Theory of Production Processes

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Lecture - 44
Heat Affected Zone in Welding

Welcome to the lecture on heat affected zone in welding so, in the last classes we discussed about the welding processes and we talked about the heat flow in welding because of that because of the thermal effects we know that there are many zones which are formed in welding and the zone which is affected because of this thermal cycling. That is which is of paramount importance is the heat affected zone because in this zone there is largest effect on the mechanical properties because of the micro structural variations in certain materials normally the material which undergoes the polymorphic transformation alolltropic transformations.

So, in those cases you have the changes in the macrostructure because as the temperatures stages you know exceeded or as the different critical temperatures are achieved you have change of the different phases so, you have the change in the macrostructure and in those materials which does not undergo that type of transformation. You have basically the change in the grain size so, that also affects the mechanical property. So, basically this heat affected zone is of paramount importance and this is basically unevitable, you will certainly get this zone the only thing is that in certain welding process it will be more and in certain welding process it will be less so, and also it depends upon certain welding parameters.

So, by choosing proper parameters you can try to see that the zone is of minimum area or so that the adverse effect on the mechanical property is minimum so, that is how the heat affected zones are important and in welding. Let us come to the introduction about the heat affected zones as we know, that it is a part of the welded joint which is heated up to solidus temperature of parent material.

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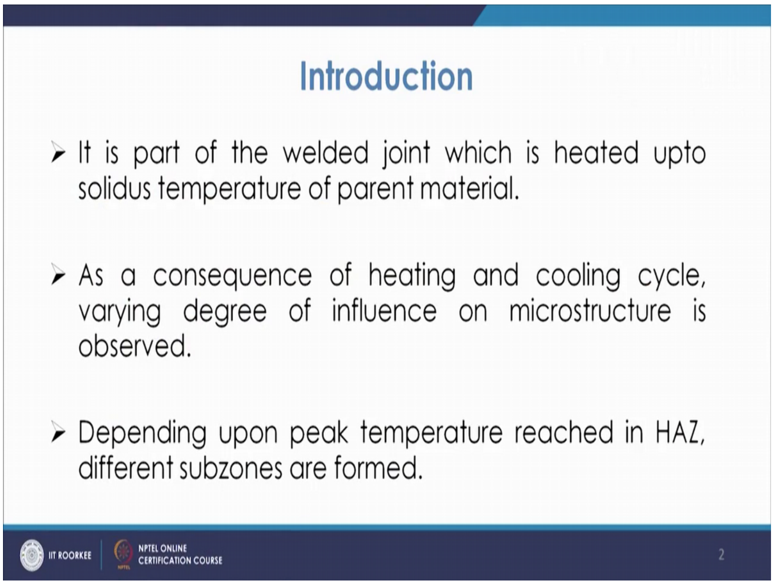

So, as we know that once you have a zone then after the weld metal zone the zone starts which is partly melted, then after that the zone is the grain growth zone under beat zone is there then you have the adjacent to its the grain growth zone. So, it has upper and lower boundaries then after that you have the, you know grain refinement zone further you have partly transformed zone and so.

So, basically if you look at the zone onwards from the, you know fusion zone or so, the maximum temperature is so, a zone is the one which is completely melted that is weld metal zone. So, that is anyway recast type of zone so, where the there is complete melting and then there is solidification, but then there are zones where the maximum temperature will be close to that just below that temperature. So, that is solidus temperature and where it goes slowly lesser and lesser towards the inner side and you have the different you know effect of these temperatures..

So, what we see is that you have the maximum temperature which is heated up to that is your solidus temperature of the parent material. Now, what happens that because of this heating and cooling cycle you have varying degree of influence so, wherever your it is heated to a larger extent the effect will be more pronounced and wherever it is heated to a lesser extent then that effect will be somewhat different? Also it because it is heated very fast then the retention is refer very small time then further it is cooled at a very fast rate.

So, you know that affects the properties or macrostructure of the welded joint in that heat affected zone. So, basically because of this heating and cooling cycle you have different degree of influence, some where it is more somewhere it is less, some where the grain is grain growth takes place, some where the refinement takes place, somewhere we will see that they will be changing in the morphology of certain phases.

So, laminar changes to steroid and structures and also all sort of changes take place and that is what we observe in the case of heat affected zones. Now, the thing is that we are going to see we have different type of materials which are welded and you have in certain metals you have polymorphous type of transformation takes place and in certain metals it does not take place.

So, in those metals like copper, aluminium or nickel that transformation does not take place as the temperature goes up to its melting temperature. So, in those cases you do not get the different macrostructure. Whereas, in the materials like steel or so, you have these polymorphous transformation taking place at different temperatures as you go above you have different critical temperatures defined and you have different phases that is defined alpha ferrite, you have then austenite then you have delta ferrite and all that..

So, in those cases as the temperature goes into different zones you will have different type of macro structures obtained. Whereas, in the cases where there is no polymorphous transformation, certainly there will be in the grain growth because the recrystallization will be there because of that you will do will have the change in the grain size and so and that also affects basically the mechanical properties.

Further depending upon the peak temperature reached in the heat affected zone you have different sub zones formed. So, as we discussed that once you have the different you know peak temperatures obtained in certain zone then you have different sub zones are defined like if you see from the top one.

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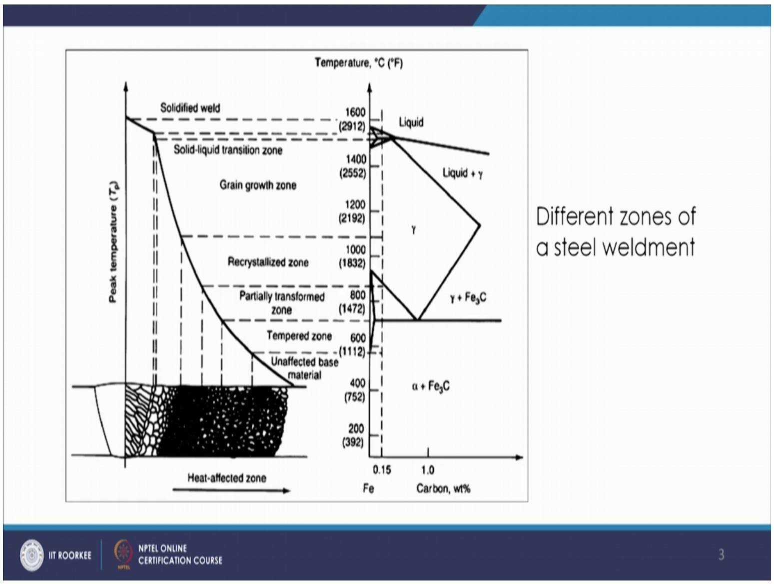

If you look at the a typical steel weld ment, low carbon steel weld ment. Now, what we see we had referred to this figure in our earlier slide earlier lecture where we saw that this is a zone which is the heat affected zone. Now, what we see is that you are heating the material and now these are the zone which is heated and completely in the weld melt molten state that is your weld metal zone so, that is your solidified weld.

Now, after that you have a zone that is under beat zone so, this zone which is just under the beat there on the weld well just after the weld metal zone where it is getting solidified after that you have a zone. That zone is normally the under beat zone and this is basically heated beyond the critical temperature of grain growth and that will be extending up to the fusion boundary zone. So, you have the fusion boundary zone and up to that it is heated so, that zone is known as the under beat zone. Further so, that comes here basically in this zone the grain growth zone its upper portion that is your basically the under beat zone will be will be there.

Then you have coming to the grain growth zone now grain growth soon as you see this is in this zone. So, the here also then go takes place where also grain growth takes place this is near the higher temperature side so, this zone all together this is known as the grain growth zone, where the grain coarsening takes place and you are going to get the coarser grain. So, as you see in these zones it is effect can be seen in these zones. If you look in the in this temperature zone which is coming to this side you see that you have these grains which are coarser and then this is also scores a little bit, but then that coarseness somewhat decreases once you come to the lower temperature side of this grain growth zone.

So, this zone is known as grain growth zone and here the temperature if you look at here this is something close from 1150 degree C up to the peritectic temperature, if you look at this temperature. So, up to that temperature is normally the grain growth zone and then adjacent to it towards the weld metal zone will be your under beat zone and you have the fusion boundary zone and all that. So, that is grain growth zone and under which zone will be coming in this region.

Further you have the recrystallized zone or it is also known as the grain refines zone so, in this zone that equalization takes place and because of that the grains are becoming finer. So, that zone is basically if you look at it will be starting somewhere from close to 950 degree centigrade to about 1150 degree centigrade will be the zone which will be basically the recrystallized zone or grain refined zone and then you have partially transformed zone.

So, partially transformed zone if you look at now this zone is somewhere if you look at this will be in between these two critical temperature zones. So, this will be normally from 750 to 950 degree centigrade in between the lower and upper critical temperature lines you have this partially transform zones, we will discuss about all these zones what typically occurs in these zones.

So, we will have that understanding about these zones. Then you have the temperate zone basically this is zone office paralyzed carbides so, here basically tempering takes place in one sense the temperature is further less maybe from 550 to 750 degree centigrade if you look at this zone. This will be close to 550 to about 750 degree centigrade..

I mean the higher temperature is close to the lower critical temperatures, a maximum temperature will be close to the lower critical temperature that is 723 or it is little slightly more 750 degree centigrade and then the lower critical term lower temperature limit will be about 550 degree centigrade.

So, in that basically the formation of spheroidal type of cementite particles occurs so, that is why you will tell it as the spheroidzed zone, spheroidzed carbide zone that is also known here as tempered zone and then after that you have the zone of unchanged base material or unaffected base material.

So, here the temperature is not going beyond 550 degree centigrade and there is no appreciable change. However, there will be certain property changes maybe because of the heating cycle because of the temperature increase and because of certain type of interaction with carbon and nitrogen of the dislocation movement and then there is certain type of grain, I mean imbrittlement which is observed so, because of the dynamic strain aging. So, that is the unaffected base material so, these are typically the different type of sub zones which are found in the case of heat affected zones..

Now, the thing is that the final macrostructure of the section of a HIZ, here the final macrostructure it will be depending upon many factors. So, that factors are like the grain size what are the grain sizes which are formed during that process then what is the peak temperature attained that also is important because you know how much is the peak temperature is higher that will be affecting the grain sizes normally higher will be the temperature more will be the grain sizes so, grain coarsening takes place..

Then heating and cooling rate also how is the heating and how is the cooling rate because that ultimately affects the transformation products, if you are heating at a very large rate then conversion may not be adequate from one phase to other. Like you are heating to a very fast rate then suppose the ferrite or the pearlite structure which you get, now once it goes into the temperature more than 950 once you go into the austenitic zone then that is to convert to austenite.

So, that now if the heating it is quite fast and the time is given very less than the whole conversion may not take place so, you will have partial conversion. Similarly, cooling also if you do very fast then there may be resultant macrostructure in different way that may lead either to pearlite a structure or to ferrite extra or to martensitic structure or to benedict structure.

So, that again depends upon in what way you are cooling and that we will discuss depending upon what kind of cooling, what type of structure we get that we can discuss later, when we talk about the heating and cooling cycle may be in terms of heat treatment cycles. So, this is the different zones of the weld ment which is there in the case of heat affected zones. Now, the thing is that when we talk about the heat affected zones in welding now what we see that it is nothing, but the heating and further cooling. So, similar to a heat treatment process so, we can say that its type of heat treatment process, but then when we talk about the normal heat treatment process and when we talk about the thermal cycling or thermal treatment which is given in terms of the welding process it has altogether a different meaning.

So, that differs in many sense the point over which it differs is that when we talk about the welding, then the maximum temperature which we get is close to the solidus temperature. Whereas, when we do the heat treatment if we tell I mean with reference to low carbon steel or so, in that case the maximum temperature which we go for the heat treatment process is normally very small.

We go to 950, 10 or 100 degree centigrade so, 1050 degree centigrade. So, the maximum temperature which is achieved in the case of heat treatment is normally very small. Whereas, the maximum temperature which you achieve in the case of welding is quite high it goes to very high temperature of around the you know 1400 degree C or so, where it is the solidus temperature is there.

So, you have that is the one of the major difference, then the thing is that there are two things which occur in the case of welding. In a case of welding you heat at a very fast rate so, because the heat input is by external source and this source either by using the arc or by using the flame. So, this heating rate is quite fast in the case of welding so, it takes very less time to reach to that peak temperature. Whereas, in the case of heat treatment we do not heat that fast we are heating at a slow rate. We can heat at fast rate also, but we can also heat at slow rate normally it is not that fast.

We are heating in a furnace normally by putting in a furnace where the heating is not so, fast so, the heating rate is normally very high in the case of you know welding processes. Whereas, it is less in the case of heat treatment processes then comes the retention time. Now, if you talk about a typical heat treatment process then what are the things one is that you are heating.

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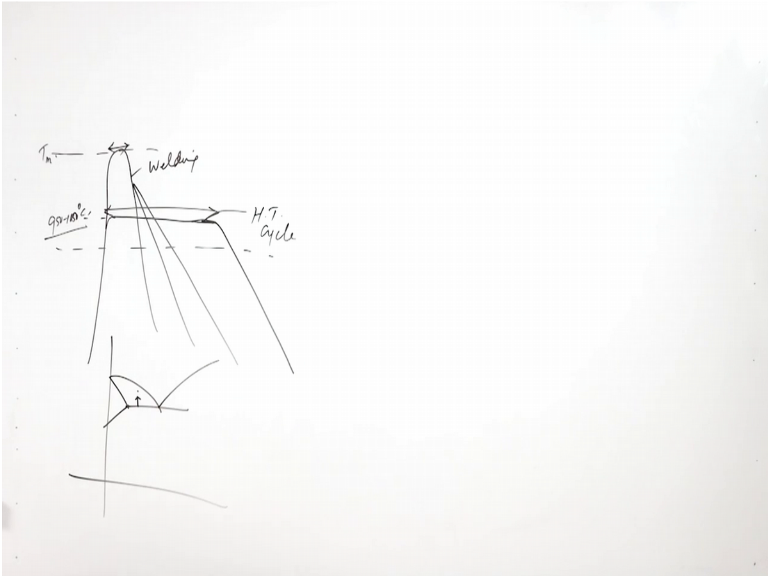

Then you are retaining and then further you are cooling so, in a normal heat treatment process you are heating first and then you are this is retaining and then you are cooling.

So, this is typically in the case of heat treatment where you will have you go a little bit this is your lower critical temperatures and you go above that maybe close to 950, 1000 or so. Now, in the case of welding what you do is you heat, but you heat very fast and then you come very quickly you do not retain so, retaining basically is you know very small retaining time. So, what you see is that the retaining time is very small here this is the retaining time in case of heat treatment and this is the retaining time in case of welding..

So, what in what welding what you see that you are going to melt and quickly it gets solidified and you are not holding it for time where you are holding it here. During the holding basically there will be you know transformation of one phase to other uniformly and then further you are cooling slowly. Whereas, in the case of this you have very fast cooling you may have little bit moderate cooling also you can control it somewhat, but then this type this way.

So, this is close to the ore melting temperature and this is your, you know this is something close to 950 to 1050 degree centigrade. So, you see that the higher temperature which is achieved in case of welding and here this is your heat treatment cycle so, this is the basic difference between a welding cycle and the heat treatment cycle and that is why there will be associated changes in the macrostructure or and once you have the associated changes in the macrostructure then you have changes in the mechanical properties and so, that is the basic difference between these two. So, basically the heating rate as well as the written some time and then also the cooling rate cooling rate also may be different. So, because of that you will have the different you know properties of the and that is why you can say that the heat treatment as well as the welding have some different you know end result in that sense.

Now, we will talk about the different type of zones which we see. So, first of all we will talk about the under beat zone or the grain growth zone which is under beat zone will be just below that you know fusion zone. Next to the fusion boundary zone and from there the green corrosion starts and then we come to the you know that whole growth gem and after that you will have greater defined zones..

So, we come to the first zone that is grain growth zone, now as we know that the grain growth zone as the name indicates here basically there will be the growth of grains. So, it will be lying next to the fusion boundary zone so, as we see you have this fusion boundary zone just below that you will have this grain growth zone.

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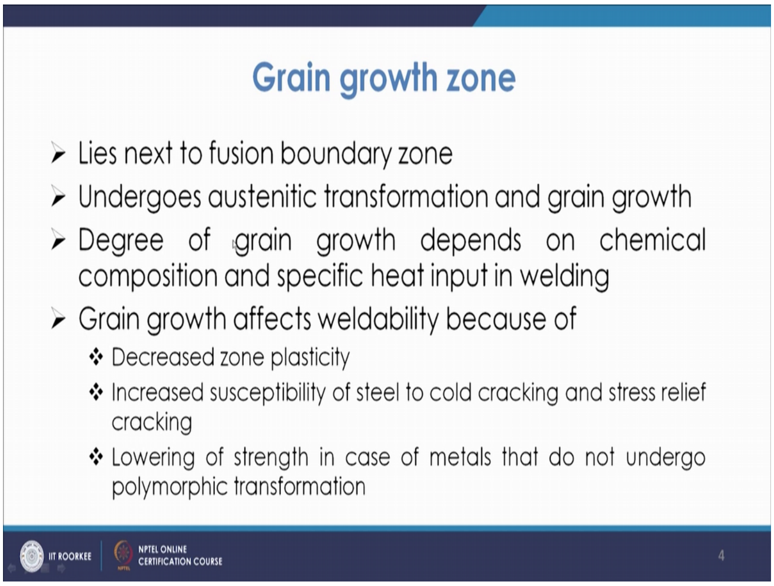

Now, it goes undergoes the austenitic transformation and grain growth so, as the temperature goes (Refer Time: 22:27) acceleration started at certain temperature and then once you go to the larger temperature zone, you will have grain growth started. So, that basically increases the size of the grains. Now, degree of grain growth will be depending upon the chemical composition and specific heat input in the welding..

So, normally what happens that the critical temperature for grain growth is, normally about 1050 centigrade for structural steels so, above that you will have the grain growth starting and for certain type of materials for certain kind of specialized steels like micro alloyed steels where the grains are even smaller with that temperature may be close to 1300 degree centigrade so, after that the grain growth is more predominant. So, in that case that is why the grain growth is becoming you know important and that is why it is depending upon certain type of composition and then also the specific heat input in the welding.

Now, what you see is that depending upon the type of process also used you will have these grain growth observed differently. Like the shielded metal arc welding you will have a smaller grain growth and as compared to the submerged arc welding and if you look at the electro slag welding it will be even you know higher grain growth which is observed in the case of electro slag welding. Now, grain growth is basically very important you know parameter because it is affecting the properties in the sense that it will be decreasing the zone plasticity..

Once you have the zone growth and growth of the grains then it will be decreasing that zone plasticity then you know susceptibility of steel to cold cracking and this stress relief cracking will be increased and also the metals which are not undergoing the polymorphic transformations that may be lowering in the strength so, that is one of the reason why this grain growth is detrimental for the material..

Then the next zone which comes is the grain refined zone so, as we see that after the grain growth zone you will have grain growth zone as we see from 1150 onwards. So, below that you will have the grain refinement zone so, for the grain refinement zone the maximum temperature is 1150. Now, from 1150 onwards you have the grain growth zone and from 1150 below you will have the grain refinement zone and it will be starting from 950 about degree centigrade. Now, what happens that it does not exceed basically 1150 so, that is the maximum temperature, now in that what happens that once you go from 950 above then the Alpha to you know Gamma transformation takes place because ferrite is no stable so, that will be changing to the austenite and that is fed to austenite transformation will be during the heating where whereas, the austenite will be transforming to pearlite when it will be cooling.

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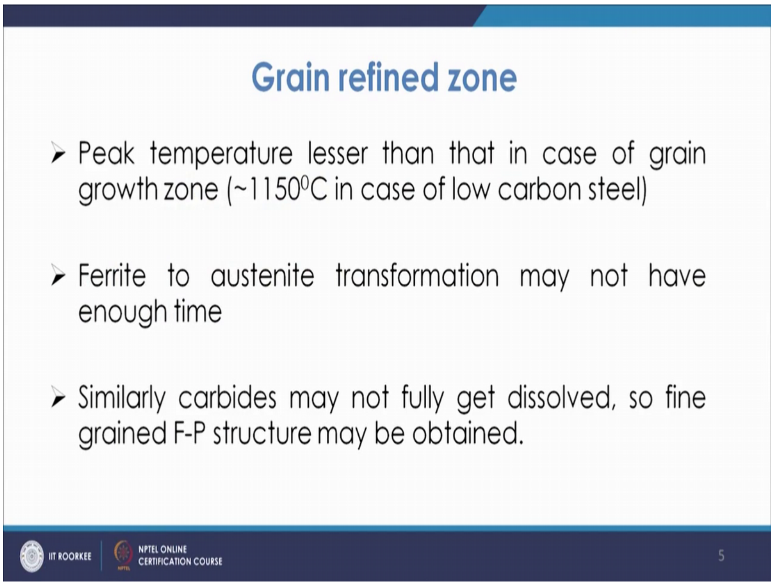

Now, as you increase the temperature from you know it goes above the 950 or so, then you have the ferrite to austenite transformation and then it does not get if they it does not get the enough time to develop properly. where temperature is somewhat lower in that case. So, you will have basically the grain size remaining smaller so, because of the not achieving that very high temperature that grain size becomes smaller in this case. Similarly, when you come to the cooling cycle that is the reverse cycle, now in that basically gamma will be transforming to Alpha.

Now, again that will be making the finer grained ferrite because the temperature is lower so, that we fine grained ferrite structure will be obtained and ferrite pearlite mixture may be obtained ferrite, pearlite type of structure will be obtained. Depending upon again the you know heat input parameter or you know like plate thickness so, based on that because that will be affecting that will be basically judging the cooling rate or so, which will be experienced by the specimen. So, based on that you will have different type of structures either you know so, you may have ferrite, pearlite type of a structure or so..

So, what happens that in this zone you have the grain refinement being taking place so, now, the thing is one thing is to be understood that once you go to the temperature above this upper critical temperatures or so. Once you go to above that temperature if you retain it be there for larger time then that case also for if you stay for long that also increases its size so, grain growth will take place.

Further if you are going to higher temperature grain growth takes place, but if you go and do not retain much time and then further come down. Then in that case the grain growth chances are normally lesser in the in those cases..

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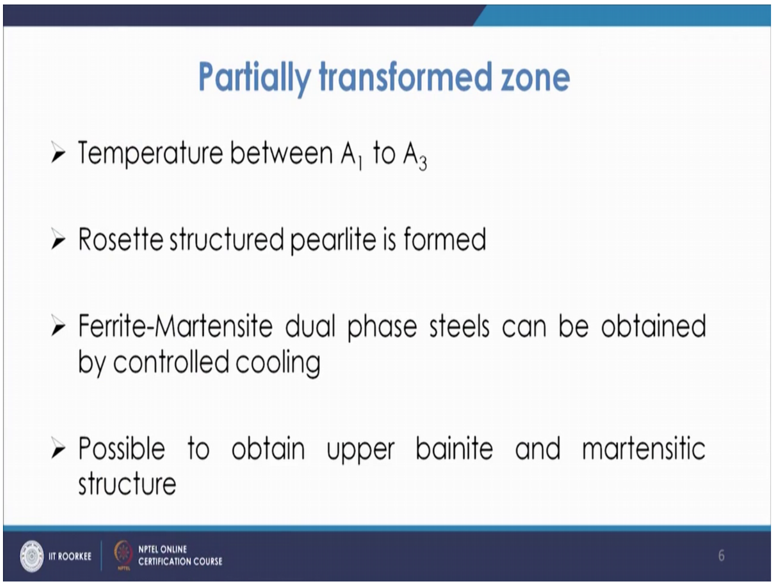

Now, next will be your partially transforms zone, now in the partially transformed zone that temperature is normally between 750 to 950 degree centigrade so, normally it is between the lower critical to upper critical temperature. So, if you look at this figure it is through this is a lower critical temperature and this is the upper critical temperature in between you see that this is the partially transformed zone which is observed.

Now, in the case of partially transformed zones what happens that when you are hitting so, you are not going to very high temperature? Now, in that case once you start cooling then in that case the you know while heating you know pearlite will be trying to get dissolved. So, first of all the pearlite will be dissolving so, pearlite will be transforming to austenite because once it goes from 950, 750 to above that I mean that is lower than more than the upper this lower critical temperature..

So, basically as you see that so, once it goes from here in this zone all the so, pearlite which you have otherwise it will be transforming to austenite. So, that transformation will be take taking place through nucleation and growth so, that takes and now since it occurs through nucleation growth, we require certain minimum time for it to take place. Now, but as you go as you finish this process at 950 so, you do not get much of the time for the full transformation to take place.

So, further you go for the cooling, now once you go for cooling back then what happens you know the reverse transformation does not lead to the lamellar structure. Rather it gets the rosette type of structure of the pearlite and that rosette type of structure is known as the chunky pearlite. So, either you have rosette structure of pearlite or you have the chunky pearlite type of structure is formed. Also this is the treatment is done in between the lower and upper critical temperatures so, that is also known as inter critical type of annealing treatment or so, that we will see later. Now, in that case depending upon the cooling rate you may have the martensitic type of structure because of that sudden cooling and because it was from here and it is cooled

So, you get even the marten site of stuff of structure and you get dual philistines which have a very good combination of properties strength as well as ductility and if you have very you know you can have such properties used for specific applications also like in the nuclear energy applications also it is used. So, you may have also the possibility of obtaining upper magnetic and martensitic type of structures. Then comes the zone of spheroids carbides.

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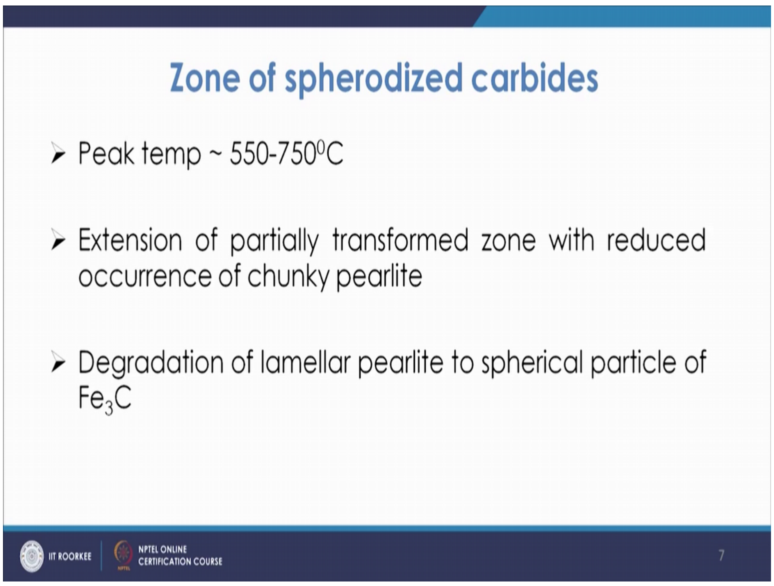

Now, this zone basically here the maximum temperature is going up to from 550 to about 750 degree centigrade. So, here what happens that you have its just the extension of that partially tossed from zone so, you have the reduced occurrence of the chunky pearlite and what happens here. That here the cementite which is the otherwise in laminar state that comes to basically a spheroidal type of structure. So, that is you know agglomeration at the grain boundaries as well at the triple junctions which are found and there will be black in colour so, you will have this spheroids type of carbides are formed, that is why it is known as zone of spheroids carbides.

So, that way you have that you know zone so, then you have after that you have the zone of unchanged base material. Where you have because of the dynamic strain aging you may have some change in the properties like imbrittlement or so..

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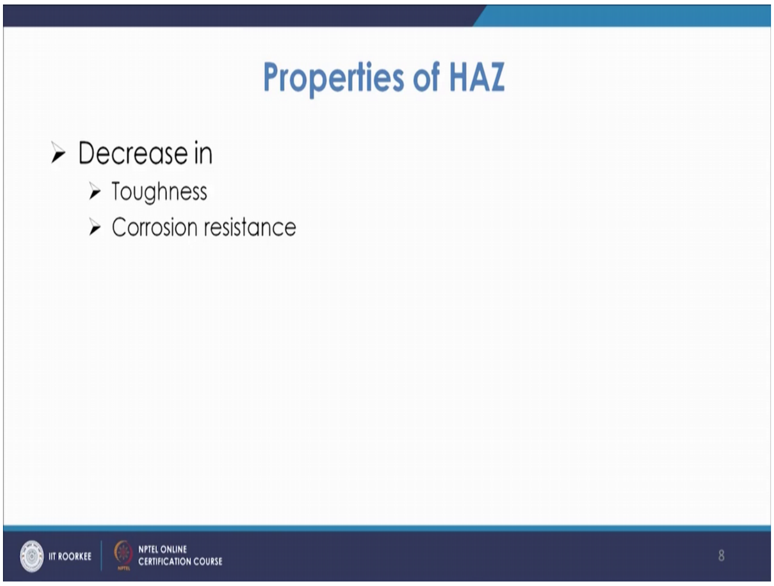

Now, why it is important to discuss about the properties of HAZ, that because of these HAZ you have some you know change in the properties especially toughness. So, there is decrease in the toughness in case of HAZ and as the toughness decreases you have you know that is very desired desirable property so, now, because this is because of many reasons and the one of the reason is because of the aging treatment below that lower critical temperature. Also due to the grain coarsening in the under bridge zone where it takes place so, that grain coarsening decreases the toughness of the material.

Then you have the decrease of the corrosion resistance also that is a stressor corrosion cracking may be observed in the case of the lowering of the toughness or in the case of these HAZ and specially in the presence of sulphur compounds like S 2 S or even CL 2 or alkalis, you have this you know stress corrosion cracking is seen to occur in the case of HAZ in the especially in the under bridge zone. So, these are this is how these under I mean HAZ is an important you know the domain which must be kept into mind, while we do the welding operations. So, that the affectivity of process is maintained.

Thank you very much.