Principles of Casting Technology
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Lecture - 04
Solidification
Freeze wave mechanism, Solidification time

Welcome to the lecture on Solidification, in this lecture we will discuss about the freeze wave mechanism which basically is found in case of solidification of alloys, and also we will try to see how to find the solidification time. Now, what we have discussed so far, that in case of alloys basically, the solidification, during the solidification process the temperature decreases. Also in case of, alloys there is formation of dendritic type of structure. After the initial formation of equiaxed grains you have a dendritic morphology, because of the presence of constitutional super cooling.

The mechanism of solidification can well be understood with the help of a mechanism known as freeze wave mechanism in case of alloys. So, solidification is complete in terms of a wave, how it looks like.

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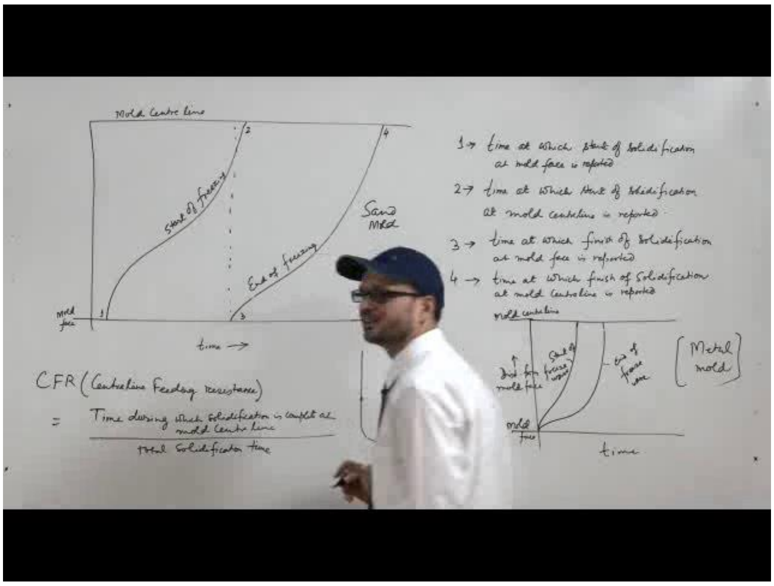

In case of alloys, what is seen is that you have solidification basically start this is the solidification start curve and this is the, end curve. This is the mold center line, and this is the mold face and this is time. Now, this is known as a start of freezing, and this is known as end of freezing.

Now, we all know that in case of alloys you have a freezing range; now what we see is the freezing is started; now this is typically for a sand mold. So, what does this characterize? This characterizes the concept that, when you have poured the liquid metal at the mold face it is start solidifying at this time. After this time has elapsed, the mold face has produced the solid crystals and that is moving towards like this. At the mold center line, it will start at this time. Whereas, at the mold face it will be completed at this point this is the time at which, so if you have 1, this is 2, this is 3, and this is 4.

So, 1 is the time at which, start of solidification at mold face or wall is reported. Now, as we move towards the mold center line, the solidification is delayed. We know why it is delayed, because of the release of basically the latent heat and also it is going so degree of under cooling is reduced and you see that at the mold center line it is starting at this point. At the mold step centre line, this is time at which 2 is the time, at which a start of solidification at mold center line is reported. It is just like you have a cavity, once you have liquid metal into it at this point, this is the point it will start first solidifying and the solidification will start at these two points if it is a sand mold in that case, and this is the point at center line when it will start here. Now, once it has started here it has to finish also the solidification at this point, and that point is 3.

So, 3 is time at which finish of solidification at mold face is reported. It has a started at this point, but by this time the solidification is complete at the mold face. Similarly, at the mold centerline the solidification is complete at this point so 4 is, the time at which finish of solidification at mold center line is reported.

Now, the shape will be like this, but the width will depend upon what is the mold material. Now, what you see is you can see that, the time at which the mold face he has finished it is solidification, at that time the solidification at the center line has not even started for this typically curve. The solidification at this center line, it starts at a much later time and once the solidification will be delayed and delayed there will be more chances of and see the solidification is all though it is started at this time, it is finished at a very later time. The solidification time, total solidification time will be from here to here, 1 to 4. Whereas, the solidification time to be completed at the mold center line will be from 2 to 4.

So, basically there is an index which tells, now the thing is that the alloys which have this has a wider range, they are very difficult to be fed this is typically for a sand mold. If we take this as a metal mold, the characteristics of this curve will be like this it will be will like this. This will be again your mold face, distance from mold face and this is mold center line, this is a start of the freeze wave and this is end of freeze wave, and this is basically in case of a metal mold or a chill mold. Now, you can see the difference that in case of metallic mold the solidification has started as soon as we have poured the metal into the mold, at zero time it has started where in the case of met sand mold it may start at a later time. It is finishing also at a very later time, whereas here it is finishing in a very small time and at the center also you can see this width is smaller as compared to this width.

These are the start of freezing and end of freezing waves. So, that the solidification is complete in case of the alloys, the only difference is that you have the metal mold because of larger heat transfer weight this width becomes less and that is why it is advisable to go for the larger cooling rate material, by which this solidification time is. This is the total solidification time, in this case which is quite less as compare to that of sand mold. Now, because of this you are likely to get certain defects known as center line feeding resistance.

This term, you have the sand mold which is your sand mold. Now, because of this mechanism there is a term known as CFR that is known as, Centerline Feeding Resistance. What you see is, there is at the centerline the solidification start is delayed as well as the solidification also is completed at a very later time. Now, because of this you will have the difficulty at the center line and as this time will be larger and larger, that will create more and more possibility of having shrinkage defects or other defects in the casting.

Centerline Feeding Resistance is divided as the time during which solidification is complete at mold center line, divided by total solidification time. This is nothing but this time divided by total solidification time and this is known as Centerline Feeding Resistance. It is typical value, if it is lower than suppose 50 percent or 40 percent it is quite good, but if it is more than 60 percent or 70 percent, than the alloy is said to be very difficult to be fed.

This, what the end of freezing and start of freezing has the meaning in to understand, how difficult or how easy it will be to feed any material and to get a defect free product.

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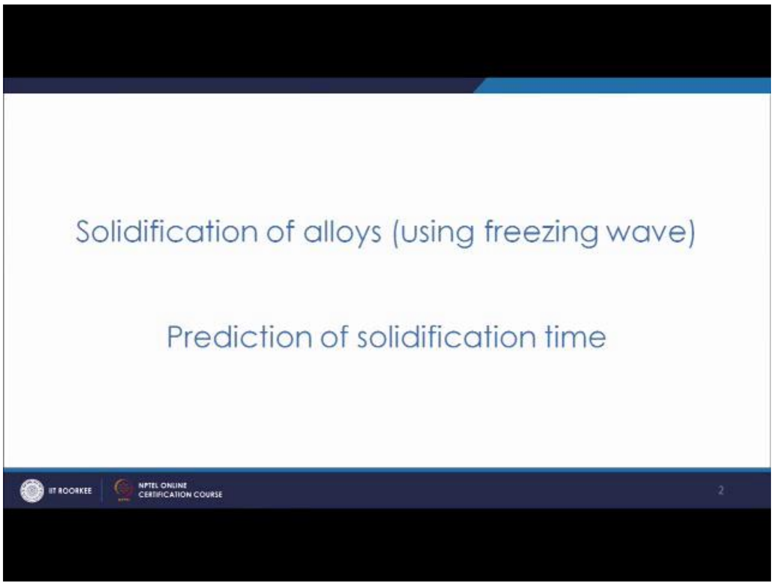

Next is to find the solidification time, so how to find the prediction of solidification time?

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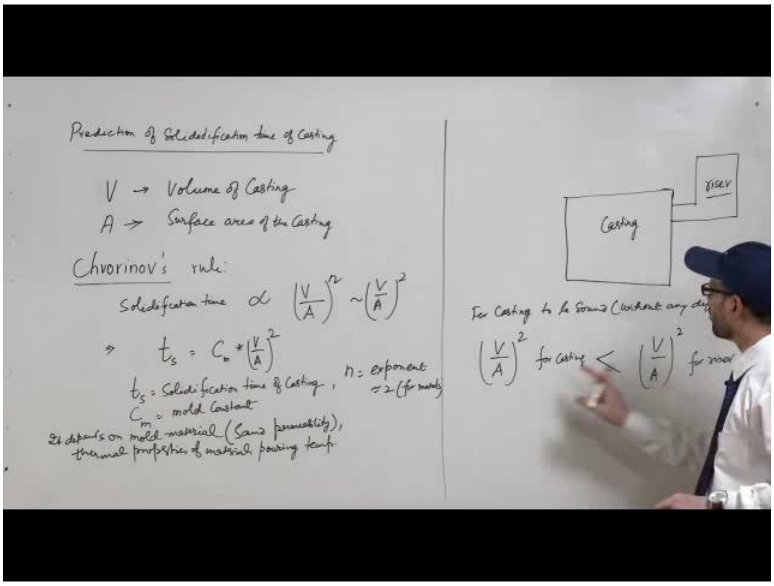

Now, what we have understood so far is when you are pouring the liquid metal in the cavity, it is starts loosing the heat from the surfaces. So you have two things, one is the surface area which is responsible for extracting the heat from the casting and another term is the volume, the volume of the liquid metal.

There are two terminologies, one is volume of casting and another is surface area of the casting, it is a surface area of the casting. The volume of the casting is indicative of the heat content in the casting; larger will be the volume of the casting for a particular surface area larger will be the heat content in the casting and in that case larger will be the time required for the casting to solidify. On the other hand, larger will be the surface area for a constant volume of the casting lesser will be the time required to solidifying because, if you have large surface area the area from where the heat extraction will be there because heat extraction will depend upon the area which is exposed. So, larger will be the area exposed more will be the heat extraction and that is why less will be the time of solidification.

So, on this basis what has been seen is that in the casting, if you want the casting to solidify quickly you will have to have a casting in such a manner that it has large expose surface area. Whereas, if in certain case you want the casting to solidify late, you will have to have a shape which should have minimum surface area for a particular volume. On that basis there is a rule which has been suggested by Chvorinov, Chvorinov's rule.

Chvorinov's rule suggests that the solidification time, of a casting is proportional to volume by surface area square. This is the rule empirical formula which is given by Chvorinov, this can further be written as solidification time t s will be equal to C m multiplied by V by A square. Where t s are solidification time of the casting, and C m is known as a mold constant. So, C m is a mold constant which depends upon, mold material. If it is sand, it is sand permeability, thermal properties of the material, like it is conductivity and pouring temperature. According to this rule, the solidification time will be proportional to V by A square. Now, this rule is basically used to find, this basically 2 value it is nothing but, this is an exponent you can have this 2 has n and this n is exponent, whose value is typically 2 for metals.

That is why we normally keep it as, V by A to the power 2. This rule is basically used to find the solidification (Refer Time: 19:36) and this value of the C m is found experimentally, and then that can be used to find the solidification time of any casting. Now, this is used when we have to find the relative time of freezing of two castings or relative time of freezing of a casting and a riser, suppose in a riser you have the metal and there is a casting. If you have a casting and you have a riser, if this is a casting, and this is a riser. Now, what we expect is that riser must solidify at a later time then the casting. What we mean to say is, that if they are of the same material other conditions are same in that case for casting to be sound without any defect. In that case, what we can see is you will have to find V by A the square for casting and we have to find V by A square for riser.

Now, in this case what we expect is that the solidification time of casting must be less than the solidification time of the riser. So, this must be and this is nothing but the solidification time. This must be less than the solidification time of the riser. So, this is basically something indicative of the solidification time, you have to have a riser of such a shape and size so that the V by A square for riser is more than that of a casting. In that case only you can expect the casting to be a sound one. We can solve a problem based on this V by A square value which can tell us how this V by A is important and how they will take more or less time for casting to solidify.

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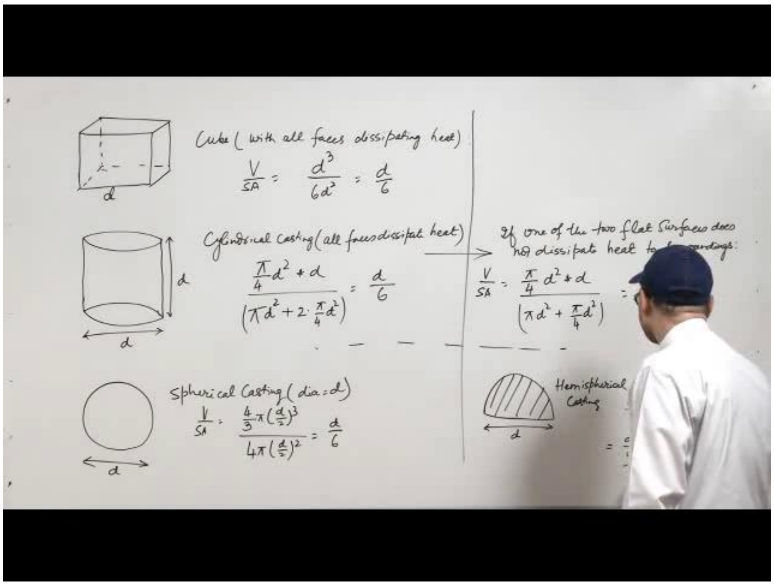

So, let us try to find the solidification time for the casting of different shapes, and let us say there is a shape of cube. In that case, there is a cube of side d, and all the faces are basically participating in dissipation of heat, there is a cubical casting where all the faces dissipate heat to the surroundings. For such a case, this is a cube with all faces dissipating heat. Now, for this case if we try to find the volume by cooling surface area or volume by surface area what we have discussed that we have to find this parameter volume by surface area. So, for this volume is basically, d cube and surface area see it has 6 faces which are taking part in dissipating the heat to the surroundings. So, you have 6 d square, it will be d by 6.

Similarly, if you have a cylindrical casting, this is a cylindrical casting with height as d, and diameter as also d so, it is height is d and diameter is d. And we assume that all the surfaces, the flat surfaces as well as the curve surfaces dissipate heat to the surroundings. For a cylindrical casting, all faces dissipate heat to surroundings. In this case if we try to see, the volume will be pi by 4 d square multiplied by d. That is volume and it is surface area will be if you look at this surface area is pi by 4 d square, the bottom flat surface area and the top flat surface area is pi by 4 d square and this curve surface area will be pi d, pi d is the circumference multiplied by the height that is d. So, it is pi d into d that is pi d square this is the curved surface area plus 2, times pi by 4 d square. It will be pi by 4 and this will be 6 pi by 4, it will again be d by 6. What we see is the cooling characteristic of a solidification time of similar castings of these different shapes will be same, because V by SA is coming out to be same.

Let us take another example of a spherical casting. If it is a spherical casting, with diameter d, if it is a spherical casting with dia d so in this case also V by SA if we compute it will be 4 by 3 pi, d by 2 cube. So, that is the volume and surface area will be 4 pi are square basically, 4 pi into d by 2 square. If we simplify this, this also comes out to be d by 6. So, what we see is if you have these three different shapes of castings and having the dimension d as mentioned, then the V by SA is same, it means there will be taking similar time for solidification.

Now, let us take the cases in this case if the, for this if you take the extension of this case if one of the two flat surfaces does not dissipate heat to surroundings. If suppose you have a cylindrical casting, where one of the surface normally what we see is in the case of castings the bottom part may be attached to the casting or it may be on the casting itself so, are it is there inside the mold. In that case, this surface does not take part in dissipating heat so basically it is near the castings it is hot or so. We assume that this surface does not take part in dissipating the heat. So, in this case if you conclude the V by SA volume will remain the same, that will be pi by 4 d square multiplied by d, but surface area will be less surf the curve surface area will be the same, that is pi d square plus one of, we will take this only one of the two flat surface area that is pi by 4 d square.

In this case, what we get is this is coming as d by 5. So, what we see is that if this surface does not take part in dissipating heat to the surroundings, the volume by surface area becomes more than this case. So, certainly it will take the larger amount of time to solidify that is very natural, that when one of this surfaces is not dissipating the heat to the surroundings it will take a longer time to solidify. So, this parameter justifies that.

Let us take the extension to this case if you take a hemispherical type of casting. If you take the hemispherical cases, hemispherical casting whose diameter is d, so for a hemispherical casting its volume by surface area if you compute. It will be 4 by 3 pi r cubes by 2 so, 2 by 3 pi r cube, r will be d by 2 and it is cube. Then it has now 2 surfaces, distinct surfaces, one is the curved surface which is the dome and another is the flat surface. So, this part will be 2 pi r square so, 2 pi into d by 2 square, and this flat surface is basically the circular in shape that will be pi by 4 d square.

If we take the value of this, this comes out to be d upon 9. What we see is its value becomes quite small as compare to these cases. So, it will take very small time as compared to these cases because V by SA value is smaller in these cases. This V by SA values can be used to find the relative time of freezing of the castings and when we will discuss about the different methods of risering, in that case also the V by SA parameter has been used by some of the researchers to find the solidification time or to find the riser volume calculations.

Thank you.