Steel Quality Role of Secondary Refining and Continuous Casting
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Module - 04
Lecture - 19
Effect of Vertical vis-a-vis Curved Mould

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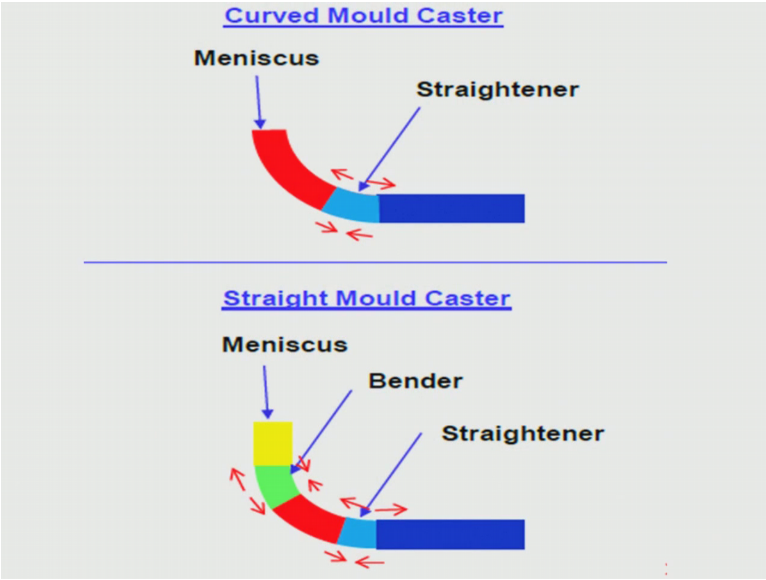

Another important issue let me talk about during continuous casting, which can generate you know problems in of entrapment at certain locations of continuous casting. I have mentioned earlier that is continuous cast product is not having a uniform quality. Certain portions of the casting are relatively inferior in quality. I have mentioned at the start of casting and the end of casting at the change of ladle, changeover at the stage of you knows certain fluctuation there is a possibility of entrapment. So, those areas are relatively inferior.

Now, this will be very interesting. Look at the two moulds. You know continuous casting mould can be of 2 types: the normal type is straight mould that means it is a vertical mould we call it vertically straight, it is coming down and then it has to be bend, and finally it has to be straighten to make it you know horizontal. Initially the mould is vertical you know, but the mould is continuously it is not a vertical one, because otherwise you will have a very may be ten storied continuous casting shop if you have a vertical mould, which is not you know practical.

So, normally the mould is initially vertical and then it has to be straightened or bend or straightened and then it becomes finally horizontal; now the cast product when which is finally coming out is horizontal, but initially the mould is vertical. Now you see here it is totally vertical, here it is not vertical it is a curved mould; you just see there is a curved mould.

So, then it has to be straightened, curved mould only straitening is necessary to make it horizontal. But if you have a totally vertical mould then what happens: first it has to be bend, then it has to be straightening. So, there is a bending, there is a straightening. All these arrows indicate that when you are doing straightening or bending of the mould, so you see what is there inside the mould. This is the mould, outside the mould it is the strand is basically the strand, this is the mould, then below the mould the strand is coming out.

So, here is a curved mould and then a strand will come out. So, if the strand is being straightened or strand is being bend and straightened. So, lot of stresses are getting generated. You know at the this inner surface and outer surface. Now one thing you must remember, look at the curvature of the mould this is called the inner radius of the mould this one, and this is called the outer radius of the mould: this is the inner radius of the mould this is the outer radius of the mould. So, the stresses on the shell something will be some at certain locations it may be something at the other the opposite outer radius it may be something else. It may be tensile here, it may be compressive, it is tensile here, it is compressive here; here it is compressive, it is tensile. So, these aspects I will discuss later on when we come to the continuous cast quality, whether they will be cracks and all. But right now try to understand what is happening.

I have mentioned that there is a possibility of some inclusions getting generated or entrapped in liquid steel which will try to float up in the mould. Now, when inclusions are floating up what is happening: if you have a straight mould inclusion will straightway go will float up like this and get absorbed at the top of the mould; that means, when that is a liquid slag here, at the meniscus level it will get absorbed.

But here what is going to happen, when they are floating up there is a possibility of, because liquid solid shell has already found there is a possibility of some inclusions getting entrapped in the solid shell which is forming during initial stage of solidification. So, here the possibilities not there, because it is going vertically; here it is also going vertically, but since mould is curved so there is a possibility of certainly inclusions getting entrapped, getting you know inside the solid shell which is forming here is high in case of a curved mould.

So, in a situation where we have a curved mould the uniformity of the in the cast product uniformity of inclusions in the cast product will not be there you know certain portion near the inner radius will have more inclusions will have less quality inferior quality this areas, but we if we have a vertical mould that possibilities not there it will be relatively uniform what about inclusions at their inevitably uniformly getting absorbed in the solidshell. But here certain areas of the solid shell near the inner radius this is the inner radius there is a possibilities of getting more inclusions near the inner radius now this.

So, from the quality point of view vertical mould is better you know this curved mould is not good is undesirable, but from the point of view of which I will be discussing. Later on from the point of view of having internal stress in the solid shell, you see curved mould is better because you only have to do straightening of the shell. Here for a vertical mould you have to first do bending and then straightening; that means, you are having some additional stresses on the shell during bending some stresses again during straightening some stresses.

But for a vertical; this is for vertical mould for a curved mould this situation. There is only straightening because no bending has necessary already the mould because of this you know curvature it is already getting bend wind is coming out cloud on the mould the shell is already bend.

So, only straightening of the shell straightening of the strand is necessary. So, the amount of stressed generation is relatively less for a curved mould compared to a vertical mould, but as I have mentioned straight mould is better from the point of view of inclusion entrapment because uniformly whatever inclusions will be there the quality will be relatively uniform, but here relatively more inclusions when they are floating up they are trying to get absorbed in the solidified shell here.

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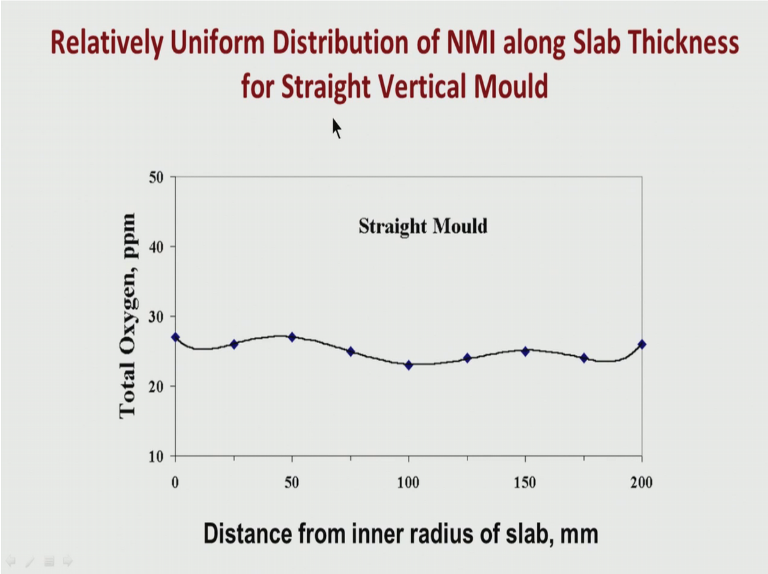

So, near the; you know this portion is called inner radius of the mould here the inner radius of the shell you have mould inclusions. This we have found out by analysing you know the cast product we just look at relatively uniform distribution of NMI along slab thickness for straight vertical mould. So, I am talking of situation here the mould is vertical. So, whatever slab is forming finally, the slab is coming like this. So, we are try to analyse what is the distribution of the inclusions from inner radius to the outer radius from top surface to the bottom surface. The inner radius will finally, generate the top surface the outer radius will finally, giving you the bottom surface here the inner radius again is giving the top surface, but the possibility of inner radius here the inner radius the some more inclusions will be there in case of curved mould.

So, we have found out this by analysing a liquid how the liquid steel when it is getting solidified as a slab. So, what is the distribution of inclusion? So, I am talking of a slab having 200 millimetre you know thickness. So, we have measured total oxygen. Total oxygen is; what is the measure of oxide cleanliness. I have mentioned several times in this course; the total oxygen is a summation of dissolved oxygen and oxygen presence as oxide inclusions. If the steel is killed; properly killed you know total dissolved oxygen will be around say 5 p p m max.

So, if you have a total oxygen of say 30 p p m or 25 p p m. So, the remaining amount will be oxygen present as oxide inclusions. So, total oxygen measured these days nowadays is being done for measuring getting an idea of oxide cleanliness in steel in that final product. So, we have in the you know slab at a distance of say 25 millimetre from the surface initially at the surface then 25 millimetre every 25 millimetre we have taken samples an analyse total oxygen how we measure total oxygen these I have discussed earlier.

So, for a straight mould we find that the distribution of total oxygen; that means, a distribution of oxide inclusion this not that bad this more or less uniform towards the thickness of the slab. This is say top portion if it is a top portion this is the bottom portion if this is the inner radius this is the outer radius of the slab.

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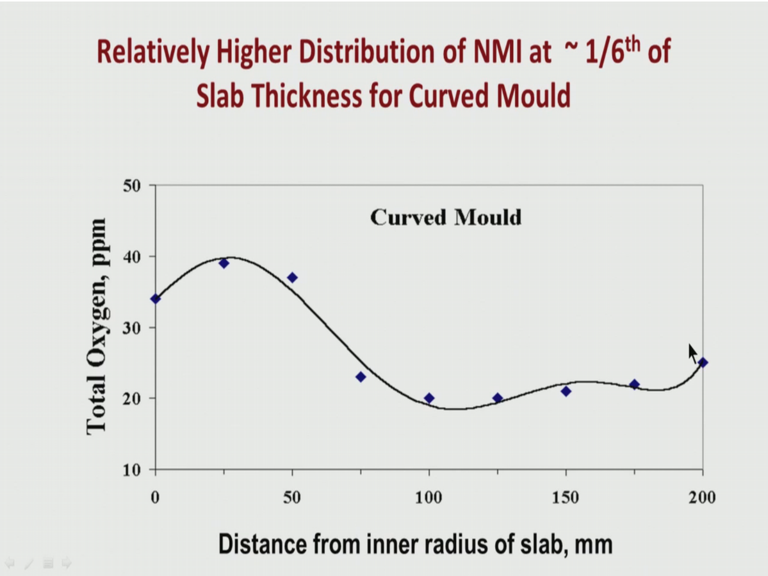

Now, look at the curved mould situation you find the same 200 millimetre slab, but the slab has been cast in a curved mould unlike in the earlier situation where it was a vertical mould. So, in a curved mould; again total oxygen, we have measured, we find that at one sixth of the slab thickness 200 millimetre somewhere here; you know the total inclusion level is quite high in this is the inner surface near the inner radius. So, these area inclusion mould of inclusions that is why mould oxide inclusions. So, that is why the total oxygen is more compared to other portion of the thickness. So, it is clear that if you have a curved mould there is a possibility of having mould inclusions near the inner radius as I have mentioned here relatively higher distribution of NMI non-metallic inclusion at about one sixth of the slab thickness of curved mould.

Unlike a situation for a straight mould it is more or less uniform that is hardly much of differences whatever difference is there may be it is a experimental area, but here you find it is it cannot be an experimental area it is around say almost 40; 35-40; and here it is around 20 maximum 25. So, this cannot be an experimental area; that means, near the inner radius inclusions are more entrapped more getting entrapped much more. So, there is a possibility of toward in poor cleanliness at this portion.

So, whenever this slab will be rolling. So, one surface from; if we have not topple; the you know slab during rolling; that means, the bottom surface will be having more defects otherwise the top surface; that means, the inner surface. So, is better to mention the inner radius surface at the inner radius will have mould defect. So, whenever that is you are rolling that you know slab. So, this surface which is near the which is at the inner radius will have more defects more defects will be exposed when you are doing hot rolling finally, cold rolling at this for this slab.

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So, what I have told is not only certain slabs which have been cast and I have mentioned if I go back not only slabs or blooms billets which have been cast from the start or end of cast area. They are relatively bad; I have mentioned you know; this sudden change in meniscus level if you takes place and the sudden change is speed during casting that particular location will be bad relatively inferior more inclusions are expected. So, start or end of casting just after ladle changeover sudden fluctuation if it takes place during casting these areas are relatively inferior. So, these products portions of the products portion of the cast whether slab bloom or billet they are relatively inferior.

Now, I have talked about also another important thing that not only those portions will be bad, but even in the thickness of the slab or bloom or billet. The surface which is near the inner radius; this portion; this is inner radius, if you have a straight mould inner radius and outer radius more or less the distribution is more or less similar, but if you have a curved mould inner near inner radius we have relatively more inclusions compared to the outer radius.

So, if you analyse the slab from this surface to the other surface on the inner radius to the outer radius, we will find inner radius. We will have relatively more inclusions outer radius, we will have relatively less inclusions in straight mould. It is more or less uniformly distributed that is what I have shown you know you see this more or less uniformly distributed. So, this is important how we have seen; how we have analysed, we have drilled samples. So, it is a 200 millimetre thick slab. So, from the surface we have drilled then we have gone into say 25 millimetre again we have drilled to get the sample we have drilled another 25 millimetre and thicken sample.

So, throughout the thickness we have; we wanted to see what are the distribution of cleanliness what are the distribution of non-metallic inclusions; so total oxygen give an indication that for a straight vertical mould throughout the thickness from the inner radius. This is the inner radius area this is the outer radius area from the inner radius to the outer radius more or less uniformly distributed inclusions.

Inclusions will be the I have mentioned earlier the no steel is free from inclusions there will be inclusions our job is to control the level of inclusions our job is to see that inclusions are within the desirable extent volume of inclusion. The amounts of inclusion as well as the size of inclusions are within control within level within desirable levels.

So, we have found that this is more or less uniform total oxygen level is around 25 say 25 p p m which is not bad these are relatively reasonably good , but here you see certain areas we are having more inclusions; that means, when you are going to process this slab. It has been found that the surface which is near the inner radius, they will have more defects; more surface defects will be generated here because it is around 35 to 40 which is very high compared to level of say 20.

So, the inclusion average inclusion levels for both the cases are more or less same you will find, but here what is happening? One particular surface near one particular surface inner radius surface it is more in the other area it is relatively clean average may be same for both the cases.

So, here when we were rolling the material the slab one surface will expose more defects more you know surface laminations. So, we will be getting more defects in this particular slab which has been cast from a curved mould. So, it is we should not get surprised with this results because it is expected it is expected that when we have a curved mould there is a possibility of some inclusions getting more entrapped here inclusions getting more or less uniformly entrapped you know because you know the solid surface is increasing this when a; so, there is a possibility of get here when they are floating they are trying to get absorbed more inclusions are getting absorbed at this locations.

But here they are floating and getting absorbed uniformly throughout the surface. So, this is the difference between a straight mould cast and a curved mould cast. So, in both the cases if the inclusions are more or less uniform you will have relatively more inclusions near the inner radius than at the outer radius, but for a straight mould it is uniform.

So, even if the level of inclusions level of cleanliness are same in both the cases the distribution are not same distribution inclusions are more for a curved mould and less or rather uniform distribution means more inclusions near the inner radius, but here more or less uniform more or less uniform throughout the thickness I am talking about the thickness of the slab here we have taken samples at different thickness levels by drilling and then analysing the total oxygen assuming that the you know dissolve oxygen is relatively less because in both the cases it was a aluminium kill steel.

So, the dissolve oxygen will be less than 5 p p m within 5 p p m. So, if the level here around 30 or 25; so, the rest the remaining oxygen is present as oxide inclusions as oxides. So, total oxygen is giving an indication of the oxide cleanliness in both the cases the average level of cleanliness is more or less same, but here certain area near the inner radius is having more inclusions this is very interesting.

So, when you process this material we will find more defects near the surface which is at inner radius which is which corresponds to the inner radius and the surface which corresponds to the outer radius are relatively more clean. So, we will have more defects at one surface and less defects at the other surface.

But for a straight mould defects are more or less uniform there even what are the inclusions of defects are there it is more or less uniform at the both the surfaces and another interesting observation is that which is from common sense you can make out, but whatever defects are there in the slab. A cast slab or cast bloom or cast billet when you are processing it the more you are processing there is a more possibility of defects getting coming to the surface this is not because the surface area is increasing, so, whatever defects were there inside the cast slab. So, as you are rolling it rolling means this 200 millimetre thickness will become when you are hot rolling it this 200 millimetre will become may be 5 millimetre, 6 millimetre or may be 4 millimetre.

So, whatever defects are there distributed in the whole bulk of the cast slab they will try to come to the surface because the surface area is increasing. So, the more you role more defects get exposed to the surface. So, if you have a good inspection speciality then you can find out at what stage this defects are coming out and what is the distribution of the defects like whether defects are coming mould on one surface or a coming near both the surfaces?

If you role a slab this slab when you if you role will find that defects are coming more on the surface which corresponds to the inner radius of the cast the other surface which is; which corresponds to the outer radius will have relatively less defects this has more defects here more or less when you are trying to role it to you know lower and lower thicknesses defects will be there defects will be getting exposed uniformly at both the surfaces.

So, I have tried to mention that what are the possibilities of entrapment distribution not only along the length of the casting, but also along the thickness of the casting if the length of the casting I have mentioned basically the distribution is because of the at the start or end of the casting that when there is a non-steady state there is a possibility of getting more entrapments.

Ladle changeover again non-steady situation you can get sudden change in meniscus level or speed non-steady. So, whenever there is a non-steady state of you know casting situation there is a possibility of more defects this is with respect to the length of the cast product at sudden location of the length you have more defects. So, you know what are those locations whatever whichever locations corresponds to the you know start or end of casting or you know ladle changeover you know during the casting process or whenever there is a sudden change in meniscus level or speed you know.

So, those locations you identify when the casting is over and those portions; those portions of length of casting you try to keep it separately. Because it is expected those portions of the casting will have inferior quality, but what I have mentioned here is not only the length of the casting even the thickness of the casting. There is a possibility of some distribution have included it is not uniform it may not be uniform.

If you have a vertical caster it is going to be uniform the thickness is going to be uniform qualities have of uniform quality, but for a curved mould the thickness will have non uniformity. So, the surface which corresponds to the inner radius will have more defects the surface which corresponds to the outer radius will have less defects.

So, till now I have tried to cover what are the possibilities of entrapments in liquid steel how they are getting entrapped in which way you can control the entrapments we can control their size at different stages of you know secondary refining that well liquid steel is in ladle. So, ladle slab is very important ladle reflect is important. So, that you do not get more entrapments the process is very important how do you do you do first de-oxidation because that is very important because when you are just tapping liquid steel from BOF on the primary level like BOF or EAF you have may be 500 p p m oxygen.

So, the dissolve oxygen is very high no steel no, but you know good quality steel should have. So, much of dissolved oxygen you can even cast that steel because what will happen to the you know liquids what will happen to the dissolved oxygen it will come out as brow holes and pin holes it, it will be like a strainer lot of holes in the in the product even the cast product. So, it is a useless.

So, the first thing is de-oxidation the first thing of improvement of quality of liquid steel is de-oxidation if you do like good de-oxidation your liquid you know soluble oxygen will come down to less than 5 p p m; that means, aluminium de-oxidation it will come down to less than 5 p p m.

Then there is desulphurization because what I have mentioned when I talked of the inclusions at the beginning of the course that the inclusions basically are either sulphides or oxides or complex oxide sulphides. So, by de-oxidation you are bringing down the oxygen level by desulphurization you are bringing down the sulphide inclusion level.

Then you can do to take care of nitrogen and hydrogen you can do de-gasing. So, these are all secondary refining techniques then for from the casting point of view I have mentioned what are the precautions we have to take and the when liquid steel is coming down from ladle to Tundish and from Tundish to mould.

So, what are the precautions in ladle; what are the precautions in Tundish what are the precautions in mould. So, that you get a relatively less entrapment relatively good quality of steel relatively less oxides inclusions and sulphides inclusions, we do not want large exogenous entrapments exogenous entrapments I have also mentioned what are the possible exogenous entrapments.

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Complex these are mostly find out mostly oxide type of entrapments aluminium oxide with some silicon or manganese oxide or slags, calcium, silicon and aluminium oxides. It might have some sodium oxides also if you had a mould slag some fluoride also calcium fluoride is added as fluidizer in mould slag.

So, and you can know also by analysis analysing the defect samples that also I have mentioned.

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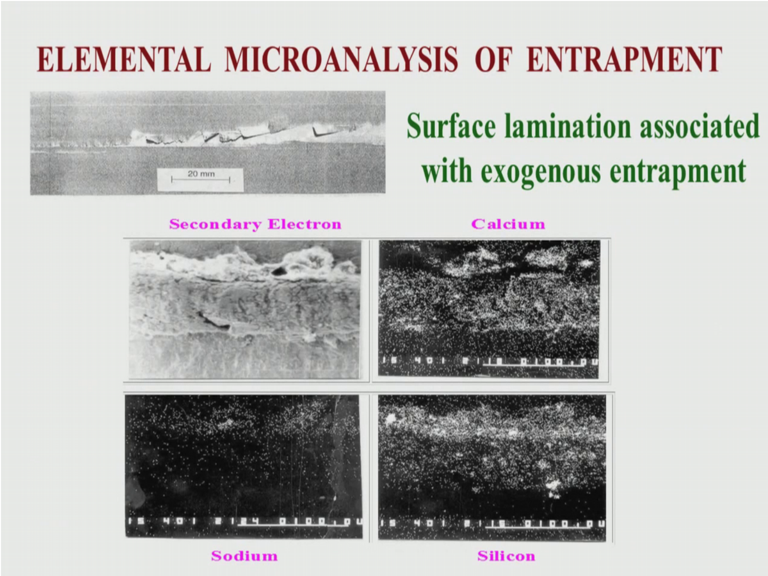

Like if you have a defect you know just under the defect whether any entrapment is there whether any exogenous entrapment is present such large defects you know there; there is a possibility of having some entrapment. So, we know we should know what are the where from the entrapment is coming.

So, what are the sources of entrapment what are the genesis of entrapment. So, this is possible by cutting a small sample without destroying the sample we put it under scanning electron microscope which has ADX or WDX. So, we know from the elements present; what are the possible sources. So, if we know the sources we know what went wrong this is of course, postmodern. So, we have to take care subsequently; that means, in subsequent stages if you know what are the possibilities of defects from the you know knowledge of steel making knowledge of secondary refining knowledge of continuous casting we know what are the possibilities of defects what defects can get inside liquid steel and they get inside the cast product how what will be the distribution if you know that we have to be careful.

I think in this process we can control the entrapments we can control the amount of entrapments we can control the size of the entrapment both are deleterious for the quality of steel one is the amount of entrapments then volume of entrapments another is the size of entrapments both will have undesirable effects on the steel quality. So, both have to be controlled.

Thank you very much.