Welding Metallurgy

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Lecture - 33
Properties of Heat Affected Zone

Welcome to the lecture on properties of heat affected zone. So, we have already seen that when we do the welding in case of fusion welding, we come across the various zones and we have the weld metal zone, you have heat affected zone and then you have the unaffected base metal. So, as we know that since this heat affected zone is subjected to the you know heating and cooling.

So, there is microstructural changes in that zone and that affects the properties of that zone and that you know ultimately will be affecting the properties of the welded joint. So, we must know that what way the properties especially the strength, toughness and related things you know are affected you know and that too especially in the heat affected zone because as you see that after the you know fusion boundary zone, you have a zone where there will be the grain growth which is occurring.

And then you have recrystallization and then you have further you know grain refinement, so and then you have inter-critical zones further. So, you know so we will be talking about you know what will be the properties of those heat affected zones especially with regard to the you know strength and toughness properties, how they are affected in the heat affected zone.

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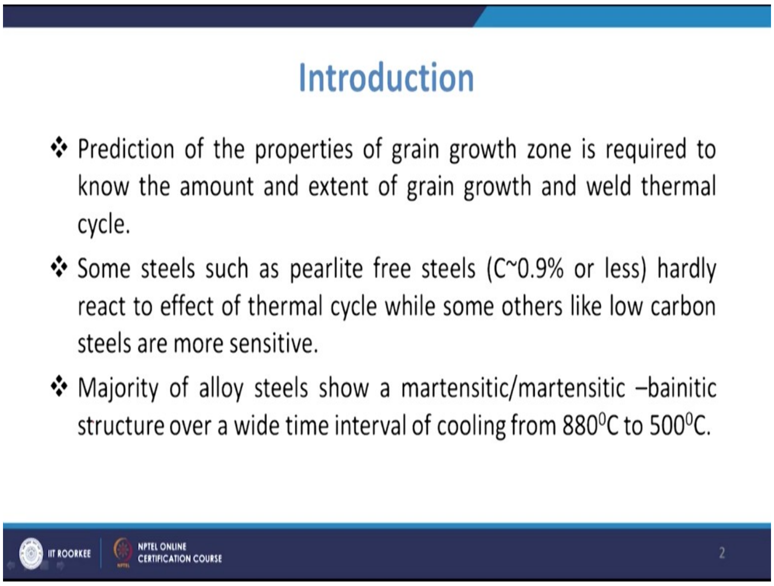

So, you know the prediction of the properties of grain growth zone is required to know the amount and extent of grain growth and weld thermal cycle because you know properties very much will be depending upon the change in the grain you know shape and size. So, as we know that grain growth is very much associated when the material is you know heated during the welding.

It is heated to a higher temperature and then further it is cooled. So, you know that there will be grain growth zone and that grain growth zone prediction itself you know is important because from there only we will be able to predict its you know properties, so knowing the weld thermal cycle under what you know thermal conditions the specimen is subjected to, we have to know that how much will be the order of the grain growth that is extent of grain growth.

And then what will be its effect on the temperature, so what happens that normally you know if you talk about the heat affected zone, so in the heat affected zone mostly you will have the increase in the strength in that you know region but at many at some of the occasions we also see that there will be even the decline in the strength also in the heat affected zone. So, you know there may be softening also you know that is also observed.

You know because you know it is heated to temperature around A_1, so you know that may be subjected to excessive tempering, so that may lead to even the softening also. Now, that also depends you know that what is the specific you know heat input of the welding process. So, depending upon the specific heat input of the welding process also, you will have the you know the extent of these tempered zone you know formation, so that can be predicted.

So, when you suppose for example when you do the welding of the large thick plates or large thickness steels using the electro slag welding suppose, so in those basically what happens these zones of these tempered zones or the soften zone they may shift towards the temperature even A_3. So, that also you know or even slightly above A_3 you know in that zone also it may be shifted.

So, normally what happens that if you talk about the you know hardness values in the case of these, you know HAZ region, so normally you may have two types of steels and you may have a steel which is having you know less carbon or in some case it is having somewhat higher. So, what happens that if suppose if you just take the example that if suppose you have a pearlitic free steel and if you compare that with the low carbon steel.

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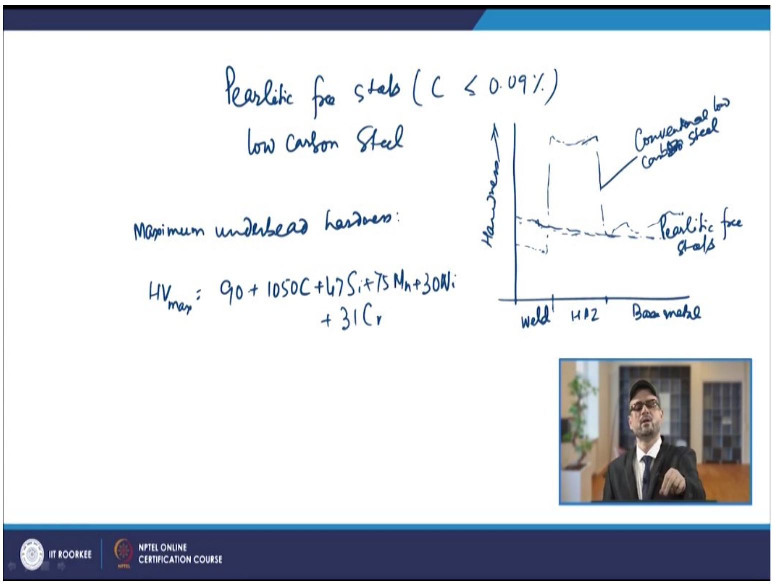

So if you have a you know pearlitic free steel where the you know carbon is less than or equal to 0.09%. So, they hardly react to these thermal cycles whereas the steels in normal case like the low carbon steels, they are very much you know sensitive to this thermal cycle. So, if you take for the low carbon steel and if you try to see that how they you know how there will be you know change in the hardness of these two specimen.

So, the graph shows if you look at the graph, so suppose you have if you look at a low carbon steel you know, in that case you will have you know normally they are very much sensitive, so suppose you have this zone is the weld zone and then you have another zone is the HAZ zone and then you have the base metal zone and if suppose this is your hardness, so if the hardness is on the abscissa ordinate and your if you take the distance along you know the length, so you will have the weld metal zone.

Then, you have HAZ and then later on your base metal comes, so if you talk about the pearlitic free steels where the carbon is very less, in that case your you know this is how the variation goes. So, this is for the you know pearlitic free steels and similarly if you but if you try to see for the you know low carbon steel you know, so in those cases you know this is a conventional low carbon steel.

So, in those cases what happens that the hardness is much smaller in this case but in the HAZ zone it increases a lot and then further it will come down so and then so this way it will be varying. So, this will be for the conventional low carbon steel. So, such is you know this is hardness can be of any scale maybe Vickers hardness or so. So, you will have about 300 or 280 that scale is there.

So, what is so is that you know some of these steels are you know more prone or they are more sensitive you know, in HAZ normally you will see that you will have larger hardness and at some places in some cases you have the hardness is not at all altered, it may be you know you can remotely connect with those concepts which we have studied like when you have the you know carbon percentage is less in those cases you know it is not hardenable.

So, basically it is because of the you know martensitic or maybe the bainitic martensitic structure which you get. So, you know because of that what you get is you get this sharp rise in this you know range. So, most of the you know alloy steels they will be showing this martensitic or martensitic bainitic structure you know over the wide interval of cooling maybe from 500 to you know 800 to 500 ^{0}C.

Now, many a times we are also concerned about you know the hardness. So, if you talk about the maximum underbead hardness, so the maximum underbead hardness which is achieved, so the maximum underbead hardness which is expected for the non-structural alloy steels you know, so that is non-alloyed structural steels. So, they are basically calculated using certain standard you know a formula and that is given by Cuo and he has even suggested that this

HV max is also Vickers hardness that maximum value will be 90+1050 C.+ 47 Si + 75 Mn + 13 Ni + 31 Cr. So, this way you know this C, Si, Mn, Ni or Cr normally they are in terms of percentages and you can see that the maximum contribution comes from the percentage of carbon and as you increase the carbon, so certainly that you know under the cooling, normal cooling conditions.

Because the cooling rate is higher, so in those cases you have you know hardenability is improved. So, that way its contribution is maximum, so you are getting, going to get you know even if suppose you are getting 0.1% of carbon, so it will be you see that it is 214. If it has 0.2% of carbons, it is going to 300, 0.3% of carbon so it will go to minimum of 400 and then you have the you know contribution by the different alloying elements.

So, that way you know underbead zone hardness you know are calculated and basically they are available also for the you know different steels or different plate thicknesses, you have standard formulas by which you can find the underbead hardness and you know that value has to be limited you know. So, normally it is supposed that it should be maximum to certain value may be up to 350 or 400 you know Vickers you know hardness.

Because for low alloy steels you know because in the area of creep temperatures, so even it is stricter, so accordingly you know for different requirements these so the value has to be you know that limit on these values are to be kept in mind because that may lead to you know failure of the material under different conditions. Then, you know so majority of steels will be showing that martensitic and martensitic bainitic you know structures over a wide interval that is you know in the cooling from 800 to 500 ^{0}C.

Now, the next property which is important you know to be kept in mind will be the toughness. So, toughness is a very important property for the material because you know when you do the welding and your weld metal zone in that zone you have very high temperatures, so that temperature is basically then the heat is dissipating towards the heat affected zone and towards the base metal zone.

So, that leads to you know various phenomena you know various microstructural changes. So, your change will be there also in the grain sizes and that will induce basically that will be affecting the toughness of the material.

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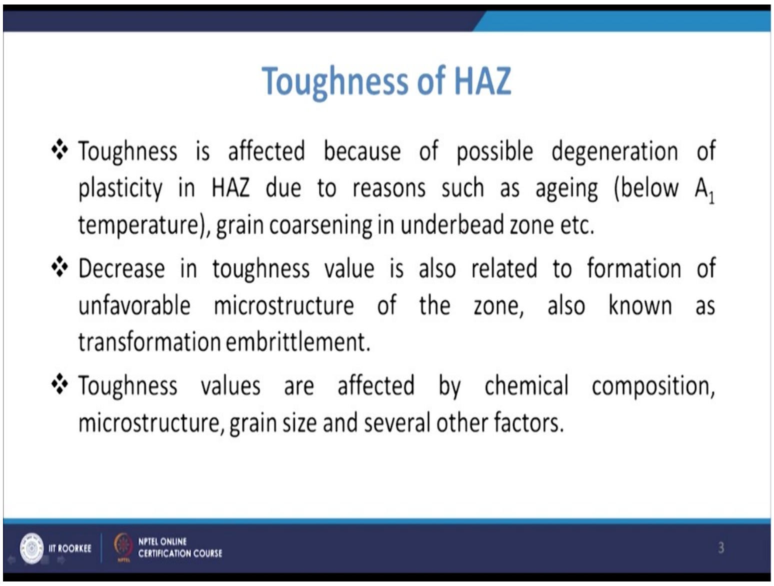

Now, the toughness you know is normally affected because of the possible degeneration of you know plasticity and that is in HAZ which will be due to reason, one is that you know aging. So, aging that results into decreasing the toughness value below the A_1 temperature because you know you are heating and then further you are cooling, so you are while heating so below the A_1 temperature it is like the aging effect.

So, that you know that leads to the you know degeneration of plasticity in the HAZ zone. So, it is basically you know one of the reason is that and another is that more conspicuous decline in toughness is observed you know that is because of the grain coarsening in you know the underbead zone. So, in the underbead zone as you know that there the grain coarsening is taking place, grain growth region is there.

So, that is extended up to that region, so because of that you know the grain coarsening is you know taking place and because of that the toughness value is you know affected. So, the decrease in toughness value is you know also related to the formation of unfavorable microstructure in the zone. So, basically you have the formation of unfavorable microstructures.

And that leads to the decrease in toughness and that is also known as the transformation embrittlement. So, basically you have the brittlement is because of the loss in the toughness. So, you know that comes into you know picture because of the decrease in the toughness value. So, if you know try to look at the you know toughness value, if you do the experimental work has been done to measure the toughness value on the you know sample.

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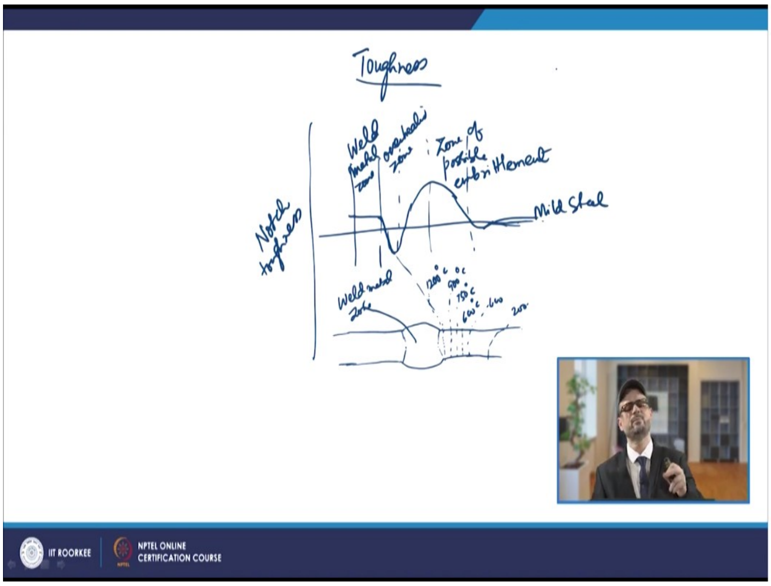

And the toughness is measured, so how the toughness is varying on a welded specimen. So, suppose that you have a welded specimen, so you have something like if you talk about a normal weld, so it is going like this and in that case you have the difference also. This is your weld metal zone and then you have the different zones. On this side, you have the heat affected zone and then on this side you have the you know base metal zone.

So, accordingly so what has been seen that if you look at the different you know zones, so this is your you know weld metal zone and you know and then if you talk about this, so it has been done for the you know alloy steel. So, it is for the low alloy steel material. Now, at this you know stage your temperature will be somewhere close to you know 1200 ^{0}C .

Then, further if you go you have the temperature as suppose 900 ^{0}C, then you have 750 ^{0}C and so it will go now further to 600 ^{0}C and then ultimately you have this as 400 and then you have 200 unchanged base material. So if you try to look at the you know toughness values, which are indicated by experiment in the different zones, so what has been seen that you know.

If you come to this zone, so at this point if you see at this point, the toughness will be very small. So, it will be like this, it will be coming down and that will be you know so in this case it will be smaller and then the toughness will further increase and then in this zone it will be you know further going this way. So, that will be the variation of the toughness in the you know mild steel.

So, basically you have the zones going like this zone will be your weld metal zone and this zone is the overheated zone basically and then you know the zone on this side where the toughness is in further decreasing, so this zone is basically the possible embrittle zone. So, that is zone of possible embrittlement. So, you know there is a decrease in the toughness. If you look into this zone, here you know as the grain coarsening is taking place, so that there will be decrease in the toughness value.

This is your on this side you have the notch toughness, so accordingly you have the you know and after that it comes to a you know constant value. If you talk about the you know high strength low alloy steels where you have that is HSLA where you have the grain refinement going on. So, in those cases you know the increase in toughness is there towards this side. So, here you have the constant value but in this case your toughness is going on increasing you know in this region.

So, that is for the you know high strength low alloy steels. Now, that basically will be depending, so this change in the toughness it is basically these values are affected by many factors and these factors are basically by the you know chemical composition, then microstructure and grain size. So, you know these are the factors basically which are you know helpful in predicting this toughness values.

So, they are affecting the toughness value whereas the prediction of the toughness in the other underbead zone is rather difficult, it is not easy to you know predict that you know toughness in that underbead zone.

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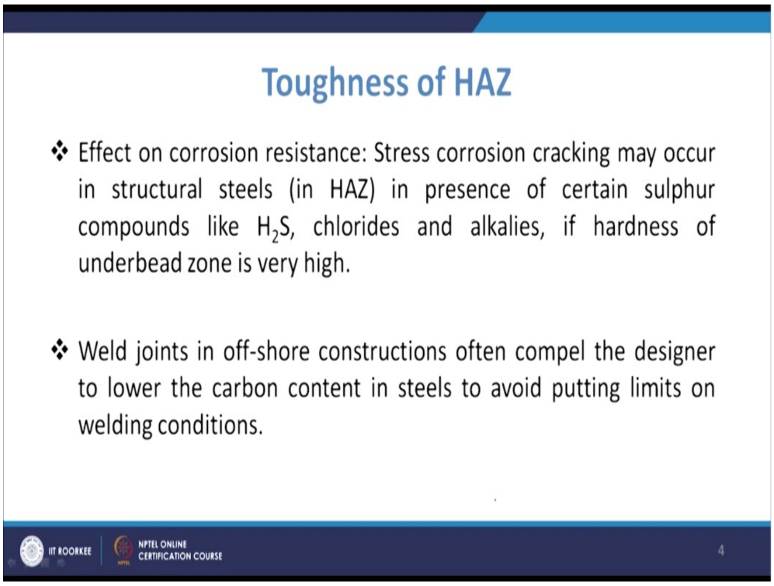

The other you know aspect of this you know toughness of HAZ, now there are other properties also, not about the toughness, basically it is about the other effect on other properties that is your stress corrosion cracking. So, that also very much takes place you know in structural steels in the presence of certain sulphur compounds like you have you know H_2S or chlorides and alkalis, if the hardness of the underbead zone is you know very high.

So, that is normally you have you know what has been seen that normally in the off-shore constructions many a times you need to have you know you have to compel, there is compelling you know on the designer to you know lower the carbon content because the hardness which is permitted, it is normally smaller. So, if you increase the hardness that is going to affect you know the properties of the materials that may fail.

So, basically many a times in the pipes or so, we try to limit the hardness to maybe the value of 150 to 200 maybe HV you know especially when you know if they are under the subjected to the shore conditions, so because you have you know sulphur and all that present there. So, in those cases you know we try to limit the hardness to maybe 150 to even the 200 or 250 maximum the Vickers hardness.

So, that stress corrosion cracking is the another you know point which is very much to be kept into mind when we talk about the properties of the HAZ. So, that is about the effect and in a nutshell, what we need to know that normally whenever we do the welding so as the structure, microstructure is changed, so that leads to change in the properties of the material, change in the you know because of the change in the microstructure.

As we have understood the you know different mechanisms, we have studied about the different type of heat treatment processes also and there also we have seen that when I mean we can always you know correlate with the type of thermal treatment the material is subjected to. We can further say that this kind of microstructural changes is going to be you know be there in the material because of the thermal treatment.

So, as we know that when you have the annealing treatment, in that case you will have the softening which is you know, softening is achieved and if you have the higher cooling in that case you have the hardening achieved. So, that way it will make the hard phases, so that way. Then, we also studied about you know different you know processes like for non-ferrous we had studied about while we discussing about the heat treatment processes about the heat in non-ferrous materials especially we talked about the solution treatment.

And then we talked about the aging you know process, so that we know that we have the supersaturated solution and then you know it is cooled and then when it is heated further, so in that precipitates grow. So, that way you get basically you know the formation of precipitates which impede the motion of the dislocation you know in the journey of the movement of the dislocation to create the fracture or the deformation.

So, you know many of the you know so and if you try to leave that, if you do the you know, if you do not do the artificial aging, so you can go for even natural aging, so natural aging also is there and normally you have certain materials which are you know in natural way the age is, so there are aluminum 4.5%, or 4% copper that is duralumin, so that is a natural aging you know material.

You know but when the steels also they are also susceptible to aging, so normally the you know mild steel is very much susceptible to the aging because you know if the nitrogen is present in the steel, in that case the precipitation of iron nitride is you know occurring. So, in that case, you know these precipitates you know they will be precipitated at the temperature below A_1.

So, when we are heating you know and we go to temperature below A_1, in that case you have the precipitation of iron nitrides that is Fe 16 and 2 that is you know formed at even room temperature and that is known as steel aging. So, you know when we try to heat in the range of 200 to 300 even so in that band if you look at towards the lower temperature side, so in that you know region you can have the formation of these nitrides.

And these are the you know precipitation, so that is natural aging taking place. So, these are you know affecting the properties of the material and these are obvious effects you know on the properties of the material because they are going to affect your microstructure, they are going to affect the mechanical properties you know or the welded joint. So, we will have you know discussion about other effects in our coming lectures. Thank you very much.