Steel Making

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Module No. # 01

Lecture No. # 34

Solidification and Casting processes

We are discussing developments in continuous casting, and I have said in the last lecture that, in all modern continuous casters, tundish plays a very important role, and I have also said that there is a residence time available during transfer of molten steel from tundish to mold.

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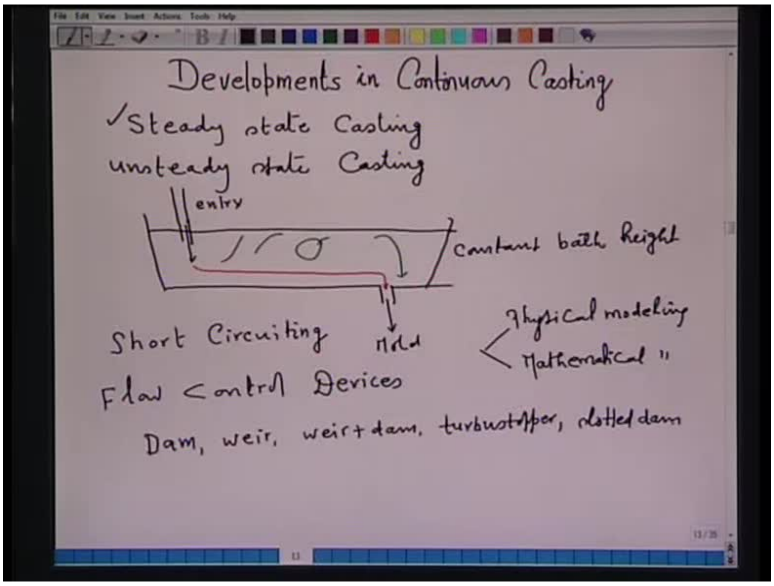

Let me introduce to you now two terminologies - one is the steady state casting, steady state casting, and other is unsteady state casting, unsteady state casting, because as you pour molten steel from ladle to tundish, it takes some time before the tundish attains the required height; between that period, the casting proceeds, and that period is called unsteady state casting, that is, during the unsteady state casting, the molten steel bath height in the tundish change.

Now, once it attains a constant bath height, then the casting is said to be steady state casting. I have also said last time that, during steady state casting, there is a availability of residence time, and this availability of residence time has given a thought that why not tundish should be used as a reactor to contribute cleanliness to the steel. As a result of this several modifications in the tundish design and tundish practice have taken place.

Now, if I just show, for example, this is the tundish. Let me take a single strand continuous casting tundish, and in the single strand, the molten steel enters from one end and leaves the other end. Now, this goes to the mold and this is the entry of molten stream and this is the molten metal bath height; the stream is submerged. This is the constant bath height.

Now, I have said that in order to use the tundish other than its transfer function, that is, for example, removal of inclusions mixing distribution, it is required to modify the flow pattern in the tundish. What I mean by the flow pattern is that, as the steel enters from the ladle, that is, somewhere here steel entering and it is exiting somewhere here.

So, that time which I have said is a residence time is a very important time. Now, how these steel flows when it enters and when it exits, that is very important. I have also said last time that, if you want to remove inclusions during the process of continuous casting in the tundish, then the flow of a steel melt from entry to exit should be such so that maximum time is available for floating of the inclusions.

Now, this has lead to the several investigations in the hydrodynamics of tundish, and the investigations were of two types - one is the physical modeling, one is the physical modeling, and another is the mathematical modeling. Now whole idea of these investigations were to understand what type of flow in fact is created by the submerged ladle stream, because the force that is responsible for creation of flow in the tundish is the kinetic energy of the turbulent stream.

In the physical model, what has been done? A porous space glass tundish was constructed by observing a static and dynamic similarity with the operating tundishes and then a treasure was injected, and it was revealed that in fact, when ladle stream enters into the tundish, then a fraction of that stream, it directly enters into the nozzle; that means if I can show that a fraction of the stream which is entering a directly enters into the tundish, whereas rest fraction, for example, it moves and mixes here and then ultimately it leaves the tundish. What does it mean?

When these fraction of the entering stream directly enters to the tundish, and suppose, if it carries certain amount of inclusion, then that portion of the liquid which is straight entering into the tundish nozzle; it will be carried or it will be carrying the inclusions and as such these inclusions will be transported in the mold.

So, this particular liquid stream which is fraction of the liquid stream, which is directly entering into the tundish nozzle; that is called short circuiting, that is called short circuiting. Also from this physical modeling investigation, it was also possible to determine what is the fraction of short circuited liquid. What is the fraction of the liquid which has a very low residence time? What is the fraction of liquid which has a very high residence time? A very high residence time made, what is the plug flow? Plug flow normally has a very high residence time. In the mixing flow, a liquid has a very small residence time.

So, what I mean to say is that, the residence time which we have calculated by dividing tundish capacity with the tundish casting rate or tundish melt rate, there is a distribution of residence time when the liquid enters into the tundish and exits into tundish. As a result of distribution of residence time, it is possible now, that if we are aiming at to remove inclusions during the process of continuous casting in the tundish, then we must do something to maximize the residence time of liquid in the tundish, of course, below the residence time. That we have calculated; that means we have to maximize the plug flow volume.

Also it was possible that the liquid which is directly entering into the tundish, something should be done so that the short circuiting liquid could be completely eliminated, and as a result of these investigations, the several flow control devices were adopted. So, this flow control devices, the objective of these flow control devices is very clear. First objective is to eliminate the short circuited liquid. If we put eliminate the short circuited liquid, then the liquid which is directly entering into the tundish nozzle is eliminated, and hence, we have contributed to the cleanliness of steel. Also the liquid which directly enters into the tundish, it may have a different temperature than rest of the liquid.

So, by elimination of short circuited liquid, we have not only removed the possibility of inclusions directly entering into the mold, but also we have tried to remove the dissimilarity of a strand by way of controlling the temperature.

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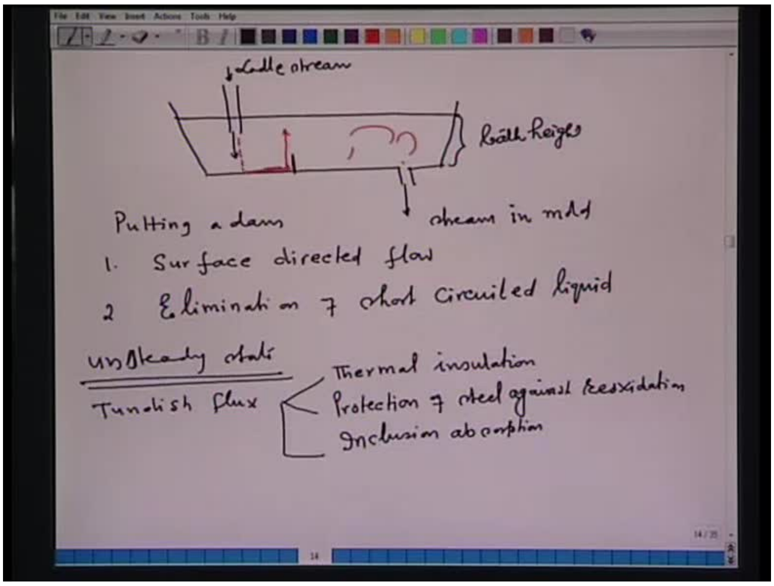

So, these flow control devices of various types we are tried and of the very important flow control devices that most of the modern tundishes of continuous casters have these are dams weir or a combination of weir plus dam or turbustopper slotted dams and so on. A tundish with dam it looks something like this. For example, if I take again a single strand caster tundish, this is the steady state bath height. Here, the stream is in the mold, and here, the ladle stream enters. So, this is the downward directed flow. I put a dam somewhere here. So, a dam it obstructs the flow of liquid steel directly to the tundish mold; so, that is what the dam is.

So, if I put a dam which obstructs the flow, so, imagine now, the liquid is flowing hits the bottom, then it will go here, and from here, it will be surface directed, and from surface directed, then it will mix here, here, here, and ultimately leaves the tundish nozzle.

So, that means by putting a dam, by putting a dam, what we could arrive? First we could arrive a surface directed flow, a surface directed flow. What it does? So, when the flow is surface directed, then the liquid which is carrying the inclusions they will also be directed to the surface and having a tundish flux at the top of the liquid steel the inclusions. There is a possibility of absorption of these inclusions on the surface.

So, one is a surface directed flow, and second, it elimination, elimination of short circuited liquid. These are the two major advantages that one gets from the installation of dam. Now, of course, the position of the dam, that is, its location with reference to tundishes stream, number of dams, height of the dams, all these are important issues and these issues were solved by having a physical modeling or mathematical modeling work, and the present tundishes of continuous caster, they are installed with either dam or dam plus weir or slotted dams or turbustopper.

Now, another important thing that came as a result of these investigation is when the ladle stream enters into the tundish, it contains large amount of turbulence. If you put a device directly below the tundishes stream, and then, this device feeds the liquid steel in to the rest of the tundish and also we could minimize the kinetic energy of the turbulent.

So, what I wanted to say is that with the installation of these flow control devices, it became possible tundish to be used as a source of removal of inclusions during the process of continuous casting of a steel. Also another important feature that came from the result of these investigations is some improvement in the period of unsteady state casting.

Now, during unsteady state casting, what happens? During unsteady state casting, what happens? Now, this unsteady state is between the two periods - one in the initial period. Well, that you cannot do it or you can either remove the cast product of the initial and then except the rest, but towards the later stages, when the ladle has emptied, you have to bring the next ladle in between the time. A continuous casting process does not stop. So, in between the time, in the unsteady state period towards the changeover of the ladle when the first ladle has emptied and second ladle has to be brought. In that period, tundish is the only supplier of molten steel to the various molds of the continuous casting into that period; the height of the metal bath in the tundish decreases.

As the result of the physical modeling or mathematical modeling investigation, it became possible to find out a height below which the vortex formation occurs, because when height of the molten steel bath in the tundish decreases, a stage comes when there is a formation of the vortex, and a flux which is kept on the top of the tundish, it gets entrained into the mold and that creates again the inclusion problem.

So, because of this a height is to be known, below which the steel from the tundish should not be taken in to the mold, that is, in to that height, the next ladle must come and supply molten steel to the tundish.

So, what I mean to say? The sequencing of ladle and the matching of the time with the vortex formation that is also an important part for unsteady state casting period. As a result of this flow control devices, it became possible that the mixing of a steel of the previous heat, and now, the steel which is coming from the fresh ladle, if it is not properly mixed, then some portion of this strand you have to reject.

So, by employing of these flow control devices which has become possible to reduce the rejection, which happens during the term, which I use is called the sequence casting. So, the number of sequences they also were increased because of these flow control devices. So, in conclusion what I want to say is that a tundish of the modern continuous casters is rather installed the dam’s, weirs, weir and dams and so on, and tundish played a very important role in the modern continuous casting machine.

Now, tundish fluxes are also very important. Tundish fluxes, there are several function of the tundish flux - first it provides thermal insulation, first it provides thermal insulation. It also protects the steel against re-oxidation; protection of a steel against re-oxidation, and third function is a inclusion absorption, inclusion absorption.

So, constantly, the molten steel in the tundish is covered by a slag layer. Now, the slag layer should have a two function, that is, for inclusion to be absorb, the slag should be liquid for protection of a steel against reoxidation and thermal insulation. Ff it is solid, it is better.

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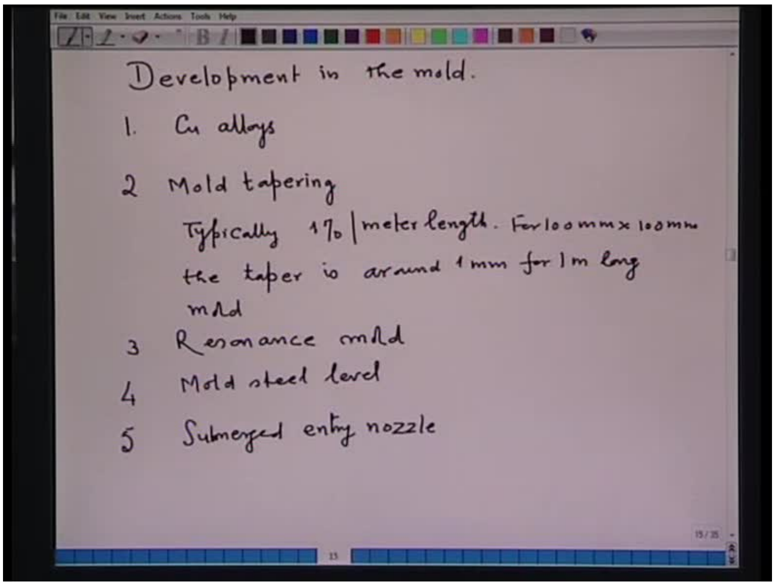

So, the tundish slag is selected such that it has both the roles during the continuous casting. So, this is about the development in the tundish. Now, say development in the mold, development in the mold. As I have said, that mold is again a very important part of the continuous caster; several developments have taken place.

Now, one is a mold are made of copper alloys. Small amounts of alloying elements are added in order to increase their strengths, because the strength is also important. Second, mold tapering is also commonly done, mold tapering. Tapering of the mold is also important for easy withdrawal of the partially solidified strand from the mold. Also this tapering is done to reduce the air gap formation.

Now, typically, typically one percent per meter length is given as a taper. For example, for 100 millimeter into 100 millimeter cross section of the strand, the taper, the taper, is around 1 millimeter for 1 meter long mold. Now also development is the use of resonance mold, use of resonance mold that also decreases. The incidence of surface defects also in the modern gadgets, it is also important to maintain a constant metal level in the mold, because the quality of a steel is decided from the properties of the meniscus at the top of the mold, because it is from the meniscus, the solidified strand begins; it is from the meniscus, the steel begins to solidify. So, the property of the meniscus is important and height of the molten steel is here also important.

So, in all modern continuous caster, mold steel level control, mold steel level control, is put and the steel height in the mold is constantly recorded and maintain at a particular height. Then also the submerged entry nozzles, that is, these nozzles they enter into the mold, in fact, in all blooms slag and billet submerged entry nozzle for carrying the tundish stream into the mold it is being practiced.

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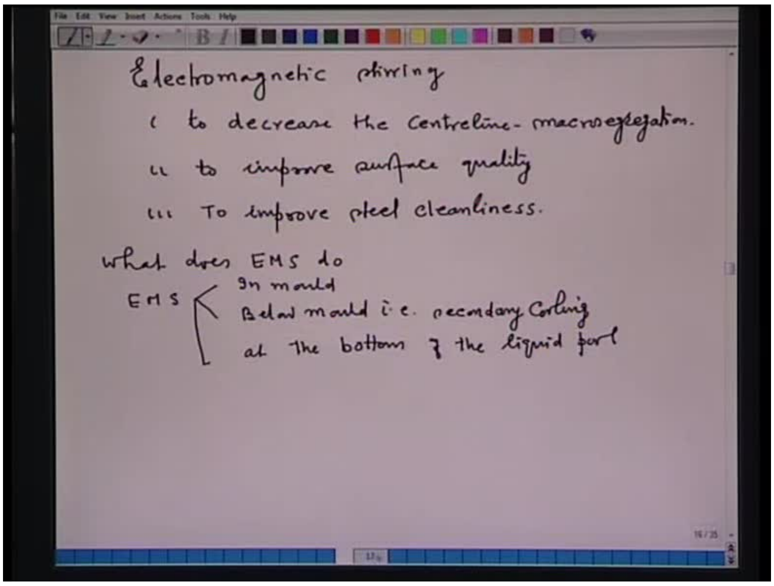

Now, another important development is electromagnetic stirring, electromagnetic stirring. Now, as the starve stirring suggest anything if you starve rather any liquid which contains impurities, and on solidification, if the impurities have tendency to segregate, if you starve naturally, the advantages would be there. So, one can obviously think of the advantages. First advantage - to decrease the centerline macrosegregation, centerline macrosegregation; to improve surface quality improve surface quality, improve surface quality, and also, since you are stirring to the chances of rotation of inclusions, they also increased.

So, that way, to improve steel cleanliness, now that inclusions can also flow. Now, how does electromagnetic stirring does? What does in short I write electromagnetic stirring? It do that is it rather modify the flow pattern of liquid strand of liquid metal in the solidified strand.

Now two types of electromagnetic stirrer are used - one is axial type; another is a rotational, that is, horizontal type. Now, you know, electromagnetic stirring can be done wherever liquid is available. If there is no liquid, you cannot do any electromagnetic stirring, because stirring is provided in the liquid. So, if you analyze the continuous casting process you see, the liquid is available from top of the mold to the last point of the solid of the secondary cooling zone.

So, everywhere, wherever there is a liquid, is a possible to have electromagnetic stirring; that means the electromagnetic stirring, electromagnetic stirring can be done either mold or below mold, that is, in the secondary cooling zone or at the bottom of the liquid pool or at the bottom of the liquid pool in the secondary cooling zone.

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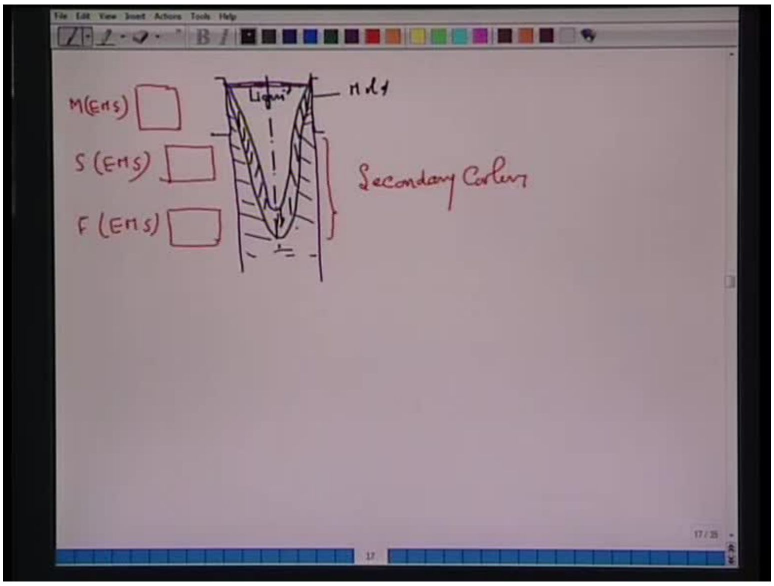

Now, if I want to show here, for example, if I draw very symmetrically, say this is the mold, here there is a partially solidified strand; this is the wall shaped mashie zone. So, here, all liquid; what I wanted to show here is all liquid. This is the mold; this is the solid; this is the solid shell which is growing in it thickness as we move downward the mold and this is here all solid.

So, where we can provide the electromagnetic stirring, we can provide one over here. You know electromagnetic stirring is a non-contact type of a stirring method; that means, you have to install electromagnetic stirrer somewhere outside, and from here, magnetic field will be created in the liquid and that causes a stirring; so, it is a non-contact type of a stirring mechanism.

So, one can install electromagnetic stirrer here. So, this let us say mold EMS. One can install from where, so, here is the start of the secondary cooling; this is a secondary cooling. So, one can install somewhere here, that is, S EMS - upper portion of the secondary cooling or upper portion of the (( )) or one can install somewhere just at the end of the liquid. So, this is if you call F EMS.

Now, you have to think also how we are going to install, because when the liquid steel enters into the mold, there is also a liquid flux is here. Mold is water cooled. So, all types of gadgets are there. There is a gadget of water cooling; there is a gadget of mold steel level control; there is a gadget of constant supply of the flux, and into that environment, an electromagnetic stirrer has to be installed.

Now also the shell of the thickness is growing as we come down from top of the mold to the secondary cooling zone. So, thickness of the solidified stirring is also increasing. So, one has to optimize these locations in order to see or in order to derive the maximum benefits of electromagnetic stirring.

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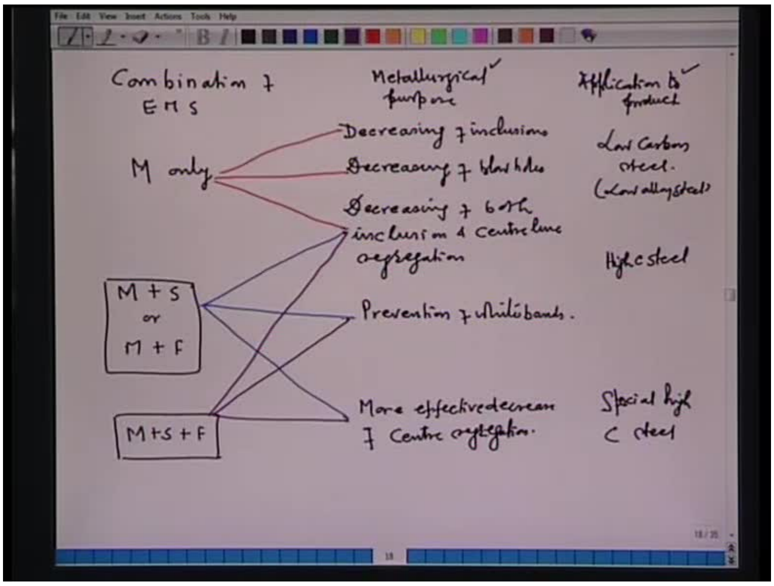

Now, say some of the say combinations of EMS, in some plant, the combination of electromagnetic stirring is done, the metallurgical purpose, metallurgical purpose, and application to product, application to product.

So, what has been done here? Electromagnetic stirrer is provided M only, that is, in the mold; then the metallurgical purpose, for example, was decreasing of inclusions, that could be obtained; decreasing of inclusions, decreasing of blow holes, decreasing of blow holes, then, decreasing of both inclusion and centerline segregation, centerline segregation.

They have also done they put two stirrer - one mold and secondary cooling or mold plus towards the end of secondary cooling zone. So, here, the prevention of white bands, prevention of white bands, then also put in the mold, in the secondary cooling and towards the end of this one.

So, here, for example, more effective decrease of center segregation steel. For example, low carbon steel including low alloy steel also; then, high carbon steel including low alloy and stirring steel and special high quality carbon steel. What I have listed here? These are the location of the stirrer; these are the metallurgical purposes for which electromagnetic stirring is done and these are the applications. Now, say for M only, one can have, for M only, you can decreasing of inclusions. Then decreasing of blow holes were also obtain and then decreasing of both centerline and inclusion is also obtained.

Now, say if you provide, for example here, then this M plus S or M plus F stirring it also provides decreasing of both inclusions and centerline segregation. Then it also prevents white bands and then it is also effective for more effectiveness of center segregation. Now, if you provide the stirrer in all three positions - M plus S plus F, then it can do also decreasing of both inclusion and centerline segregation. It is also effective of center segregation and it also helps in prevention of white bands.

Let us go now to the another developments in continuous casting, that is the high speed slab casting. The conventional casters, they cast slab at around 1.52 meter per minute. Actually, the slab casters are synchronized with the hot strip mill. If you want to increase the productivity of hot strip mill, then you have to increase the productivity of continuous casting slab. So, it is this particular objective, it is given birth to the so called the concept of high speed slab casting.

Now the whole idea is that, the high speed slab casting must match with the hot mill strip production. Now, I thought what I should tell you in the high speed slab casting. The conventional casters they cast at 2 meter per minute. Now, you should cast at 3.5 to 4 meter per minute you. Do it, it is a more or less a technological question. I thought of it and I thought that let me tell you some of the important issues in development of technologies. It is simple to say that now you increase the speed of the caster to from 2 to 3 or 4 meter per minute, but then, how to realize? Technologically this increase in slab casting, because there are so many things you have to think and so many things you have to do it.

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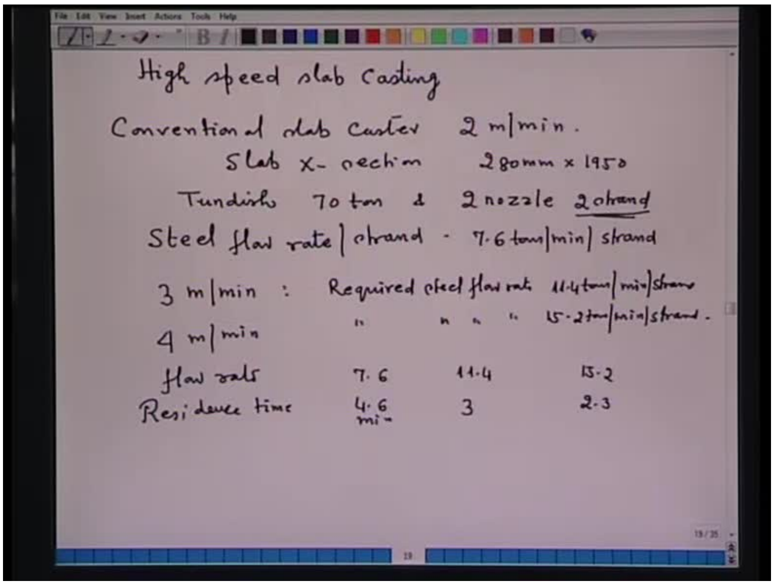

So, I have thought let me take it. Say let us consider a conventional slab caster; say let us consider a conventional slab caster, which is casting at 2 meter per minute. The slab cross section is 280 millimeter thick into 1950 millimeter white. It is casting having a tundish 70 ton capacity and 2 nozzles at the bottom of the tundish; that means 2 strand caster; it is a 2 strand caster. So, if I calculate now a steel flow rate per strand, very simple. I calculate steel flow rate per strand could be how much I have to find out the volume multiply by the density. I take density as 7 gram per centimeter cube or 7000 kilogram per meter cube.

Then I get steel flow rate per strand that is equal to 7.6 tons per minute per strand. This is what you are doing it already producing slabs from these particular arrangements. Now, we want to increase the speed, and let us say, now we want to increase the speed to 3 meter per minute or we want to go to further 4 meter per minute for the issues. I calculate now required steel flow rate. Now, required steel flow rate would be 11.4 tons per minute per strand.

And if I want to go at 4 meter per minute, then required steel flow rate will be 15.2 tons per minute per strand. If I have a 17 tons tundish capacity, the flow rate which was corresponding to 7.6 tons per minute, then the residence time, then the residence time of steel melt in the tundish capacity divide by 7.6 into 2 because there 2 strand. So, here it is 4.6 minutes.

Now, I increase to 3 meter per minute. The flow rate is 11.4 tons per minute, and here, it is 15.2 tons per minute. Then, here it is 3 minutes as a residence time; here, it is 2.3 residence times. Now, what these calculations indicate? Why I have calculated for you? Now, if you imagine based on this calculation, this calculation suggest that we have to do several technological changes.

Now, first thing that you note from this calculation is that residence time of the steel is decreasing earlier from the conventional slab caster; the residence time was 4.6 minute. If you want to go to 4 meter per minute, the residence time is comedown 2.3 minute. What does it mean?

If you are planning for inclusion separation in the high speed slab caster, then this residence time may not be sufficient, because you required around 4 minutes earlier because of your downstream, because of your upstream steel processing units. If you require the same residence time for high speed slab caster, then probably you have to increase the tundish capacity.

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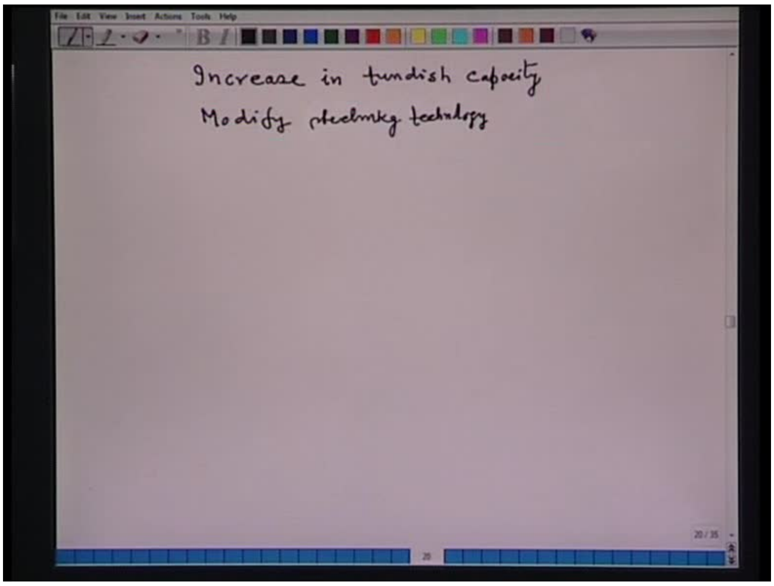

So, what one thing you have to require? You increase in tundish capacity, you increase in tundish capacity. If the tundish of a high speed slab caster has also to remove the inclusions during the process of continuous casting. So, increase in tundish capacity. Well, if you cannot increase the tundish capacity, then what you have to do? You modify steelmaking technology. These are the two solution that are coming in my mind; may be still another solution you can think of and see what can be done.

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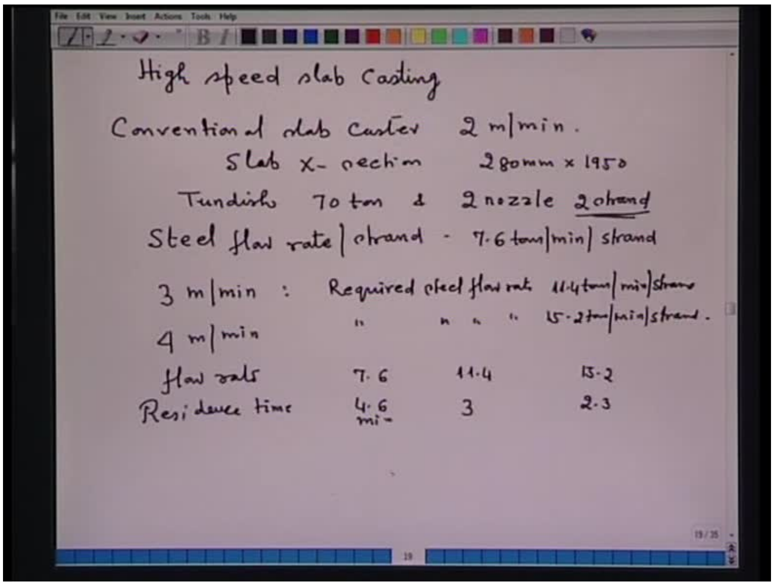

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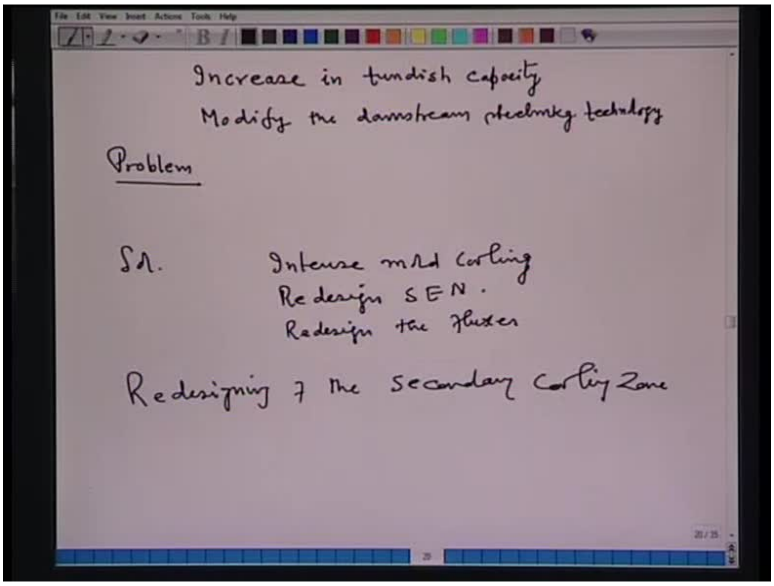

Another thing that you are seeing steel flow rate is increasing. You see now the steel flow rate for 3 meter per minute has increase to 11.4 ton per minute to 15.2 per minute where it is increasing. If the tundish exit, so, the steel melt flow rate is also increasing in the mold. So, what is the problem? Problem is in the same length of the mold and for the same cooling rate, more amount of a steel is available in the mold; so, it has to be solidified so that a partially solidified strand is withdrawn from the bottom of the mold.

Now, the quantity of a steel has become more. How the same amount of cooling and same technological gadgets which has been provided on the mold in the conventional slab caster can meet that requirement that has to be thought. What can be done? First thing is to be done. You increase the mold cooling. So, the solution is that intense mold cooling is required, intense mold cooling is required. Also in the steel flow, steel melt flow rate has increased. In the conventional slab casters, you have some diameter of the nozzle.

If you use the same diameter of the nozzle, then velocity of the steel melt entering the mold will increase. So, you have more turbulence in the mold. So, you have to redesign a submerged entry nozzle; that means redesign submerged entry nozzle. This thing only because length of the mold you are not going to increase, it will remain between 0.9 to 1 meter of the mold. So, these are the two issues, for example, in case of mold.

Now, you are still doing something more in the mold. You imagine, you think you are constantly supplying mold powder at the top of the melt. So, increasing amount of metal in the mold, you have to redesign probably the powder injection rate or mold flux injection rate.

Also the flux now should melt at a faster rate because you are withdrawing the partially solidifies strand in a faster rate. So, it should also melt at that particular rate. So, accordingly, you have to redesign the fluxes so that they can melt at the rate at which the partially solidified strand is withdrawn from the mold. A mismatch between the two will cause or may cause the air gap formation or increase amount of friction between the mold and the partially solidified strand; these are the issues.

Now, you have solved this particular issues thing another, because of the increase in the speed. The secondary cooling zone which is start from the bottom of the mold to the cutter is also to be redesign, that is, redesigning of the, redesigning of the secondary cooling zone, why redesigning? Now, the partially solidified strand is coming at a faster speed. Earlier it was 1.5 or 2 meter; now, it is probably 4 meter per minute and the industry is thinking to go for 5 meter or 6 meter per minute because they want to increase the capacity of the hottest treatment.

So, my dear young friends, probably you have to design or you have to redesign the secondary cooling, because at the end of the cutter, the solidified strand should have a temperature of 800 to 850 degree celcius one, and second the steel must be solidified just before the cutter.

So, a redesign of the secondary cooling zone is equally important. What does it mean by redesigning? May be you have to see the size of the spray. See, size of the nozzle, may be you have to see the water flow rate, the water pressure, the location of the nozzles. I mean these are all the several small but important issues that are to be addressed while employing high speed slab caster; that means there are two things over here.

If you want buy a new high speed slab caster, there is no problem, because it will come with all these requirement, but if you want to modify the conventional slab caster into the high speed slab caster, then all these issues are becoming important, because the important point is that at no point of time or at no point of technological changes in the existing conventional slab casters, your production should stop. If the production is stops, then it is not good.

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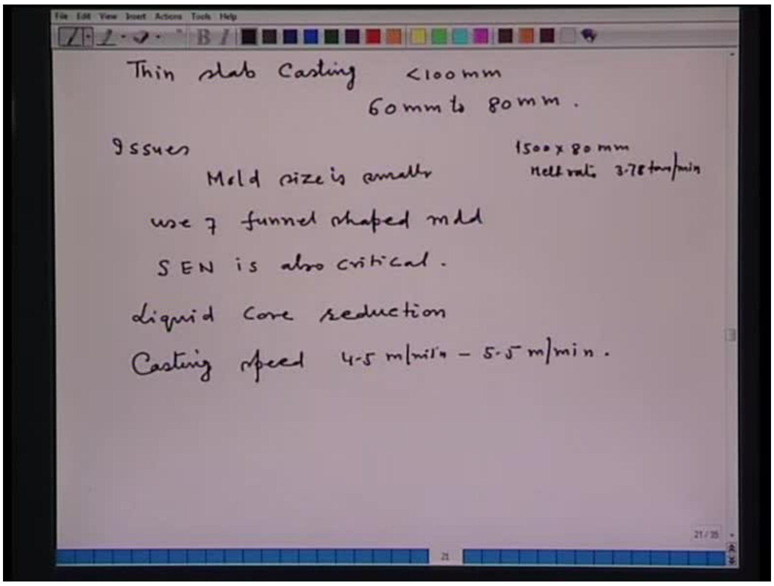

So, in these bottle necks, one has to think these all are the technological changes. So, this is about the high speed slab caster. So, another development is thin slab casting, thin slab casting. Now, in thin slab casting is less than 100 millimeter is called a thin slab casting. Normally, the thickness varies between 60 millimeter to 80 millimeter. Now, what are the issues in case of thin slab casting? Just now we have discussed high speed slab casting. What are the issues in case of thin slab casting?

Now, for example, if I am casting say 1500 millimeter width into 80 millimeter thin, the melt rate we require around 3.78 tons per minute. What we are doing now? The melt rate has become very low. So, accordingly, again everything is to be redesign. So, what are the issues over here? You need probably mold size is smaller, mold size is smaller. Then use of funnel shaped mold. These all together a different technology use of funnel shaped mold.

Then SEN nozzle is more critical; design of submerged entry nozzle is also critical. It is possible that the when the strand is exiting from the mold, it is still very large amount of liquid. So, everything has to be solidify. So, these issues were solved by developing the so called liquid core reduction, liquid core reduction. In the liquid core reduction technology, what is done? Solid in that with liquid core is subjected to online rolling.

So, this can allow further reduction in slab thickness from 80 to 90 millimeter to 65 to 70 millimeter. So, these are all the technologies which have been developed and the casting speed, casting speed, varies from 4.5 meter per minute to as I as 5.5 meter per minute. Now, say entire processing in thin slab casting is completed in the hot condition. So, these strip which are produced from thin slab caster. They are suitable both for hot strip mill as well as for cold rolled strip because of dimensional accuracy and surface quality.

So, actually this thin slab casting concept, it fits very well into the mini steel mill having electric arc furnace, because their capacity is small. So, it can be very well integrated with the electric arc furnace, and hence, the mini steel mills employing electric arc furnace with the thin slab caster, they can very well enter into the market of plate products that is the strip.

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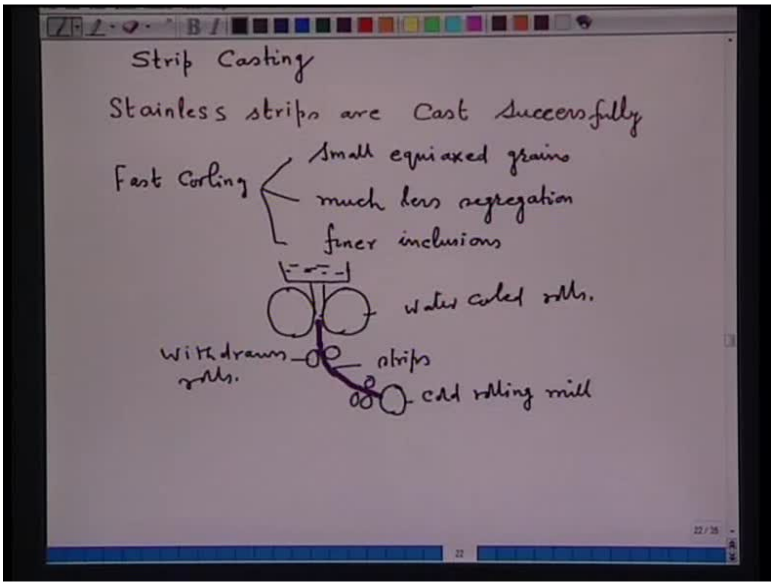

So, at present, stainless steel stripes are cast successfully though attains are also being made to cast carbon steel stripes, carbon steel stripes. Now, as molten steel is cast directly into the strip to the cooling is to be very fast. Now, the fast cooling has some very important features. So, the fast cooling may result in small equiaxed grains, much less segregation.

The strip casting can be very easily visualize. For example, we have one water cooled roll, two water cooled rolls. These are water cooled rolls. The top we have a tundish contains molten metal, and here, the metal is feeding and here are getting a short of strip, and this is strip. For example, we are having the rolls here, withdrawal rolls. So, this is a strip; these are the withdrawal rolls; this is strip roll. There are the breaking rolls, and then, it directly goes to cold rolling mill. That is how the simplest idea of a continuous strip caster works.

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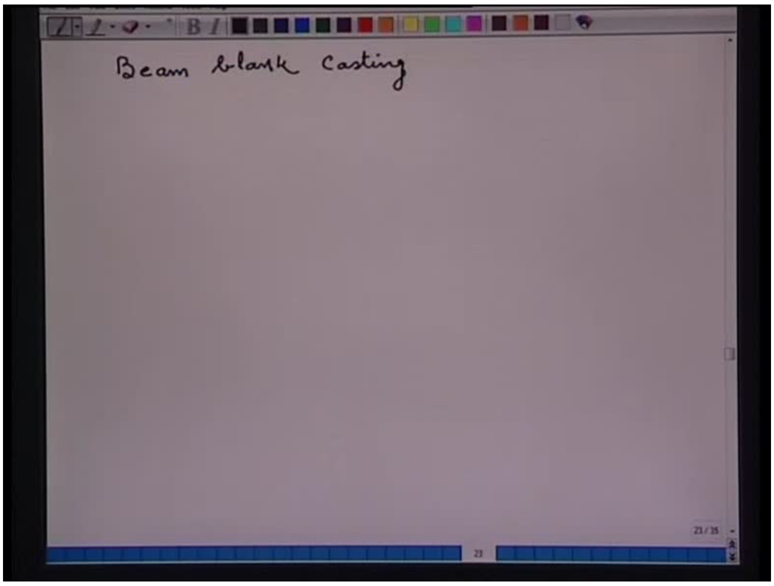

And this particular strip caster may be very well suited for again for the mini steel plants employing electric arc furnace. Another important development is beam blank casting, beam blank casting. This is in fact a near neck shape casting technology. Beams are used for building heavy structures in the construction and infrastructure sectors. Conventional methods they require hot rolling of slabs including intermediate hot rolling; that means start from the bloom or billet, extensive rolling is required, and then, we get a beam blank in steel. A direct method for casting from liquid steel is in the progress and one of the plant is reported they are producing beam blank casting also.

So, these are all the developments in continuous casting. My dear friends, technological developments have no limitations. It is the time changes; the technology will also change. As you have seen, we started from ingot casting came to continuous casting, then came to high speed slab casting. Ultimately, we have moved to strip casting and then so called near net shape casting.

The technology development drivers are the industries. The infrastructure industry is the demand from them will be in fact the technological drivers. May be one of you could develop a new technology for continuous casting of a steel directly into the different type of finish products. Thank you.