Welding Metallurgy
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Lecture - 32
Heat Affected Zone

Welcome to the lecture on heat affected zone that is when we talk about the fusion welding processes then we discussed in the last class that you have the distinct zone formation and among the distinct zones you know the heat affected zone which is also known as HAZ. This is of paramount importance because in certain metals typically where the allotropic transformations take place.

So, in those cases what we see that we see you know microstructural changes taking place because the material is subjected to the thermal treatment, a kind of heat treatment and so you know that affects the mechanical properties. So, we will talk about the heat affected zones in this lecture.

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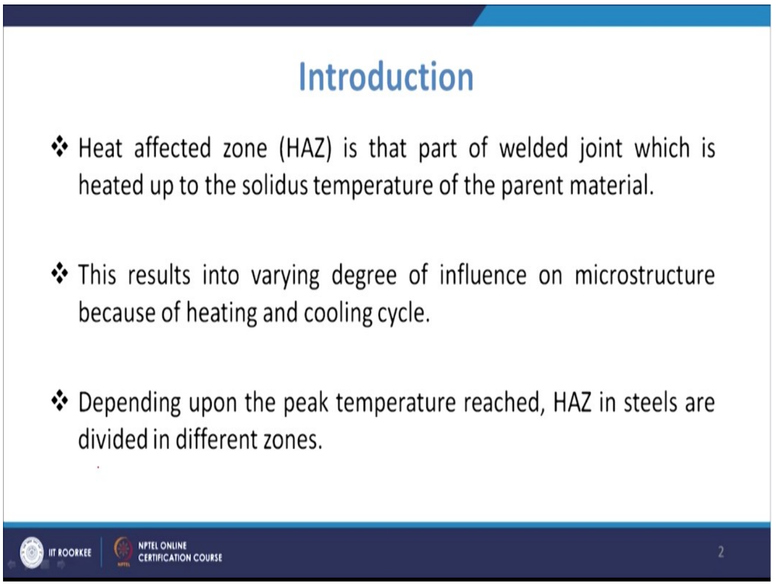

So, as we have already discussed that heat affected zone is that part of the welded joint which is heated up to the solidus temperature of the parent material. So, the temperature may go up to the solidus temperature in that you know because in the middle part you have the weld metal zone and then once you are coming near the fusion boundary zone there basically you have unmelted grains, so basically you are coming till the solidus temperature.

So, from there the heat affected zone starts and it goes inward towards the parent metal. So, now because you have the heating and cooling cycle, so in that case you have the varying degree of influence on the microstructure you know and further if there is the effect of the microstructure, then there will be effect on the mechanical properties because mechanical properties are related to the microstructure.

So, depending upon the peak temperatures which are achieved we get to know you know the different you know zones of even the heat affected zone. So, it is basically subdivision of the heat affected zone and as you take from the temperature you know in decreasing order, so you will have initially the underbead zone, then you will have the grain growth zone, then further you will have the grain refined zone where the recrystallization is basically taking place.

Further down, you will be having the partially transformed zone, then you will have the zone of spheroidized carbides where the temperature basically is somewhat lesser and then how the cementite is changed to some other shape spherical shape and then ultimately towards the end you have the zone of unchanged base metal. So, these are the different regions which we discussed in our earlier class also.

Now, before that you know as we have seen that in the case of welding, as you know that it is something like when we call you know we relate it with the heat treatment process but there are certainly some basic differences between the welding and typically the heat treatment process. So, if you talk about the difference of these two process in welding as we see, we go to higher temperatures, we take the example of steel.

So, we are going till this solidus temperature, so maybe close to 1400 ^{0}C we go in case of welding whereas if you talk about the heat treatment processes, then normally you know we are going to smaller temperature, we go till above the upper critical temperature. So, somewhere we are going maybe some degree 100, 50 ^{0}C above that temperature we are going into the austenitic range.

And then we are you know further cooling, so the peak temperature which you are achieving in these two cases are different. It will be higher in the case of welding and it will be on the lower side in the case of heat treatment. Then, you know next is the retention time. So, if you talk about you know the so the difference between this.

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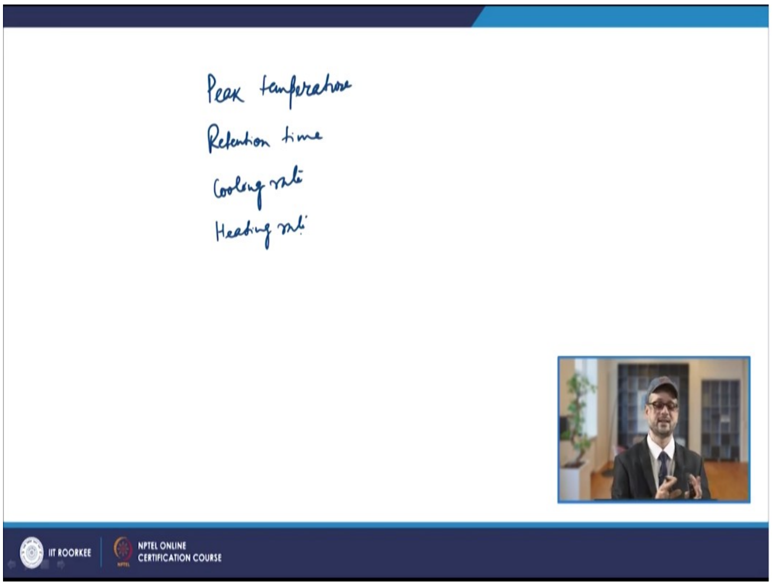

So, you have the parameters like peak temperature which you are achieving, so that is the difference you know, in welding you are going to about 1400 ^{0}C and in heat treatment we are going close to 1050 ^{0}C. Then, I will talk about other parameter which is important is the retention time. Now, retention time is when you go to the you know peak temperature then how much you are retaining there, for how much time you are there at that temperature.

So, in welding basically that is very less. We are not you know we are not staying at that temperature that is very less but in case of heat treatment we try to you know we go to that temperature and then you allow the material to stay at that temperature for some time and then you are going to cool it. So, the first is peak temperature, second is retention time and third is you know the cooling.

So, if you talk about the cooling rate, then you know cooling rate will be quite high in the case of welding whereas in heat treating, you have the varying cooling rate. So, if you talk about quenching, fast cooling there certainly the cooling rate is higher but otherwise you can have the smaller cooling rate like annealing or so or even air cooling. So, that cooling rate is also that is controllable in the case of heat treatment you can have higher.

But otherwise it is on the lower side whereas in the case of welding, the pool is very small, the liquid metal is very small and it is surrounded by very conductive material, so it is cooling fast. In the case of heat treatment, you are basically heating the whole material and then it is subjected to cooling. So, that is the difference you know between welding and heat treatment. So, you have also if you talk about the heating rate.

So, in the case of you know if we talk about the heating rate, so heating rate is also higher in the case of welding because quickly you are putting the amount of heat that is able to melt it quickly. So, you have your case of very high heating rate and very low retention you know. So and then you have further cooling, so quite high rate of cooling. So, basically very high heating rate, low retention time and then further cooling that leads to the non-homogeneous you know austenite formation you know normally in the case of welding.

That is the trait of the you know welding process and because it subsequently gets cooled, so you will have the localized regions of you know martensite that is you know high carbon martensite which is formed in the case of welding. So, when you take the microhardness in a welded specimen over a range of you know area, so in that case you get a range of a microhardness values in a welded specimen.

So, that is what you get in the case of so that is basically the difference between these two processes. Now, coming to you know different zones which we talked about the heat affected zone. In that zone, so you can have a look at this heat affected zone in the case of you know ferrous material steel.

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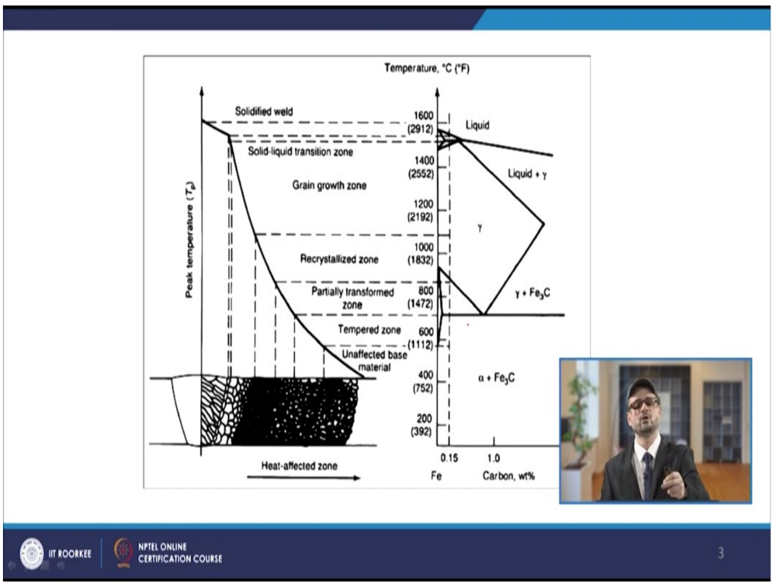

So, here what we see you on the right-hand side, we see the you know iron-carbon diagram, so and we can have a feel about you know the different zones which are formed in the case of the steel. So, what you see this is your iron-carbon diagram, what you see this is your alpha iron and then you have this is your gamma iron, in this side you have delta iron, you have liquid and so you have above this temperature you have all liquids.

So, once it comes below this temperature, you will have some solid+liquid zone will be formed. So, as you see from in this to this so for this composition of steel, you will have from this zone to this zone you have that is solid+liquid. So and then after that so based on that basically you have you know different zones which are shown. Now, this is the temperature, this zone is known as the grain growth zone.

So because here the temperature is towards the higher side, so in this zone your grain growth is predominantly taking place. So, that is your grain growth zone, then you have the recrystallization going on. So, based on that you have you know grain refined zone or recrystallization zone, you have the partially transformed zone. So, that is normally between the critical temperatures.

So, for that you have this is your partially transformed zone and then you have other zones where you have you know the zone of spheroidized carbides and then that is this zone and then you have the zone of unchanged base metal. So, that way you have the different you know zones which are formed.

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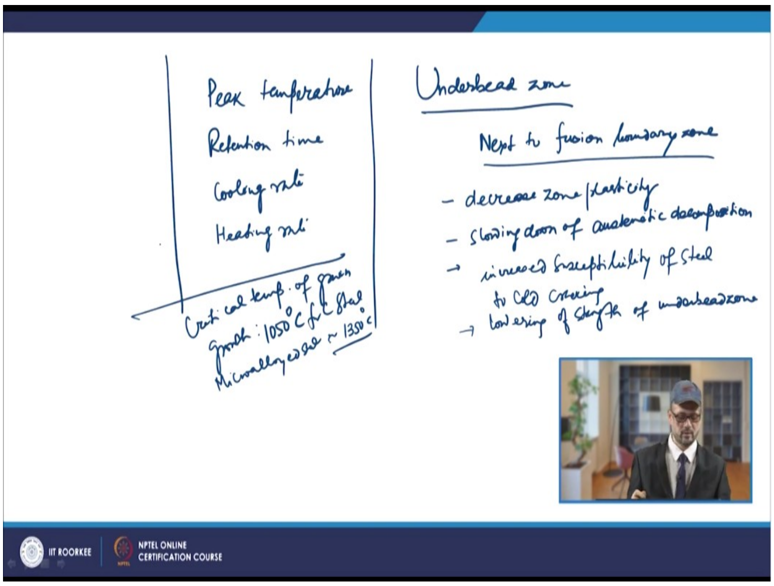

So, the first zone which is typically you know there, so after you have the weld metal zone and after that you have the you know so once you go towards the base metal, so where the weld metal zone ends you have the fusion boundary, so you have the fusion zone. Now, after that you have the underbead zone. So, below the bead you call it as the underbead zone. So, your next zone becomes underbead zone.

So, this zone the characteristic of this zone can be understood by its placement. So, it is just under that bead position. So, it is next to the you know fusion boundary zone. So, certainly because in this case, the temperature as you see that it will be just to next to that fusion boundary zone and you can also have, so here this undergoing, it is undergoing that austenitic transformation because in that case the austenite is getting transformed.

And also you know because of the very high temperature certainly, the growth is also one of the you know a phenomena which is prevalent there. So, you know in every fusion welding process, you will have a zone where the temperature is higher, so you will have the growth of the grains. So, you know you have the underbead zone and that zone as you see you know here, so you will have as you see this is your solidified weld.

And then you will have this solid-liquid transition zone, so that tells you about the placement of that and normally what we say so if you try to define you know this underbead zones, we have already talked about you know the temperature where this so it is going nearly this 1400 ^{0}C. So, if you refer to as we discussed that if you refer to this, so you will have the underbead zone which is basically you know just below this range and it will be taking care of two zones it will be taking care of you know.

So, it is above the critical temperature of grain growth which normally occurs in the metals at certain temperature and it will be varying upon the steel composition. So, that there will be a certain value of certain temperature value of the critical temperature for grain growth. So that so upper limit will be going towards that fusion boundary zone and on the lower side, it will be coming up to the grain growth zone.

Because you will have a critical temperature for grain growth, so that temperature will be the lower boundary for that underbead zone. Now, as we discussed that in this zone, you will have so that basically this underbead zone you will have certainly you will have the grain growth which will be taking place in that you know zone more predominantly and certainly there are many disadvantages because of the grain growth which is taking place in the case of metals.

And those you know disadvantages are like you have you know if you have the coarse grains, so you may have the challenges like decrease you know zone plasticity, then you have the slowing down of austenitic decomposition. So, basically sometimes that favors the ferritic formation or ferritic precipitation and you have some different type of microstructure is also formed, so that way that is you know the outcome of you know the coarse primary grains.

Then, you have also if you have the you know growth of the grains, then you have increased susceptibility of steel to cold cracking. So, that is you know another you know disadvantage with these grain growth zones and then you have also the lowering of strength. So, you will have the lowering of strength of underbead zone you know in metals which do not go the polymorphous transformation like the aluminum or copper or nickel.

So, there when there will be you know growth of the you know grain size that in that case it will be resulting into the lowering of the grain sizes. Now, as we discussed that this critical temperature of grain growth, so as you know and in this case we are talking about the zone which is below that fusion boundary zone, next to the fusion boundary zone. So, now it will be depending upon how much there is growth and that depends upon the critical temperature value of the grain growth.

And you know the critical temperature of grain growth, it has normally the value of you know this is 1050 ^{0}C for normal carbon steel whereas for carbon steel and for if you go for microalloyed steel, so for microalloyed steel that means going till the order of 1350 ^{0}C. So, this way you know when for the critical temperature of growth grain growth is higher, in that case the grain growth will be somewhat smaller.

Because you know the order of temperature which is going above that temperature that will be smaller in these cases. So, for these microalloyed steel where the steel is basically microalloyed with certain elements which are strong carbide formers which are basically the basically used to refine the grain structure. So, in those cases your critical temperature of grain growth is you know very high.

And in that case your grain growth will certainly be at somewhat lesser level. Now, it will also be the grain growth will also depend upon the composition of steel.

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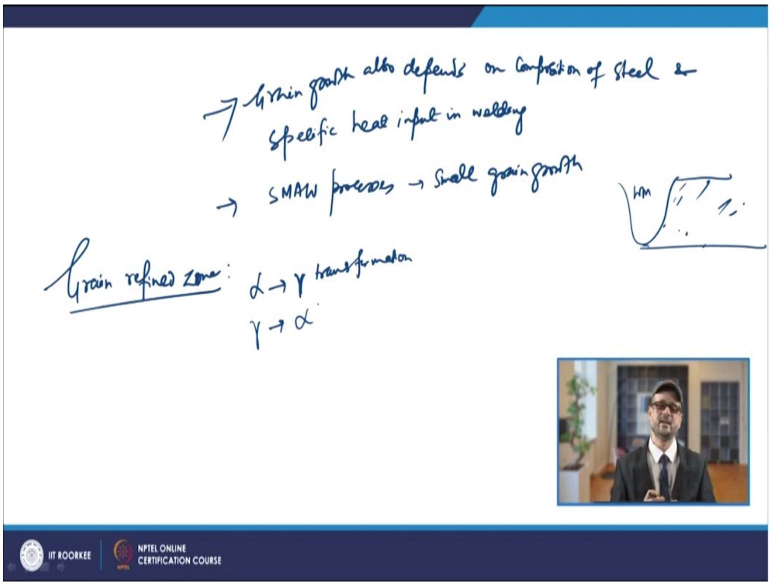

So, if you say so see that so the grain growth also depends on composition of steel and specific heat input in welding. So, in the different welding processes, we provide the different specific heat input and you know if you talk about the SMAW process, shielded metal arc welding processes, now in these cases the growth expected it is small. So, you have you know here you get small grain growth.

Then, you know from as compared to SMAW, in SAW it is more than SMAW and if you talk about the electro slag welding ESW, even it is quite high in those cases so the grain growth you know phenomena is seen to be more you know prominent in those processes. So, basically it also depends upon the you know type of welding process that is specific heat input in the welding.

Because it is less in the case of SMAW, then you have the SAW and then you have certainly the ESW. So, accordingly that grain growth which is observed will be you know changing. Next, you know if you talk about the next zone, which is formed which will be there below that grain growth zone, so you will have the recrystallized zone or also we call it as the grain refined zone.

So, you know in this zone, the grains are you know refined, grain refined zone so because of the recrystallization process you know in this zone you will have the finer grain structure. So, towards the, so in the upper side where in the grain growth zone, the temperature is higher and once you come down in that case you will have you know, so if you talk about the gamma to alpha transformation on cooling.

So, normally they will be providing your fine you know ferrite pearlite structure that will be depending upon what is the heat input or what is the plate thickness. So, based on that you will have you know the so basically you are going to that temperature. So, once you come towards the you know base metal side, so if suppose this is your, you know this is your weld metal zone and then this is your you know different zones of.

So, initially you will have the fusion zone and then you have the underbead zone, you have grain growth zone and then after that these zones. In this zone, basically your temperature is heated and it will go maximum to maybe 1100 or 1150 ^{0}C that will be maximum temperature. Now, above that you have normally the grain growth range. So, there the growth takes place.

But in this zone, you are heating and you are going into that zone and then from there it is the temperature is coming back. So, basically you are heating to so when you are heating, you have so while heating you have α to γ transformation and you know it does not have you do not have, you do not give them sufficient time for the development properly. So, your grain size will be remaining small itself.

It will not grow, so that way you know, in this case your you know grain size remains smaller. All the carbides which are there, they are not completely dissolved. So, you know so because anyway in retention it is very small in the case of welding, so your all carbides are not fully dissolved and when you go for the as we discussed and when you go from γ to α transformation, so you will have the fine grained ferrite pearlite structure which will be formed in these cases.

Now, the grain boundaries, the large grain boundaries they will provide you know so they will be promoting the you know ferrite nucleation on the grain boundaries and austenite will be remaining at the grain centers in such cases. So, normally you know for the you know this zone is you know it is basically it is useful when we talk about the microalloyed steels because this zone is quite wide in the case of microalloyed steels.

Because you know the effective you know the effectiveness of the carbonitrides in preventing this grain growth will be there at these temperatures. Normally, at the temperature of 1150 or so you may have the experience of grain growth but when your carbonitrides are there in those you know microalloyed steels, so they restrict the further you know grain growth. Now, the next zone after this you know the grain refined zone, the next zone in that will be your you know partially transformed zone.

And basically this zone, the grain refined zone so it will be starting from the value of a particular temperature and it will go maximum to 1100 to 1150 ^{0}C and after that you have the zone of you know partially transformed zone.

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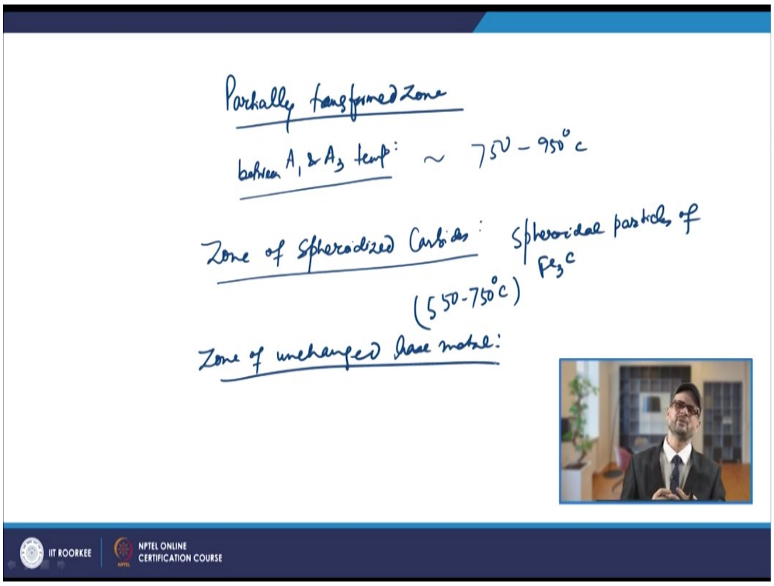

So, you have partially transformed zone, so this zone in this zone this zone is characterized by that zone in between the upper and lower critical temperature. So, basically this is a zone so for this composition this is your upper critical temperature and this is your lower critical temperature, so this zone is basically that zone which has which you know is there between you know the critical temperatures between A_1 and A_3 temperatures.

So, normally you will have you know the range from 750 to 950 ^{0}C. So, that kind of you know you have the temperature range where which is signifying the partially transformed zone. So, you will have the eutectic pearlite which is there, so they will be beginning to dissolve when they are heated beyond this temperature. So, in this case, you know normally what happens that you are getting a chunky pearlite type of structure you know in such zones.

So, now the thing is basically because of as you know that you are heating, you are going into that temperature range and then you are you know the temperature further comes down. So, you know there is not much of the time you know, so as you go above the A1 temperature, then your eutectic pearlite will start you know dissolving, eutectoid pearlite basically and then quickly the temperature will start coming down.

So, the carbon will so that there will be failing of the carbon to further diffuse back into the former pearlite grains. So, that way you have the formation of the you know chunky type of pearlite. So, in this case you have chunky pearlite structure which is there and many a times you know this inter-critical you know that leads to a dual phase type of a structure. So, when we do the higher speed of cooling, so you know the former pearlite grains can be quenched to you know martensite.

So, the extreme case you may have the dual phase type of a structure that is ferrite and martensite type of a structure that is formed, so dual phase steel are very much used. Basically, they have the ferrite+martensite that is dual phase. So, that kind of structure is likely to be you know obtained, it has very you know good strength, so that way they are very much used in structural fabrications and so.

So that inter-critical type of heat treatment is also used to be normally to have this dual phase kind of you know structure in many situations. Then, next to that you know as we see is you have this is your partially transformed zone. Then, below that also there are certain transformations taking place and there basically you get the tempering zone or also we call it as the zone of spheroidized carbides.

Now, in this zone the peak temperature will be from 550 to 750, so it is below that you know lower critical temperature, so below that and maybe from 600 to 700 normally what we see. So, now this is the extension of the partial transformed zone just below that and what happens that when you have little α to γ transformation, then you know what we see in this case that there is spheroidization of the you know pearlite.

So, you get you know spheroidized particles of cementite, so what you see is you see the spheroidal particles of Fe_3C. So, since that heating rate is higher, so that you know breaks this lamellar structure of pearlite and then they will glomerate, they will be having the formation of you know the spheroidal type of you know cementite and that is why it is known as the zone of spheroidized carbides.

And this is you know normally occurring in the temperature range of you know 550 to 750 ^0C. So, that is seen next to the partially transformed zone and then next to again adjacent to this zone of spheroidized carbides, you have the zone of unchanged base metal. So, now here the temperature is even you know smaller than 550. So, in fact there is no considerable change in that you know.

As far as the morphological constituents are concerned, there is not much of the change but you know you have the effect of heating and then you have you know the residual stresses. So, basically sometimes there may be you know effect like dynamic strain aging may occur also so in those ranges because you know in that case you are heating and then you have so and there are residual stress developments also.

So, they may interact and there may be you know formation of the you know there may be presence of those situations whether that is you know representing those dynamic strain aging behavior because in that case there will be interaction of carbon and nitrogen atoms with the dislocations and then you know that gives a certain different type of you know behavior when the material is subjected to you know tensile loading or so.

So, that is your dynamic strain aging, you must have the idea about it. So, that zone your zone of unchanged base metal you know that is you know that is normally you know more you know prominent when you are using the multipass weld kind of things, so you have further you are so after certain time again it is second pass and third pass if you are going, so that you know reason is subject to the changes and that gives you this you know dynamic strain aging behavior.

So, these are the different kinds of you know subdivision of the zones in the heat affected zone, which we have talked about. So, you must have you know they got some idea about these different zones based on the temperature because they are all based on the different temperatures where the different reactions take place and you have the different you know effect on the microstructure and further the mechanical properties.

So, we will talk about the effect on the properties you know in the HAZ in our coming lecture. Thank you very much.