Welding of Advanced High Strength Steels for Automotive Applications

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Lecture - 19
Quantification of Microstructural Constituents in Automotive Steel Welds Part - II and Mechanical Properties

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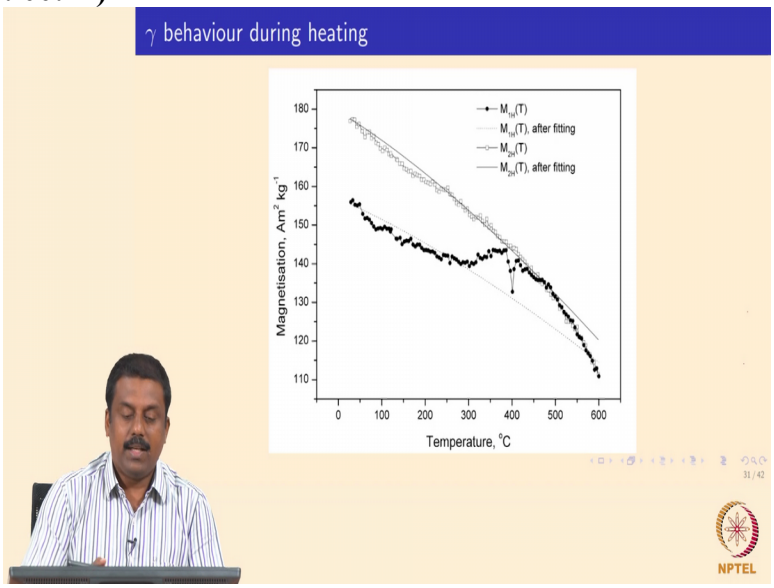

So, we looked at the stability of the retained austenite when you are heating at higher temperature using magnetic saturation method. So, we looked at the effect of temperature the on the Mass magnetization on the sample containing retained austenite. So, when the sample containing the retained austenite heated to higher temperature where the retained austenite decomposes into Ferro magnetic phases for example I look at; I showed you graph which is shown in the slide where the mass magnetization is actually measured as the function of temperature.

So, in case of temperature what will happen the retained austenite start decomposing when the temperature reaches in case for high silicone steels case, I mean the temperature goes beyond 300 degree centigrade use see decomposition of retained austenite this decomposition leading to a formation of ferromagnetic ferrite and then a tungsten carbide we looked at in earlier class. So, we look at it further what happens in the heat affected zone and diffusion zone of welds when

you apply weld thermal cycle has I already explained in thermo cycle the peak temperature across the regions can change.

Can reach at varying degrees starting from above melting point in the weld centre line to base material far away from the temperature at room temperature and the base material far away from the weld center line, so in order to understand how retained austenite fraction change along the heat affected zone as well as in the weld zone. So, we will have to measure the magnetic saturation at varying points for example you have weld region, this is weld central line as I always draw.

Now we need to understand and as a function of distance from weld center line how the retained austenite fraction can change because that is going to determine the microstructure of the various regions from; across the heat affected zone as well as weld zone. So, if you want to measure the magnetic saturation you want take the samples from the varying regions. For example in the base material in the subcritical heat affected zone.

Where the temperature reaches below the inter critical temperature and the samples at the intercritical regions as well as the fine grain and coarse grain affected zone. The disadvantages of the magnetic saturation method is when you are measuring the retained austenite in fraction. You need to have a significant amount of volume of the sample measured in order to get the reasonable magnetization measurements carried out on the sample. It is a bulk measurement, what do you mean by bulk measurement? You are measuring at the; throughout thickness of the sample ok in a bulk concentration not as analyst.

For example when you are doing a optical microscopy for the austenite when you are measuring local efficiency right. Here you are not measuring what is below the surface you are just measuring on the surface. Whereas in magnetic saturation method you are measuring through the sample in a bulk measurement also it is an advantage. But the disadvantage is we need to measure over wide regions. For example in this drawing I looked; I have drawn circles where we are missing the samples out and then do the magnetic saturation measurement. So, what happens here suppose this is your thermal profile after welding for example if I change the colour.
So, if this is my thermal profile after welding so, now if you imagine if a temperature is decreasing as a function of distance from weld central line. And if you look at for a example this region the temperature would vary to 100 degree also. So, if you take a sample of so in this case

the thickness is say 3 mm. If you take 1 mm diameter sample from in the weld zone along that 1 mm you may have variation of 100 Kelvin. So, you are averaging the measurements over wide a region that means that effect is actually not really clearly alienated effect of peak temperatures right.

You are measuring the effect of weld thermal cycle where the peak temperature, say for example ranging from 800 to 900 degree centigrade in one region. So, we need to measure it much more accurately with respect to the spatial distance. So, if you want to have the effect of peak temperature on the retained austenite fraction say for example we need to measure it with much finer resolution is it not. Say for example when you are measuring at given location the temperature should not vary say for example 5 Kelvin.

So, if that is the case we have to make the measurement at very small area of the sample, where as in the magnetic measurement it is not possible because we have to machine out the sample with reasonable size in order to measure the bulk retained austenite concentration. It is very good to carry out measurement like in this graph. I showed you how to measure, how to study the effect of temperature on and retained austenite stability. So, we can take the sample from the un-welded base material and then put it inside and heat it up to various temperatures.

And identify what temperatures you see change in the magnetisation and that will give us how the retained austenite transforms to other phases while heating. From that we can and understand that what is the maximum temperature of up on which their retained austenite start performing to other ferrite and other carbide phases, so in order to have very refined fine measurements so we have to go for some other techniques to measure retained austenite.

So, one such technique which can be used to measure the retained austenite at very local regions in the weld zone is by using x-ray diffraction ok x-ray diffraction is another technique which can very effectively use to measure the phases that are; the amount of phases that are present in microstructure. The principle of x-ray diffraction I am not in detail.

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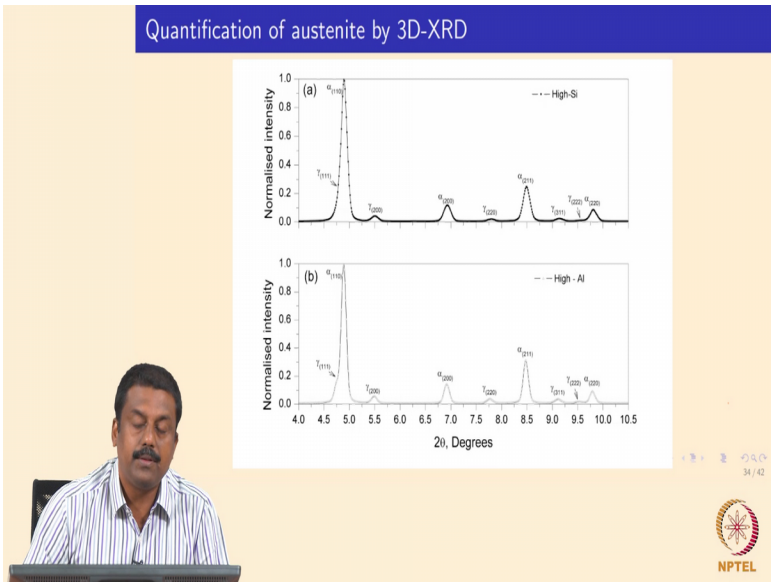

But you can refer some of the textbooks; I referred in the beginning of the classes in the beginning of this course. So, the idea of the X-ray diffraction is to get the diffraction peaks of individual phases in the microstructure. Say for example in the trip Steel we have phases right one is BCC phase which is ferrite and say for example in this case carbide free bainite and FCC phase is retained austenite. So, now what we are interested is the volume fraction of retained austenite present in the microstructure at a given location.

So, what do we do now so we can carry out X-ray diffraction measurement at individual locations where the beam size of the X-ray diffraction can be as small as few microns. So, gauge volume the volume on which you measure the X-ray diffraction is very small compared to the measurement you do it in the magnetic saturation method. So, in this case because of the gauge volume is very fine. And we can measure in highly localised regions in the heat affected zone and as in the weld zone.

So, using the X-ray diffraction technique we can precisely measure by the various ways I am going to explain in the previous next slides. We can measure the amount of retained austenite present in the microstructure in the welded material. So the principal is very simple so we get diffraction pattern so the intensity of the diffraction as the function of 2 theta ok diffraction that is an angle between the incident and the diffraction beam. So, you can refer some of the textbooks which is described X-ray diffraction. So, right now we can assume because it is too much for this course to explain about X-ray diffraction.

So, we can assume now that we get the diffraction patterns of BCC and FCC phases that are present in the microstructure and in our case trip Steel what we have is ferrite and carbide free bainite which is also ferrite and both of them are BCC and then FCC which is retained austenite. And these two phases will give you the diffraction patterns what you showed in this figure for example I put to two patterns of high silicon and high Aluminium Steels and trip Steel which contains the mixtures of and ferrite and retained austenite BCC and FCC.

And they would give you the diffraction pattern that given individual 2 theta and at the Planes of FCC and BCC would diffract when they satisfy the Bragg's conditions which is 2D sin theta = n Lambda is the wavelength of X-Ray when the D spacing's of the inter Lambda spacing are the of the Crystal planes if they satisfy the Bragg's law for example if it satisfies the Bragg's law you will enter a fraction pattern, in case for example D is of 11 110 of ferrite and austenite respectively and diffract in given angle for a given wavelength of Lambda. And then we record the diffraction patterns and based on the intensity of this diffraction peaks you can calculate precisely how much amount of austenite and ferrite present in the microstructure.

Say for a typical BCC, FCC mixture in the microstructure would give the diffraction pattern what I showed is here this graph we record the intensity versus 2 theta diffraction patterns. And then identify peaks positions and then from the peak positions precisely know what plain it is diffracting because each plane will have a defined D spacing's. For example if you know 2 theta and then you calculate for a given wavelength what is D spacing and from the D spacing precisely whether it corresponds to ferrite or austenite. So once we identify the plains of diffraction now we can see that at what is the intensity during the intensity of ferrite and the austenite.

For example in this case it is 200 austenite intensity it is 200 ferrite and this is the peak first peak ok. It is the mixture of ferrite 100 austenite 111 generally we neglect that because it is very difficult to separate. And this peak so, reduce the others peak what you see over here for example austenite 200, ferrite 200, austenite 220, ferrite 211 and austenite 311, 222 and then 220.So, we can measure the intensity of individual ferrite and austenite in peaks, so once you know the individual intensity then we can combine it and calculate ratio.

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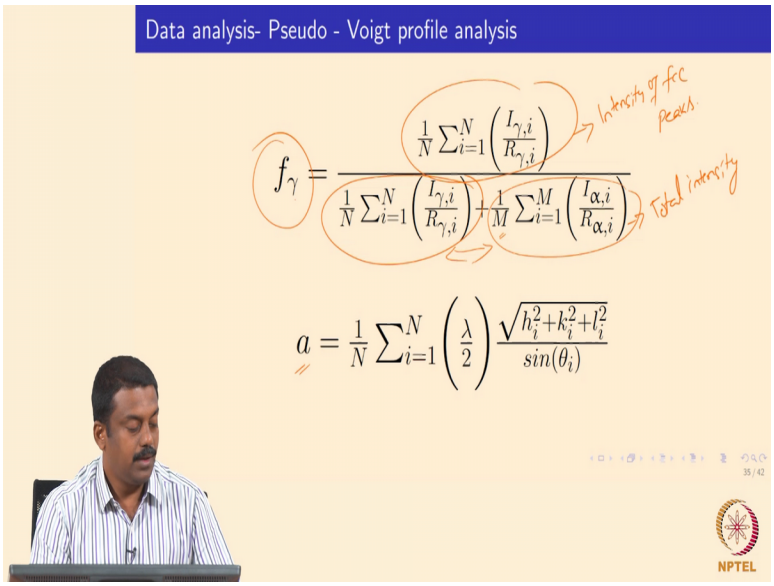

The amount of retained austenite present in microstructure is nothing but at the total intensity t in the diffraction intensity in the diffraction over the intensity of FCC peaks right. The total intensity over the intensity of the FCC peaks right the total intensity over fcc right the ratio between total microstructure right. So, that will again give us the amount of retained austenite present in the microstructure. So, this is very straight forward technique so, if you have a good equipment it so you can measure the entire diffraction pattern for all the diffraction peaks over the intensity of the FCC peaks.

And of course we have various factors and multiple phase factors that you no need to worry about it. So basically this equation is very simple we have a total intensity for example this is total ferrite intensity this is total austenite intensity and combined together it will give you the total intensity of the microstructure diffraction intensity of the microstructure over basically intensity of FCC peaks that will give you the volume fraction of retained austenite in the microstructure. Similarly you can also calculate the lattice parameter of the individual FCC and BCC which we may not need unless you calculate this strain and the residual stress in the microstructure which is not needed for this course.

So, we can measure from the diffraction patterns which I showed you from the previous slide by measuring the intensities of ferrite and austenite peaks by calculating the ratio of total intensity over the FCC peak we can calculate the amount of retained austenite present in the microstructure.

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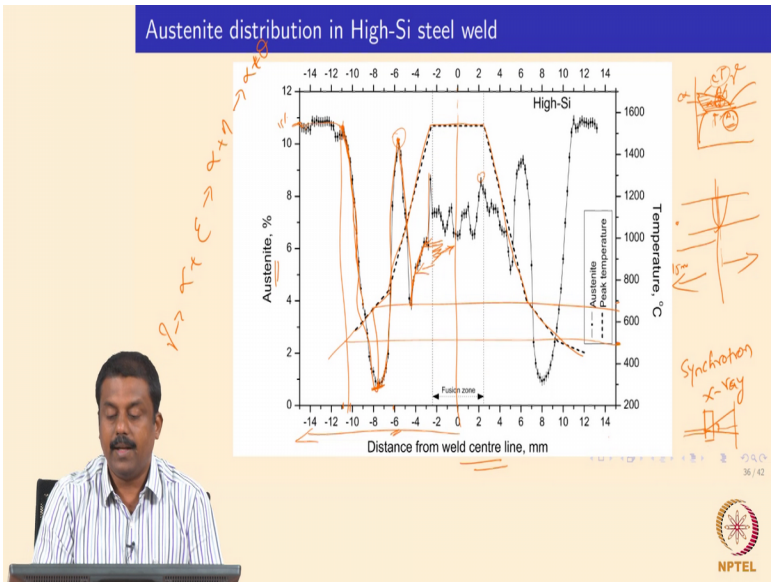

So, now what will happen in the weld zone so we can measure over the region in the welded trip Steel? For example we can start from the base material for away from the weld zone. And I am showing you graph describing the retained austenite variation along distance from the weld centre line. In case of weld centre line is over here. So, that is over here and this weld was made in high Silicon Steel high Silicon containing trip Steel bead on plate which I showed you even in previous lectures. And you can refer the figures and then identify I can look at the weld zone region in the slides which I showed you nearly video.

So, now if you look at the retained austenite variation along this line it is very, very interesting to see this it is symmetric. If you look at it along the weld centre line from this side and this side it looks very symmetric but we will see one by one. So we are measuring it very, very small regions individual points over here shows individual measurements of X-Ray diffraction. And for measuring this graph we used very high energy X rays which is known as Sychrotronics X-rays sorry Synchrotron X-ray which are very high energy X-rays and which can penetrate for example 3 millimetre thick plates. So, you can measure the diffraction other side of the sample.

Which is known as transmission X-ray diffraction and in laboratory scale we will be doing it only in reflection mod because we use very high energy X-ray which can penetrate this sample and the weld and can come out from the other side and we measure the diffraction on the other side in transmission and due to that this measurements are done for example you have an simple beams comes here the diffraction happens ok. So, this is for example angle between incident and diffracted beam. So, if you measure the diffraction in the other side of the sample.

Because it happens in transmission ok we can measure precisely by controlling the beam size and we can measure the retained austenite along with thickness of the sample for a given region. So, if you look at this graph is made with various points for example if you move far away from the weld center line about 15 mm from the weld Centre line. So, 15 mm from the weld Centre line you see that; you are in the base material. So, the retained austenite fraction is about in this case is 11 right. And then if you are moving close to the weld centre line what happens? Nothing happens until some temperature some regions ok.

Say for example until you go about 11 mm are so from the weld centre line. So, then you see that there is a decreasing in retained austenite fraction. So the retained austenite start decrease, say if you go about 11 mm from the weld center line. And if you look at the temperature for your reference I also given here, the temperature cycle or peak temperature reached during welding on the plate on which you may be measure the X-ray diffraction say temperature at this region ok. So, for example around 10 mm from weld Centre line it goes around. So, in this case it goes around say 500 degree centigrade ok you see over here is it not.

At this temperature at this region say11 mm for example is somewhere over here ok. If you send this so it goes about 500 degree centigrade. So, in this case we already see that when temperature say increased to 500 to 550 degree centigrade at 10 mm you see a decrease austenite start decreasing composing into various phases. And within the magnetic saturation measurement we look that the temperature at which layer retained austenite transforms around 300 degree centigrade. Because here we see that in real case is about 500 degree centigrade.

Because the heating rate in the weld is very, very high so you may have to increase the temperature much further. So that you know the kinetics can be; can lead to increasing in the decomposition rate. Whereas in magnetic saturation measurement they decrease very slowly ok. So, you can see the effect of heating rate already and the decomposition mechanism in the retained austenite. So what happened here in this case so moment the temperature goes around 500 degree centigrade the retained austenite fraction start to decrease that means, so you recall from the magnetic measurement.

The retained austenite is transforming into ferrite and other carbide mixture. So, the austenite will start transforming into first epsilon carbide and carbide subsequently and cementite right.

So, you see that at the temperature goes above 500 degree centigrade in the weld zone the retained austenite decreases continuously at this point ok, somewhere over here around 650 to 700 degree centigrade you reach the minimum value ok. The value of retained austenite is almost close to 0. So, that means that we have not nucleated the retained austenite. It nucleuates when the temperature goes above your A1 temperature right ok.

This is the temperature at which it start nucleating new austenite when you heating up ok. Now with the temperature is below the A1 temperature what will happen only the retained austenite present in the microstructure start decomposing ok. And this decomposition would lead to the formation of ferrite and cementite in the austenite. And when the temperature is just below the A1 temperature just somewhere around 650 degree to 700 degree centigrade all the austenite completely in micro structure completely decomposing ok that is why it shows over here. The austenite fraction decreases to close to 0% and then if you move further close to the fusion zone the austenite fraction start increase.

That means that we are reaching the intercritical temperature region the peak temperature during welding goes above, in this case 700 degree centigrade that means that you are nucleating new austenite ok. You are reaching to the inter critical temperature region. So, then what will happen then the intercritical temperature region through moment the temperature reaches the intercritical regions there will be local partitioning of carbon right. As I already explained explaining you the trip Steel heat treatment. Moment the temperature reaches to the intercritical temperature the sample the austenite in the sample would start enriching in carbon.

Because of the partitioning of the carbon between the coexisting ferrite and the austenite you can see Alpha line and gamma line right moment your temperature goes to the inter critical temperature your austenite would start getting enriched in carbon that means that testability of austenite increases ok. Subsequently when you cool back to room temperature, this retained austenite can be stable whereas the temperature, below this temperature austenite is not nucleating ok.

So, what happens then austenite it is not nucleating that means that whatever present in the retained austenite would decompose completely and would lead to almost 0% retained austenite in the regions where the temperature is below A1 temperature. So, then when you go above A1

you will reach to the inter critical temperature region where you will have a ideal temperature region at which you know the maximum portioning.

It is very similar to the heat treatment we have seen in the conventional trip steel heat treatment where the temperature would be in the intercritical temperature region. And whereas; see for example in this case somewhere around 900 to 1000 degree centigrade when the peak temperature reached. We should also be careful here we are not welding or nucleating condition here right. So, we are heating up extremely rapid case so the entire temperature, the phase diagram would shift above.

So, you would form A1 temperature where if it is 800 degree centigrade conventional case it may be different because non equilibrium case but in principle fundamentals are same ok. So, at this temperature when at this location when you reach ideal volume fraction of both ferrite and austenite it can lead to maximum stabilisation due to the intercritical annealing right where two phases are coexisting. So, when reached the maximum temperature maximum volume fraction at this location which is roughly say around -6 mm from weld Centre line and this can change. Suppose if you are hurt if you are heating up very fast laser beam welding for example and then this region would change because it will shrink ok the entire region.

So, in this because the again temperature gradient are much different ok but it will have a similar pattern when the temperature reaches an inter critical temperature where both ferrite and austenite is coexisting and will have an optimum portioning of carbon to the austenite it can lead to the increasing fraction. So if you further move about out for example A1 temperature what will happen A3 temperature? You will have a single phase austenitic microstructure and again there is no partitioning right. So there is no partition in that means ferrite it will decrease continuously when you reach fully austenitic microstructure.

And if you move closer to the fusion boundary and again it will increase austenite fraction why because the carbon can also migrate from the weld zone when it is solidifying and carbon can also migrate to the adjoining austenitic microstructure and because delta ferrite nucleates at the fusion boundary delta ferrite since the carbon because of low solubility of carbon in delta ferrite. And this can also send carbon to weld Centre line as well as towards austenitic region in the heat affected zone the most heated zone and due that the carbon can enrich the disability of the austenite in the fully austenitic region the austenite fraction increases again.

And subsequently you will have enrichment leading to increase in the austenite fraction at the fusion boundary. So, if you look at this graph lesson what you will have learn is even though you have uniform temperature gradient based on the peak temperature reached. You will also change the microstructure significantly. In the conventional ferritic Steel, ferritic pearlitic steels this effect is not significant. Why because there is no retained austenite in the microstructure ok. But because of the presence of retained austenite as you see you have the effect of the peak weld thermal cycle in this case until minus 15 mm from the weld centre line ok.

Whereas in conventional Steel you would not see any effect until when you reach above A1 temperature where you will have microstructure change into austenite during heating subsequently will transform to martensite or any other low-temperature products. So, because of the presence of retained austenite the enlarge heat of affected zone. Remember what is the definition of heat affected zone. So when you see the; when you can measure the effect of peak temperature in the microstructure. Effect of peak in the microstructure if any noticeable effect is seen that is what heat affected zone.

Now we already see the effect until in this case 11 to 12 mm from the weld Centre line that means that the enlarge heat affected zone too much larger distances compared to ferritic pearlitic steel ok. And you should also be careful in retained austenite in microstructure. The heat affected zone will be broader and the peak temperature reached during welding would determine stability of the retained austenite. As I already explained using this graph.

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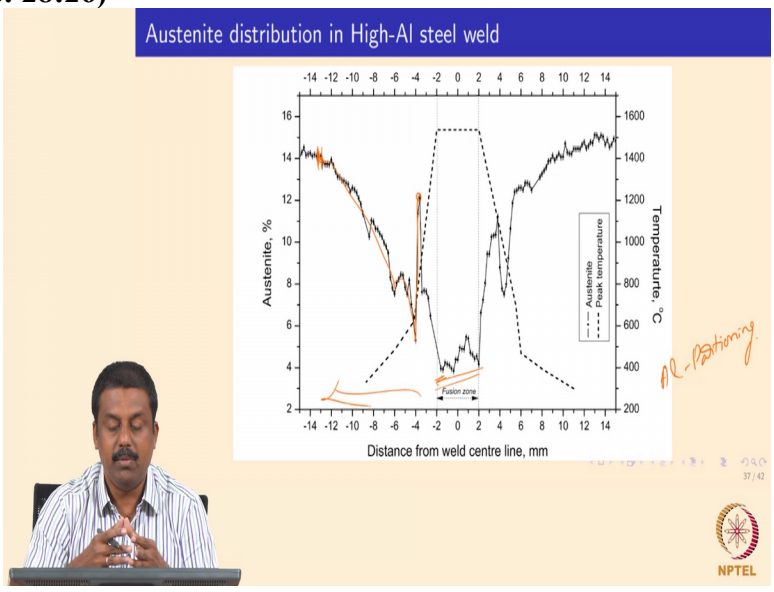

So this is in the case of high Silicon Steel and high Aluminium Steel you would see the similar effect only thing is stability of retained austenite is much lower in high Aluminium Steel than the high Silicon Steel. So, you see again the effect until the minus until 11 millimetre or so see no effect and subsequently it decreases ok until you reaches and the peak temperature reaches to the A1 temperature.

And once the A1 temperature is reached you will have the intercritical regions leading to partitioning of carbon resulting in increasing in volume fraction of retained austenite and subsequently when you go towards the fusion boundary obviously you will reach single phase austenitic region and that will lead to decreasing austenite faction ok.

In high Silicon Steel also saw the austenite fraction is increasing when you moving to the fusion boundary whereas in aluminium steel it does not show that affect mainly because of delta ferrite formation ok. So, the formation of delta ferrite can stabilize on delta ferrite leading to decrease in retained austenite fraction ok. And you have only delta ferrite stabilizing at this temperature because of the aluminium partitioning which I already explained in previous videos. So, you have a continuous decrease in retained austenite fraction and then of course in fusion zone.

You do not have any intercritical treatment or any other phase transformations other than complete martensitic transformation where as in this region peak temperature would change the austenite formation and decomposition mechanism. So, even though you have a similar microstructure in the base material both high silicon and high Aluminium Steel and you may end up getting different volume fraction phases in the heat affected zone. And it is always you should be very careful in welding the multiphase microstructure especially if retained austenite is present in the microstructure.

The volume fraction between the austenite can change as function of peak temperature reached during welding. So, I already explained the effect off peak temperatures. When the peak temperature is less than the A1 temperature, the A1 temperature is the maximum temperature upon which nucleate new austenite while heating and if it is less than the temperature whatever retained austenite in the microstructure would decompose ok based on the peak temperatures, again so when temperature below A1 temperature you will decompose all retained austenite to pictures of ferrite and carbides.

And moment if you go to the inter critical temperature above A1 you will end up having a partitioning of carbon between co existing ferrite and austenite and that can leading to increase in austenite fractions in the inter critical region and subsequently the temperature goes above the A3 temperature where you will have fully austenitic microstructure. So, there is no partitioning so you just cool down where ever temperature whatever temperature at the fully austenite region based on the carbon concentration.

In that region you would end up getting retained austenite there would not any enrichment subsequently when you are moving to the fusion boundary either in high Silicon and high Aluminium Steel and high Silicon steel there is a partitioning of carbon. Whereas in aluminium steel and fusion boundary you have a stabilized delta ferrite the fraction decreasing rate in austenite fraction. So, is that clear for you how the retained austenite changes along the weld zone starting from this material to the weld central line. Based on the peak temperatures you can have varying amount of retained austenite fractions.

The other lesson I want to give you here is if you have a meta-stable phases like retained austenite in microstructure you will also enlarge the heat affected zone. Conventionally he would not see any effect if you have ferritic pearlitic steel noticeable effect until your peak temperature reaches close to A1 temperature. And you will see maybe some sort of very small effect which is noticeable in terms of properties as well as the microstructure. But if you have meta-stable phases like martensite or retained austenite you will see the effect significantly.

There by you can say that the heat affected zone is enlarged in this kind of Steels due to the change in microstructures you observe the function of peak temperatures.

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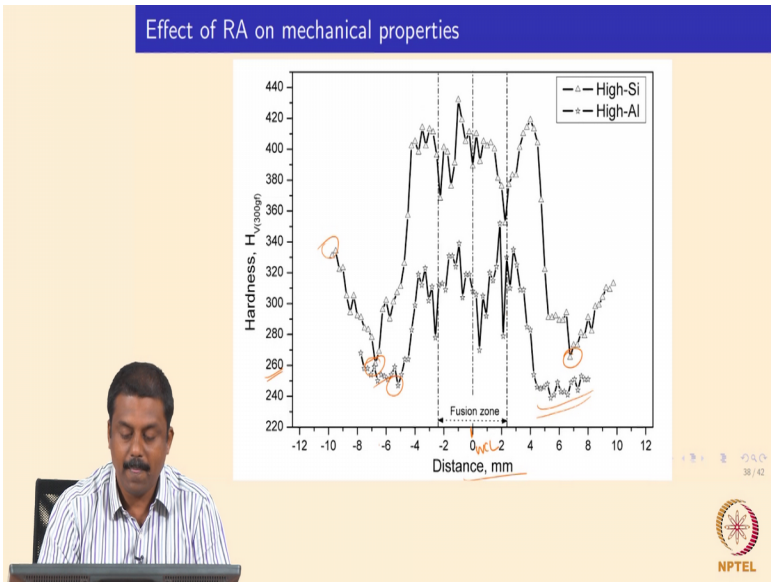

And you can also see the effect very clearly in the mechanical properties the effect of retained austenite fraction and you see that whenever you regions at which the temperature reaches to who just close to below A1 temperature where you do not nucleate. Where you have a minimal amount of retained austenite right so when you have a very minimal amount of retained austenite for example around where I showed you.

So, in the regions where 0% retained austenite is there say close 0% -6 to -8 ok where the temperature reaches just below A1 temperature you see extremely softening. So, this is the hardness so this is your weld central lines. Whenever the peak temperature reaches just below A1 temperature where we have minimal retained austenite you see the material soft and significantly ok. So when the base material hardness is 340 Vcos this region where the austenite fraction is Nil the hardness decreased to 260, why because the retained austenite is transforming to soft pearlite in the carbon mixture leading to decrease in hardness ok.

In the regions where we have a 0% close to 0% austenite it we have extreme softening and this effect you seen in both the cases and in high Silicon Steel significant because the effect is also very significant high aluminium Steels over retained austenite it is very poor and you will have a extremes softening. Of course in the weld zone you will have it's own retained austenite fraction as well as based on the segregation micro structure you will have a very high peak hardness.

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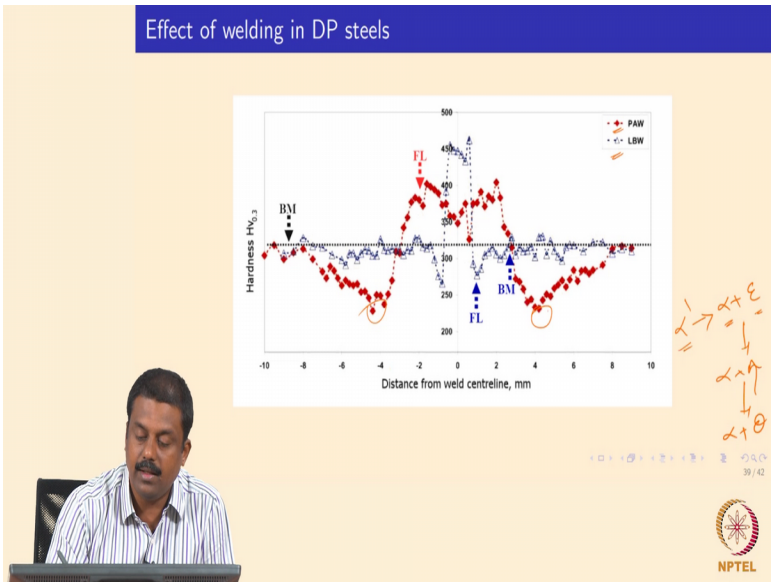

So we conclude here with this trip steel and we can also look at when same effect in dual phase Steel as well. And dual phase Steel instead of austenite we have martensite in ferrite matrix right. So, like in austenite is decomposing to ferrite and cementite mixture. The martensite in the microstructure would also so temper. So, the effect which is also similar when martensite is there the martensite will also temper and then the martensite would again transform to the set of ferrite and cementite.

Ok in the same way where the austenite would transform as I already explain to ferrite and cementite mixture your martensite will also transform into to ferrite and the carbon mixtures in the same manor and you that you also see the effect similar to what you see in trip Steel where the temperature is just below the A1 temperature where you will have a significant transformation of austenite into soft ferrite and cementite and that will lead to the transformation.

And the tempering of martensite leading to the softening what I showed over here is in two cases one is laser beam welding and other is Plasma welding in both the CCA especially in plasma see the effect is very significant and the significant amount of softening you would observe because of the tampering of martensite when the peak temperature reaches is below A1 temperature.

And that will lead to softening of in the heat affected zone where the peak temperature reaches below A1 temperature and you can see the effect and the effect is not significant and because of very narrow temperature region where weld region. So, with this we will conclude the retained austenite fractions and we looked at two techniques the magnetic saturation method to measure

the retained austenite fraction and it is the bulk measurement and it can give information about the retained austenite over wide area.

So, we have to found out; we have to use other techniques where we can measure the retained austenite very locally at with very good special resolution so we can use the X-ray diffraction and explained using x-ray diffraction how retained austenite fraction changes over the weld regions from the base material to the weld center line. And based on the peak temperature range and we also saw fraction also change whether it is completely decomposes to mixture of ferrite and austenite or ferrite and cementite.

Or the temperature reaches to intercritical temperature in the critical temperature where in both ferrite and austenite coexist and you will have local partitioning which will leading to which leads to the transformation of retained austenite. The stabilization of retained austenite at room temperature and when temperature reaches to fully austenitic region there would not be any part petitioning so based on the carbon concentration and at that region and you have low retained austenite when compared to inter critical regions ok, thank you.