Steel Quality Role of Secondary Refining and Continuous Casting

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Module - 06
Lecture - 34
Role of Chemistry on Solidification Behaviour

Good morning. In the last session I talked about you know the strength and toughness of the solid shell, because when the solidification is taking place the strand which is- for continuous casting of course I am taking about which is coming out of the mould and you know it is taking a different shape and finally becoming horizontal. So, lot of strainers; you know if the shell is subjected to lot of strainers. Thus solid shell and the strand they are undergoing lot of strain.

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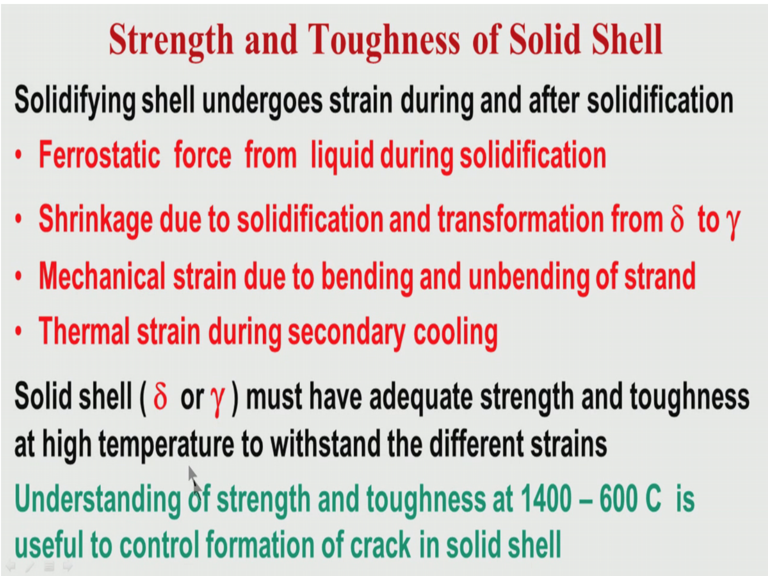

Now I have mentioned what are the sources of the strains. Solidifying shell is undergoing strain during and after solidification, during solidification also and even beyond that there is lot of strains.

So, what are those? First and foremost it is the ferrostatic force, from liquid during solidification. During solidification ferrostatic force of the liquid which is present in the strand; strand is having liquid, solid and the mushy zone. Three distinct zones are there. So, the liquid which is present in the strand will give lot of ferrostatic force, will give some force on the solid shell. So, this is important. Then of course, there will be shrinkage due to solidification.

So, in steel you know there is a shrinkage; means solidification takes place. So, solidification taking place means there will be shrinkage. Now additionally there will be shrinkage from the transformation of delta to gamma. I have mentioned that for certain grids chemistry initially you will of delta, then you have gamma and for certain grid of chemistry you have only gamma during solidification and beyond that. After solidification for all chemistry of steel different types of steel you have only gamma, but for certain chemistry you have initially delta and then gamma.

So, what is important is for those chemistries the transformation from delta to gamma when is it taking place, to what extent its taking place, at what temperature region it is taking place these are very important. So, they might also add to the shrinkage value.

So, this is important then I have mentioned there is a mechanical strain due to bending and unbending of strand. You know that the last session I have discussed in detail that if there is bending of the strand; that means when from a vertical mould custard; custard which had only vertical mould straight mould. When the strand is coming out it is also vertical straight. So, it has to be first bend otherwise it will continued to move only in vertical direction, which is not a much use.

Finally, it has to be made horizontal. Initially vertical strand you make it we give it a bend. To during bending at the inner radius shell at the inner radius will have sudden strain. Shell at the outer radius will also have certain strain of different type. If it is you know the internal side is compressive t the outer radia; shell at the outer radia will have just the reverse of it in tensile.

So, again after certain time it has to be stranded. That means, there has to be unbending. So, initially during the bending there is certain mechanical strain, during unbending you have just the reverse type of strain; again mechanical strain on the strand both at the inner radius also at the outer radius. So, mechanical strain during bending and unbending of strand- again we have to keep in mind because this might cause formation of crack unless the shell has sufficient strength and toughness. Then there may be thermal strain during secondary cooling. We are cooling the strand surface with the water or mist, so it will creates create thermal strain. So, this is again important.

So, the solid shell if it is delta or gamma must have adequate strength and toughness at high temperature to withstand the different strain. This is the important. By high temperature I mean in big range of temperature from 1400 to 600 degree centigrade. Because, solidification only the start of the activity of continuous casting. After solidification is complete the strand is again getting cooled in the secondary cooling zone by water or mist.

So, again the temperature of the strand will come down slowly the internal portion of the strand will also come down slowly so at a different rate surface is getting cooled relatively faster. So, whole temperature range; that means when the solidification is starting to even has low as 600 degree centigrade which is quite low in temperature. So, what are the relative values of strength at toughness in the strand is important, because it should be adequate to resist the formation of crack. That is why it is important.

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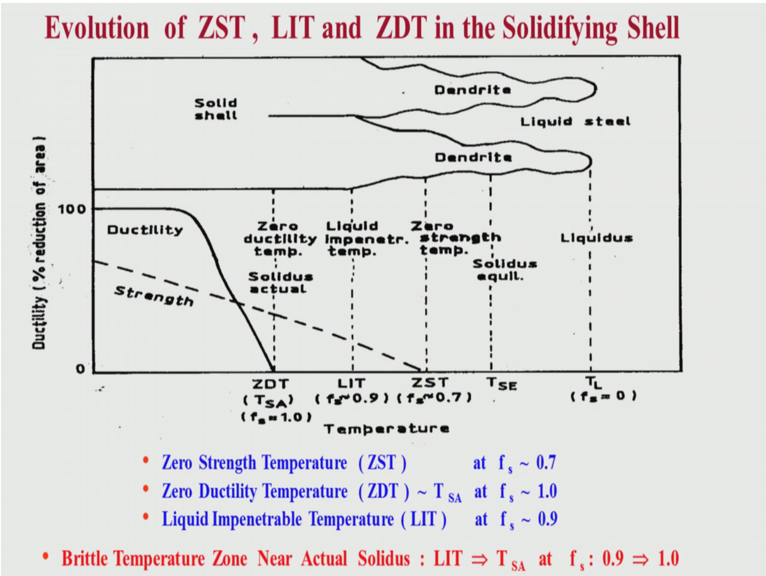

Then I have given the concept of 0 strength temperature 0 ductile temperature and the liquid impenetrable temperature. So, and I have mentioned the 0 strain temperature is around solid fraction of 0.70 ductility temperature is around solid fraction of one; that means, around solidification complete actual completion of solidification in actual solidus temperature is 0 ductility temperature and another important parameter is a liquid impenetrable temperature is called LIT which corresponds to around solid fraction of 0.9.

So, this temperature region between LIT and ZDT; that means, between the solid fraction of 0.9 to 1; that means, towards the end of solidification this region is really critical because this in this brittle temperature zone, if there is crack formation liquid steel cannot hill up because the 2 dendrites are touching each other; that is why it is called liquid impenetrable temperature liquid cannot penetrate beyond this temperature in this zone of temperature the region. So, that is why the difference between LIT and ZDT the temperature differential between this is; that means the solid fraction between 0.9 and 1 is in true sense the brittle temperature zone near actual solidus. So, solid fraction between 0.9 to 1. Please remember this is really a matter of worry we have to be careful about that.

So, the temperature zone between LIT and TSA liquid in impenable impenetrable temperature and actual solidus is the real brittle temperature zone near actual solidus. Now I have also mentioned that depending on the chemistry of the steel grade 2 opposing forces are acting on solid shell 2 opposing forces are always acting.

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Sticking or Depression of Solidifying Shell

Two opposing forces are acting on solid shell

- Ferrostatic force pushes solid shell towards mould

  Sticking / Bulging Strain $S_B = F / \sigma \; S_A^2$

  F is ferrostatic force, σ is strength of shell, S_A is actual shell thickness

- Shrinkage due to solidification, cooling and transformation from δ-ferrite to γ pushes solid shell away from mould

  Thermal Strain $S_{TH} = \beta (T_{SA} - T_0)$

  β is coefficient of thermal expansion, T_{SA} and T_0 are solidus and surface temp.

Transformation strain S_{TR} is relevant only in britle temperature zone LIT – T_{SA}

- $S_B > (S_{TH} + S_{TR})$ results in Sticking and Bulging tendency
- $(S_{TH} + S_{TR}) > S_B$ results in formation of Surface Depression

It depends on their value their amplitude which is again a consequence of the real chemistry of the steel. Now how the chemistry is affecting this I have mentioned that chemistry affects the mode of solidification; that means, how solidification is taking place whether initially delta is forming then when delta to gamma is forming when solidification is getting completed whether it is only through gamma when solidification is starting.

Finally it will be gamma, but initially whether delta is there then at what temperature delta will transform to gamma is it during solidification at what stage of solidification or lower than solidification when solidification is complete transformation from delta to gamma is taking place these are all important issues which issues related to chemistry if these all depends on the chemistry carbon equivalent or carbon for plane carbon steel and first stainless steel. As I have mentioned earlier then ratio of nickel equivalent by chromium equivalent these factors will determine will decide how the transformation will take place number one at what temperature transformation will be taking place at what temperature solidification will be complete.

Everything depends on chemistry number 2; I have mentioned the role of micro segregation micro segregation is also affected by what are the alloying elements present in steel and I have mentioned the 2 elements phosphorus and sulphur are very deleterious fortunately for sulphur. There is a severe element has known as manganese combines with sulphur forms manganese sulfide and the deleterious effect of sulphur is taken care of unfortunately for phosphorus there is no such severe element in liquid steel in steel rather. So, phosphorus has to be kept at lower level otherwise there will be too much of micro segregation and the consequence is the actual solidus is suppressed or depressed and if it comes down the solidification temperature interval increases if that happens the consequences the actual shell thickness is lower less and the mushy zone is more during solidification.

So, the actual thickness of the solid shell is very important you know the shell strength is very important and then how much of transformation is taking place due to delta to gamma where it is taking place is important. So, this factor; that means the chemistry influences factors and these factors in turn will influence what will be the solidification characteristic for definite chemistry for a particular chemistry. So, let us see how it is happening 2 opposing forces are acting on solid shell during solidification; one is the ferrostatic force which is pushing the solid shell towards the mould away from the liquid it is pushing towards the mould. So, this strain I have mentioned if I; if we call it S B; that means, taking out bulging it is equal to the ferrostatic force divided by the sigma;

that means, the strength of the shell and the square root and thus not the square root square of the actual shell thickness S A.

So, these 3 factors are important that is why I had mentioning strength of the shell is important shell thickness is important these this 2 are a consequence of the chemistry. I have mentioned what whether delta or gamma. We will form it depends on the chemistry and the strength of the shell sigma depends on whether it is delta or gamma; gamma has a strength high temperature strength about five times then delta ferrite. So, this is important and this actual shell thickness is determined by as I have mentioned many times by micro segregation see if the micro segregation is more the shell thickness is also less. So, the sticking or bulging strength can be found out from this relation another force I have talked about the 2 opposing forces one is ferrostatic, another is the shrinkage; why shrinkage is taking place? It may take place due to solidification it may take place due to cooling take place due to transformation from delta ferrite to gamma.

Now, the effects of all this 3 are; this shrinkage are basically to loop the shell away from the mould towards the liquid. So, ferrostatic force pushing the solid shell towards the mould away from the liquid here shrinkage is pushing the shell away from the mould and towards the liquid. That is why these 2 are opposing forces. So, which force is mould for a particular chemistry is dictated by the relative values of SB and STH plus STR; that means, thermal strain or transformation strain summation of that because both thermal and transformation strains are adding up to and causing shrinkage. So, shrinkage is due to solidification cooling and transformation solidification and cooling basically you can find out due to the shrinkage of there is a temperature effect and transformation is due to the effect from transformation from delta ferrite to gamma.

So, the thermal strain and the transformations strain together I have to be looked into if S B; that means, the bulging strain is more than the summation of thermal and transformation strain which is causing shrinkage then it is a sticking or bulging rate; that means, that particular grid will have sticking and bulging tendency, but if the reverse is two; that means, the shrinkage from the thermal as well as from the transformation together this value does the summation is more than the strain of bulging. If the thermal you know shrinkage strain is more then what is the consequence that this will result in formation of surface depression shrinkage is more.

So that means, there will be surface depression the solid shall will have some depression on the surface and if the ferrostatic force is mould into the strain due to ferrostatic force is mould than we have sticking or a bulging tendency this is very important we should remember that all the steel depending on their chemistry can be subdivided into 2 basic categories depending on whether the bulging strain is more or the shrinkage strain is more.

If the bulging strain is more we call it is sticking or a bulging grid those grids we will have sticking and bulging tendency inherently bulging and sticking tendency and if the shrinkage strain is more shrinkage due to both thermal as well as transformation is also very important for certain chemistry; if the summation is more than the bulging strain then, the consequences formation of surface depression. So, certain grids; we will have surface depression. So, the whole chemistry range can be subdivided into 2 broad categories of sticking and bulging tendency one and the other one is depression tendency these are inherent tendency depending on the chemistry of the grids.

Now, let us look at what is the effect of carbon you know and normal steels. So, what I have talked about the brittle temperature range during solidification which is towards the end of the solidification towards the final stage of solidification between you know solid fraction of 0.9 and solid fraction one between LIT and ZDT.

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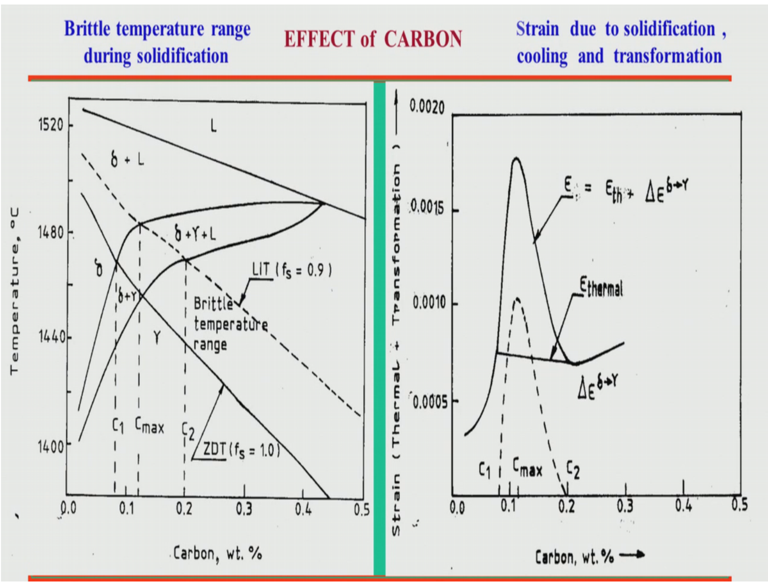

So, now, let us see with carbon how is it changing if you look at this particular figure; we will find that initially during solidification that is liquid then from liquid; we have delta plus liquid or delta plus gamma plus liquid depending on what are the chemistry or you may have here you may have liquid plus gamma only at high you know carbon or carbon equivalent.

So, towards the end of solidification this is the solidification complete line; that means f s is 1; that means, ZDT this is that line solidification is starting at this line. This is the you know temperature is called liquidus temperature and this is the actual solidus temperature which is equivalent to ZDT is zero duct temperature and a line has been drawn within this solidification range equivalent to nearly equivalent to around point nine solid fraction which is LIT. So, what is the temperature I have mentioned that this is the temperature range you know which is brittle the temperature range between LIT and ZDT temperature range between solid fraction of 0.9 and 1.0. We should be careful about this temperature region. Here also it is brittle this temperature is in, but as I have mentioned earlier even if there is crack formation liquid will go and heal those cracks.

So, the cracks cannot sustain cracks will not remain, but if there is a crack formation in this brittle temperature region those cracks cannot be healed because liquid steel L cannot penetrate if this temperature region because the dendrite is the started passing each other. So, towards the end of the solidification this temperature region is the brittle temperature region and if you have high strain in this region, we will have formation of crack. So, we have to be careful.

Now let us see with carbon how the solidification is taking place when it is very low; that means, L a as 0.5. So, initially it was delta solidification and solidification is complete at that is temperature. So, it is delta only solid. So, solidification is through delta. So, delta to gamma is not taking place during solidification delta to is gamma is taking place only at much lower temperature here.

So, now let us come to this C 1 temperature, what is C 1? C 1 is the intersection of this delta to delta to gamma line; that means, this line with ZDT line this is. So, what is the situation here if it exceeds this C 1 if the carbon exceeds this C 1 then this delta to gamma transformation which is taking place you know here delta to gamma is taking place here?

So, if the temperature a sorry if the carbon content is less than C 1 as I was talking about say point five when what I means delta to gamma is transformation is not taking place during solidification, but above C 1 delta to gamma has started forming towards the end of solidification. So, what is this? This chemistry C max here the delta 2 to gamma transformation which is taking place here is taking place entirely in the brittle temperature region you see and what is this temperature C 2 say around 0.2 beyond C 2 delta to gamma this was the delta to gamma line above this is delta plus liquid here is delta plus gamma plus liquid. So, delta to gamma transformation is not is completed delta to gamma transformation is completed above this brittle temperature region is it clear.

The implication of C 1 C max and C 2 when carbon content is less than C 1 say a 0.05 delta to gamma transformation is taking place only after solidification is complete during solidification no delta to gamma transformation is there beyond 0.2 percent carbon when it is more delta to gamma transformation is taking place during solidification, but above this critical temperature brittle temperature range at C max is delta to gamma is taking place entirely in the brittle temperature region that is why this chemistry C max we have to be very careful because when delta 2 to gamma transformation I have told you it has some shrinkage. So, it is that shrinkage is taking place in the brittle temperature range; that means, that strain due to shrinkage from delta to gamma transformation is taking place within this brittle temperature range I have mentioned that we have to be careful about this brittle temperature range.

If the transformation takes place less than or above this temperature range we are not we need not worry, but if this delta to gamma transformation is taking place within this brittle temperature range of you know solidification it is a matter of worry. So, the significance of this 3 chemistries please try to remember C 1 less than C 1 say 0.05; 0.04 percentage of carbon solidification is through delta and delta to gamma is forming at temperature much lower than solidification above C 2; that means, around say 0.2 delta to is gamma is complete above this brittle temperature range at C max this delta to gamma transformation this is the delta to gamma transformation range this is taking place entirely in the brittle temperature region that is why this chemistry which is the around point one is the matter of worry because some people called this around point one percent carbon as a peritectic chemistry which is not which is not true of course, peritectic range is starts from point one and goes up to 0.5.

But this chemistry; that means, around point one is a matter of worry because here the entire delta to gamma transformation is talking place in the brittle temperature region of solid fraction between point nine and one between LIT liquid impenetrable temperature and ZDT this is the ZDT temperature. So, we have to be very careful about that. Now let us see with carbon how the strain due to solidification cooling and transformation how they are changing here there is a 2 components have been shown is a thermal; thermal means basically is a summation of solidification and cooling and another is this one you know delta epsilon delta strain due to you know delta to gamma transformation this one. So, you will find that as I have shown here between C o 1 and C 2 it is dotted line you see in the dotted line the dotted line is maximum at C max why it is maximum because the entire delta to gamma transformation is taking place in this temperature in brittle temperature region.

So, this has been plotted having a maximum value at C max C 1 it is 0 C 2 it is 0; that means, less than C 1 in this particular transformation has no consequence above C 2 it is a no consequence because it is forming above this brittle temperature region, but within the brittle temperature region this delta to gamma transformation is a matter of concern I have told you and the maximum is at a value near point one percent carbon C max. So, if we add this with the you know thermal strain if you had transmission strain with the thermal strain the actual curve looks like this; this is the you know transformation strain dotted this was the thermal strain and when this 2 are added we get this one this peaks. So, you just look at what is happening say at C max or around point one we have a very higher strain this transformation strain is adding to the thermal strains. So, we have a relatively very high strain around say you know 0.1 percent carbon.

So, we have to be really worried about this chemistry because what is happening here along with the thermal strain the transformation strain is acting in this temperature region and which is I have told you is a brittle temperature region between LIT and ZDT between the solid fraction of 0.9 and 0.0. So, as I have mentioned the chemistry plays an important role. So, here also I am trying to show that with change in carbon percentage what is happening to the different phases what is happening to the solidification what is happening to the delta to gamma transformation. Here as I have mentioned at carbon concentration less than C 1 total solidification is through the delta mode delta to gamma transformation this line delta to gamma transformation takes place and starts and is completed only after solidification at much lower temperature beyond 0.2 percent carbon delta to gamma is taking place and up to say 0.4 or 0.45, it is taking place during solidification, but above this critical temperature the zone.

So, less than C 1 carbon you know it is not a matter of worry above C 2 again is not matter of worry because this is taking place above this particular temperature above this particular brittle temperature range. So, is not a matter of worry, but beyond C 1 and C 2 we have to be very careful particularly you know carbon concentration near C max where the entire you know delta to gamma transformation delta to gamma is starting here at around 0.9 solid fraction I; it is almost complete towards the end of solidification; that means, the entire del at to delta to gamma transformation. It is just say what is happening here entire delta to gamma transformation is taking place within this brittle temperature range beyond this it is slowly decreasing because it is the amount of transformation is coming down and above C 2; that means, when carbon concentration is more than C 2 it is 0 percent; that means, delta to gamma is taking place above this brittle temperature range.

So, the same thing has been shown here some quantitative estimation has been done. So, actual strain values have been you know have been used. So, it can be seen that the strain level can increase in double you see then it is doubled you say about point one so; that means, more than it is increasing at here at this level it is around say point seven or point eight, but at about C max it is increasing to almost 0 0 1 8 so; that means, from 0 0 0 8, it is increasing to 0 0 1 8. So, it is more than getting doubled because of this transformation delta to gamma transformation.

So, what I have mentioned is the brittle temperature range during solidification which is between solid fraction of point nine and one; that means, near the solidification complete region this temperature is very important because this is the brittle temperature region if there is a crack formation. So, in a liquid steel cannot reach the dendrite at the cat locations and heal up because dendrite say touching each other.

So, there is no possibility of the liquid steel healing up the cracks forming on the dendrite surfaces. So, this is the temperature region if there is lot of strain formation in this temperature region there will be crack formation. So, it is a possibility of crack formation goes up for certain chemistry ranges between C 1 and C 2 and the maximum is at chemistry around C max which is around slightly above 0.1. Now this diagram is for a particular amount of you know manganese and silicon.

So, this is basically carbon equivalent one should be interested in carbon not carbon what was and is a carbon equivalent if you change the manganese silicon in other alloying elements with actual diagram will change, but it qualitatively shows that for each chemistry of the steel you can draw it similar diagram and you can find out what is C 1 C max and C 2; that means, you can find out what is the range of carbon within which there is a possibility of crack formation in this brittle temperature in; that means, towards the end of solidification the solidification crack formation how is it varying with carbon 1 can find out for any steel if you draw such diagrams.

So, for this particular carbon range; that means, between C 1 and C 2 you see the strain values are quite high so; that means, you have more of surface depression. So, this carbon range you have more of surface depression; that means, between C 1 and C 2 we have surface depression and it is the highest at C max that is why these particular carbon range around point one; that means, slightly less than 0.12 maybe 0.5 or 0.16. Normally people tell it is better to avoid the chemistry because this chemistry will have lot of surface depression on the cast product whether it is blue mar you will find lot of surface depression why surface depression is forming because this delta to gamma transformation is taking place mostly in the brittle temperature range in you see the strain due to transformation is quite high in this temperature region and this is forming in the brittle temperature region only. So, this is a real matter of worry while we are continuous casting this chemistry.

So, this is called the so called depression grids the; so, called peritectic grids. Basically it means the starting of the peritectic chemistry. Peritectic starts from 0.1 and it is goes up to 0.5, but as you have shown here the temperature the chemistry range around say 0.08 or 072 say around 1.7 or 1.8 is the real matter of concern the real matter of worry the actual values of C 1 C max and C 2 will depend on what are the other alloying elements are present, but normally it is find around 0.1 only; that means, a range maybe form 072.16; it may be from 0 8 to maybe 0.17.

So, basically what I am telling is around 0.1 only. This chemistry is critical which is known as depression grids because the surface you have lot of depressions and this chemistry has to be cast with lot of care you have to do we have to use a particular amount of particular type of casting powder which I have discussed earlier because the heat transfer in the mould has to be controlled I will touch this issues later on, but what I am trying to harp on is that chemistry plays an very important role in deciding what will be the type of solidification type of what is the main characteristic of the grids whether they will be depression or they will be sticking you see this strain of depression strain of you know shrinkage is quite high for this type of chemistry you see here the strain of depression is relatively less for very low level of carbon it is also relatively low when high amount of carbon.

So, for low amount of carbon and relatively high amount of carbon you do not have depression you have rather sticking and bulging, but between C 1 and C 2 with the maximum ten is and C max you have depression. So, you can make out from these figures how different chemistries how different carbon content will behave whether it will be depression grid whether the characteristic of this grid will be depression or it will be sticking these intrinsic behaviors this either sticking or depression behavior depends on the chemistry. So, accordingly the casting parameters have to be selected to take care of these issues. So, that the quality of the cast product is relatively good.

Thank you very much.