

Welding of Advanced High Strength Steels for Automotive Applications
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Lecture - 18
Quantification of Microstructural Constituents in Automotive Steel Welds Part - I

So, we looked at the role of alloying elements how these alloying elements behave during solidification of the weld pool, okay. So now, we will move on to the other aspect in the development of micro section in the heat affected zone.

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What happens to retained austenite during welding ?

$\alpha + \alpha_{\beta} + \gamma$

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How the microstructure can change during applying a weld thermal cycle while applying weld thermal cycle. So, we looked at the micro section of trip steel for example, contain three important phases ferrite, the carbide free bainite and retained austenite. And so when the temperature is reached above the three temperatures, the austenite formation temperature is the entire microstructure what is shown over here would completely transform into austenite.

But then, you would also have a regions in the heat affected zone where the peak temperature reached is less than the austenite formation temperatures. So then, you would expect the austenite would also change its morphology or it will also even destroy completely during heating. So, we will have to understand how the retained austenite fraction change in the heat affected zone based on the peak temperature reached.

So we have already looked at the variation in the peak temperatures when you move along from the real center line so suppose if this is your well center line and when you move are going away from the well center line to what the base material or peak temperature would range from close to melting; then we will go to room temperature and far away from the weld.

And so the regions where the temperatures range to the temperature below the A3 temperature the austenite formation temperature then you may expect his retained austenite would completely destroy. But we need to understand and how the microstructure can change when you heat up the material in the heat affected zone. Temperatures ranging from say room temperature to A3 temperature. So, regions where you would expect no transformation but you may expect a change in the microstructure.

So, we will see what happens to retained austenite in the microstructure because this austenite is a very important constituent to get the properties of the trip steel or even in complex based steels and we have to have austenite to achieve the combination of a strength ductility.

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Quantification of retained austenite

- Optical microscopy with tint etchants ✓
- Magnetic saturation (vibrating sample magnetometry) ✓
- X-ray diffraction (synchrotron) ✓
- Electron back scattering diffraction (EBSD) ✓
- Thermal diffusivity ✓
- Laser-Ultrasonics ✓
- Thermoelectric power measurements (Seebeck effect) ✓

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And first of all you know we need to look at the, what are the techniques available to quantify your retained austenite in the steel microstructure. So, once you have these techniques ready then we can analyze the retained austenite concentration in the welds and then based on the measurements carried out at the very ingredients in the weld and we can say how the austenite conservation change as a function of the weld thermal cycle because well thermal cycle is not as in a typical heated treatment done to a trip steel right.

So, you may have the peak temperature varying from foreclosed melting point you know about melting point freeze and zone to room temperature I mean far away from the weld center line. So, some of the common techniques we use to quantify retained austenite you name Steel's you can use a simple optical microscopy with color agents like for example this microstructure was made using an a color etchant and where we can see the presence of three phases very clearly and you have an alpha. We have an, the Alpha matrix and you have the brown color here is carbide free bainite, carbide free bainitic ferrite.

And the bright lines over here you see these are all the retained austenite as I have explained. So, now we can use an a simple point counting method to calculate the volume fraction of individual faces but again I mean it will not be accurate when compared to the other techniques it is listed over here because what you are seeing over here it is not a representative full representation of the volume, so some of the techniques like, you know the magnetic saturation method which can be used to measure the retained austenite concentration in bulk, in the entire sample.

I will explain the principles in a subsequent slides and we can also use an x-ray diffraction and x-ray diffraction gives the quantitative information from the diffraction peak analysis and we will also see in subsequent lectures how the x-ray diffraction can be used to quantify the retained austenite and some other uncommon methods. And they are sophisticated techniques to quantify retained austenite.

For example you can use the back electron back scattering diffraction EBSD or thermal diffusivity, Laser-ultrasonics or thermoelectric power measurements. So, in this case, the magnetic saturation and to some extent you may even use a synchrotron x-ray diffraction, you may also have measure retained austenite in bulk or in the entire volume. EBSD again is similar to an optical microscopy where we have only two dimensional imaging so that you know you may get only the retained austenite fractions at a given locations of the scans.

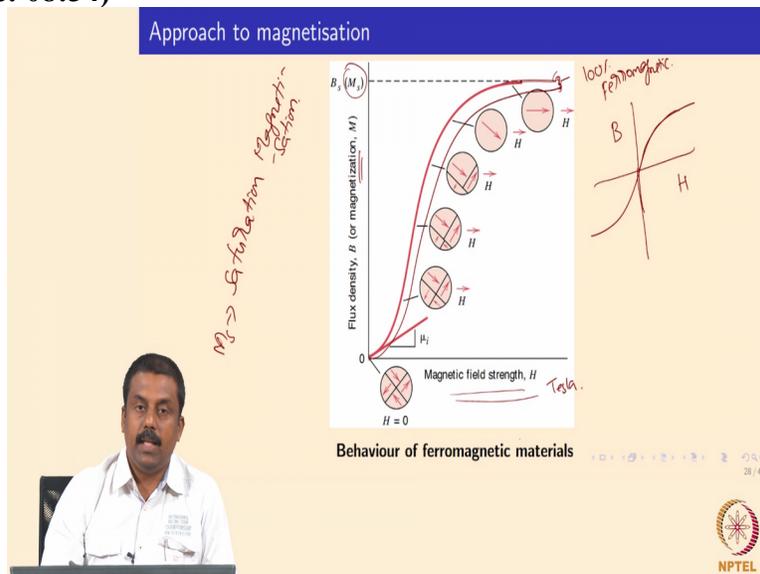
And the thermal diffusivity method work the by measuring the heat transfer as a function of microstructure constituents and then by changing the transfer characteristics we can also measure the exact amount of retained austenite and also we can also use a laser and ultrasounds were from the attenuation velocities of when the laser and ultrasounds we can clearly see the difference in the microstructure constituents and we can quantify from the attenuation the volume fraction of the retained austenite percent in the microstructure.

And same goes with the thermoelectric power measurements. We use the Seebeck effect through, to understand the variation in micro structures and by seeing the variation in the aim of generated as a function of micro cyclic constituents they can also measure the retained austenite concentration. But the most common method is used for quantifying retained austenite in steel is the magnetic saturation method. So why magnetic saturation method because when you look at the micro structure constituents of steel the austenite is a paramagnetic.

That means that it is not magnetic and compared to the other the commonly present micro circular constituents. For example, ferrite is ferromagnetic cementite is ferromagnetic below Curie temperature and martensite is also a ferromagnetic below Curie temperature so by measuring the paramagnetic microstructure constituents quantity, so we can also measure the quantitatively how much of the retained austenite is present in the microstructure.

So, the technique we use for measuring retained austenite is known as vibrating sample magnetometer so you can refer in literature's now the technique work but I will explain the principle how we measure the retained austenite concentration using this technique.

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So, how we get the retained austenite concentration is to get the saturation magnetization values. So, we measure the magnetic the saturation or mass magnetization as a function of applied magnetic field strength in Tesla. So, we have a typical magnetic hysteresis curve we must have studied in, in a +2 physics. So we generate such a hysteresis curve and if you look at this curve

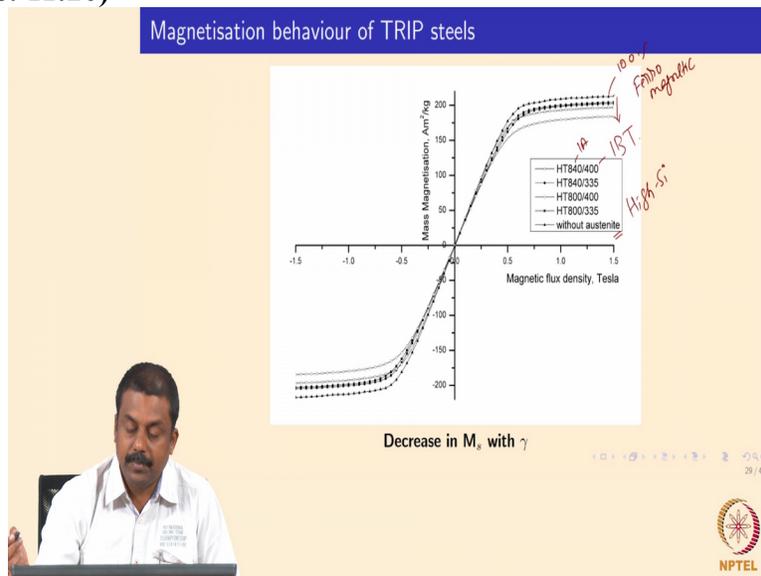
and typically when you start applying a magnetic field the ferromagnetic material get magnetized as a function of the applied field.

And then upon reaching an critical field strength the magnetization saturates to a value. And this saturation value is known as magnetic saturation M_S or a saturation magnetization. And this M_S value, the magnetization saturated value change if you introduce a paramagnetic constituents in the micro structure. For example if you have a fully 100% ferromagnetic material and you have an M_S value say, for example, this value corresponds to 100% ferromagnetic microstructure.

So, now you introduce retained austenite into this micro structure that means that you are introducing and some component of paramagnetic constituent. So then, the magnetic saturation decreases which may not be in this value so we may expect a saturation value decreases compared to a micro structure with completely ferromagnetic constituents. So, the difference between the structures with the 100% ferromagnetic to the saturation values with the paramagnetic constituents.

And this difference can give us quantitatively how much amount of paramagnetic component is there in the micro structure. So, that means that by measuring a micro structure saturation value saturation magnetization value with and without paramagnetic component and we can see we can quantify the retained austenite concentration which is paramagnetic in the micro structure.

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So, a typical mass magnetization curve for a trip steel is given. For example, in this case, the top curve is without retained austenite for a typical trip steel composition and image these

measurements were made for the high silicon steel which is showed in the previous lectures. And if you look at it and I by changing the, inter critical annealing temperatures and integrating temperature and isothermal bainitic holding temperatures and we may also change the retained austenite fraction in the microstructure.

Say in one case, in the first case and we have micro structure without retained austenite and we have a 100% ferromagnetic material sorry and by introducing the paramagnetic component your magnetic saturation value decrease compared to the micro structure without retained austenite. So, by calculating the differences, we can calculate how much amount of retained austenite is there in the micro structure, okay.

So, that is the basic principle behind using the magnetic saturation method where we measure the magnetic saturation value with and without austenite. And the difference would give us the amount of for retained austenite percent in the micro structure.

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Calculation of γ fraction

$$f_{\gamma} = 1 - \beta \left(\frac{M^s(c)}{M^s(f)} \right) \quad (1)$$

f_γ → Volume fraction
β → Non-metallic inclusions
M^s(c) → M_s with RA
M^s(f) → M_s without RA

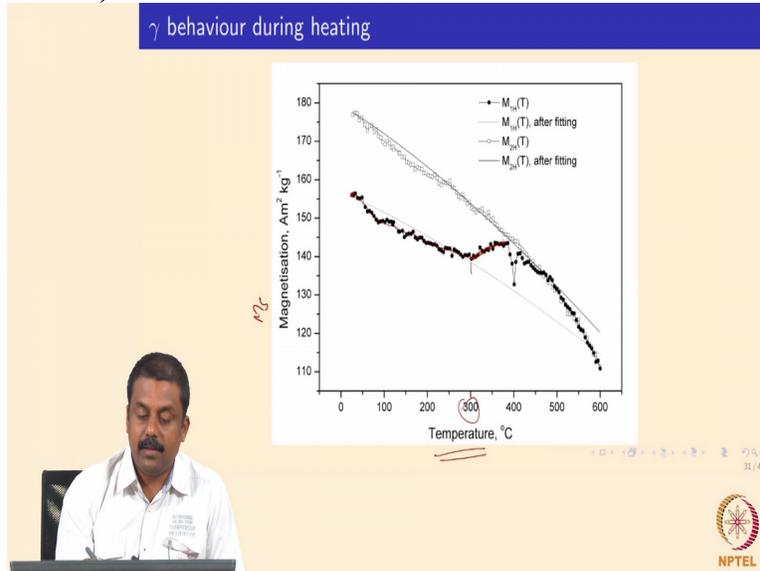
So, the equation goes like this so the volume fraction of retained austenite f_{γ} , this says nothing but an one minus an coefficient which takes care of the presence of non-metallic inclusions. Generally these non-metallic inclusions can also be paramagnetic. So, the beta takes care of the presence of other non-metallic phases which are paramagnetic. And generally if you do not have inclusions in the microstructure and this goes away.

And then the ratio between the magnetic saturation without austenite to a magnetic saturation with austenite would give you the diffraction of retained austenite present in the microstructure.

So, M_S is M_S saturated magnetization without RA, to the M_S with RA. So, this would lead to the calculation of RA volume fraction in the microstructure. So, this is the basic for the measurement of retained austenite using magnetic method where we measure this mass magnetization with and without austenite.

And then we can calculate accurately from the saturation values the amount of austenite present in the microstructure.

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And the same technique can also be used to understand the stability of retained austenite in the microstructure, especially for example, in heat affected zone and we may also heat up the microstructure to various temperatures and then cool down. And we will also have to understand how austenite stability is affected by this heating. So you can clearly see here what you see over here is the M_S the magnetization measured as a function of temperature. So, if you look at this, at room temperature that is the temperature mass magnetization value in a trip steel at the room temperature.

So, when you have a trip steel containing micro structure heated up retained austenite containing micro structure heated up to a higher temperature, so what will happen then retained austenite what will happen over here is the magnetization decreases as a function of temperature effect and once you reach a critical temperature your retained austenite present in the micro structure its microstructure is transforming into the α phase another phase which is ferromagnetic.

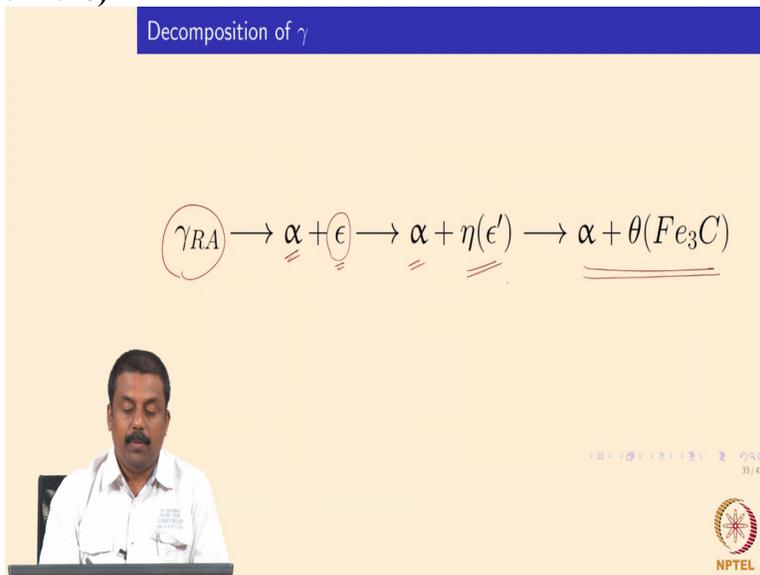
So, what implies this reaction is you have an retained austenite containing a trip steel, but even you heat it up your MS the mass mechanization, saturation suddenly increases upon reaching a critical temperature. For example in this case, around 300 degrees centigrade that means that the microstructure is becoming more ferromagnetic right? So if there is increasing saturation, what does it imply? It implies that the microstructure is now becoming more ferromagnetic.

That means that something happens to retain austenite and retain austenite is converting into more ferromagnetic structure. And we will see in subsequent slides what happens to retained austenite. Now we can see from the measurements of magnetic saturation over a temperature and you would see an increasing maturation upon reaching critical temperature. And thus that can happen only when the microstructure became more ferromagnetic and you also see that some other where the change in slopes.

So, in during this transformation we also see certain decrease and increase in saturation values during heating and subsequently when you increase the temperature further and you would expect a thermal effect leading to an decreasing saturation. So this sudden change in slope we can relate to the decomposition retained austenite during heating. So, what happens when you heat up the retained austenite containing microstructure?

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Decomposition of γ

$$\gamma_{RA} \rightarrow \alpha + \epsilon \rightarrow \alpha + \eta(\epsilon') \rightarrow \alpha + \theta(Fe_3C)$$


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This is the retained austenite present in a Steel's is transforming into the mixture of ferrite and iron carbides, in steps described in this equation. So, first retained austenite is transforming into ferrite and epsilon carbide. Epsilon carbide is another transition carbide you will expect, when either austenite or a martensite is a tempered. So what you will see over here is austenite,

austenite is heated up to higher temperature heated austenite is transforming into Ferrite and transient carbon mixtures ultimately leading to a formation of equilibrium structure, now which is a ferrite and cementite.

So, what happens here when you heat up the retained austenite is retained austenite is decomposing into Ferrite and epsilon carbide mixture and then subsequently may expect an ferrite and eta carbide and then ultimately if ferrite and eta carbide will change into a ferrite and cementite mixture. And how do we know that there is a transient carbide formation? And if you look at the magnetic curves you also see an decreasing in magnitude saturation values when you are doing it these transient carbides are also a pair of paramagnetic carbides.

So, therefore you can understand very clearly that when it retained austenite is transforming into a ferrite and cementite mixture and do you expect an increasing ferromagnetism because of ferromagnetic a ferrite the forming from retained austenite and subsequently because of the transient carbide formation you see an decrease in a saturation and once you have complete transformation of retained austenite into an ferrite and cementite mixture, then, you will have a ferromagnetic microstructure.

So, what this implies is if you look at the onset of transformation of austenite during heating so we expect a transformation of austenite to ferrite, there are the temperatures around 300 degrees centigrade. So that means that in an actual welding case so when the peak temperature in the heat affected zone reaches even as low as 300 degree centigrade you expect an change in microstructure.

So, therefore the heat affected zone, the width of the heat affected zone in an compared to conventional Steel's where you would not see any change in the microstructure when the temperature reached to 300 degree centigrade whereas in trip steel. So, we expect a significant change in the microstructure because of the transformation of retained austenite. So, we summarize here. So we looked at the variation of retained austenite along the micro structures of the heat affected zone.

And we also looked at the stability of retained austenite as a function of temperature and how what are the techniques we can use to measure the retained austenite in the microstructure. And

we move on subsequently in next lectures how they retained austenite fraction varies as a function of peak temperature range in the heat affected zone.