Steel Quality Role of Secondary Refining and Continuous Casting
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Module - 04
Lecture - 22
Primary Cooling in Caster Mould

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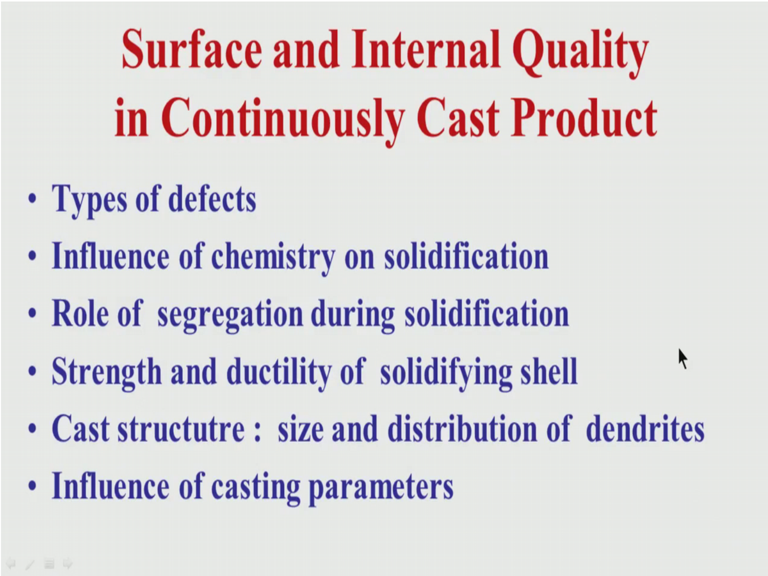

Last session I was talking about the surface an internal quality in continuously cast product. Actually it will be surface sub surface and internal quality because you know whatever sub surface defects are there in the cast product whether it is bloom slab or billet during rolling they will come to the surface, so that is those are also important. So, it is basically surface sub surface and internal quality issues which are it should be looked into and which are very important for getting a good final product.

Now, I mention that basically types of products, types of defects and influence of chemistry, role of segregation, strength, ductility of the solidifying shell, cast structure, what is the distribution of the dendrites, what are their sizes, you know columnar, vis a vis (Refer Time: 01:05) equiaxed then the influence of casting parameters these are very important. All these issues will be taken up one by one.

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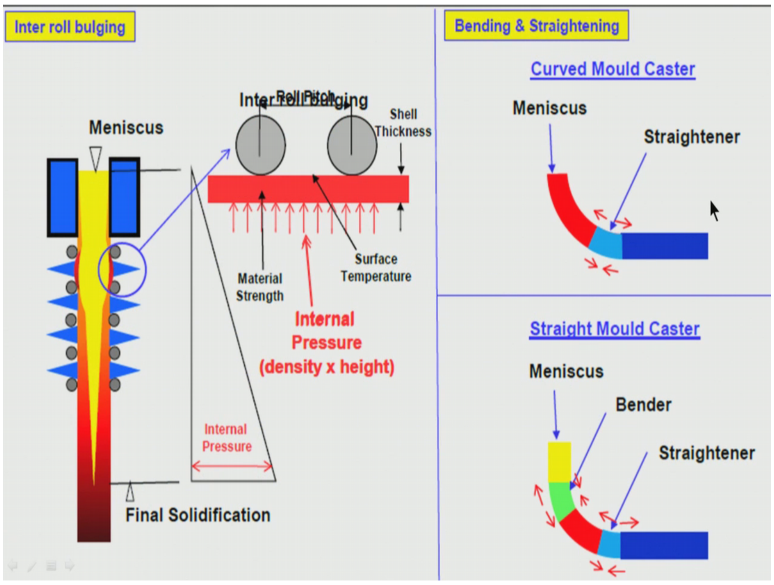

Then I talked about you know the different types of moulds which can create mechanical strain on the solid shell whether it a curved mould whether it is a straight mould we have a straight mould, first it has the shell has to bent the strand has to bent and then it has to be straightened. So, accordingly you have sometimes the inner you know radius surface on the inner radius some type of stress at the outer surface areas defined stress you know these are if it is like in the bender it is something straightener it is just the opposite.

In case of curved mould it is only the straightener which is coming into plane because the strand itself is coming out in a curved fashion because from the curved mould. So, you need not bend it only thing is you have to straighten it you have to make it horizontal that is what is measured here.

So, accordingly what are the type of stresses or strains on the shell, these are important because the strain will have to be withstood you know it is necessary to be withstand the strengths otherwise there will be crack formation. Then I have mentioned that you know like in a continuous casting the shell is under continuous movement it is not fixed. So, and lot of stresses are you know getting into the shell.

So, first is the from the liquid there is a what is that called ferrostatic pressure it is called internal pressure or ferrostatic pressure from this liquid column. So, that is important not only in the mould, as we are going down the stress is increasing ferrostatic stress is increasing ferrostatic force is increasing the pressure is increasing. So, that we have to take into account this.

And then you know when the stress the strand is coming out of the mould then the shell is increasing in thickness, but just when it is coming down I mean the shell is not very thick. So, there is a possibility from the internal pressure to bend it and there has to be some support. So, there are rows this one this one these are the rows and in between the two rows there is a possibility of bulging this is called bulging you know and in between the rows you can either use water spray or you know air mist spray for secondary cooling because primary cooling is within this mould, but there has to be secondary cooling to take out of the heat from the liquid steel. So, that solidification can continue and finally, solidification is over at this point of time.

So, you have internal stress; that means, the internal pressure from the ferrostatic you know pressure is valid till solidification is over.

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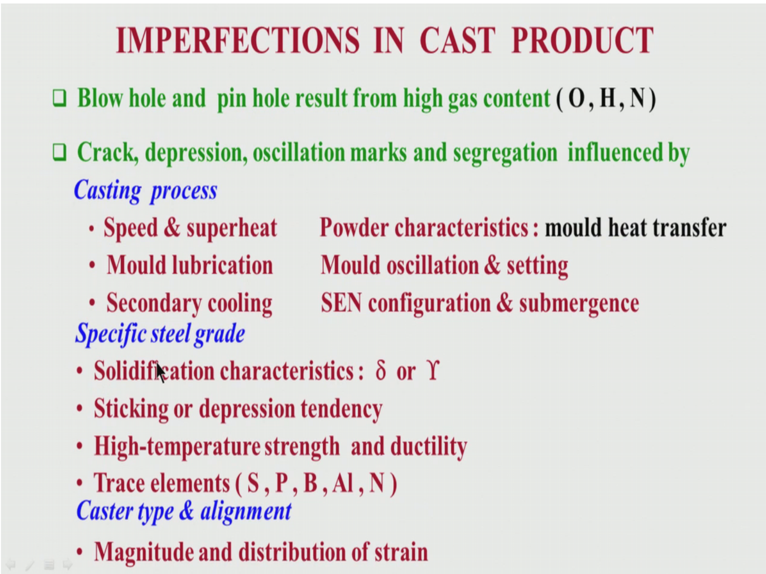

Then I talked about what are the different types of you know imperfections in cast product blow holes and pin holes, then there can be crack, there can be depression in certain grades, there can be oscillation marks I had mentioned that you know mould is under continuous oscillation.

So, there are certain marks in the surface of the shell, surface of the cast product if they are not very deep they are they are not taken as defects, but sometime they are very deep it depends on the types of oscillation depends on the type of steel which is being cast then there can be segregation. So, these are all defects cracks, depression, deep oscillation marks segregation. (Refer Time: 04:43) so, these are influenced by three major issues the casting process as such, under the casting process basically we are talking about the casting speed and the super heat we are talking about the powder characteristics it is very important.

Today I will discuss how the powder characteristics will you know influence the mould heat transfer, but heat primary heat transfer primary cooling in the mould how the powder characteristics are going to influence that. Then there is a you know situation called mould lubrication because this powder it is getting mould melted and there is a you know it is coming inside the between the gap between the shell in the mould and it is giving some lubrication that is very important. So, the characteristics of powder also influence lubrication you know the oscillation pattern also you know influence lubrication these are important. Then of course, mould oscillation frequency and their amplitude these are important.

Secondary cooling; that means, beneath the you know mould beneath the primary cooling we are cooling by either water or you know mist. So, what is the intensity of cooling, how it is changing from top to bottom these are important. Then SEN configuration and sub mergence are very important sub entry nozzle, what are the port size, what are the port shape circular or elliptical, what are their angle all these are important. Then steel grade is very important because you know how it is solidifying solidifying through delta if I write austenite this will dictate what are the strength and toughness of the shell where the delta to gamma transformation takes place during solidification at the all the part of solidification or the later part of solidification or after solidification these are very important. These will dictate whether the casting will give rise to sticking or depression.

The depression or sticking tendency this depends on the specific steel grade. Then as I mentioned the high temperature strength and ductility of the shell is important, trace elements, sulphur, phosphorous, boron, aluminum, nitrogen these are very important as far as you know segregation is concerned. Then caster type of alignment I have talked about whether it is whether it is a vertical mould or whether it is a curve mould that will dictate what are magnitude and distribution of strain under solid shell.

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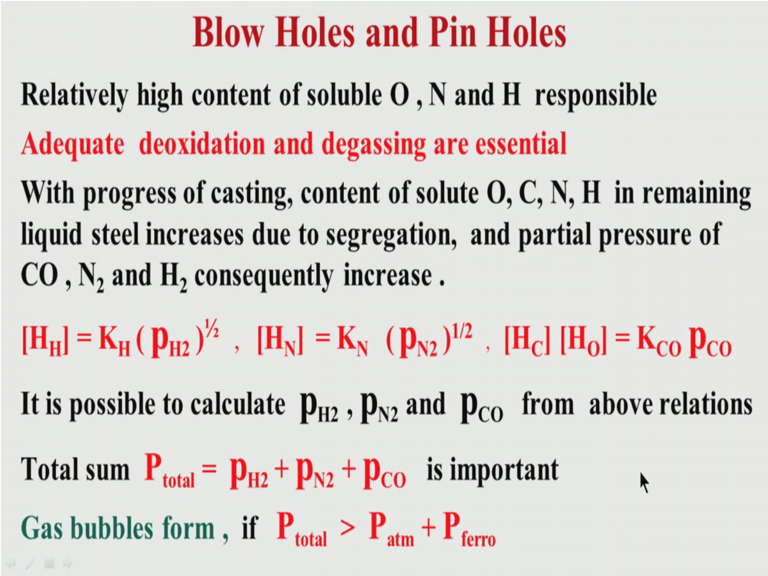

Then I talked about you know why blow holes are pin holes are created basically it is high due to the high content of soluble oxygen nitrogen and hydrogen. So, if you know this you know amounts you can find out the partial pressures of hydrogen nitrogen and carbon monoxide and finally, when you add this strain the total pressure if it exceeds the atmospheric pressure and the ferrostatic pressure then you have formation of gas bubbles and blow holes and pin holes will generate. So, the whole idea is to restrict the content of soluble oxygen nitrogen and hydrogen. So, that you do not get blow holes and pin holes.

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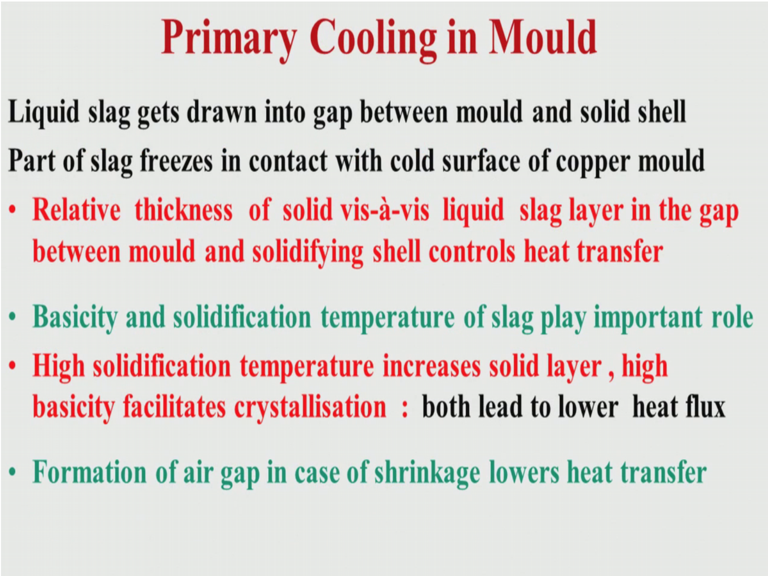

Now, today I will be talking about what is happening inside mould the proper continuous casting I will be starting today; that means, the first heat transfer for solidification starts in the mould. So, it is called primary cooling. So, what are the issues, what are the factors which control heat transfer in the mould I will be discussing those issues.

I have told that you know liquid slag which is forming from the powder after melting of the powder you get liquid slag which first forms on the top of the liquid slag liquid, liquid surface in the mould that is near the meniscus, but due to the you know mould oscillation this liquid slag which has formed on the top of the moulds top of the liquid steel in the mould on the top of the liquid steel you have liquid slag.

Now, this liquid slag gets drawn into the gap between mould and solid shell this happens because there is oscillation of the mould if you look at this here this mould is getting oscillated in vertical manner you know this way because of this whatever liquid slag has forming here it gets drawn insider because of this oscillation this is very much necessary because this controls heat transfer this controls lubrication.

So, that is why without oscillation you cannot do continuous casting unlike in got casting continuous casting in continuous casting oscillation of the mould is a must and because of the oscillation this slag will get drawn inside this between the gap between the mould and the solid shell that is why I was talking about this liquid slag is getting drawn in the gap between mould and the solid shell.

So, what is happening the part of this slag is freezing in contact with the cold surface of the copper mould please try to remember that copper mould is getting cooled with water insider copper mould there are channels through which water is passing. So, the whole idea is to cool the copper mould then only heat transfer is possible

Now, in contact with the cold surface of the copper mould the liquid slag whatever gets squeezed in between the gap of the mould and the solution. So, part of its part of it is getting frozen; that means, it is becoming solid. So, try to remember what is happening one part is liquid which is in contact with the hot shell and one part of it which is in contact with the mould it is frozen; that means, it is solid.

So, this relative thickness of the solid vis a vis liquid slag layer in a gap between mould and solidifying shell this is what is important this controls the heat transfer. So, please try to remember the zing between the gap between the mould surface and the solid shell there is a layer of first there is a layer of solid slag and then in contact with the mould surface cold mould surface you have a layer of solid slag and then you have a layer of liquid slag in contact with the hot shell surface.

So, the relative thickness of this because you can easily understand more solid shell you have more solid slag layer you have mould will be the heat transfer mould. So, heat transfer is that is by dictated by what is the relative thickness of the slag layer that is what is important. So, this controls the heat transfer.

Now, this relative thickens it is dependent on what, it depends on the obviously, it depends on the powder characteristics. What are the constituents there in the powder? Powder is basically what you have some calcium oxide you have some alumina, you have some silica, you have some calcium fluoride, you have some sodium oxide, you might have some small amount of barium oxide. So, all these will determine what is the solidification temperature of the slide what is the viscosity of the slag these are very important. So, this basicity of the slag and the solidification temperature of the slag they play very important role in controlling the relative thickness of the solid vis a vis liquid slag layer.

Now, high solidification temperature try to understand what is happening? High solidification temperature means solidification of the liquid slag is taking place relatively earlier. So, you have relatively thick solid layer and high basicity it facilitates crystallization of the solid layer, the solid layer initially it is a slagy slagy in nature it is the slag type, but then this basicity of the you know slag basicity of the powder this facility is higher the basicity crystallization there will be layer part of the layer becomes crystallized part of the solid layer. So, both of this will lead to lower heat flux.

So, what is causing lower heat flux relatively thicker solid layer compare to the liquid layer, if you have thicker solid layer there will be lower heat flux because you know the heat will be conducted faster. So, high solidification temperature and high basicity these two characteristics of the powder two characteristics of the mould slag they will determine the heat flux higher the solidification temperature higher the basicity lower will be the heat flux; that means, relatively less amount of heat conduction will be this is this is very important.

So, another important issue is that formation of air gap then why this air gap forms because you know whenever the solid shell steel shell from liquid steel you are after during solidification you are having solid shell and it is slowly increasing in thickness as you are coming down.

So, during solidification there may be shrinking there is expected to be shrinkage. So, basically there are two forces I will discuss this later on the force from liquid steel this is called the ferrostatic force it tries to push the solid shell to as the mould. And the shrinkage due to solidification due to cooling of the shell it will try to take the shell away from the mould. So, there are two opposite forces it depends which force is more. The shrinkage force is more then you have shrinkage the ferrostatic force is more then you have the shell trying to get in touch with the mould; that means, it is a type of different type of thing, different type of issue. So, whether there will be shrinkage or there will be sticking other one is called sticking; that means, the solid shell will try to stick towards the mould. So, if there is a shrinkage formation then there is a air gap. Air gap means you know air is insulation it acts as a insulator, so you have lower heat transfer. So, this is very important.

So, heat transfer is basically controlled by the powder characteristics, what are the solidification temperature, what are basicity they will determine, what is the heat flux and if there is a air gap in case of some of the grades you have shrinkage then you have formation of air gap and consequently heat transfer also will be affected becomes lower.

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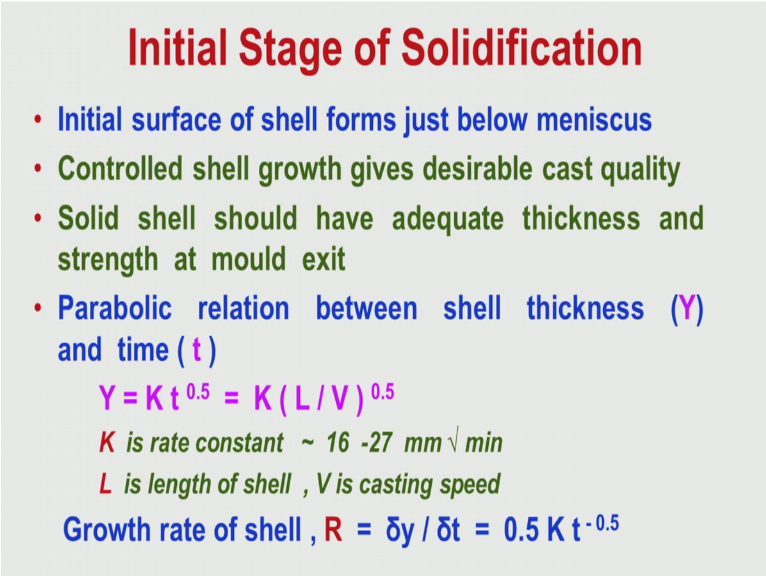

Now, let us try to see what is how the initial stage of solidification is taking place. The initial surface of the shell it is forming just below the meniscus. Then what is necessary is the controlled shell growth you know shell should grow in a controlled manner then only you have a good cast quality because the quality is basically dictated by the shell growth if the shell suddenly grows and there is a you know decrease in shell growth all these non-uniformity creates problem.

So, the shell growth should be controlled and it is dictated by what dictated by the heat transfer within the mould within the mould shell is very thin. So, all the mould necessary to have a controlled shell growth to control heat transfer this is an important requirement.

Now, the shell when it is you know the strand is just coming out of the mould what is happening it is very important to understand. The solid shell should have adequate thickness and strength at mould exit please try to see what is happening here, the shell is slowly increasing thickness that is as it is coming down the mould when it is coming just out of the mould that is the exit of the mould the shell thickness has to support the ferrostatic pressure from liquid steel otherwise what is going to happen the whole shell will snap shell will puncture and there will be a catastrophe there will be a breakout. So, the whole casting operation has to be interrupted.

So, this thickness of the solid shell at the exit of the mould is extremely important if it is not adequate, the strength is not adequate it cannot withstand the ferrostatic pressure sos there will be a rapture of the shell there will be breakout. So, that is why I was telling the growth heat transfer finally, we will tell you whether the solid shell should have adequate thickness and strength at mould exit. Strength depends on what? Strength of the shell depends on the thickness as well as what is the type of shell whether it is delta or it is austenite because you know it is your high temperature strength and toughness they are different for delta and austenite. So, this is also important that is why.

Now, how the shell grows what is the relation with time this is called parabolic relation between shell thickness and time, this is very important to understand. If the shell thickness is y and the time is small t shell thickness is equal to some constant into t to the power half 0.5. Now this K depends on what this constant it depends on many things depends on the heat transfer basically it depends on the heat transfer.

So, normally it has been found during the continuous casting this rate constant capital K where is between 16 to 27 around this figure millimeter root over minute why root over minute because time is in minute shell thing is in millimeter. So, this has to be in millimeter root over minute, minute to the power half. So, if K is known you can find out with time how the shell is increasing in thickness

Now, sometimes how do you know K, for knowing K there are two ways one is a modeling of heat transfer if you know the heat transfer different characteristics of heat transfer you can find out capital K or whenever there is a breakout. So, breakout is happening at a certain location. So, you try to see what is the thickness you do not want breakout, but suppose breakout has happened in a particular instance solid layer at what level breakout has taken place just try to see what is the shell thickness.

Then you know at what length it has taken place mean this t is basically what - length of the shell divided by the casting velocity. So, if you know L that means, the depth at what depth breakout has taken place, at what depth the shell thickness is you are thinking about you know the you know casting speed V t is basically L by V. So, either you know time at what time you know after what time breakout has taken place all if you know the casting speed you and you know what is the length, what is the depth at which shell has you know raptured solid layer you can find out the shell thickness. And if you know Y and if you know t or Laughter, so you know ok. So, that is the way you can find out K without modeling what is the way of finding out K that is the rate constant. I have mentioned here L is the length of the shell and V is the casting speed. Length of the shell means at what depth vertical depth you know you are looking at the shell that is what is important.

Now, what is that growth rate of the solid shell this is again important. This shell is increasing at a particular rate this is del y by del t. So, it is basically if you differentiate this equation, so 0.5 K into t to power minus 0.5. So, the rate of growth of shell are is basically one can find out if you know what is K.

So, at what rate the shell been increased this is very important you know shell growth is very important because this has some implications on the you know what will be the crystal sizes, what will be the you know dendrite sizes and all this. So, growth of shell is basically is depended on the heat transfer.

Heat transfer is finally, determining K please write down remember. If you have a different type of heat transfer in the mould you have different type of shell growth. Now heat transfer with a if you have a oil lubrication you are using oil as a lubricant heat transfer is slightly higher, if you have a powder lubricant; that means, the powder is melting there is a liquid slag liquid slag is solidifying there is a solid slag. So, because of the solid slag heat transfer is controlled. So, you have some other heat transfer. So, K depends on the type of heat transfer in the mould please try to remember.

So, initial stage of solidification is important because where the solidification is starting quality is basically dictate at this stage also the surface is being because once the surface is forming in the mould only afterwards the surface does not change what change is sub surface and internal quality. The surface quality is dictated by the initial stage of solidification. Please try to remember that is why initial stage of solidification within mould is very important.