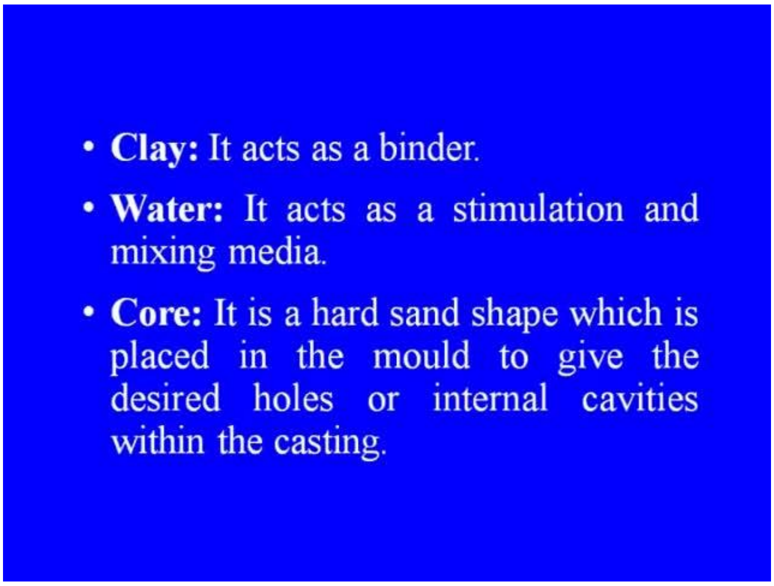

Then the core, what is a core? It is a hard sand shap,e which is placed in the mould to give the desired holes or internal cavities.

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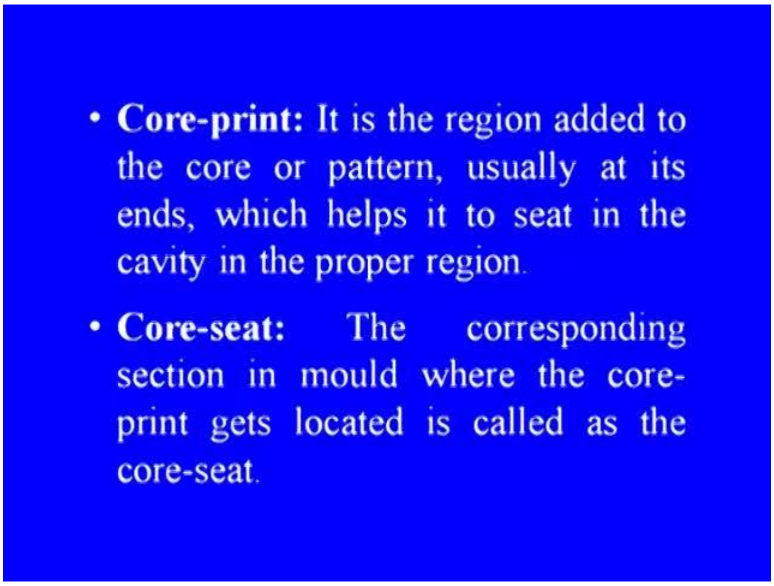

What is a core print? This is another important term, it is the region added to the core or pattern usually at its ends which helps it to seat in the cavity in the proper region. Then core seat, the corresponding section in mould where the core print gets located is called as the core seat. Another important term is ladle. Ladle is a device having a crucible with handles as it its ends. It is used to carry the molten metal from the farness to the moulds. There are different types of ladles to show different requirements.

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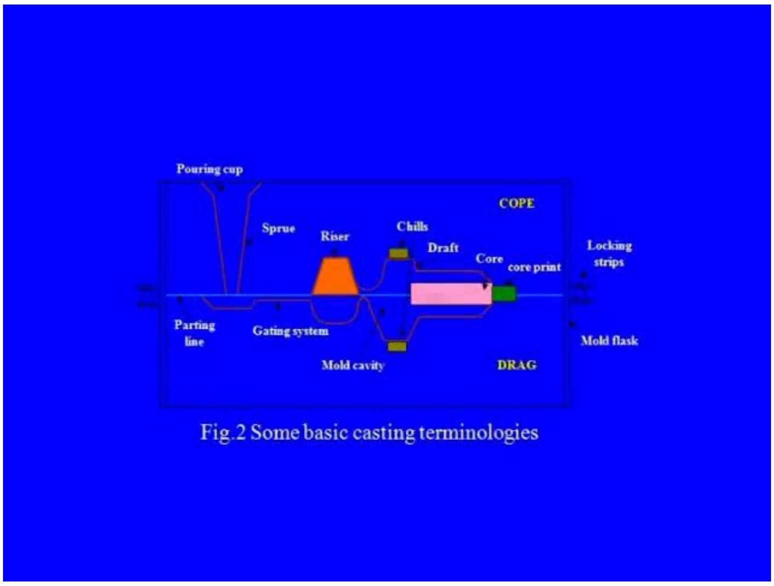

Fig.2 Some basic casting terminologies

So, this is a generalized picture as displayed in the screen. So, this figure describes almost all the important terminologies associated with the cast, casting, casting process. Like this is the core as we were talking about and this is the core print. This core is the hole or the passage, for the molten material to past from. Say this is the pouring cup, this is where the molten material will be poured and the material will settle here, then it will flow through this, and this needs to be flown to this part, and this part. These are the chills, that we were talking about.

The metallic portions, those are provided for enhancing the heat transfer inside the core, inside the casting. So, here we can we can as we have already indicated, so this is the, I think this is, as the figure shows, this is the largest section of this particular casting. Therefore, it ideally contains more quantity of molten material and therefore, it will take longer time to get solidified, because heat content will be high. This this contained heat to be transferred out it will take more time, provided the area around it or area through which the heat will get transferred remains same.

To improve upon this situation because this here, this casting has got different sections, like some sections are relatively smaller than this section. Therefore, there is a possibility, that these thinner sections will get solidified earlier to that of larger sections. To eliminate this in-homogeneity in solidification, these chills are provided as can be seen here. These are metallic plates, which acts as the heat sink and helps in providing better heat transfer rate in these large sections.

So, that that non uniformity in heat transfer, rate of heat transfer at different sections of the casting, gets reduced. As far as the box is concerned, I was talking about just few minutes back, here in this particular figure, there are two boxes provided. One is called cope, the top box and this is the parting line and this is the drag, lower portion, lower half of this box, this is called drag. Next is the pouring cup or pouring basin, this we have seen in the figure also just now.

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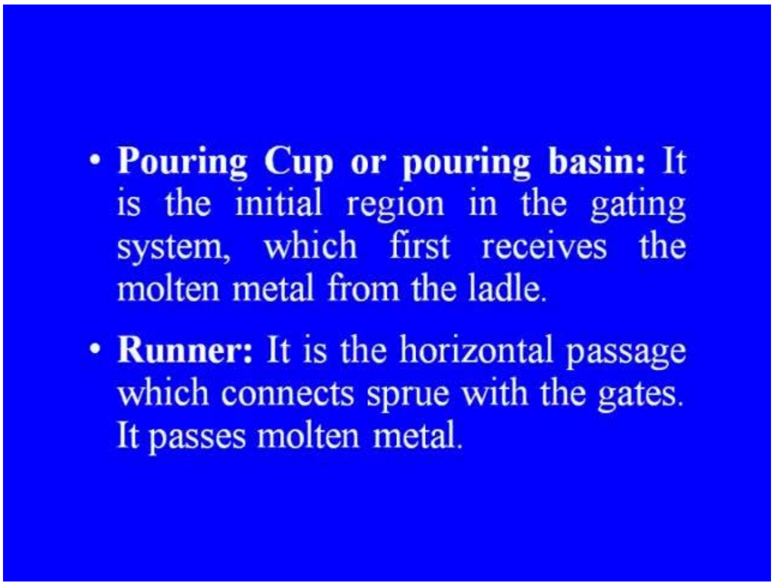

It is the initial region in the gating system, which first receives the molten metal from the ladle and allows it to move through. Then the runner it is the horizontal passage, which connects sprue with the gates, it passes molten metal to the subsequent sections.

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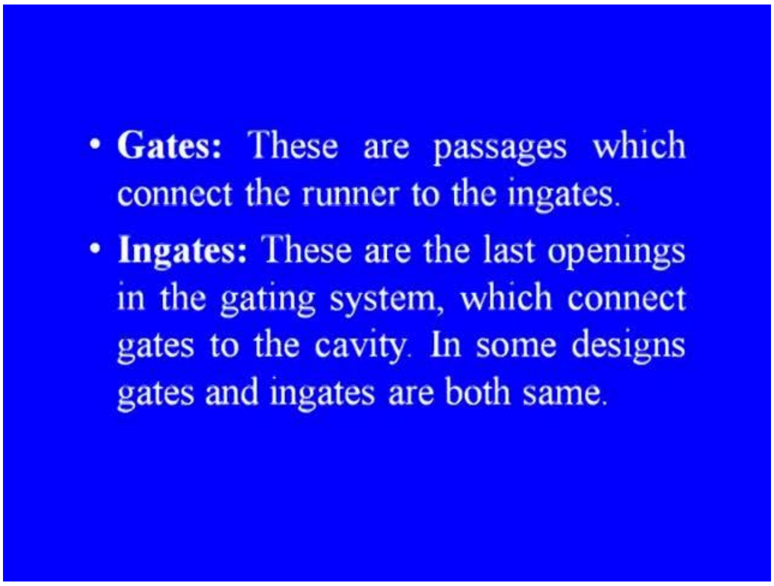

Then gates, these are passages which connect the runner to the ingates. Ingates these are the last openings in the gating system, which connect gates to the cavity. In some designs gates and ingates are both same. So, this is a typical gating system, we were talking about.

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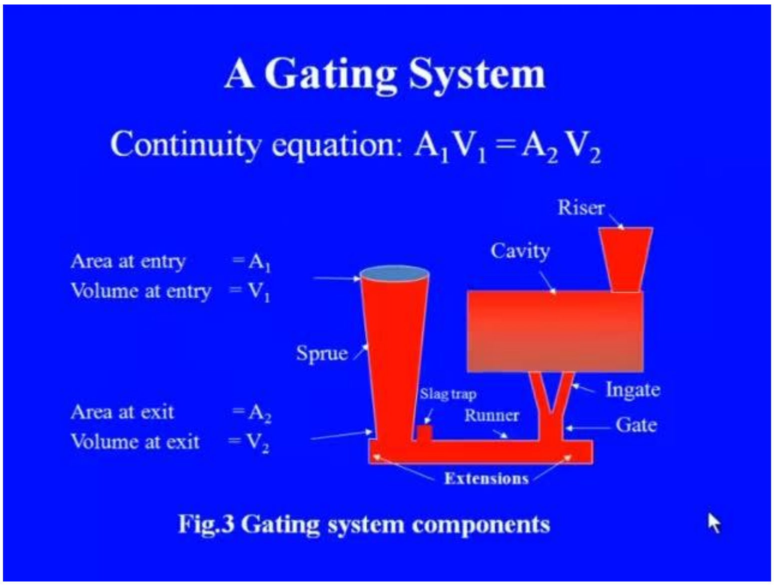

So, this the sprue and this is where the molding cup we can, this pouring cup we can say. From the ladle the liquid molten material will be poured here, this will facilitate the molten material to flow through and this is the gate through which the material will be delivered, through the casting, to the cavity when the casting is to be produced. These are the ingates ,there is number of branches are being created, so that the distribution of the molten material will be at uniform rate. And of course, this will help in maintaining uniform temperature as far as possible while delivering.

This is the riser, which provides additional molten material, so that during solidification if the molten material shrinks, which usually happens, liquid occupies more volume in most of the cases and while solidification the volume gets shrunk. Then to fill the remaining portion, this riser provides additional molten material, which it keeps as the reserved one or uses this reserved molten metal will be used, so that no void or volume is left unfilled inside the casting because of the solidification.

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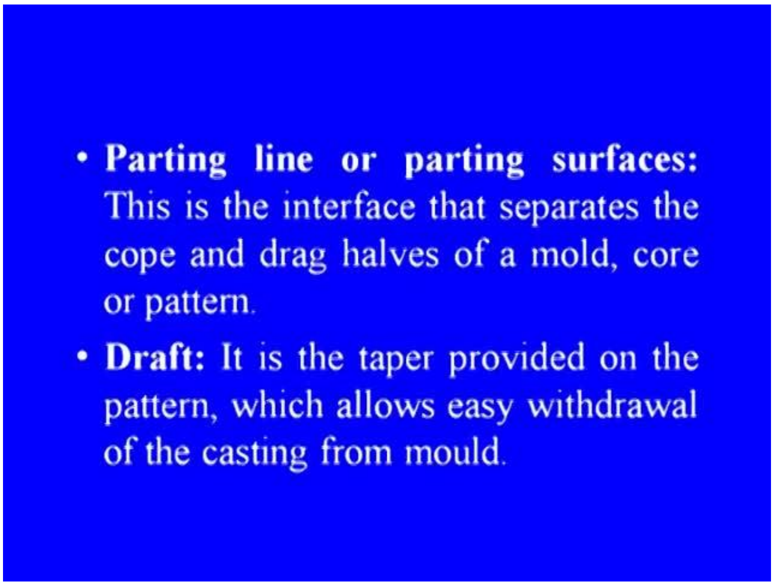

Then another terminology very important as far as the casting concerned is the draft. It is the taper provided on the pattern, which allows easy withdrawal of the casting from the mold. This we we can see in the previous figure as well, at taper. Now, let us summarize what we have discussed in this particular session. We have discussed the basic features and terminologies in casting process; gating, risering systems and their design aspects, the basics in solidification or the casting formation. We hope this session was informative and interesting.

Thank you.