Steel Quality Role of Secondary Refining and Continuous Casting
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Module - 05
Lecture - 25
Cast Structure and Dendrite Size

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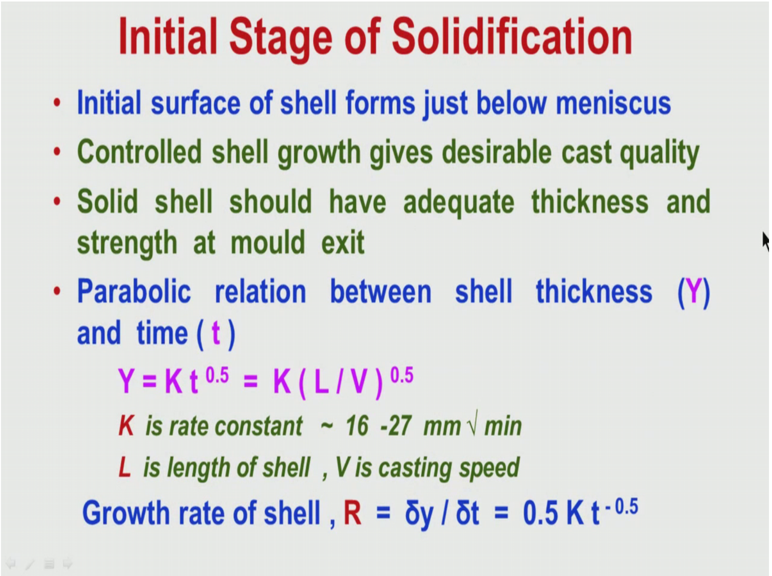

So, what is the initial stage of solidification? Initial surface of shell is forming below the meniscus controlled shell growth is very important desirable quality you know. So, the solid shell should have adequate thickness and strength at mould exit otherwise there will be shell raptured and there will be breakout I have mentioned.

So, I have mentioned that the thickness of the solid shell depends on the solidification time at you know local solidification time, and since time is you know the length of the shell divided by velocity. So, it is related to velocity also this casting velocity also. As I was telling you if you have a high casting speed Y will be less. So, this is important we cannot go to very high casting speed we have to operate within a limit of higher limit of casting speed, then to get a relatively thicker shell which can be stand the stress strain which are getting you know on it which are forming lot of stress and strain, it can be you know solidification stress, it can be some mould you know when you are bending, when you are straitening, the mould straitening the you know strand will can have lot of strain as I have mentioned earlier.

So, these are the important issues we have to remember.

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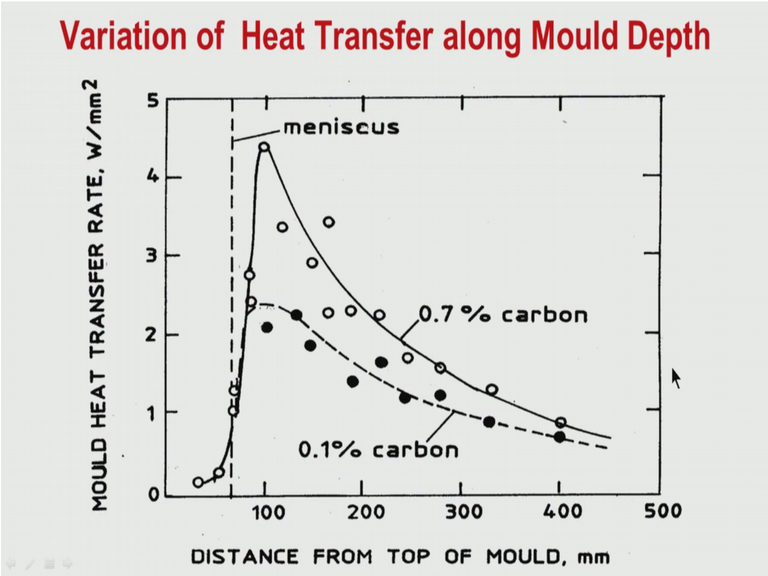

Now, this also I had discussed that what is the heat transfer along mould depth I am talking of the horizontal heat transfer through the mould, you know is the mould which is getting cooled with water, what is the heat transfer across the mould and how the shell is increasing. So, it heat transfer is you know at the. So, just at the top of the meniscus it is slightly lower and then its goes on increasing.

So, from the meniscus at certain depth, at a depth of say 30 millimeter from the meniscus down the mould, we have the peak of you know heat transfer and it is different for different you know grades. The 0.1 percent carbon I will discuss later on, why heat transfer is relatively less because you know there is a air gap formation it is the depressions form I will discuss in details, but it is just to show that how the heat transfer is dependent on the grade of thee steel also.

So, the heat transfer is at the peak at a certain depth say 30 millimeter from the meniscus, 0 means top of the mould meniscus is somewhere here, you do not have meniscus at the top of the mould otherwise you know what is going to happen is, due to fluctuation I mean there might be spillage which we not desirable. So, with the meniscus is at a depth of 70 millimeter from the top of the mould.

So, from the 30 millimeter below that below the meniscus you have the maximum heat transfer and which comes down. You know why it should come down? Because solidification is taking place, solid shell is forming thicker the solid shell as you are coming down. So, less is the heat transfer. You do not require so much of heat transfer and more over there is lot of resistance to heat transfer because of solid shell.

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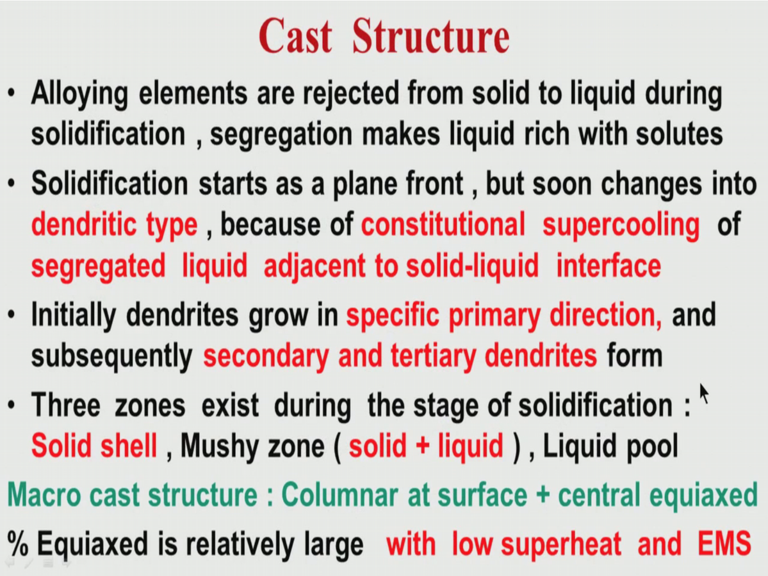

So, heat transfer comes down from in the mould from top to bottom. I have also discussed about the cast structure. I have mentioned that this in steel it is not a just pure iron, if you had if you have casted pure iron, may be we have a plane front of solidification. But since we have lot of solutes the alloying elements in the steel, we have carbon, we have silicon, we have manganese, we have phosphorous, sulphur and other alloying elements different to the steel grade which will have lot of segregation potential; that means, during say solidification, the solutes will come out from the solid shell to the liquid; that means, we have more enrichment in the liquid.

So, as the solidification is taking place the liquid which is ahead of the solidification front it is getting more and more rich with solutes. So, because of this there is a change from the plane solidification front to a dendritic time. Because of this constitutional supercoiling this is supercoiling is due to what? It is due to segregation that is why it is called constitutional supercoiling. All alloying elements will cause segregation it is less or more distribution of this you know the alloying elements from solid to liquid you know you know in solid it is always less, soluble it is less. So, solutes will have less amount of solutes and more amount in the liquid. So, liquid is becoming more and more rich as the solidification is progressing. So, this is called constitutional supercoiling.

So, the liquid steel are adjacent to the solid liquid interface will have more segregation. So, there is a because of that the solidus of that liquid is less so it is called super cooled. So, because of this the solidification front become dendritic. So, initially dendrites grow in specific primary direction, near about the direction of the you know direction of heat transfer near to that not exactly to that because actual direction takes place certain crystals of direction of 1 0 0. So, 1 0 0 which is nearer to the you know heat transfer direction, that will have the primary direction of dendritic formation. So, it is called primary direction.

But after sometime there are secondary and tertiary dendrites as well. So, these are important to know that it is a dendritic solidification which take place in steel because of alloying nature. Its nature it is basically an alloy there are lot of segregation of the solutes. So, it is dendritic form of solidification. So, at the time of solidification there are three zones which has already become solid that is the solid shell. Liquid pool is there from which solid shell is forming and in between there is a mushy zone; that means, it is a combination of solid and liquid.

Solid shell means at that zone solidification is complete, liquid pool means solidification has not started here it is in between; that means, the solid fraction in the mushy zone is between 0 and 1, in percentagewise it is between 0 and 100. So, that is called mushy zone it is the combination of solid and liquid.

Now this macro structure, I will show certain figures it will be clear, this macro cast structure is columnar at surface and central and then we have equiaxed at central, and how this equiaxed zone increases I have told you it depends on superheat and electric magnetic studying.

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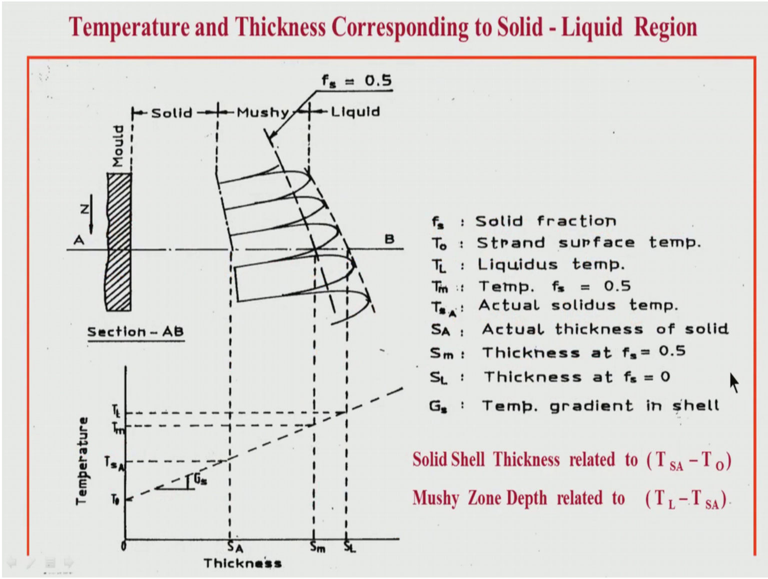

Now, if you look at a time off solidification what is happening look at this figure. This is the liquid pool this is the solid shell which has already found because of solidification. In between we have a mushy zone and this relative thickness of the solid mushy zone during solidification will depend on what are the different temperatures, what is the temperature of the solid surface, what is the temperature of the liquidus, this particular temperature liquidus, what is the actual solidus temperature. So, this three temperatures; that means, the liquidus temperature TL, this temperature TSA; that means, actual solidus temperature and T 0 the temperature on the solid shell, temperature on the surface of the solid shell these three will determine what are the relative thicknesses.

So, if you have more of segregation, what is going to happen? TSA the actual solidus temperature is getting suppressed. So, the difference between liquidus and TSA increases. So, this becomes low. So, if this becomes low, the mushy zone becomes more void and the solid shell becomes more narrow. So, relative thickness of the solid shell and the mushy zone is determine by relative temperatures liquidus temperature and the solidus actual solidus temperature. This since this temperature is more or less constant because if the surface temperature it depends on the temperature of the mould or when it is it has come out of the mould depends on the cooling secondary cooling. So, this is we can assume that this is more or less constant temperature. This liquidus temperature is depends on the particular grade, but is not very much affected by segregation.

So, you know for a particular rate which is liquidus, but because of segregation this actual solidus temperature is supressed. So, what is happening is with more of segregation this temperature goes down; that means, the mushy zone increases in thickness and the solid shell becomes narrow during solidification. This has lot of implications on the quality of the solid shell which will be discussing later on.

But please try to remember that at the time of solidification, the relative thickness of the solid shell and the mushy zone will be determined by how segregation is affecting this temperature actual solidus temperature. More is the segregation for certain elements I will be discussing that segregation you know extent is more. So, the lower will be the solidus temperature because of the impact of that. And lower is this temperature solid shell will become thin and the mushy zone will be will become more void.

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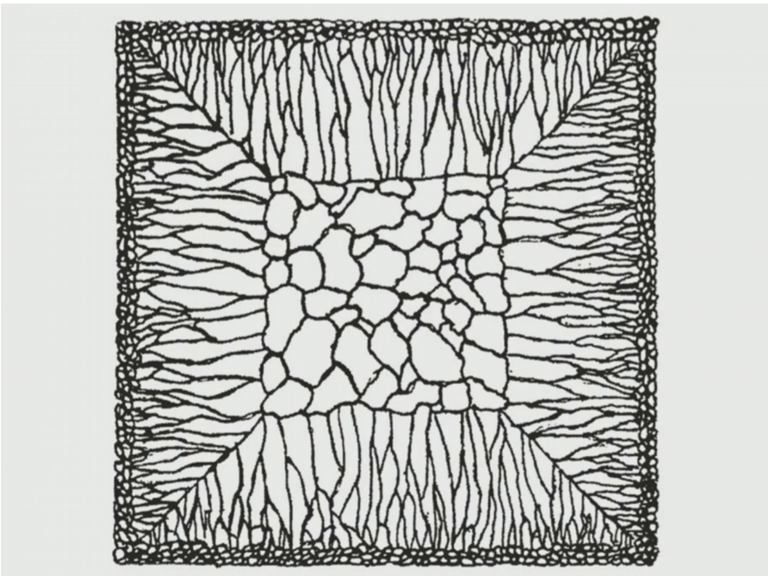

Now, let us look at how the solid structure actually looks like. I have told the basically there are two broad areas in the solid structure mould is the; look at this these are the mould surfaces here, here, here, here. So, we have columnar grains initially, but look at here just at the mould surface because of the chilling effect, people tell that there are fine equiaxed grains just at the surface and then, once the solidification goes ahead just after sometime a few fraction of the second the columnar dendrites, dendrites in columnar fashion increases the primary dendrite goes on increasing in length.

So, basically though we have this, but this is only for a few millimeter and only for a fraction of a second during the solidification time, we have a surface chill zone sometimes you may not find this chill zone even. So, what is important is the two broad areas in the cast structure.

First is the columnar structure; that means, the dendrites are columnar in nature here, and then in the central portion also we have dendrites, but we have equiaxed why equiaxed grains form here? Because you know the superheat comes down and due to some segregation due to some you know due to generation of some defects or some elements which we try to accumulate of the central region we have heterogeneous nucleation here.

So, more number of nuclei form here in the liquid which is solidifying at the last portion of solidification; that means, at the central location of the you know cast structure, we have equiaxed zone. We have dendritic solidification, but in equiaxed shape here it is columnar long dendrites of column.

So, what is important to remember is that, this ratio of columnar zone is to equiaxed zone depends on superheat; that means, the actual temperature of the liquid steel which is getting solidified or during casting what is the temperature of the liquid steel, how high is the it relatively, what is the you know difference of this temperature with the liquidus temperature. So, that is called superheat.

Lower the superheat more will be the equiaxed zone; that means, if you have high superheat say 40 degree or 50 degree centigrade, you may have columnar zone extending even at the even to the centre of casting; that means, you have columnar zone stating from the beginning of the casting to the end of casting, we have hardly any equiaxed zone if you have relatively high superheat.

But if you can cast in low superheat zone of say 10 ort 20 degree centigrade, your equiaxed zone will be slightly more may be 30 percent 40 percent 20 percent starts from 22 may be 40 50 percent. But for that you must have very low superheat, but as I have mentioned earlier low superheat is a problem during casting, your you know entrapment possibility are there you know premature cooling of the liquid might create problem during casting. So, we have to operate at certain superheat maybe 20 degree centigrade not less than that, maybe 15 degree centigrade not less than that. So that means, if you have low superheat of say 10 to 15 or 20 we have some amount of equiaxed zone which is good, as I will be coming later on to the central segregation. If you have this equiaxed zone then what happens? Segregation and the cast abnormality of the centre gets distributed.

If you have high superheat means columnar zone extending to the centre, and this the centre becomes highly segregated and high amount of you know solidification shrinkage at the centre portion; that means, we do not want high amount of segregation central segregation, we do not want high amount of central porosities in a cast structure, because that is a defect we do not want that. So, we must have some central segregation that is one.

Another is I have mentioned that electromagnetic studying during continuous casting helps in making the grains finer, helps in generating equiaxed solidification at the central portion of the casting also. So, we have we can have less columnar and slightly more equiaxed zone if we have low superheat number one and if we do electromagnetic studying during continuous casting.

Nowadays for billet and bloom people are using electromagnetic studying, this is a typical you know bloom sort of thing, slightly rectangular you can have square you can have rectangular bloom as well. So, in such solidification such casting of such steel it is better to have electromagnetic studying, this facility not very expensive many casters billet and bloom casters have this facility, where even at slightly higher superheat maybe a 20, 25 degree you can have maybe say 30 percent equiaxed zone 30, 35 equiaxed zone.

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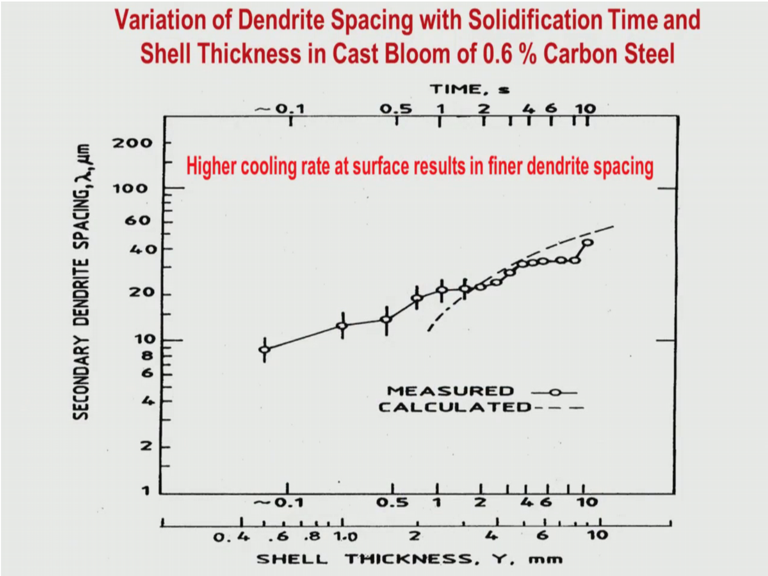

So, lower superheat and magnetic studying these two are useful for getting good solidification structure. This I had mentioned earlier that how the rate of cooling determines the dendrites size. I have mentioned that you have primary dendrites, we have secondary dendrites, perpendicular to them and then maybe we have tertiary dendrites again perpendicular to them.

Now, primary dendrites are relatively codes, and then you have secondary dendrites. So, it is normally secondary dendrites thickness are measured to give an indication of what is the size of the casting, what is the size of cast dendrites. So, we measure secondary dendrites spacing. So, this secondary dendrites spacing gives an indication of the coarseness of the cast product; finer this spacing, lesser this spacing, finer is the cast structure.

So, this depends on what? Basically depends on the cooling rate at the surface; that means, cooling rate of the heat transfer, at what rate the solidification is taking place you know it depends on that. So, you can see higher the cooling rate finer will be the dendrites spacing? At the surface the cooling rate is more I have told as you are going inside the heat transfer decreases. So, the cooling rate also decreases. So, you have relatively coarser dendrites.

So, look at the dimensions, maybe at the shell thickness of say you know 0.63; that means, just at the surface at a time of say 0.1 second; that means, when the casting as just started you know secondary dendrites spacing is just 10 micron. Now when you are going to say 10 millimeter at a depth of 10 millimeter shell thickness; that means, at a time of local time of solidification of 10 second, after 10 second we are getting a maybe 10 millimeter of shell thickness.

So, what is happening there what is those dendrite size. It started with 10 millimeter now it has become coarse? It is may be 60 millimeter so; that means, as you are going inside the cast product you are dendrite size is becoming more and more coarse, because you know the casting or the cooling rate is becoming less and less as you are going inside.

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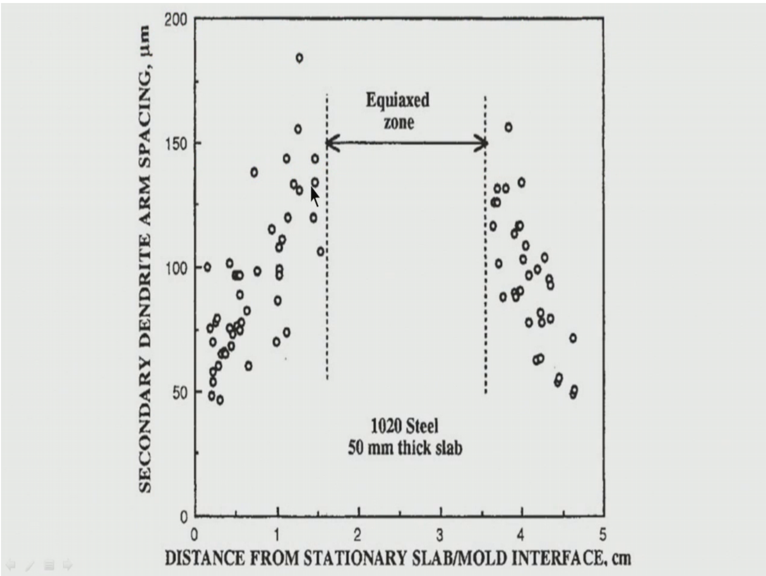

So, at the surface you have fine structure, and the inside you have relatively coarse structure. Same thing will be visible in this figure look at what is happening here this is distance from the stationary slab or mould interface. That means say this is 0 means this is the mould location, as you are going this way means we are increasing the solidification distance. So, the shell thickness is increasing.

So, as I have told you at the surface at the both the surfaces you have columnar zone in between in the central portion of the casting you have equiaxed zone. So, in the dendritic zone columnar zone this also dendritic, but equiaxed dendritic in. The columnar zone in the surface it is very fine, you see the what are the dendrites spacing secondary dendrites arm spacing about 50 say it is increasing to as high as may be 150, as you are going inside.

So, it is at 10 20 steel 50 millimeter thick slab. So, in a slab of 50 millimeter, 5 centimetre you see as you are going inside the slab from the surface. Surface is having finer dendrites as you are going inside the dendrites becoming more and more coarse columnar dendrites then you have equiaxed zone and then the other surface; that means, solidification taking place from both the surfaces from here and here is the slab.

So, you see the surface as relatively finer as you are going inside, from the both the surfaces the secondary dendrites are becoming coarser. And finally, you have equiaxed zone. As I was telling then there are two things we have to remember first the solid structure is not uniform, it is having a columnar zone near the surface which is extending towards the centre and we have a equiaxed zone.

Now, relatively I have told you equiaxed zone can be increased in depth by two factors by taking records to two factors; first low superheat and use of electromagnetic study. If you use high superheat and no electromagnetic study; that means, there may be a situation where you do not have an equiaxed zone at all, you have only columnar zone extending from the both the surfaces. That is not desirable because you know the coarseness of the structure at the centre it is goes on increasing as you are going inside.

And the final central location you have very coarse structure, you have too much of segregation, you have too much of porosities. So, that area is really bad in quality central quality, quality at the central location is bad because of high segregation and high porosity high shrinkage solidification shrinkage.

So, you require good structure good structure means you require relatively more equiaxed at the central, you require more finer dendrites, if you have coarser dendrites during rolling there is a possibility of crack formation because, at the boundaries inter columnar zones there may be a problem there is normally segregation there may be a problem there may be crack generation. So, what is required is a relatively finer dendrites and relatively void equiaxed zone at the centre this is what is desirable in a good cast structure.

Thank you very much.