Manufacturing Processes - Casting and Joining
Prof. Sounak Kumar Choudhury
Department of Mechanical Engineering
Indian Institute of Technology Kanpur

Lecture – 09
Steps in Sand Casting Processes

Hello and welcome to the course of Manufacturing Processes - Casting and Joining. Right now, we are discussing casting, it will be followed by joining. Let me remind you that in my last discussion session we have discussed few numerical examples which will help you in understanding how to use the theory that you have gone through.

What is the theory? Particularly up to this point what we have learned is how to design the casting process. That includes the design of a riser. And, once again I emphasise, that the riser design is very important, because this will compensate for the shrinkages that happens during the casting process, during the solidification of the metal.

I have gone through different kind of examples. There are four examples that we have discussed so far that probably will clarify the use of the Chvorinov's rule, which says that the total solidification time for either casting or the riser is equal to the mould constant into $\left(\frac{V}{A}\right)^2$ where, A is the area, C_m is the mould constant, if you remember.

Now, the mould constant of course, depends on the kind of material you are using, mould material you are using, what kind of metal you are using for casting and so on. And, important thing is to know that the C_m, this mould constant for the riser and the casting will be the same because, the same molten material for the casting is involved here, which also goes into the riser.

After that, we started discussing about the shrinkage process itself. And, we said that during the solidification the shrinkage happens in three different stages.

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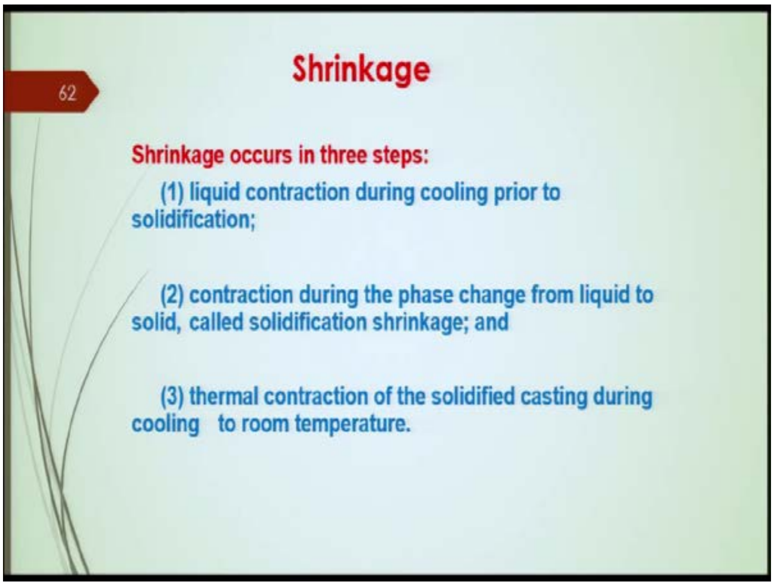

It will happen during the liquid contraction, during cooling prior to the solidification. Just before the solidification starts, the cooling process started in the molten metal. And, because of that the contraction happens.

Next stage is the contraction during the phase change from liquid to solid. After the freezing stage starts, where the molten metal starts getting into the solidified state.

Contraction during the phase change from liquid to solid is called the solidification shrinkage. And, the third stage is the thermal contraction of the solidified casting during the cooling to the room temperature. The freezing point ends, the casting is completely solid after that, but the temperature is still very high, it is very hot.

So, after that, the solid casting has to reach the room temperature. It has to cool down to the room temperature. During that stage the contraction happens again. These are the three stages, prior to solidification, during that phase change from the liquid to solid. And, after it has become solid up to the room temperature is another stage. So, these are the three stages where the contraction or the shrinkage will take place.

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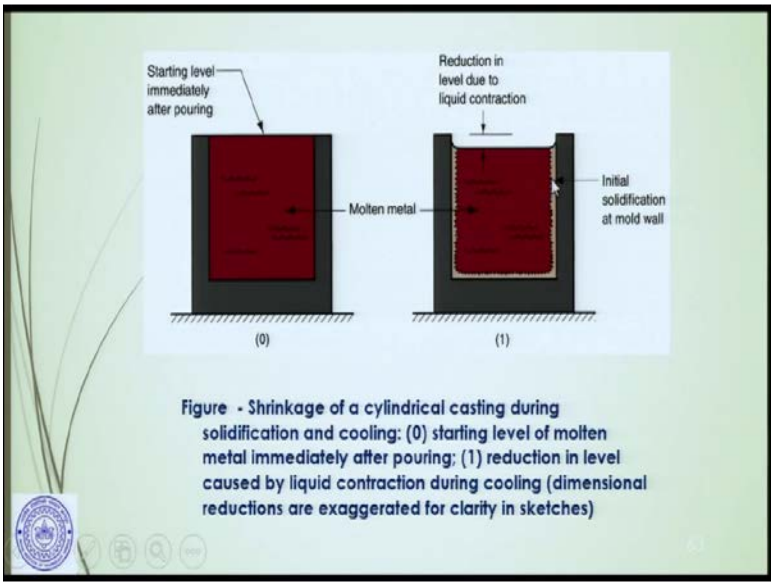

Figure - Shrinkage of a cylindrical casting during solidification and cooling: (0) starting level of molten metal immediately after pouring; (1) reduction in level caused by liquid contraction during cooling (dimensional reductions are exaggerated for clarity in sketches)

Here it is shown that molten metal is just poured into the mould cavity. Immediately after pouring of course, the level will be filled up I mean like this, there is no shrinkage, it is just filled up.

Now, the reduction in the level due to liquid contraction starts. The level was up to this. It has been contracted and the liquid contraction is here. This is the liquid contraction during the cooling prior to solidification. This is how it looks like and then also here this is the initial solidification. This is the first stage.

Now, let us see the shrinkage of a cylindrical casting during the solidification and cooling. This is the starting level of the molten metal immediately after pouring. And, here we are showing that this is the reduction in the level caused by liquid contraction during the cooling - that is the dimensional reduction. These are exaggerated of course.

But, just to give you an idea that this is how it can happen actually, this is the reduction in the level due to liquid contraction and this is also the initial solidification at mould wall and, because of that there will be some contraction.

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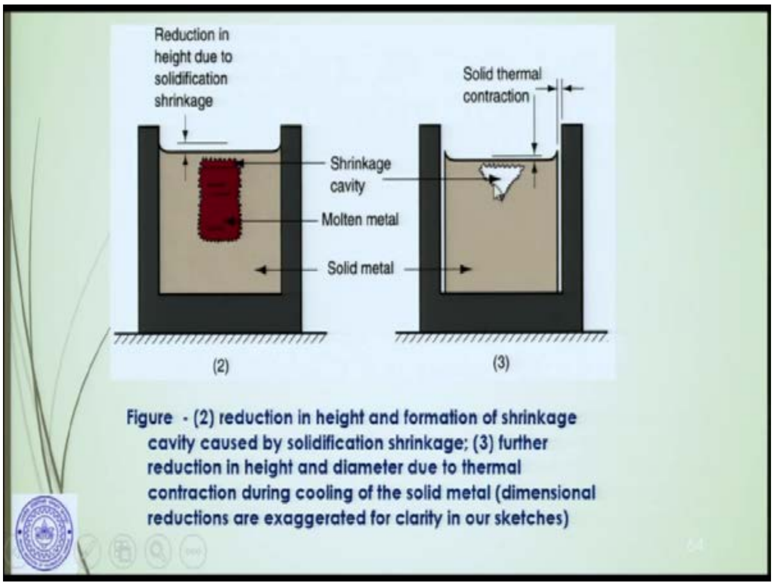

Reduction in the height due to solidification has taken place and here we have the shrinkage cavity. All around this is actually solidified and this is the area where the molten metal is left over. And, then it can be shrinkage cavity like this. When this will be solidified finally, there will be a a shrinkage cavity, this kind of a shrinkage cavity.

Here, this reduction in height and formation of the shrinkage cavity has been caused by solidification shrinkage. Further reduction happens in the height, here as you can see, and the diameter due to the thermal contraction, during the cooling of the solid metal. This is the dimensional reduction that is exaggerated for clarity in this sketch.

Here it is exaggerated and shown that there is a solid thermal contraction. There is a solid thermal contraction from here to here. Here the shrinkage cavity is shown.

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Solidification shrinkage occurs in nearly all metals, because the solid phase has a higher density than the liquid phase. Thus, solidification causes a reduction in the volume per unit weight of metal; this will always happen because the solid phase will always have a higher density than the liquid phase.

Therefore, the solidification causes a reduction in the volume per unit weight of metal. The exception, as, that in cast iron with high carbon content this phenomena does not happen, does not happen as prominently as it happens in the case of the steel for example.

Graphitization during final stages of freezing causes expansion. That is the cause why it does not happen - that counteracts volumetric decrease associated with a phase change. Therefore, you will not find this kind of a phenomena in the cast iron with the high carbon content. The graphitization will counteract the volumetric decrease associated with the phase change that would have happened, that is being neutralised.

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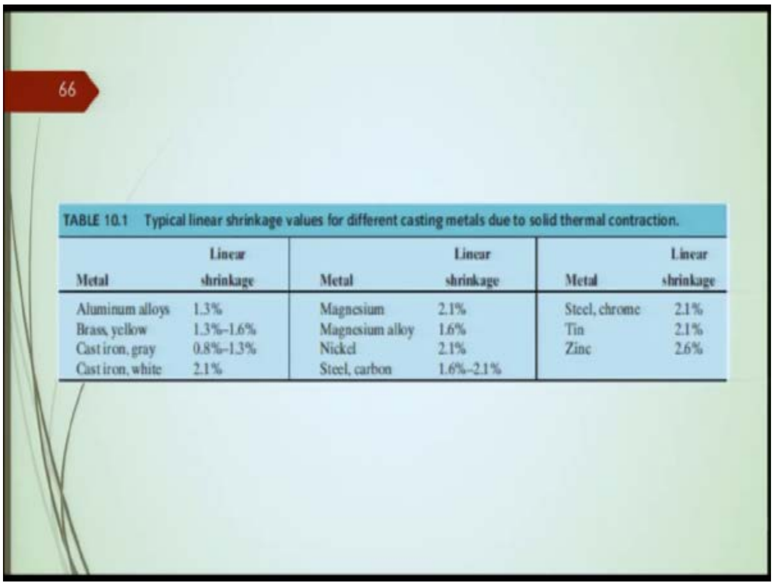

TABLE 10.1 Typical linear shrinkage values for different casting metals due to solid thermal contraction.

Metal	Linear shrinkage	Metal	Linear shrinkage	Metal	Linear shrinkage
Aluminum alloys	1.3%	Magnesium	2.1%	Steel, chrome	2.1%
Brass, yellow	1.3%–1.6%	Magnesium alloy	1.6%	Tin	2.1%
Cast iron, gray	0.8%–1.3%	Nickel	2.1%	Zinc	2.6%
Cast iron, white	2.1%	Steel, carbon	1.6%–2.1%		

Here in this table some values have been shown for your idea so that you could get a fairly good idea about the shrinkage values for different kind of metals. If you see here, these are the typical linear shrinkage values for different casting metals due to solid thermal contraction.

Let us see, aluminium alloys have 1.3% linear shrinkage, 1.3% of the entire volume. Whereas, the brass, particularly the yellow one, can go from 1.3 to 1.6%. The cast iron, particularly the gray cast iron, can go up to 1.3% percent and the white cast iron can go up to 2.1% of the linear shrinkage, of the total volume.

Magnesium has 2.1%, same as the white cast iron. Magnesium alloys will have 1.6% percent, so this is equivalent to this yellow brass. Nickel, magnesium and white cast iron have the same value of 2.1% of the linear shrinkage. Similarly, carbon steel will have up to 2.1%.

Depending on different kind of contents of the carbon in the steel, it can have from 1.6 to 2.1%. Chromium steel will have 2.1%, tin 2.1%, zinc will be 2.6%. So, you can see that zinc has the highest thermal contraction. Many of these metals like, tin, steel, chromium steel, nickel magnesium, white cast iron, they all have very high value including the carbon steel, it is in the order of up to 2.1% of the total volume.

From this you can have a fairly good idea of the kind of linear shrinkage that different metals can have. This will be always available in the handbook. As, I said that this is the material property; once the when the material is produced, it is tested, and these values are tabulated.

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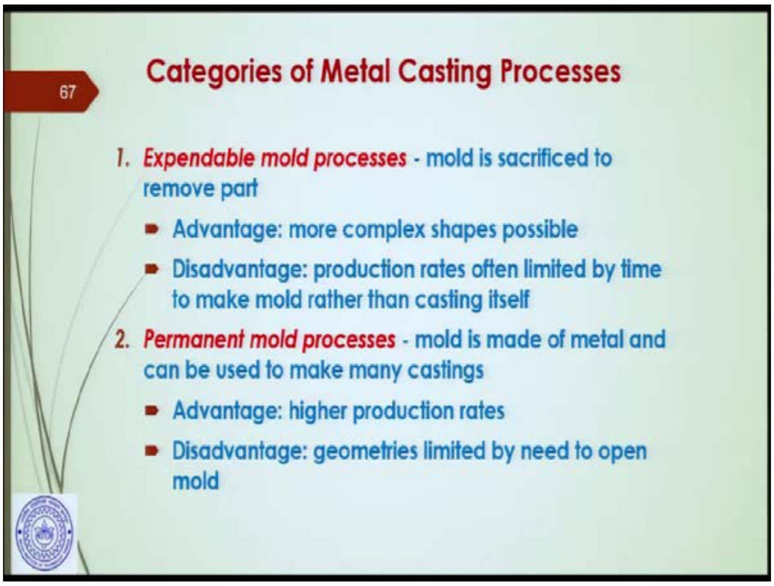

Now, let us see the categories of metal casting processes. These are basically two types - expendable mould processes and permanent mould processes. I already told you in the very beginning that there are two types of moulds; expendable moulds and the permanent mould.

Expendable moulds are those moulds that you use only once and to get the casting you have to destroy the mould. It is like sand casting, shell mould casting etc. and in the permanent mould casting, the mould is permanent that you can use more than once. Obviously, in that case the mould will be metallic.

Now, about expendable mould processes; mould is sacrificed to remove part as I said that to remove the part you have to destroy the mould. Advantages - more complex shapes are possible to cast, because it is the pattern that you have to make only. In case of permanent mould, you have to make the mould, fabricate the mould. Since it is metallic, the machinability will be lower.

Disadvantage is that the production rate is often limited by the time to make mould rather than the casting itself. I have already shown you some video clips, where if you remember it was demonstrated how to make the mould; particularly the sand moulding in the foundry practice.

You have seen how scrupulously sand mould is made. You take the flask, you take the box, put the pattern, put the gating system, put the sand, ram the sand, then you put the another half of the pattern and so on so forth, so you have to then finally get the mould cavity. And, that too it may be destroyed while taking out the pattern for example.

You have to again repair it and so on. You have to also sprinkle the refractory material or apply the refractory paint and so on. Therefore, the production rates are often limited by the time to make the mould rather than the casting itself.

However, when there is a very complicated casting and very large casting, then it is of course, justified, that the time to make the cavity is much more because it is a very big casting. But, for small castings which are produced at a large production volume, in that case the permanent moulds are of course, feasible economically.

In permanent mould processes, mould is made of metal and, can be used to make many castings that I already told you. Advantages are the higher production rate, particularly when you are making small castings at a very large number. Production rate will be also very high because you are not making the mould all the time like the sand casting or like expendable mould. The mould is already made.

You are just pouring the metal and only time that is required is the solidification time. You have to actually wait for the metal to be solidified, inside the mould cavity and then you can pour another portion of the molten metal, to get the next casting.

Disadvantage is that the geometries are limited by the need to open the mould. Meaning that it cannot be very complicated, because you cannot destroy the mould, you have to open the two halves. Therefore, it should be able to be opened.

And, in case of sand mould it does not matter since you have to destroy it anyway. So, very complicated shapes can be made. In case of permanent moulds, you cannot because otherwise you cannot just open the two halves. Therefore, geometries are limited by the need to open the mould to get the casting without destroying the mould, because it is a metal mould and it has to be used several times.

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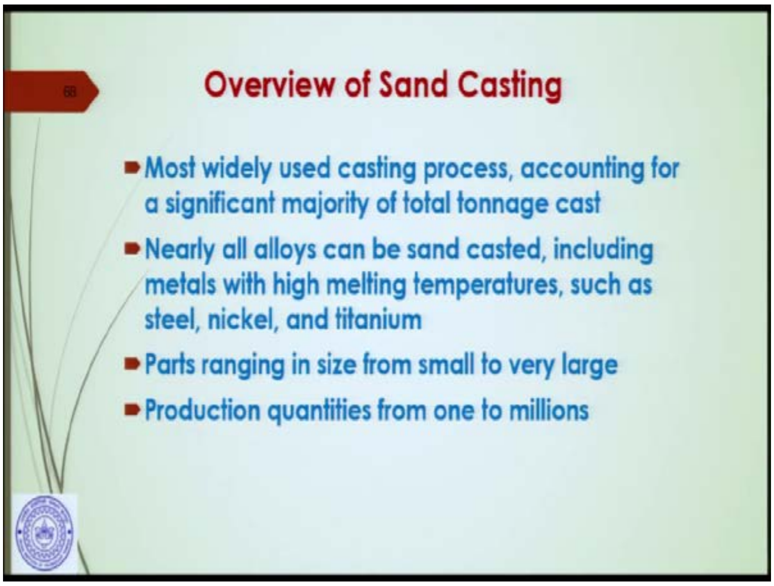

Overview of sand casting: I have already shown it to you the features of sand casting. Most widely used casting process, accounting for a significant majority of the total tonnage cast. Mostly the sand casting is used.

Nearly all alloys can be sand casted, including metals with high melting temperatures, such as steel, nickel, titanium which have very high melting temperature, but as long as a metal can be melted, as I said in the beginning, it can be casted. That is the biggest advantage of the casting that anything that can be melted can be casted.

Parts ranging in size from small to very large, small ornaments - I gave you examples, as large as up to 1000 tonne of the Buddha statue. Of course, not the entire statue was casted; 1000 tonne was divided into few castings, each may be few tonnes, but up to 100 tonnes examples are there.

Production quantities from 1 to 1 million. Many of the casting processes can be automated and because of that the production rate can be very high.

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What are the steps? You may recall from the video clip that you have seen. You can go back and once again you can see that, because I have given you the link, YouTube link, and those videos can be watched from the YouTube.

Now, first step is to pour molten metal into the sand mould. We are not discussing of course, the mould making, melting of the metal that you have seen of course, it is obvious that those steps are to be followed. Then, allow metal to solidify, inside the mould cavity, break up the mould to remove the casting, clean and inspect casting.

The final step is an important part. Because, in sand casting for example, it will always have the wrapping of the sand, or the refractory material. Some sand will be wrapped around the casting that have to be cleaned. Normally, it is the sand blasting, or the small steel ball blasting process is used to clean the casting. This also has been shown in one of the video clips, how they are being cleaned up.

And, another point that is important for cleaning up is that, when the casting will be extracted, the gating system will be attached to that; that means, that riser, the runner etc., all those things will be attached. You have to cut it off, shear it off, and then you have to grind properly that place and the entire casting. Because, as we said that the casting is not a very precise process, there are certain allowances kept.

Apart from the shrinkage allowance, there are certain allowances kept that we will discuss later, which are the machining allowances. Because, we keep in mind always that by casting we will not get the final dimensions. To get the final dimensions we have to use the machining process. It can be turning or milling or grinding process.

For that also we have to keep some sort of allowance in the pattern itself. Because, how you are making the pattern depending on that you will get the final casting since it is a replica of the casting. Depending on those allowances, you make the final casting by removing those allowances. Shrinkage allowances are to compensate for the shrinkages, machining allowances, to remove that portion of allowance to get the final dimensions.

After cleaning the casting, you have to make sure that the casting dimensions are proper. You have to inspect them. Heat treatment of casting is sometimes required to improve the metallurgical properties particularly, when it will have the internal stresses.

Because of the temperature gradient, gradient during the solidification, internal stresses may arise. To remove this those internal stresses, you need to have certain kind of heat treatment or the heat treatment for improving the metallurgical properties like, strength, hardness and so on.

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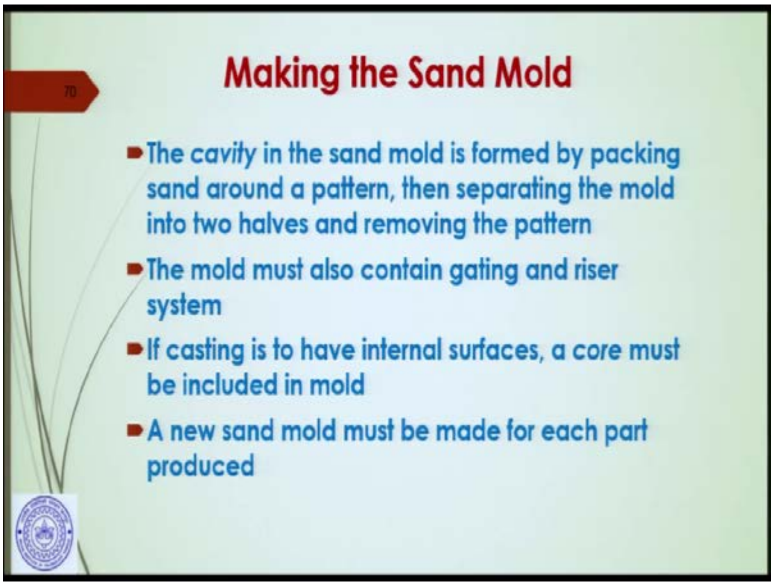

Making the sand mould: you have seen the steps in the video clips. Now, I am repeating so that it stays in your mind. The cavity in the sand mould is formed by packing sand around the pattern, then separating the mould into two halves and removing the pattern. We are talking about the sand mould, that is the expendable mould.

The mould must also contain gating and riser system, because it will be part of the casting and through the gating system, the molten metal will flow to the mould cavity and the riser. We have talked enough about the riser. If casting is to have internal surfaces, a core must be included in the mould.

I also talked about the core. The core material is different; that is also sand material in the sand casting, but this sand is different, this material is different, it is stronger. Therefore, some percentage of molasses is added for better binding. Apart from the clay that is used in the sand for the mould making, in the core making the molasses is used.

A new sand mould must be made for each part produced, because it is expendable mould. Therefore, to get the casting you have to destroy the mould. And, for the next casting you have to make another mould. That is one of the disadvantages that slows down the process, because making the mould takes more time than making the casting.

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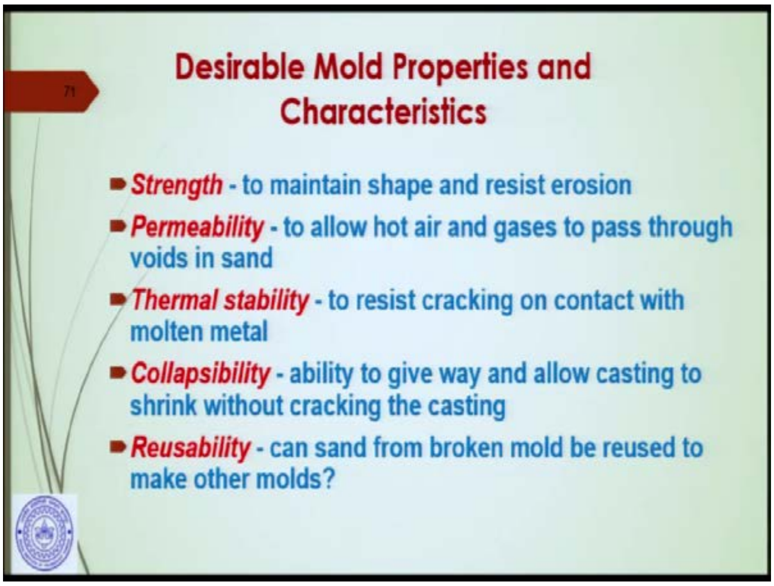

Desirable mould properties and characteristics: these five characteristics or properties are very important. One is the strength that is to maintain shape and resist erosion, because when the molten metal goes in it is very heavy and it may create turbulence, it will have a particular velocity, initial pouring velocity that may actually destroy the mould if it does not have the appropriate strength. We are talking about the sand mould, expendable mould.

Permeability is to allow hot air and gases to pass through the voids in the sand. This I already told you. I will remind you that in the sand we add clay. Clay is added in the form of powder initially, then we add water. When we are adding water, the moisture gets into these clay particles and the clay particles will be expanded, they will be blown up.

They will actually separate out the grains in the sand and they will increase the void. As the voids are increased, the density will be decreased. But the permeability will be higher, because through the void the gas can come out since it is becoming more. Gas which is evolving because of the burning of the additives, those additives which are added into the sand, that I already told you in the beginning.

But when the water content is more than required, then the clay is saturated with water. It does not need more water, but if we add more water after that then the voids will be occupied by the water, density will be more, permeability will be less. and the strength will decrease. This is a very important phenomenon that you have to keep in mind always. The permeability is to allow hot air and gases to pass through the voids in the sand.

Thermal stability is another characteristic or another property. This is to resist the cracking on contact with the molten metal. Molten metal comes with a very high temperature; this is the melting temperature of the metal. Depending on the meta,l there will be different temperatures, but the temperature will be still very high. When it is poured at that temperature, there will be very high temperature gradient.

Temperature of the mould will be at the ambient temperature, and this is much less than the temperature of the molten metal. So, when the molten metal is poured in the mould cavity, because of the very high temperature gradient, there will be a thermal shock. That should be resisted by the mould cavity or the sand. That is called the thermal stability; this is to resist cracking on contact with the molten metal.

That is one reason why these refractory paints are used. You remember in one of the videos it has been shown that there is flood sprinkling of the refractory material after the mould cavity is made. That is to make it thermally more stable, to increase the thermal stability.

Next is the collapsibility, which is the ability to give way and allow casting to shrink without cracking the casting. So, collapsibility means that whenever the shrinkage happens, mould cavity should allow it to happen. If it does not allow, in that case it can actually crack, it can actually break, or it can expand. It should give way to that expansion. If those expansions and contractions are not allowed by the mould material or the mould cavity or the sand itself, in that case the mould can actually collapse.

Reusability: can sand from broken mould be reused to make other moulds? Yes, it can be reused. That depends on what kind of mould material you are using, what kind of sand you are using. The ability of the sand to be reused is one of the properties. This will reduce the cost, because every time you are breaking the mould to get the casting.

Additionally, you need fresh sand as well as fresh clay, and the additives. That will add to the cost of the casting overall. Then the reusability is one of the factors therefore, that will reduce the cost of the casting.

Once more, it is the strength, it is the permeability, thermal stability, collapsibility, and the reusability - these are the five factors or five properties that the mould should have. By mould we mean of course, the mould sand and overall, the mould material when it is made after adding the clay and the moisture that is the water. Rest of the material we will discuss in our next discussion session.

Thank you.