Steel Quality Role of Secondary Refining and Continuous Casting

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Module – 08
Lecture – 42
Remedial Measures to Control Defects: part I

Good morning. In the last session, I talked about the location and direction of cracks in different cast products; whether it is billet or bloom round or slab what are the locations and the directions.

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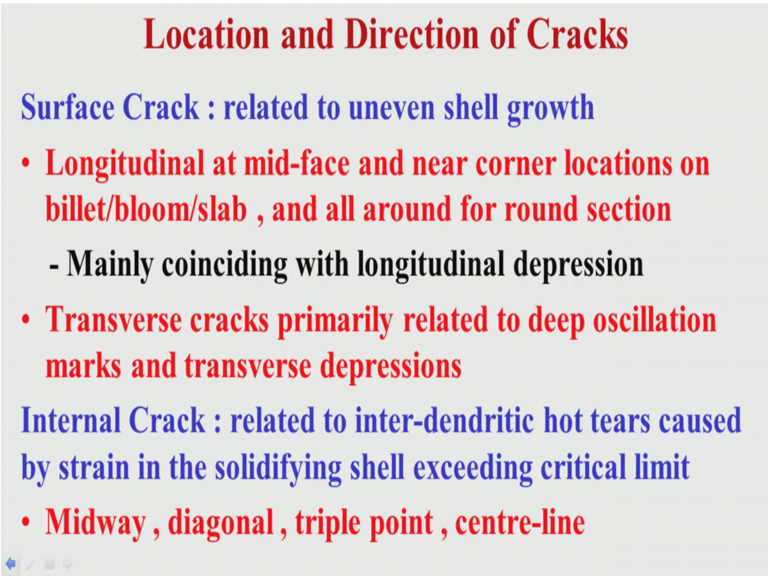

So, I talked about 2 broad areas; one is the surface crack which are visible on the surface of the cast product, it is billet bloom or slab or rounds another is a internal crack which normally you cannot see unless you take a sectional view of the cast product; that means, you have to cut the product whether it is billet bloom round or slab in the cross section to have a view at the internal cracks.

So, surface cracks you can see on the surface of the cast products. So, straight away you can have some idea of it, but for internal cracks, normally you have to take a sectional view and what I have mentioned that related to their inter dendritic hot tears. So, basically those inter dendritic exomes are relatively weak. So, those areas; there is rapture, there is a crack formation tearing at high temperature. So, we call it inter dendritic hot tears caused by strain in the solidifying shell exceeding critical limit. So, as I have mentioned several times that the shell solidifying shell during solidification even after that; it is undergoing some strain lot of strain.

Strain can come from different; you know sources, I have mentioned form the ferrostatic pressure that can be one type of you know strain from the shrinkage that can be another type of strain from the delta to gamma transformation where it takes place is important at what temperature, it take place is important. There can be some strains, then there can be additional mechanical strains due to bending of the strand due to unbending of the strand; that means, straightening.

So, all this will impart will cause generation of lot if strain on the solid shell. So, it depends what is the magnitude of the strain, what is the type of the strain, if it is tensile, then it is a matter of concern know, all of you know the tensile strain or stress will cause crack formation. So, we have to be careful about all the strain they should not exceed a critical limit. This critical limit depends on the type of the material of course, for different type of materials, you know the critical limit changes, but what is important is the strain should not exceed certain limits the strain which is imparted on the solidifying shell whether during solidification after solidification due to ferrostatic force due to shrinkage due to delta gamma transformation or it may be mechanical strain due to bending or un bending straightening of the strand.

So, all these are important issues, we have to keep in mind to get a good quality cast product. Now I have mentioned that internal crack it, it can be located at somewhere midway at the diagonal may at the triple point or at the center line. Now the center line crack or center line you know defect shrinkage is very difficult to avoid why because you know the last portion which is getting solidified; obviously, it will have some amount of solidification whatever alloying elements you have will definitely segregate it is a question of more or less. So, if you have elements like phosphorous and sulfur, I have mentioned; you will have extensive segregation and the central portion which is solidifying at the last will have relatively more of this segregation there will be shrinkage as the at the location of the center y because that is a last area which is going to be solidified.

So, at the center line, you can have both segregation as well as crack. So, now, what you can do in the normal circumstance, you cannot avoid center line segregation and crack only thing; what you can do is you control the undesirable elements like sulfur and phosphorous. So, that you can have less amount of central segregation less amount of you know what is that called the change in the or the depression of the solidus temperature and what you can do is you can use low super heat casting so that you can have more equiaxed zone at the centre. So, the this cracks and segregations they get distributed and do not concentrate at the centre line, if you have; I have mentioned if you have equiaxed zone at the centre you have less amount of you know central crack and central segregation.

Because what is happening is this is getting relatively distributed, but if you have columnar zone extending to the centre of the cast, why the columnar zone will extent because of high super heat, if the super heat is high the columnar zone which starts from the surface of the cast product will extend till the central portion of the cast. So, this is a matter of concern. So, we have to do low super heat casting, we should have low amount of phosphorus and sulfur, we should have more amount of manganese by sulfur ratio. So, that the segregation of sulfur deleterious effect of sulfur can be taken care of in spite of all this precautions, there will be some amount of segregation and there is a possibility of central line cracks in the cast product like you know as I was telling you. So, if you look at the internal you know defects and billet bloom or round or even slab I will come to slab.

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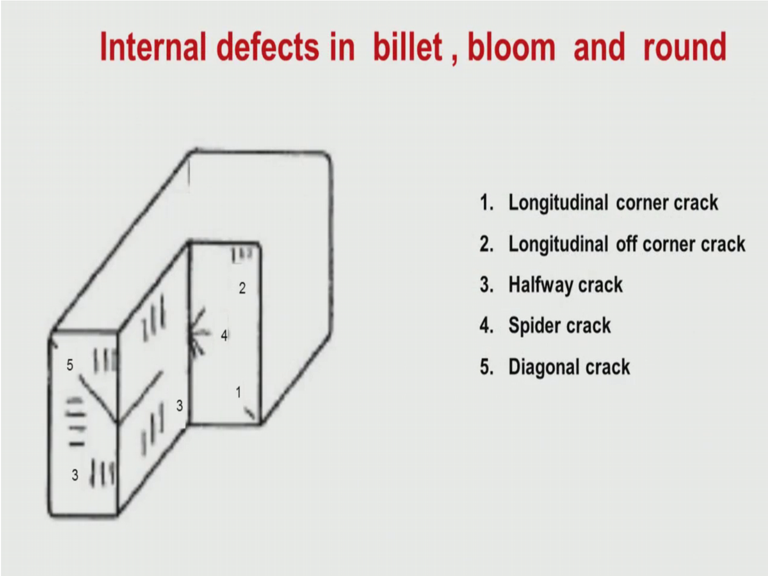

So, you can have this is particularly the central line crack or segregation at the centre of the cast product you can have this. So, it is normally, if it is a long product like you know billet bloom or round or even in slab. So, it is more of longitudinal nature that the central location will have crack as well as segregation. So, which is called central segregation or central crack similar is a case for slab, yeah.

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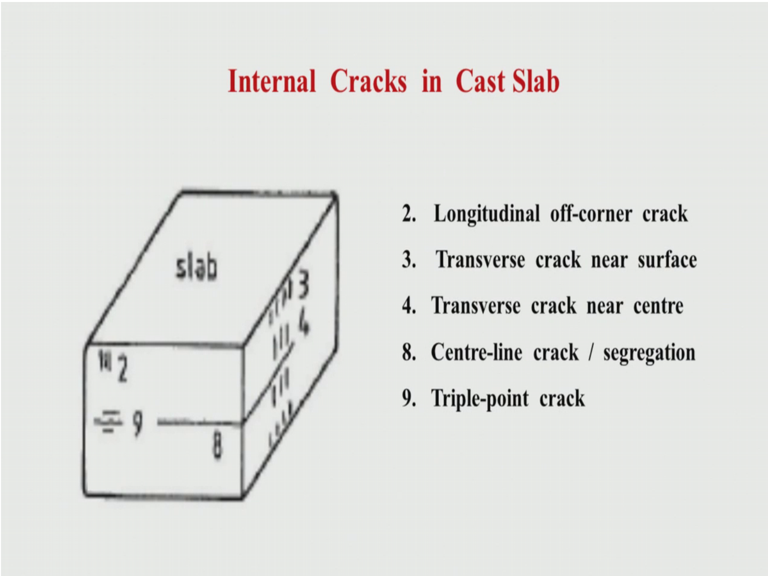

This is the centerline crack or segregation normally some you can had both crack and segregation. So, why the crack is following predominant of the centre because there is extensive shrinkage towards the end of this is a last area which is getting solidified. So, there is shrinkage solidification; shrinkage and more about these area is relatively more pollute, more what should I say more this is having too much of segregating elements because of high segregation it is impure elements purity is relatively less here. So, this area is relatively weak, I have mentioned you that you know this triple point, this diagonals at a solidification front are meeting. So, central area again the solidification front are meeting and more about if you have columnar zone extending till the central portion. So, you have additional chances or higher chances of formation of central crack and segregation.

So, even if you take some precautions during normal casting, what are the precautions, if you use low super heat, you have less amount of phosphorus less amount of sulfur higher ratio manganese by sulfur using. This you can have less intensity of segregation and crack formation at the centre, never the less you will have some amount of segregation and some amount of shrinkage crack at the centre always. So, what do you do? This is a very important you know defect, this is a very typical defect fore cast product and you know for certain applications you do not want that there should be a crack or heavy segregation at the centre. So, some attempt will be necessary additional attempt additional precautions will be necessary to control the incidence of this crack and segregation at the central line at the central location.

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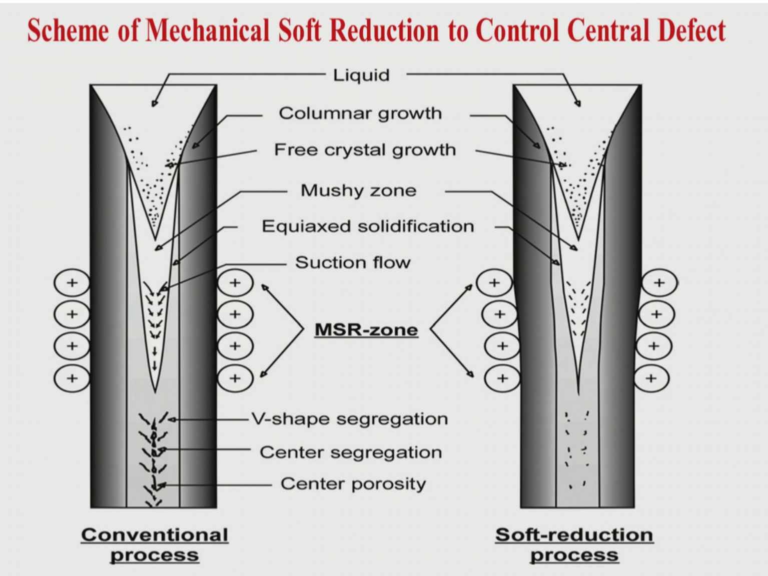

So, what is that this is called mechanical soft reduction, I have mentioned that normally the you know the last portion of the cast product is basically almost horizontal; that means, initially the solidification is starting in the mould when it is vertical or curved depending on which type of mould you are using then it is coming out of the mould and if it is a curved mould then you required only unbending or straightening of the strand to make it horizontal and if it is a straight mould. So, first you required bending and then unbending or straightening to make it horizontal.

So, in a horizontal section finally, when the horizontal movement is there for the strand the cast product. So, there the thickness; that means, a dimension which is perpendicular to the longitudinal direction. So, that is called the thickness. So, the thickness is determined by how much gap you are giving between the different rolls the rolls are basically used in the strand to keep the shape of the strand to give the proper dimension to the strand. So, now, look at what is happening if you want to do soft reduction soft reduction, basically means you are introducing intentionally a small amount of mechanical reduction in the central; in the portion of the in that portion of the strand, when it is getting finally, solidified strand has started from a from the mould, it has come out mould solidification front is slowly increasing and finally, reaching the centre point.

So, the area where the final solidification is taking place that area is very important because in that area that zone you know, you are likely to have segregation and crack segregation due to; you know partitioning of the alloying elements I have mentioned. So, this phosphorus sulfur which will give you heavy amount of segregation. So, the control is necessary, but even if these elements are less even if the manganese, sulfur ratio is more, then also you can have some amount of segregation; segregation may be the; they are also from other elements like carbon like you know, these are part of the part of the chemistry of the grade you cannot avoid them steel is not just iron, it will have some amount of carbon depending on the grade and the composition desired composition, you may have manganese, you will have some silicon you will have some amount of other alloying elements, you may have titanium you may have small amount of chromium you may have small amount of molybdenum you may have small amount of nickel. So, all these elements, there is a possibility of some segregation and as I have told you the amount of segregation is more towards the end of the solidification.

If you remember correctly, there is a term solid fraction in the segregation; you know shell modified shell you know relation for segregation. So, the last amount of liquid which is going to be solidified in the final you know, central region of the cast product is relatively having more amount of solutes because of segregation and again at the last stage of solidification, there is going to be some amount of shrinkage always will be there shrinkage has started in a solidification itself, but the final shrinkage always will be there in the last portion of solidification; last area which is solidified. So, in a central area, this is the you are looking at this is the longitudinal direction; that means, whether it is bloom or billet or you know slab it is going like this solidification is you know continuous casting is taking place in this way that the means direction of casting is this way it is coming out is going this way.

Now, look at the central area where the final stage of solidification is taking place this is the liquid you know this is the mushy zone I have mentioned about you what is mushy zone, it is basically solid and liquid. So, this the liquid this is the mushy zone and this areas are the solid which has already formed solid shell.

So, you see here; columnar initially from the surface, there was I was mentioning earlier you have columnar growth now how much columnar growth will be there, it depends on the super heat or if use electromagnetic stirring then also you can extend the rather you can control the extension the columnar growth and you will have some amount of equiaxed growth here, but anyway here, it is being mentioned you see after columnar some amount of equiaxed solidification is there towards the central area and this area is the mushy zone.

So, what is happening final solidification will be taking place in this area where they you have some mushy zone. Now if under normal conventional process during the last stage of solidification, we will have some V shape of segregation you have central segregation and you have central porosity; porosity is because of the shrinkage at the last stage of solidification segregation is because the extent of segregation is typically more at the final stage of solidification. So, you have central segregation you have central porosity and the segregation is sometimes distributed in V shape because of the; you know because of the flow of the final liquid in this area sometimes they take a V shape.

So, in the equiaxed, if we have equiaxed solidification in the final stage you have a V shape segregation, but if the super heat is more and you are not using you are not using electromagnetic stirring EMS then as I have told you equiaxed solidification can extend rather, the columnar of the solidification, this is the columnar zone, it can extend till the central area there will be no equiaxed zone in that case. So, in that situation your crack formation is more extensive your segregation is more extensive and you may not have V segregation V segregation is present when it is distributed segregation is distributed.

But when you have columnar you know zone extending till the central area instead of V segregation we have pronounce central segregation segregation is concentrated at the line central line only. So, this is a normal situation here you know that this distance this width or thickness rather the thickness is maintained by here you know this rolls which are the distance between the rolls will give you a final dimension.

Now, if you can create some amount of squeezing; that means, if you can generate some amount of mechanical pressure in this area in the final area where solidification is taking place this is very important where you give the pressure if you put the pressure beforehand it will be of no use if; if you put the pressure after solidification is over then also it will be of no use rather it may create generic crack I will come to it later on. So, what is important is you put pressure only at the final stage in the area of where the final solidification is taking place this is very important. So, how do you decide where the final solidification is taking place you can use modeling you can use empirical relationship you know as I have mentioned the solid shell how it is increasing the finally, when it is reaching the centre point you know at what time and what depth it will reach.

So, all this is possible to having some idea. So, from those ideas you can identify the area where you want to put some reduction it is called mechanical soft reduction you are giving some strain some pressure you are inducing, but it is soft; it is not very high if it is very high it may cause; you know crack formation which we do not want. So, it is a mechanical soft reduction you are reducing the thickness in these area by certain extent look at here what is happening this was the original thickness dimension you are putting some additional pressure in the final solidification zone.

So, what is happening the thickness is slowly coming down not in one step not at only one location, but slowly; that means, there is a gradient how the thickness is coming down and thickness is how it is coming down you are putting pressure in the rows you are decreasing the distance between the rows in these areas here it is you know normal to whatever distance was here, but slowly as you are coming down; that means, you have reached the final zone of solidification; solidification front is coming to an end you are trying to put some pressure; that means, you are reducing the thickness.

And finally, it is becoming certain thickness. So, initial thickness was something like this before the final solidification front slowly you are decreasing the thickness and in the process you are increasing the pressure and finally, the thickness is like this; that means, you will find the thickness original thickness has become slightly lower due to mechanical soft reduction.

Now, what is the benefit of this you see this liquid you know which will try to come in the solidification front these are indicated free crystal growth because of these you know you have equiaxed zone, but this is possible only when super heat is relatively low. So, it is a similar situation it is being shown here. So, now, what is happening this mushy zone will be there when you are there is a suction flow; that means, whatever you know liquid is there, it is trying to get sucked more and more is going to get sucked in the this area in the mushy zone area and look at the difference between the 2 here the mushy zone front has certain shape here you see, it is coming to an it is you know completing; that means, the solidification front is becoming more and more narrow because of the pressure you are putting.

So, what is the advantage? Advantage is whatever shrinkage was supposed to be there in the final stage of solidification you do not have them. So, you are trying to compensate for the final solidification shrinkage by putting some soft reduction minor amount of reduction. So, the effect of this reaction will be absence of solidification crack at the final central region absent of absence of porosities absence of you know final solidification crack there was some porosities and cracks in the final solidification front. So, you do not find them here that. So, you can control the extent of segregation and porosity by putting soft mechanical soft reduction. So, this is an important development my understanding the; you know solidification front by understanding what; what is going to happen in the final stage of solidification people have device this. So, this is an afterthought initial you know when continuous casting is to take place the technology was not having the idea of mechanical soft reduction.

So, this is a conventional process what happens when you do not put mechanical soft reduction. So, in that case you have V shaped segregation you may have central segregation you may have central porosity, but when you are putting MSR means mechanical soft reduction the zone of mechanical segregation again I am telling you is very important I will discuss this in greater detail after sometime, but what is important is this MSR zone mechanical soft reduction zone when you are giving this soft reduction at the final stage of solidification that is very important.

So, identification of the final stage of solidification is important then only you can decide where you will put the mechanical soft reduction what is the zone of mechanical soft reduction what is effective area of mechanical soft reduction if you give mechanical soft reduction in instead of these you have putting soft reduction here and the solidification is you know may be eighty percent complete it, it will be of no use and why if you put mechanical soft reduction after solidification has taken place is completed again it will be of no use rather it might create some crack in the solid shell.

So, what is important is to identify the optimum zone where you have to put mechanical soft reduction, what is this zone? This zone is where solidification is getting completed; that means, maybe from 90 percent to 100 percent solidification that area is very important here where you want to put this some amount of you know pressure some amount of pressure for the soft reduction and I had mentioned that this you know area is relatively prone to brittle crack formation also that is why the pressure the strain formation is gradual you are not putting a sudden pressure at any point of solidification you are putting slowly you are putting the pressure that is why it is called soft reduction and that to reduction, there is a gradient or reduction it is not one step of reduction slowly it is increasing reduction such that the total reduction is not much, but it is also there is a gradient; that means, slowly it is increasing.

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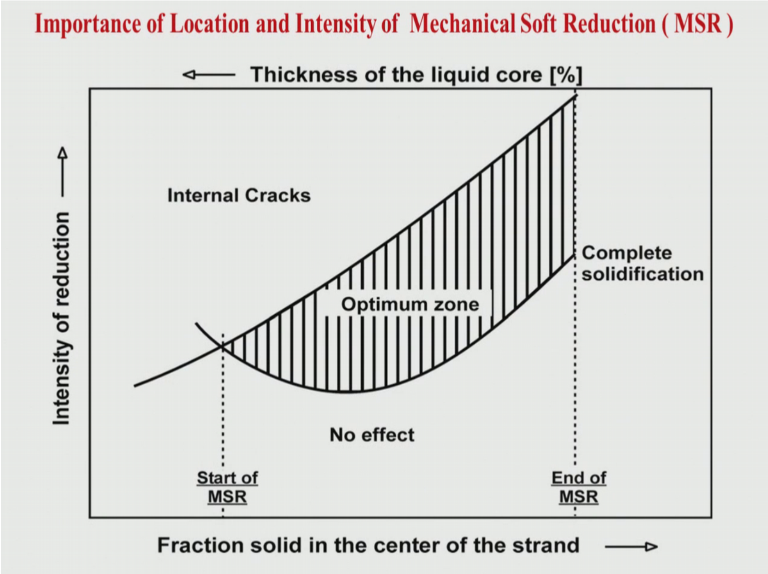

So, this is an important concept now as I was telling you let us try to understand how do you decide where to keep the pressure and how much pressure do you give this is again important as I was telling you. So, this is the intensity of reduction; that means how much amount of reduction you are giving. So, if intensity is increasing this way and fraction solid in the centre of the strand; that means, how much of liquid will be there in the mushy zone how much of liquid will be there; how much of solid will be there. So, that this and these are basically dependent fraction of solid increasing means the liquid core will be decreasing yeah.

So, now, you see here you are putting starting mechanical soft reduction at certain location you are finishing the mechanical soft reduction at certain location where are you finishing where the complete solidification is there beyond that; you are not putting any soft reduction, the whole idea of giving mechanical soft reduction is to compensate the shrinkage porosity at the final stage of solidification. So, beyond that you do not want to give it.

the whole idea is to stop the mechanical soft reduction finish the soft reduction at the point of complete solidification and you start it before complete solidification; that means, the whole idea is to give if to as I have told you the whole idea is to determine this area affective area. Now you look at it if you do too much of pressure too much of intensity of reduction there might be formation of internal cracks as I have told you. So, too much of pressure will generate internal cracks if you if the pressure is less than the required amount, this is the area, there is no affect at all you might give small amount reduction in this zone, but it is of no use. So, what is interesting is that this intensity of reduction you are slowly increasing as you are reaching the solidification completion front you see intensity is initially less slowly, you are increasing the intensity. So, this is very important that optimum intensity is important optimum location where you put mechanical soft reduction is also important.

If you put less pressure insignificant pressure there will be no effect there is a whole idea for putting mechanical soft reduction will be of no use if it is not adequate, but if the amount of reduction is more then you may have internal generation of internal cracks. So, what is important is this optimum intensity of reduction. So, optimum zone is basically it contains both the intensity as well as the area. So, optimum zone means first the area where you will put the soft reduction and how much of soft reaction you will put. So, both are important you do not put you know mechanical soft reduction beyond complete solidification area once solidification is complete it is no point putting you know the soft reduction rather it might create problem it might generate crack.

So, do not put beyond this. So, important to find out what is the optimum zone optimum zone first the area in which mechanical soft reduction has to be given and then how much of soft reduction has to when initially, it is less and as you are going towards the complete solidification which is relatively more as I have shown in this diagram initially you say the thickness is coming down to a little extent slowly it is increasing and finally, stabilizing at certain point and beyond this you are not increasing the pressure you are not decreasing the thickness that mean you are under increasing the pressure it is getting stabilized. So, the intensity is coming to an end at this point slowly it is increasing from here it is increasing, it is increasing, it is increasing and then it is coming to an end this is what has been shown here.

The level of intensity is increasing and then finally, coming to an end when the solidification is complete beyond that you do not put any mechanical pressure any mechanical soft reduction. So, the whole idea is to identify that zone where there is final solidification is expected to be there that is number one this area is important where you are putting the mechanical soft reduction where you are starting where you are completing beyond complete solidification we should not give mechanical soft reduction the number 1, number 2 how much of soft reduction you will give what is the intensity of reduction that is also important.

If you give less amount of reduction there might not be any effect. So, it is of no consequence if you would too much of pressure there might be internal formation of internal cracks you know this too much of pressure if you give, there will be internal crack. So, you give pressure only to the extent which is optimum. So, this you can find out by trial and error may be you can use certain initially some small amount maybe initial then increase the amount and then see when does you know the effect has started and finally, do not go beyond that if you go beyond that maybe you will be find that there are crack generation additional crack generation in the shell. So, to control crack porosity and segregation in the central area in the near the central line mechanical soft reduction is a very useful technology which is being used by many continuous cast uses to get good quality of cast product at the centre.

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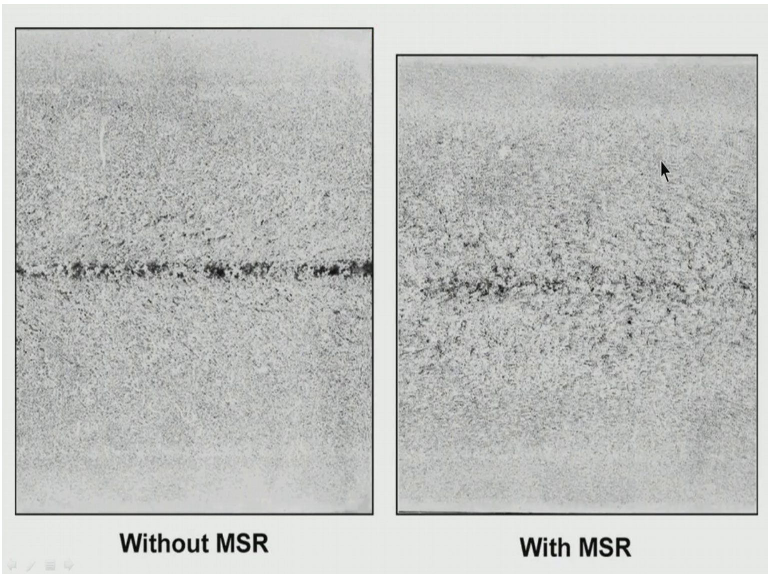

So, this location and intensity I am again telling is very important now let us see what is the effect this is without mechanical soft reduction you see the intensity of segregation and there will be some cracks also at the central region these are some you know V shaped segregation near the central region. So, this is when you are not using mechanical soft reduction and when you are using mechanical soft reduction look at the central region the intensity has come down quite a bit and you see it is slightly you know thickness is slightly less compared to the normal situation why this is. So, because as I have told you, I have mentioned that if the normal thickness is this by putting mechanical soft reduction you are what you are doing is; you are slightly reducing the area where final solidification is taking place.

So, the thickness; final thickness is slightly less compared to the; what would have been the normal final thickness. These are normal final thickness and if you are using mechanical soft reduction your final thickness is slightly less because you have put some pressure you have decrease the thickness in between gap for the rolls between the rolls in the final stage of solidification. So, this is an important concept. So, because of this what is happening you get less amount of segregation you get less amount of crack in the final central line or central area? So, I have mentioned that to take care of the centerline crack centerline segregation, what is important is to use mechanical soft reduction where do use the mechanical soft reduction you use it in the area where the final solidification is taking place you do not use anywhere else, you do not use at you know solidification level is say 50-60 percent, do not use which is of no use you use only when the final solidification is taking place. So, that there you are putting the mechanical soft reduction.

MSR; so, what is happening segregation at the centre and the porosity at the centre area are coming down the intensity is coming down. So, this is what is important instead of pronounce central line, it is getting distributed that is what is important. So, the effect of soft reduction is to control the level of segregation and crack at the central line. So, this is getting distributed instead of concentrating at the centre things are getting distributed segregation and porosity and cracks are almost eliminated you can give at equate amount of you know soft reduction should may not get central porosity at all you may be not get central you know crack formation at all because shrinkage is getting compensated. So, this is an important concept what I have mentioned.

So, what is important is the using of optimum zone optimum zone means first the location of the mechanical soft reduction area where do you put the area mechanical soft reduction and how much of pressure do you put. So, both are important location of mechanical soft reduction and the intensity of soft reduction that how much of pressure do you put it has to be adequate as I was telling you if it is less it will not have any effect, if it is more than the required amount you may have internal cracks which is again not desirable. So, it is a combination of location and intensity which will impart the desired effect which will give us sound product where there is no central crack the central segregation is not pronounced centre segregation is rather distributed. So, we have a relatively good quality cast where the central area is of desirable quality now I have mentioned about the central crack and central segregation problem that on the surface of a slab; you can have some defect.