Steel Quality Role of Secondary Refining and Continuous Casting
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Module - 05
Lecture - 24
Role of Mould Oscillation

Good morning. In the last session I have started covering you know the surface and internal quality in continuously cast product.

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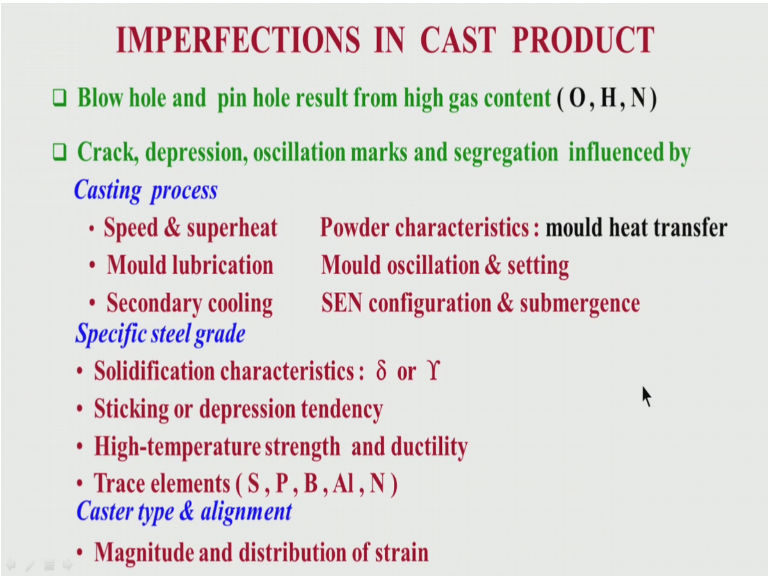

I have mentioned what are the imperfections in cast product what are the possible imperfections what are the types of imperfection in cast product, I have mentioned about this blow hole pin hole and crack depression oscillation marks, and segregation about the influenced by casting process for the specific steel grade, what are the casting type of alignment these are the possible factors I have started the different issues one by one.

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Blow Holes and Pin Holes

Relatively high content of soluble O , N and H responsible

Adequate deoxidation and degassing are essential

With progress of casting, content of solute O, C, N, H in remaining liquid steel increases due to segregation, and partial pressure of CO , N_2 and H_2 consequently increase .

$[H_H] = K_H (p_{H2})^{1/2}$, $[H_N] = K_N (p_{N2})^{1/2}$, $[H_C] [H_O] = K_{CO} \, p_{CO}$

It is possible to calculate p_{H2} , p_{N2} and p_{CO} from above relations

Total sum $P_{total} = p_{H2} + p_{N2} + p_{CO}$ is important

Gas bubbles form , if $P_{total} > P_{atm} + P_{ferro}$

I have mentioned about how this blow holes and pin holes are generated, I have mentioned that our whole idea is to control the content of soluble oxygen nitrogen hydrogen. If you can control these then you know the partial pressures of hydrogen nitrogen and c o will be less during solidification, and you know there will be less amount of gas bubbles formation because the total pressure which is the summation of partial pressure of hydrogen, nitrogen and carbon monoxide will be less than the atmospheric pressure or the ferrostatic pressure.

So, there will be no gas bubbles which can generate which will form in the cast product. So, this is the basic principle for avoiding you know blow holes and pin holes in the cast product.

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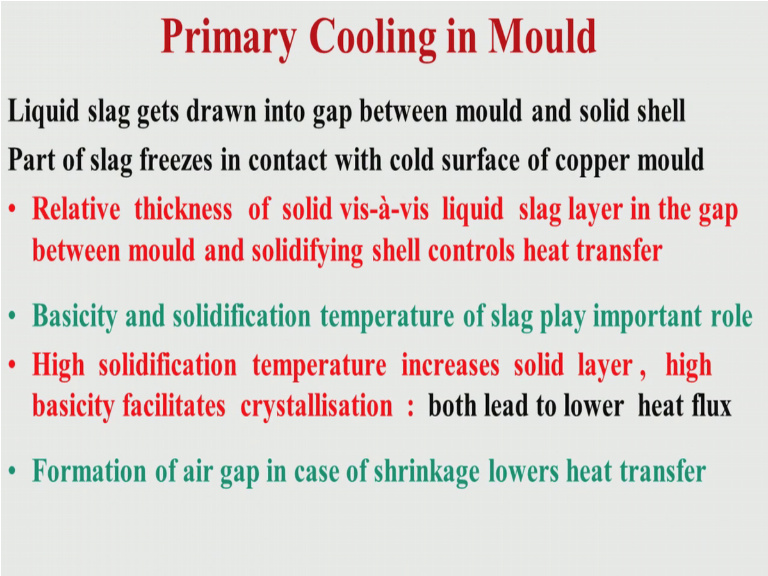

Then I have mentioned that when the solidification is starting in the mould there we call it primary cooling in mould. So, how it happens? Liquid steel they gets drawn into gap between mould and solid shell. So, this part of slag freezes in contact with cold surface of copper mould.

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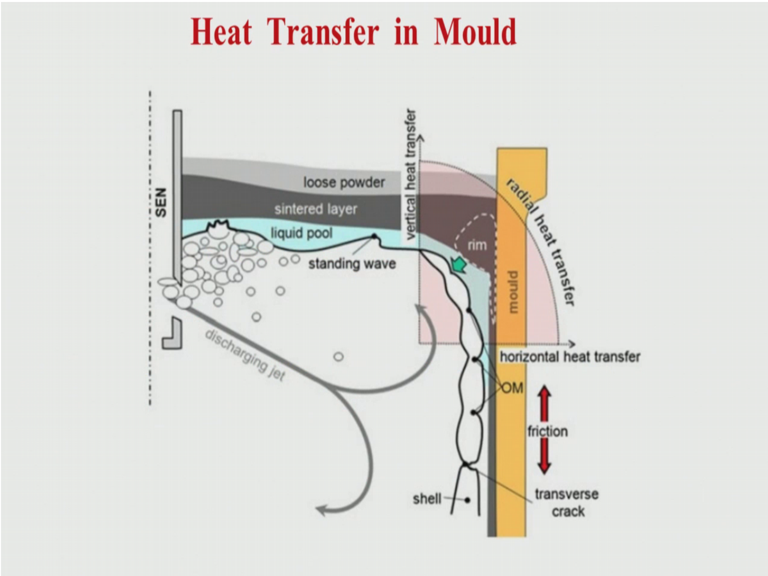

So, these I am trying to show with an image like what is happening in mould.

This is the mould surface you know copper is water cool mould surface and we have the subentry nozzle here. So, the liquid steel is getting discharged from the port of the subentry nozzle and getting inside the mould. Now if you look at the inside the mould what is there this is the liquid steel, this is the liquid pool of this what about powder you are adding at the top of the liquid steel in the mould, that powder is going to get melted in contact with the hot liquid steel. So, there are basically three layers one is the loose powder at the top, then the sintered layer and finally, the liquid pool of slag which is just at the top of the liquid steel.

So, basically in the mould we have a loose powder, we have a sintered layer we have a liquid pool on top of the liquid steel. So, what is happening is important. The horizontal heat transfer is taking place this direction because it is the water cool mould. This is the liquid steel which is having some lot of high temperature. So, heat from here will try to come out through the water cool mould. So, this is the horizontal heat transfer.

I have also told the some amount of heat will also like to come out you know from the liquid steel to outside in the vertical fashion through the powder. So, the amount of heat of course, is less compare to this because you know there is a big insulator loose powder is a big insulator. It does not allow too much of heat to come out. So, this surface also has to be maintained hot. So, otherwise they will be some heat loss. So, if the surface is maintain hot then you this heart transfer is relatively less and you know here your this horizontal heat transfer some small amount of heat transfer vertically. So, some amount of radial is transfer also will be there.

So, what happens is that one radium is formed is called the solid rim which is forming form the pool of liquid pool of slag. Some this molten slag after you know it gets frozen this is a rim, and then what is happening please look at here this is the liquid slag then this is the rim and then this dark area is basically the solid you know slag. So, from the liquid slag which is in contact with the mould copper mould some amount of solid slag has formed this will be clear.

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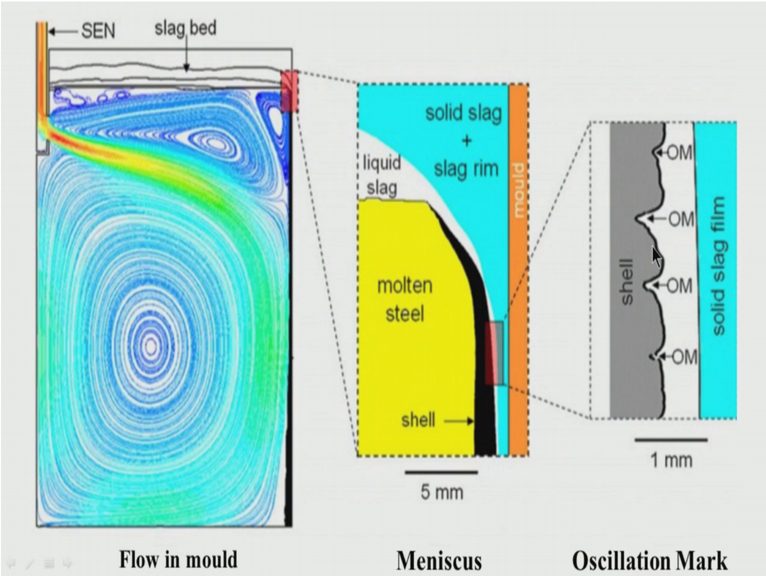

More clearer than in this picture. Here this is the mould area this is the flow in the mould people have found out through some modelling what is the flow what is the type of flow you know the liquid steel is coming inside this is the temperature distribution, this very hot here and then slowly the temperature is coming down inside the mould.

So this area, that means the meniscus area has been magnified and shown in this picture. So, you please look at here the molten steel is this yellow, we have the shell solid shell which is forming in you know in contact with the molten steel the part of it is getting solidified. So, this is the solid shell and then we have the liquid slag in contact with the molten steel, then we have a solid slag and solid rim and finally, the mould.

So, the gap between the mould and the molten steel as I was telling you the solid slag will first the liquid slag will be dragged in, and in contact with the mould this is get solidified. So, we have a layer of solid slag and then liquid slag and then the solid shell and of course, the molten steel.

Now, this particular area if it is magnified, look at the you know what sizes what are the sizes this is 5 millimeter is this; that means, from the liquid shell thickness here is hardly when it is starting the solidify in the mould at the top of the mould is hardly less than 1 millimeter. It is increasing as you are going down the mould may be here it is two millimetre, 3 millimeter as you are going down shell thickness will increase, but at the top of the mould it is hardly one or 2 millimeter.

So, this area is if it is magnified you see what is the what are the different phases which I have present, was the solid slag film, this is the liquid slag film and this is the shell, solid shell which is getting solidified. So, this liquid slag will generate because of the movement of the you know oscillation the vertical and vertical movement top and bottom top and bottom this movement of the mould, this will generate oscillation marks at this shell. So, these are the oscillation marks which will be forming and the meniscus I have shown what is there is the molten steel on top of that liquid slag, on top of that solid slag. So, this is the area meniscus area which has been magnified and this particular area has been magnified here.

So, as I was telling that the primary cooling on the mould the liquid slag is getting drawn into the gap between mould and solid shell because of the mould oscillation. Then part of the slag freezes in contact with cold surface of copper mould as I had shown you in those figures and this relative thickness of the solid vis-à-vis liquid slag layer in the gap this is very important.

Part of it is solid part of it is liquid what is the relative thickness. That determines; what is the heat transfer how is it controlled control by two factors of the powder of the mould or the mould powder or the mould slag. First is the basicity what is the ratio of calcium oxide SiO_2, and the solidification temperature of slag they play important role. So, if you have high solidification temperature then what happens? As the liquid slag is getting solidified; that means, high solidification temperature means it will get solidified at relatively higher temperature.

So, at a particular temperature lower than that the higher the temperature thicker will be the solid shell, solid layer of the mould slag. So, this is important high solidification temperature increases solid layer and high basicity of the slag these facilitates crystallization; that means, from the slag which is slaggy in nature from slag it will go to the crystalline space if you have a high basicity.

So, both of these will lead to lower heat flux this is important. So, the during primary cooling how the heat flux in the gap between the shell and the mould how it is dictated dictated by two factors of mould slag, one is the basicity and is the solidification temperature. So, these two factors will determine; what are the relative thicknesses of solid slag layer and liquid slag layer.

Now, if you have a air gap formation in case of shrinkage then air is an insulation causing insulation; that means, in insulator. So, this will have lower the heat transfer will be affected. So, this is again very important to understand how the cooling is taking place in the mould, what are the causes of heat transfer horizontal heat transfer which I was showing here how this horizontal heat transfer is dictated by the two layer thickness one is the solid layer and the liquid layer. The relative thicknesses of this solid and liquid layer will determine the horizontal heat transfer and this will determine how the shell will grow this is very important to understand. Same thing I have seen in this figure this meniscus you have basically molten steel on the top of that liquid steel on top of that liquid slag, molten steel on top of that liquid slag and then you have a solid slag.

So, solids here in between the gap of the solid shell, which is forming and the mould which is relatively cooler because of the water cooling inside so, here you can show you can see the solid slag then you have a liquid slag and then the shell. The surface of the solid shell as I have told we have lot of oscillation marks.

Now, what are the depth of this oscillation marks that will determine whether this is the surface is good or bad there will always be oscillation marks since there is oscillation in during continuous casting mould oscillation there will be oscillation marks, but the question is whether they are deep or not. I will come to it what determines the depth of the oscillation marks; if you have deep oscillation marks it is not desirable.

So, it is very important to understand what are the factors which create deep oscillation marks which is a quality problem on the surface of the solid shell and finally, the surface of the steel cast steel where the slab or bloom or billet. So, oscillation mark will be there it is part of continuous casting, but we do not want deep oscillation marks, that is what is important to keep in mind.

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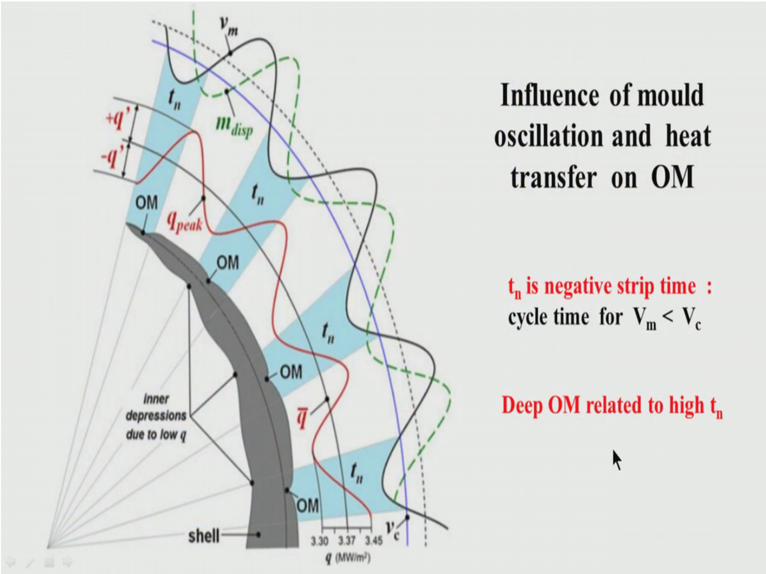

Now, please look at here what is happening this is showing how the oscillation marks are forming in the mould what are the mechanism of formation of oscillation marks this is the solid shell on surface I have told oscillation marks are forming now please look at what is happening here. The mould is oscillating let us assume which is the most common oscillation form in a sinusoidal fashion. So, this green dotted line indicates the movement of mould, the movement of mould in a sinusoidal fashion in the vertical direction. The mould is going up and down and the movement the displacement is sinusoidal; that means, going up going down in a sinusoidal fashion.

Now, if you differentiate this you get the velocity of the mould this is V m this is the black line this is also sinusoidal, but at a space angle from the displacement, displacement was this green and the black one is the velocity. Now what is casting speed? Casting speed means the solid shell of the strand which is always coming down the mould is going up and down up and down. So, some part of the movement of the mould is up and then down, but the strand is always coming down, then only the continuous casting is taking place. So, the strand is coming down.

So, what is happening please try to understand what is happening. The mould is going up and down there is a velocity profile of the mould see the displacement is sinusoidal the velocity is also sinusoidal, but at an angle space angle with the displacement, but it is the sinusoidal velocity also of the mould. But let us say V c is the casting speed; that means, the strand at which the liquid the shell everything is coming down; that means, the strand is coming down. So, this is fixed. So, this is this blue line. So, the blue line is always if this is the 0 line. So, blue line is always down, but this mould velocity is sinusoidal; that means, at certain you know portion of the cycle of its movement it is going up and then it is going down.

So, please try to understand that at certain portion of this sinusoidal cycle this portion this portion what is happening? Here this blue line is the velocity of the strand with the casting velocity casting speed and this one is the velocity of the sinusoidal velocity of the mould. So, this portion the velocity of the mould is less than the velocity of the casting velocity, this is the whole cycle please try to see this is the whole cycle.

So, the in the whole cycle some portion of the cycle the velocity of the mould is upwards or it is higher than the or larger than the upwards relatively upwards compared to the casting speed, but at certain portion of the cycle it is more at the lower portion it the velocity is more, downward velocity is more compared to the velocity of the casting velocity.

So, this portion of the cycle causes you know oscillation marks please try to see. This is the area which is called t n, t n is negative strip time; that means, the cycle time where the velocity of the mould is less than the velocity of the casting it is called negative strip time. So, in the whole cycle there is some portion of the cycle where the velocity of the mould is more than the velocity of the casting speed. So, that portion of the cycle is called or the time is called the positive strip time and when the velocity of the mould is less than or relatively less than the casting speed is called the negative strip and less than means, but the downward velocity I am talking about so; that means, this is the negative strip time.

So, this mould oscillation and heat transfer now look at what is happening to the heat transfer. Because of the oscillation mould heat transfer there is a you know best heat transfer on top of that there is a cycle of heat transfer the best heat transfer line is this may be it has been calculated this is basically this figure is based on some modelling. So, some calculation has been done. So, the best heat transfer line is say 3.37 megawatt per you know meter square and then there is a oscillation in even heat transfer. This oscillation heat transfer is basically because of the oscillation of the mould there is oscillation of the mould displacement there is oscillation in a mould velocity. So, there is a oscillation in the heat transfer as well.

So, look at what is happening heat transfer here is maximum 3.45. So, at the peaks and at the tuff it is relatively less 3.30. So, average is 3.37 along this line. So, there is also some cycle in the heat transfer you know what is happening in the mould.

Now, look at here where this negative strip time is taking place. Negative strip time is taking place as I have mentioned when the velocity of the mould is relatively lower compared to the velocity of the casting, velocity of mould less than velocity of casting. So, negative strip time is this part of the cycle in time in second. So, we find that oscillation marks are forming in this regions, but look at what is happening at some depressions in a you know side of the this is the solid shell this is the outer shell you know, this shell is forming here this is the inner shell; that means, the shell is increasing in the this direction heat is pin taken this direction. So, it is increasing in this direction.

So, this inner depressions is where the relatively it is coinciding with the relatively lower portion of the cycle of heat transfer, this is the lower portion of the heat transfer. So, this is coinciding with the depressions. So, depressions are basically coinciding with the lower portion of the heat transfer. That means, when the heat transfer is slightly lower, but depressions are also forming.

So, oscillation marks are forming during negative strip time we have to remember, high is the t n value; that means, higher is the negative strip time; that means, in the whole cycle of say one second or whatever it is the few microseconds, what is the portion of that in the whole cycle which is having a negative strip time the more is the negative strip time more will be the deep oscillation marks.

So, as I was telling you deep oscillation mark is the defect. So, this is the related to high negative strip time. Now try to understand; what is negative strip time it depends on what. If you have higher you know casting speed then what is happening this blue line is going down. So, with the whole cycle the portion of negative strip time also will be less because this is low if the V c is relatively high. That means, casting speed you negative V m which is you know sinusoidal. So, the portion of V m when it is less than V c will be relatively low. So, negative strip time will be low less.

So, slightly higher casting speed is beneficial you have relatively shallow you know oscillation marks because negative strip time is less oscillation marks also will be relatively shallow. So, casting speed is one factor what are the other factors? Other factor is the frequency, if you have very high frequency then negative strip time also will be less mould is fluctuating in a frequency and amplitude there is both a frequency and amplitude.

The frequency; that means, the number of cycles per second that is called frequency, if you have higher number of cycles per second; that means the frequency is high then you have relatively less negative strip time. If the amplitude is small relatively less then you have less negative strip time. So, what are the factors which are helping in having low negative strip time? Higher frequency of oscillation, lower amplitude of oscillation and higher casting speed.

So, these three factors during sinusoidal oscillation of mould will give us or will indicate what is the negative strip time and if the negative strip time is low because of high frequency less amplitude, and high you know casting speed then we have shallow oscillation marks. So, which is not a defect we have deep oscillation marks we have a defect.

Now, I have talked about the casting speed, of course there is a limit of casting speed you know if the casting speed is high then the shell thickness I think I will just discussed in the last session, today also I will discuss if the casting speed is high; that means, the heat transfer how it is will change the shell thickness also the shell thickness also will be less. So, there is a limit of increase in the casting speed, but what I am telling is within that limit if you operate at the higher range of the casting speed within the safe limit you cannot go to very high casting speed because then the shell will be thin, and because of the lot of stresses you know lot of strains and stresses which are forming on the shell that might be rapture of shell. So, that is not desirable.

So, the casting speed there has to be limitation, and within that limitation if you operate at a high casting speed the negative strip time will be less, we should have high frequency of oscillation negative strip time will be less we have you know less amplitude of oscillation. So, the negative strip time also will be less. So, we have shallow oscillation mark this depth of this oscillation marks will be shallow. So, we have relatively better quality of the casting.