Steel Quality Role of Secondary Refining and Continuous Casting
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Module - 07
Lecture – 39
Brittle Temperature Regions

In the last session, I had talked about you know two broad categories of solidification. That means, what are the two intrinsic solidification characteristics for different alloys whether it is carbon, steel, valor steel or you know different standard steels. So, basically the whole gamut of chemistry whether for carbon, steel or low alloy steels or even for stainless steels, it can be divided into two broad categories.

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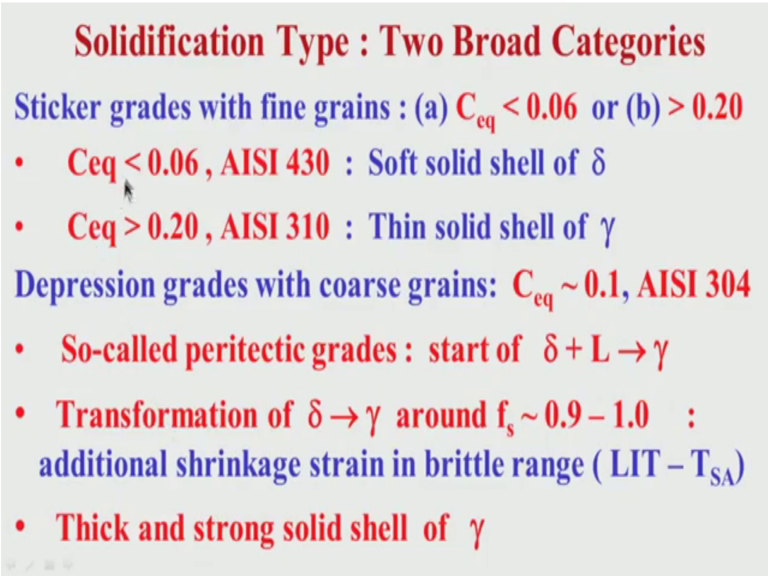

Depending on their solidification characteristics what are those basically either there will be sticker take of grades, that means some of them, some of the grades, some of the chemistry ranges will show sticking tendency. We will indicate sticking tendency during solidification, during continuous casting and some of the grades should depression characteristics.

So, we call them depression grades. Where there is sticking, we call those grades as sticker grades. So, you will find that these are the two broad categories into which the whole chemistry range can be distributed. That means, it can be sub-divided. Either they will be sticking characteristics to some of the grades will indicate this ticking tendency and the other grades will indicate depression tendency. Depression means the surface will have lot of you know undulations surface is rough. So, then I had also mentioned the sticker grades for you know carbon, steel or even low alloy steels. Normally they belong to either the carbonated value should be less than 0 6. That means, the lower range of the carbonic even or higher range, that means greater than 0.2. So, these two broad ranges, we will indicate sticking tendencies.

So, now for the lower carbonic equivalence I had mentioned and also for ferritic type of stainless steel AISI 430, where the nickel equivalent divided by chromium equivalent is very low. Those are the grades. You will find the details indicate sticking because the solid shell is soft going to its nature. That means, this is a delta ferrite during solidification even slightly below solidification. Also, delta ferrite will continue to be present austenite transformation. We will start only at quite low temperature much below the solidification completion temperature. So, because of this delta ferrite, the shell is soft because it is soft, it cannot withstand the ferrostatic pressure. So, there will be tendency for sticking when it is in the mold, when the shell is coming out of the mold. So, then it will indicate bulging tendency.

So, sticking and bulging are basically wing or originating from the same, you know same mechanism. So, either it is sticking within the mold or bulging below the mold, this tendency, this characteristics is typical for certain chemistry ranges either very low or very high. So, I have talked about very low you know chemistry ranges, carbon ranges. Then, the carbonic equivalent is relatively high more than 0.2.25.3 or may be more. It makes like you know ball bearing steel where the carbon content carbonic equivalent is almost 1. So, in such type of steels what you have is a very thin solid shell of austenite. Here it is austenitic solidification particularly for carbonic equivalent which is more than 0.5 or even when it is more than 0.3, initially it is delta ferrite, but then subsequently delta ferrite transforms to austenite at you know all these stage of solidification itself.

So, during solidification you have thin shell. Why it is thin? It is because it is austenitic solidification. So, lot of micro segregation will be there, phosphorous will create lot of micro segregations, sulphur will create micro segregation, all elements you know will create lot of micro segregation and because of that solid shell is thin during solidification, the marsh zone is quite wide, quite deep. So, you have thin solid shell of austenite. So, it is thin and it cannot withstand the ferrostatic stress. So, for carbonic equivalent more than 0.2 and 3 1 0 type of stainless steel which is the totally austenitic solidification, you will have thin solid shell of austenite and it will again indicate sticking type of solidification characteristics, but what is going to happen for the depression grades.

What are the depression grades? I have mentioned depression grades with coarse grains. I have also mentioned that if there is depression means the surface is rough surface, rough means there will be you know air gap between the solid shell surface and the mold surface. Because of this heat transfer is low and consequently that grains cast, grains are coarse, dendrites are having coarse structure. So, what are those chemistries for the carbonic equivalent? It is around 0.1 or for stainless steel 304 type of grade. Well, then nickel equivalent by chromium equivalent is around 0.55.

So, for this chemistries you have depression tendency along with coarse grains. For the other chemistry range is you have sticking tendencies with fine grains. Why? Fine grains because you know heat transfer is quite high, there is no air gap. So, these are two broad categories of chemistry and these are basically for the depression grades. These are basically the so-called peritectic grades because there the chemistry lyes at the beginning of the peritectic reaction, peritectic range of chemistry.

So, these are the beginning delta 2 rather delta plus liquid giving right to austenite delta ferrite, add liquid reacting and giving austenite. These peritectic reaction takes place you know for certain range of chemistry and when typical chemistries are the beginning of this peritectic range, that means, around 0.1 and for stainless steel, it is around 0.55 nickel equivalent by chromium equivalent. So, they are called so-called peritectic grades. They belong at the chemistry range are the beginning of the peritectic range of chemistry. So, where you know the transformation from delta 2 gamma. It will take place in that you know critical brittle temperature zone corresponding to the solid faction of 0.921 and in the temperature range between liquid impenetrable temperature LIT and the spinal of solidification temperature, actual solidification temperature. So, when that is in this range and it was the end of the solidification, this delta 2 gamma transformation is taking place. It causes additional shrinkage and because of that there is relatively high amount of strain because these shrinkage is adding up to the thermal shrinkage. So, total shrinkage is mode for this type of chemistries, where delta to gamma is taking place, transformation is taking place around end of solidification, towards end of solidification.

So, there you have this depression grade surface is rough and you have coarse grains because of that. So, here what is happening, the solid shell is thick because micro segregation is relatively less because you know this transformation is taking place, peritectic transformation is taking place towards the end of solidification. So, initially there was delta. So, the micro segregation was relatively less during all the stage of solidification. Only towards the end, this transformation is taking place. So, therefore micro segregation takes place during solidification. So, most of the time of the solidification, we have only delta. So, the micro segregation is less.

Solid shell will be relatively thick, the marsh zone is relatively narrow and towards the end of the solidification this delta is transforming to austenite. So, we have thick and strong solid shell of austenite. Because of this additional shrinkage of this, we have depression tendency. This I had try to explain the two broad categories now.

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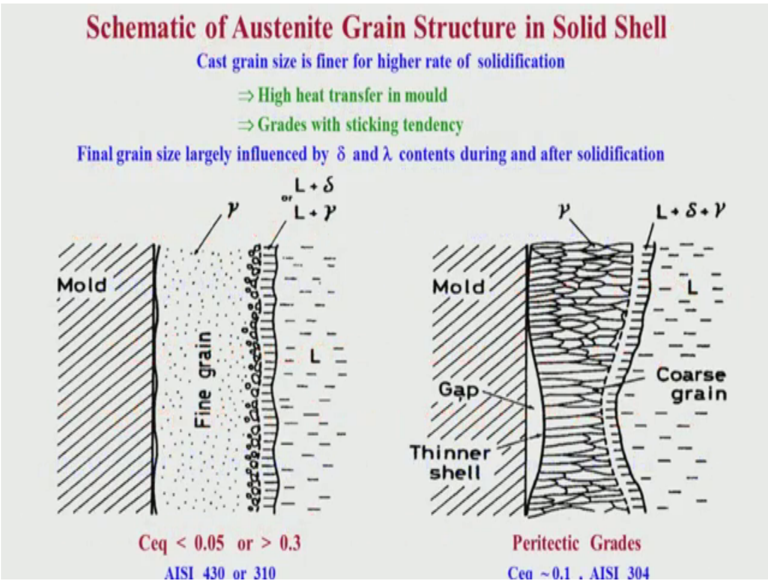

These also I try to explain MAT for the peritectic grades so-called when carbonic equivalent point is in 0.1 or for 305 stainless steel is where nickel equivalent by chromium equivalent is around 0.55. Because of the depression this rough surface there is gap here, relatively larger gap. So, heat transfer is less. So, you will call it hotspot formation because of this and because of this, consequently the grains cast grains are relatively coarse, whereas for you know sticking type of characteristic is the grace which indicates sticking. They are what is going to happen. The solid shell is trying to come in contact with the mold. So, there is sticking and that is why we call it sticking. So, the grains are relatively fine, but there is a sticking tendency and if there is a sticking tendency between the solid shell and the mold. So, we have lot of friction at this inter face between the mold and the solid shell here. You know sticking tendency is not there because there is depression rather heat transfer is low. So, here you have because of sticking, you have too much of friction. So, the mold slag should take care of this friction mold slag should be characteristics which can resist this friction.

So, friction is the issue for sticking type of grades and for you know other type of grades where you have depression, heat transfer is the issue because here heat transfer is coming down because of this gap formation. So, here the mold slag should control the heat transfer should make it uniformed throughout the mold periphery, so that you get relatively less depression. There is air gap formation and relatively less coarse you know structure grains. So, that is why I have mentioned based on these two broad categories, we have to design the continuous cast in parameters. I will come to this after some time, but please remember these two basic characteristics solidification characteristics where to keep in mind and we have to design the casting parameters based on these observations.

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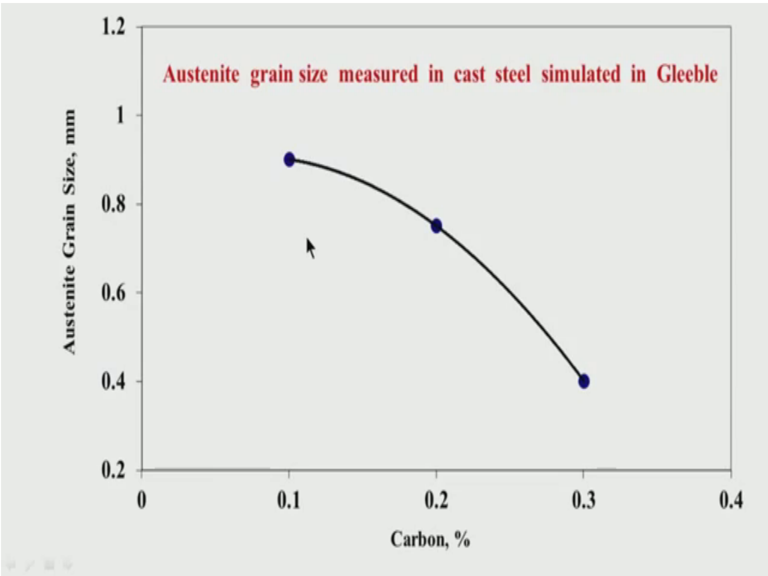

Then, I mentioned that earlier whatever I have had shown was schematic, but when we measure the actual austenite grain size by simulating the continuous casting condition in gleeble, we can see that for 0.1 percent carbon where I had mentioned you know surface is rough because of depression formation and I had mentioned the cast grain size is expected to be coarse which is you know validated by actual observations 0.1 percent. Carbon cast grain is relatively large compared to say 0.3 percent carbon, where cast grains are relatively finer.

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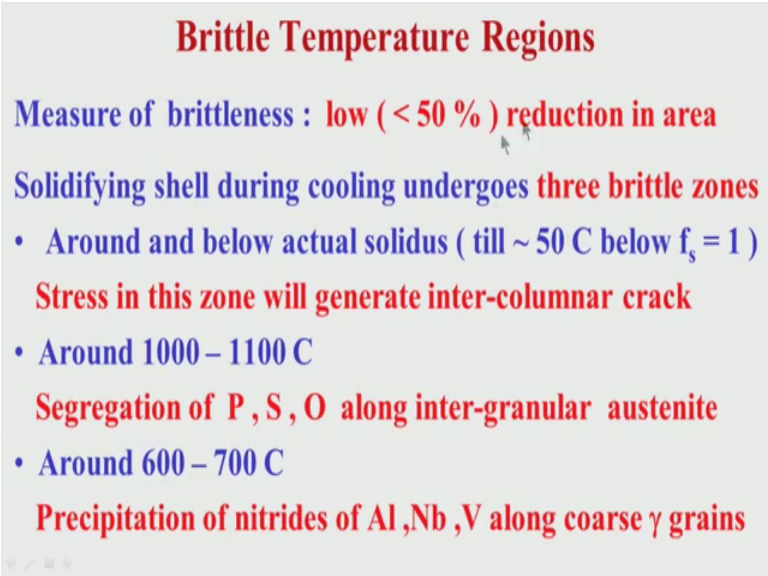

So, today I will talk about, I have earlier talked about one brittle temperature region which is around solidus, but when the liquid steel is getting cooled initially during solidification and even beyond that even lower than that, there will be certain other brittle temperature regions. Why you are bothered about the brittle temperature regions? Because since it is brittled, that means the shell is brittled, relatively brittled. It cannot withstand any strain, whatever strain will be generated during the coarse of solidification and even lower than temperatures, lower than solidification. The strains should not be very high, otherwise you know when the shell is passing through this brittle temperature regions, they may be in crack formation and because of the crack formation, I have told you only about the brittle temperature region around solidus, but even lower than that there also be sudden brittle temperature regions. Let us try to understand.

Now, when we are talking of brittle temperature region, what do you mean by brittle? What is the measure of brittleness? Brittleness basically indicates that the reduction in area or the ductility of the solid shell is relatively less.

Now, what is the quantity figure, what figure we call it brittled and what figure we call it relatively less brittled and more ductile and more tough? So, normally this 50 percent reduction in area is taken as the bound region between brittleness and toughness. So, if the reduction area is less than 50 percent at any temperature region, if the solid shell has reduction in area, that means the ductility or reduction in area it can be measured you know this ductility and reduction area, it can be measured.

So, if it is less than 50 percent, that means when you are deforming that particular shell, how much area is reduced, how much cross-section area is reduced, from that you can actually find out the ratio, the percentage of reduction in area. So, if the reduction in area at any particular temperature region is less than 50 percent, then we call in that particular region the material is brittled and if is more than 50 percent, 70 percent, 80 percent, 90 percent, then we call that particular area temperature region is ductile. That means, the solid shell will behave in a ductile region, ductile manner and why ductile is good because it can withstand some deformation, it can withstand lot of strain. Even if there is strain, it can accommodate that by getting deformed. So, if the deformation of the shell is there, that means the reduction in area is more. It can deform more, it can withstand higher amount of strain and because of that crack formation will be less.

So, whenever the reduction in area of the solid shell is less than 50 percent, we call it brittled. So, what are the temperature reduction area? It is less than 50. We call it those temperature regions, we call it brittled temperature region. Now, the solidifying shell is coming during you know solidification. It is from liquid, it is becoming solid and from solid again it is cooling down. So, there is a temperature loss from the liquid steel till we come down to the solid and almost a low temperature region. So, this solidifying shell during cooling, they are basically under growing 3 brittle zones. I have talked about one brittle zone only. What is that brittle zone Ihave talked about? It is around and slightly below actual solidus temperature.

So, I have mentioned you know details that this actual solidus you know slightly above that and slightly below that is really brittled because this reduction in area is 0 at solidus temperature and at temperature slightly lower than that, it is only increasing, but still it is less than 50 percent. So, till about 50 degree centigrade below solidification is completed, we have brittled temperature region at solidus, at actual solidus. You know reduction area is 0 because mill ductility temperature we call it, that means the reduction area will be 0. It is still brittled. So, as the temperature is coming down from that, from the solidus as you are cooling, so till about 50 degree centigrade, ductility is lower. It is less than 50 percent reduction area.

So, that means it is below actual solidus. Below means till 50 degree centigrade. Below the actual solidus is the brittled temperature region. I have talked about this. Then, what is going to happen, why are we bothered about about this area? It is because if there is some trace in this zone, if there is some strain in these temperature region, so they will be inter columnar crack. I have mentioned that the structure of the solid shell is columnar. So, between the two columnar zones, we have weak area, we have lot of segregation in those areas. So, those are relatively weak. So, we call it that in those inter columnar areas, there will be crack formation. So, this inter columnar cracks will form at the relatively high temperature around solidus.

So, we have to be careful about this temperature region. Next when it is getting cooled, this temperature is you know it depends of course on the chemistry, but it can be 14 and 15. It can be 1400, it can be 1350, it can be 1300 depends on if the carbonic equivalent increases or you know nickel equivalent by chromium equivalent increases. This solidus temperature also decreases for the different chemistries. So, what I am talking is around solidus and about less than 50 degree centigrade of the solidus. This is the high temperature brittled zone, first high temperature brittled zone. Next when the solid shell after solidification has taken place, solid shell is coming down in temperature that is, it has become less unless hot. It has become more and more cold.

So, what is going to happen, it is around 1200 degree centigrade, about 1250 centigrade toughness is relatively high. Toughness of reduction area is more than 50 percent. So, it is good, but when we come to this particular temperature region about 1000 to 1100 degree centigrade, what is going to happen here phosphorus, sulphur, oxygen, these are all, some of them are surface active. They are going to segregate to the inter granular austenite. That means, whatever austenite grains have formed at this temperature region, you have only austenite grains. Whatever delta ferrite was there, grains of delta ferrite, they have got transformed to austenite either during solidification or for the very low carbon. You know chemistries or very low nickel equivalent by chromium equivalent standard grades, they get transformed at lower temperature during cooling at temperatures, lower than solidification.

During solidification, it is delta ferrite with very low carbon, but when it is getting cooled at lower temperature, this delta to gamma transformation in solid state will take place. So, around this temperature 1000 to 1100, it is only austenite. So, what is going to happen is, this segregation of phosphorus, sulphur, oxygen along inter granular that means, austenite grain boundaries if they segregate, grain boundary becomes relatively weak and there is a possibility of crack formation along this grain boundaries. So, here it is inter columnar. That means, between the columns you know I have told you about the cast structure, the coarse cast structure there we will have lot of columns and inter columnar reduce. You have relative weak areas because of those areas have too much of segregation. So, inter columnar cracks can form here, inter granular austenite are forming in solid state here. It was columnar zones during solidification.

So, that was relatively high temperature, but this particular inter granular austenite you know problem is around 1000 to 1100 degree centigrade. Now, when temperature is coming down to less than 1000, again the reduction area is relatively more. So, that is not a brittle area. That is relatively ductile area, but when the temperature is coming to less than 700 degree centigrade, then what is going to happen is, there is a problem of precipitation of nitrides of aluminium, niobium, vanadium. These are micro alloys niobium vanadium. So, in micro alloy steels, you have this micro alloying elements and aluminium you can have in LE aluminiumical steel. So, the problem is the formation of nitrides of aluminium or nitrides of niobium, nitrides of vanadium. They can form along the grain boundaries of austenite around this temperature and as I have told certain grades of steel, particularly those feature of depression type. That means, when the carbon quantities around 0.1 or the nickel equivalent by chromium equivalent is around 0.55, those grades are proven to depression. Depression means the grains are relatively coarse.

So, if the grains are coarse, what is going to happen is, the grain boundary areas are relatively less. If you have coarse grains, the grain bound areas are relatively less in area. If you have finer grains, grain bound areas are quite numerous and quite relatively high in area. So, this formation of these aluminium nitride, niobium nitride, vanadium nitride if you have coarse grains, the grain bound areas get relatively more dense because of this formation of these nitrides and if you have fine grains, the grain bound areas are quite large. So, the density of these nitrides will be relatively less in fine grain situation, but for coarse austenite grain situation, you have relatively higher density of this nitrides along the coarse austenite grains.

So, again this particular temperature because of this formation of this nitrides at the coarse austenite grains, certain chemistries are relatively more proven to brittleness around the so-called peritectic grades around 0.1 percent carbon or 304 stainless steel which as nickel equivalent and ratio nickel equivalent by chromium equivalent around 0.55.

So, those chemistries are proven to this brittleness around 600 to 700 degree centigrade. So, you have to be careful that during continuous casting, the shell should not come to this temperature region. You have to avoid this temperature region. How you can avoid it? You can cool it in a particular cooling rate, so that you do not allow the temperature to come along this temperature region. When you are actually cooling here, strain rate is also important at you know certain strain whether it is low or high. You know these brittle temperature regions will indicate relatively more brittleness, more crack formation, but right now I am talking only about the temperature regions.

So, what I mentioned there are three brittle temperature regions relatively high temperature. That means, just around solidus we have one brittle temperature region which is around solidus. Then, as we are cooling you know steel around 1000 to 1100, again there will be a brittle temperature region which is because of segregation of phosphorus, sulfur, oxygen along inter granular austenite, along the grain boundaries are austenite.

Now, as we are still coming down to at low temperature, that means during cooling because of secondary cooling, the surface temperature and the interior temperature is also coming down slowly. So, we have to avoid another temperature region 600 to 700 because what happens at those temperature regions is that nitrides are going to form along the coarse austenite grains of austenite. So, we do not allow them to form. That means, if we cool the continuous cast product in this temperature region relatively faster, so what is going to happen is, this nitrides they do not get adequate time to form at the coarse gamma austenite grain boundaries.

So, you have to cool them relatively faster. We do not give sufficient time for the formation of the nitrides or aluminium niobium and vanadium. So, these are scared of avoiding the brittleness around this temperature. We cooled relatively faster, so that this temperature region you can avoid the secondary cooling. You can design in such a way, so that these particular temperature you can avoid it for those chemistry grades have been around 0.1 percent carbon or 304 stainless steel when nickel equivalent by chromium equivalent is around 0.55. So, what I was telling was depending on the characteristics of the grades, we can design your continuous casting parameters. What are the continuous casting parameters? You can design what will be the heat transfer in the mold.

How do you control it? You can control it by using particular characteristics powder. That means, powder will finally melt and give you mold slag. So, what is the viscosity of the mold slag, what is the solidification temperature of the mold slag? These will give us a particular heat transfer, these will give us how to resist the friction because you know as I mentioned for certain grades like those are sticker type of grades, very low carbon or very high carbon. There is a problem of sticking, there is a tendency of sticking. So, the mold slag must resist, this sticking mold slag should have sufficient characteristics to resist this sticking tendency. So, that mold powder characteristics we have to design based on whether it is a sticker grade or it is a depression type of grain. So, this is 1. Number 2, the secondary cooling and that means, when the shell has or the strand has come out of the mold, then you use secondary cooling. How much secondary cooling, how much water you will use, how much you know mist you will use, whether it is the mist formation.

Mist formation incident is relatively you can better control the heat transfer during secondary you know cooling. So, how much do you use, what is the distribution of the cooling as you are coming down from the mold till the continuous casting is over at a finer stage of cooling. So, these are dictated by a type of steel. What is their characteristics? So, mold cooling, secondary cooling casting speed you know the oscillation characteristics I had mentioned earlier. You know for sticker type of grades because oscillation is basically done for what, done to avoid sticking. So, for those grades you use relatively larger amplitude and lesser amount of frequency of oscillation, but for the other type of grades, the depression type of grades, there sticking is not a problem. There is a problem is surface roughness. So, what do you want the frequency should be relatively more and the oscillation should be relatively less just the reverse of the sticker type of grades. So, the mold oscillation characteristics should be different for these two types of grades. Mold powder should be different for the two types of grades. Secondary cooling characteristics should be different. How much water, how much of you know mist will be used, what is the distribution, all these will depend on what type of grade we are using. The whole idea is to avoid formation of crack.

So, the chemistry will dictate, the solidification characteristics will give us what the solidification characteristics is where sticker grade or you know depression grade and depending on these two broad categories, we have to design our continuous casting parameters. So, I am mentioning again and again, continuous casting parameters like extent of primary cooling which is dictated by the powder characteristics or whether it should take care of you know friction because sticking grade, that means friction is the problem. So, the powder characteristics should be such that friction is taken cared of for sticker type of grades, but for the depression type of grades, sticking is not a problem, friction is not a problem. Not an issue. There the issue is heat transfer in the mold. So, there the powder characteristics have to be different, number 1. Number 2, mold oscillation characteristics again have to be different because of these two types of grades.

Also, the secondary cooling characteristics, that means how much water will be used, what is the intensity of cooling, what is the distribution of cooling from you know top of the secondary cooling zone to the bottom of the secondary cooling zone, all these will depend on the type of grades, the chemistry of the grades. Now, I have mentioned what should be done to prevent the cracks, but in spite of all our efforts, in spite of lot of care whatever we take if you do not take care, there will be definitely lot of crack formation. So, the quality is bad, but even if we do lot of if you do casting with lot of care, that means we take care during continuously, there is a possibility of crack formation because as I have mentioned there are certain brittle temperature regions when continuous casting is taking place during solidification, end of solidification and that temperature region and also, when the cooling is taking place, there are certain brittle temperature regions. So, we have to avoid crack formation during those regions.