Welding of Advanced High Strength Steels for Automotive Applications

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Lecture - 01
Introduction to the course,
Introduction to physical metallurgy of steels

Hello friends welcome to the NPTEL certification course on building of advanced high strength steels for automotive applications my name is Murugaiyan Amirthalingam, I am working in the department of a metallurgical materials engineering and the Indians of Technology Madras. In next four weeks I am going to talk about the welding behaviour of the modern automotive steels. So, I hope you enjoy attending this course and yeah you are most welcome to ask any questions if you have during this course in the forum as well as you can contact me in through the NPTL and NETPL website.

Now you must have also seen me in the introduction video I hope you attend this course with a keen interest and learn about this advances high strength steel's and the welding behavior of these Steel's ok. Before going into details I request all of you to do the assignment 0, I hope you must have done it so make sure that any score minimum of 6 out of 10 I asked because that is very important to judge yourself whether you are capable of attending this course to and understanding the concept I am going to explain during this four weeks.

Even if you do not do score 6 marks it does not matter you can still go through these subjects what I am going to describe in the introduction video you know what I described in video and I am what I am going to talk about now for next often hours or so you brush up your basic and then no you can also ask me if you need any help in terms of literature's reference books or any materials which can make you comfortable attending this course okay.

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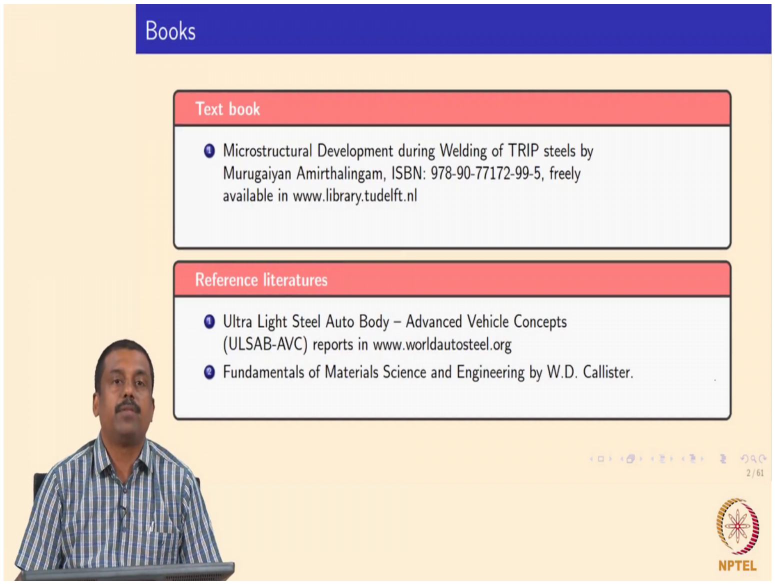

So, having said that and I can refer following these textbooks for your code for your reference so you can refer one of your books the microstructure development during building up TRIP Steel's so you can freely download this book from the repository of library. tudelft. So, the chapters I am going to talk about in introduction to advanced high strength Steel's basic and the welding metallurgy of advanced high strength steels are all covered in the textbook.

Please refer to that book and plus I will be giving out the handouts and the slides what I am going to show you in during the course of these lectures. So, you can refer that and of course and you can also ask any questions if you have during this course through the forum I will be glad to answer all the questions. Some of the literature's I am going to use for these lectures actually you know from the ULSAB documentation.

So, what is ULSAB? ULSAB is Ultra Light Steel Auto Body the advance high strength concepts it is actually a body set up by the steel and automakers. So, you can download the various reports the materials what I am going to refer from the website www.worldautosteel.org it is nice website you can go and learn about advanced high strength steels as well as they are processing and the applications. So, I am also going to teach some fundamentals about the steel physical metallurgy which is very important.

Because your fundamentals of welding metallurgy of advances high strength steel's are all from these the physical metallurgy the heat it meant the effect of thermal cycles or the weld welding process on the phase transformations okay. So, those I will be teaching anyway during the first introduction hour and you can also refer the fundamentals of materials and engineering by

William Callister book which is also very handy ok. So, apart from that I will also be giving these slides and some of the literatures of my own for your reference good.

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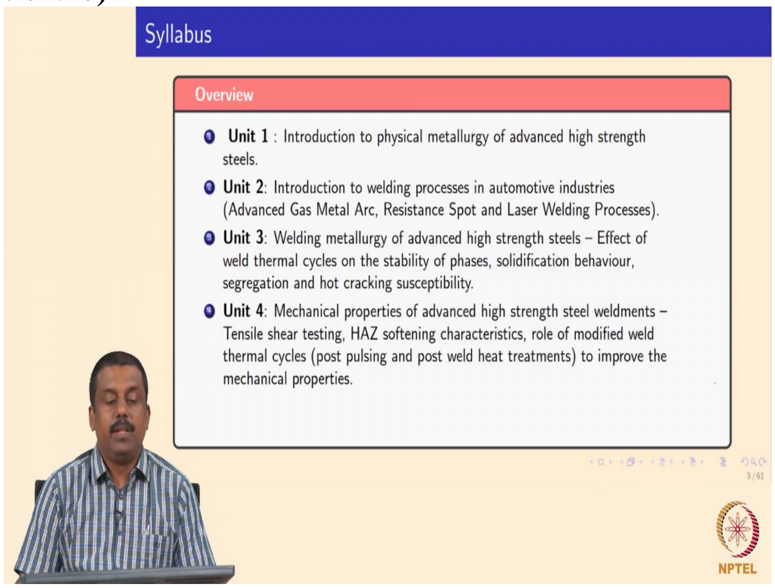

So, this slide shows the overview of the course content right. So, the first unit I will be giving introduction about steel physical metallurgy. So, basics fundamentals about iron carbon system. And so, what is a microstructure for a given composition? What are the microstructure phases you may expect for a given heat treatment. For example in a weld thermal cycle in particular and then I will move on to the introduction about the advanced high strength steels.

So, why we why do we need these Steel's and what makes them interesting for automotive applications, so what is the driving force for development of these Steel's and what are the advantages in terms of economy, in terms of cars, in terms of environment. What are the advantages we are going to gain by replacing the conventionally used Steel's in the advanced high strength steels in auto bodies okay.

Then I will move on to the introduction to various welding processes that are commonly used in automotive industries to weld Steel's and other alloys. I will concentrate on some of the interesting and important three welding processes. The advanced gas metal arc welding process and the resistance spot welding process and the third and finally laser welding processes. I will give you an introduction about all these three processes what are the important term parameters those dictate the weldability and the final mechanical properties of the weld.

And how we can favorably modify those welding parameters to achieve better micro structures and good mechanical properties, the second unit in third week I will be moving towards the actual welding metallurgy of advanced high strength steels. So, I will talk about the effect of weld thermal cycles on the various micro structural developments, stability of phases that are generally present in these Steel's.

And what are the roles of alloying elements that we add for example we add carbon, manganese silicon, aluminum in some cases even as a moment of boron and some of the impurities like phosphorus, sulfur they are always present. And what are the roles of for the alloying elements during the development of microstructure while applying the weld thermal cycle and so there are some interesting phenomena that are happening while welding of advanced high strength steels such as the segregation, micro segregation and the hot cracking during welding.

These are all interesting topics and important topics you need to understand to understand the developing behavior of advanced high strength steel's. And the final week then we move on to the mechanical properties of the advanced high strength steel elements. So, we will start with an introduction to the common testing methodology that are used in for to evaluate the mechanical performance of wells in automotive industries.

For example will see a tensile steel testing and for example cross tension testing and see what are the standards that are actually used to govern the testing methodology of evaluating the mechanical properties of elements? And then we want to be the effect of micro structural changes that are happening in the heat affected zone on the mechanic properties such as a HAZ softening that is commonly observed in some advances high strength steels.

And we will look at the how the weld thermal cycles can favorably modified to achieve good mechanical properties. So, we see the effect of the common weld thermal cycles as well as we can also modify the general value thermal cycles to achieve good mechanical properties. For example and use of post pulsing and possible heat treatments to get the desirable microstructure in the fusion as well as the heat affected zone.

So, this gives the overview of the actual the course which I am going to take for next four weeks so I will try to make it as easy as possible I know most of these students who are attending this course are not from metallurgical background. It does not matter even if you are for a mechanical

Sciences or any other background. I will make it as simple as possible and I hope you enjoy attending this course.

So, before going into the detail about advanced high strength steel the first thing you know a first thing you need to understand is the steel physical metallurgy because that is very important in order to cope yourself for the subsequent topics okay. So, I will just give you the basic introduction about the steel physical metallurgy.

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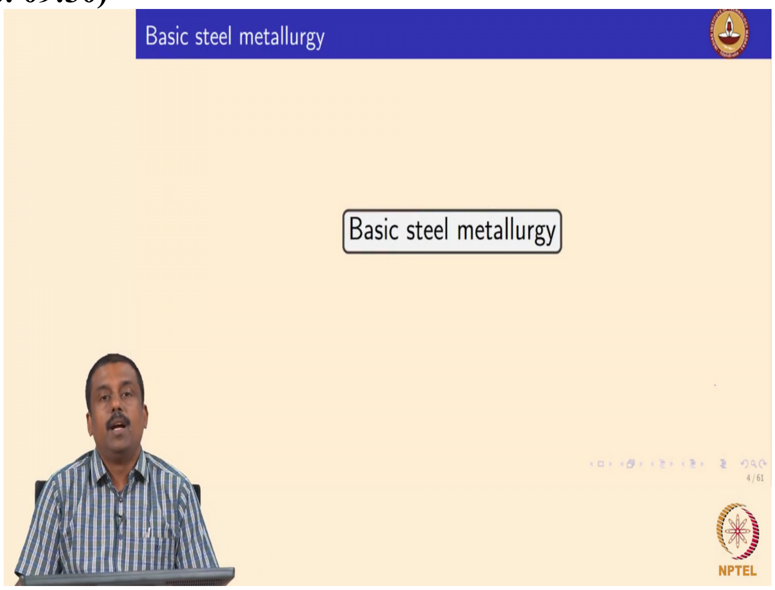

So, you still me you all know that I mean you know it is an alloy of iron and carbon okay. So, do we add a carbon into iron apart from carbon we also add other alloy elements various alloy elements is possible. I think most common are manganese, silicon, chromium, nickel and other alloy elements which are added to improve various performance as mechanical performances like you know an niobium, titanium, vanadium these are all micro alloying additions to cause precipitates.

Or some special alloying elements sometimes we even I have boron apart from these alloy elements we also have impurities generally phosphorus and sulfur they are all concerned purities it is very difficult to remove them so we like to work with them. Even though if they are there in a trice element trace amount I mean they may still cause various problems during welding. So, we look at the effect of alloying elements and the role of heat treatment and the role of both combination of alloying elements and heat treatment on the micro electric generation okay.

So, we go one by one first to understand the fundamentals are iron-carbon system okay. So, if you look at the moment you say the iron carbon system we look at the phase diagrams okay so yeah I hope all of you familiar with the iron carbon phase diagram if you are not?

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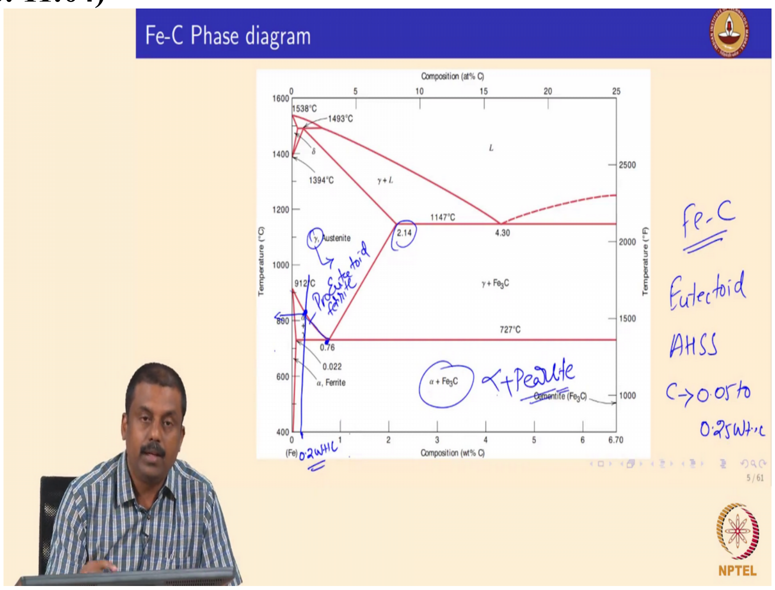

I am going to show you now the iron carbon phase diagram what do you see over here various lines which each line actually means a lot in this phase diagram if you look at the axis's what we have it here is the temperature axis in y axis and the Composition x axis the composition generally because this is an iron carbon diagram. So, we have the composition in x axis which is actually a carbon and the temperature is no y axis.

The moment you say steel we restrict the composition of the carbon less than the 2.14 so the carbon concentration is less than 2.14 is considered 60 the reason is the solidification behavior what you see over here which I am not going to in detail so you can refer some text books about it. So, what is interesting in this here in this course perspective is the regions that are present the temperature ranges over 1000 degrees centigrade maximum carbon concentration is of 1% okay.

This region what you know what you see over here is known as the eutectoid region of the phase diagram. So, eutectoid is okay it is nothing but we have here the transformation of austenite which is an FCC phase the high temperature the electric phase of the iron is transforming to the mixture of the what do you call the ferrite under cementite okay. And this happens 100% that means that austenite transforms to pure ferrite plus cementite mixture.

At the carbon concentration of 0.76 so this is the eutectoid carbon concentration it is very important. In this course as I said we will be looking at advanced high strength steels. Generally the advanced high strength steel the carbon concentration vary somewhere from say 0.05 to not more than 0.258%, so, our carbon concentration range; so in this steel once again still generally lie somewhere over these regions okay.

And what you see over here in this region is the lines corresponding to the carbon concentration in various phases' right. So, if you look at this line over here; so this line indicate in the carbon concentration in ferrite which is in equilibrium with austenite. And this line indicates the carbon concentration of austenite which is in equilibrium with ferrite so that we need to understand clearly.

So, this line indicates the carbon concentration of ferrite which is an equilibrium with austenite okay. So, if you look at it these two lines your carbon concentration of austenite decreases with decreasing temperature. Similarly you have a line which indicates sorry which indicates the carbon concentration of ferrite which is an equilibrium with austenite which is also a slightly decreasing but not as significant as and the other line.

And this point corresponds to the eutectoid comparison where the austenite can completely transform into the mixture of ferrite and cementite and this mixture is known as ferrite right. And we will see how the microstructure of pearlite looks like in subsequent slides. So, in this slide it should be understand and you should be clear that the carbon concentration of advances high strength steels which are of interest to us.

It actually very ranges from 0 to say about 0.25 weight % right. So, now if you look at this diagram, so if you heat up a steel containing say 0.2 weight % carbon to higher temperatures okay. And whatever microstructure you have would transform to austenite the moment sorry your temperature reaches at this temperature when you heat it up your entire microstructure would transform into austenite under equilibrium conditions.

So, if you are heating up above say for example in this case 820 degree centigrade in a pure iron carbon system you expect your micro structure fully transforming into an the austenite okay. So, if you are heating up the microstructure containing a 0.2 weight % carbon of a pure iron carbon system the moment to the temperature reaches above say 820 degree centigrade you will form a complete austenitic microstructure okay.

When you cool down subsequently to room temperature okay based on the you would end up forming the microstructure which can have a mixture of ferrite, pearlite or the other variants of paralytic structures such as bainite or you know if you cool very rapidly you may end up forming martensite okay. So, first you need to understand from this graph is so suppose if we have 0.2 weight % carbon and you are cooling down to room temperature you austenite would keep on enriching because of the formation of first the ferrite.

And then subsequently the moment to the austenite which is untransformed reaches the carbon concentration eutectoid carbon concentration then you will end up forming pearlite okay. Now the whatever the ferrite that formed before the reaction the pearlitic reaction is known as the pro eutectoid ferrite because it is actually forming before the eutectoid reaction. So, that is known as pro eutectoid ferrite.

And subsequently the moment or a carbon concentration of austenite reaches eutectoid carbon concentration the remaining austenite were transformed into pearlite okay. So, if you are cooling steal content 0.2 weight % carbon you may have a mixture of pro eutectoid ferrite and pearlite right. So, now this diagram does not tell you about the time okay. So, what are the effect of cooling rates and what are the effects of alloying elements because apart from carbon we also have various alloying elements that are actually added.

So, based on the concentration of all other alloy elements and cooling rates the nature the morphology of the phases that are forming austenite can also change right.

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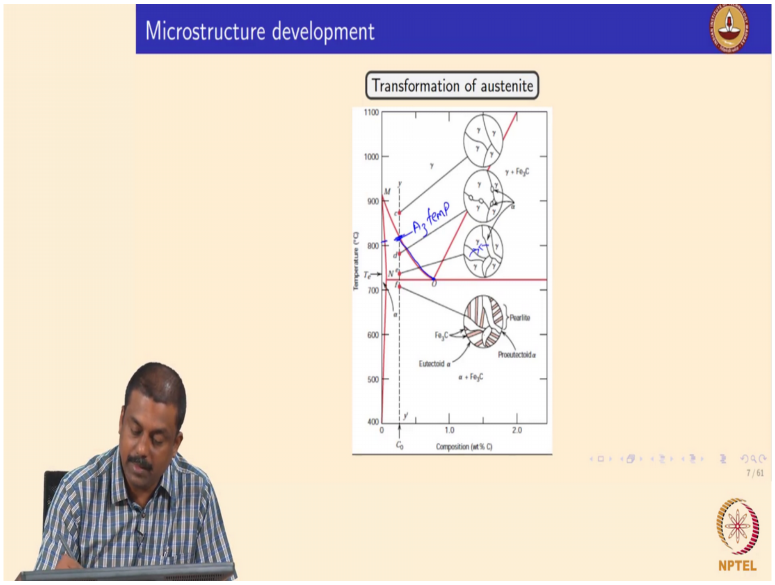

So, now we look at in detail firstly what are the farming mechanism are for pearlite from the austenite when you are cooling down at various compositions and we want to the effect of allowing elements on the transformations and subsequently will go to see the effect of cooling rates are the time in there the time variant at the factor time factor in this transformations. So, I like to explain that in the 0.76% carbon which is your eutectoid carbon concentration.

So, suppose if you start with the steal it is not advance high strength steel, a steel containing say 0.76%, 3% weight percent carbon. So, if you are cooling this steel containing this carbon so obviously the transformation of austenite would be completely too pearlitic transformations where you would expect the mixture of ferrite and cementite forming okay. So, what you see over here the ferrite and cementite will be forming in a laminar manner.

We will see in subsequently in subsequent slides or slides how exactly the deformation mechanism of pearlite for this eutectoid composition steel. So, this composition is already explained is known as eutectoid composition and this generally happens in the iron carbon pure iron come system at .76 weight % carbon. If you have alloying elements you would also change the eutectoid composition based on the nature alloying elements.

We will discuss about it also in later suppose I already explained about advanced high strength steels contain the carbon concentration in between around say 0.05 to the 0.25 weight % right. Then the steel composition lies in this region okay. So, we define the steel composition that are actually less than the eutectoid composition is known as the hypo eutectoid steels because the carbon concentration is less the eutectoid right ok.

Hypo-eutectoid steels the steels that are having a carbon concentration above the eutectoid point they are known as hyper eutectoid steels right. So, our advanced high strength steels are all hypo eutectoid steels where the carbon concentration is less then eutectoid composition right. So, yes I already explained in previous slide our composition slides somewhere over here right. So, imagine we have the composition something about 0.25 weight %.

If you go and look at the transformation mechanism as already explained in previous slides. So, we have the austenite which is you know a personal cubic structure. So, when you cool it to subsequent temperatures the moment your temperature reaches below this line you would start nucleating ferrite not based on your cooling rate okay. Suppose if you are cooling to a temperature below a temperature of say which is actually known as an A3 temperature.

So, you would start nucleating ferrite so the moment is nucleating ferrite what happens the carbon concentration ferrite is I already explained is actually given by this line right. So, this is your carbon concentration of ferrite and this is your austenite carbon concentration. If you subsequently cool further your carbon even ferrite would start growing in the austenite matrix. In this case is ferrite and during this process the carbon would start be going out of ferrite to austenite.

And segregating the austenite and your carbon concentration austenite would change according to this line. The moment the austenite carbon concentration reaches this point you would trigger the paralytic transformation this nothing but a mixture of ferrite and cementite, good.

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Now if you look at the actual microstructure of the steels the both steels I talked about. The steel's containing 0.76% close to eutectoid carbon concentration, you will have 100% pearlite because there is no other transformation. The entire austenite will be transforming into pearlite and the microstructure looks like what you call is then a fingerprint of your a finger where you see a lamb glass of here is black is cementite and this is ferrite.

If the steel contains the carbon concentration less than eutectoid carbon concentration your micro structure contains first the ferrite which is pro eutectoid ferrite and upon sufficient enrichment in carbon the austenite would transform into eutectoid, pearlite. So, this is a eutectoid pearlite okay. So, a condition for this is your carbon concentration is must be less than eutectoid composition which is 0.76.

And most of our advanced high strength steals the composition would lie in this composition range where if you are a cooling sufficiently slow you would end up forming ferrite plus pearlite which is nothing but mix of ferrite and cementite. Yes it is clear, good.

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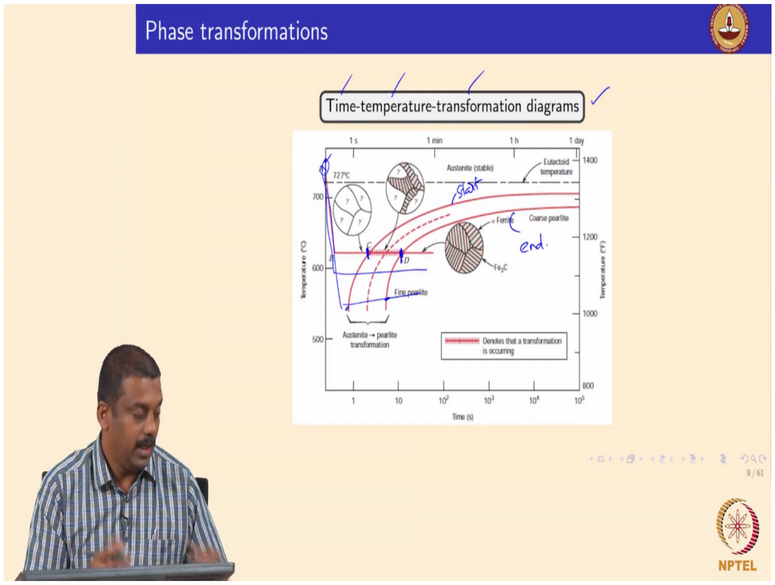

So, now as I explained the iron carbon phase diagram does not consider the time effect all right. So, we need to incorporate a time effect in the; to understand the phase transformations the kinetics of phase transformation. How fast the reaction can takes place in whether and holding at some temperatures are subsequently cooling to room temperature continuously from austenitic temperatures okay.

So, we use two types of diagrams to understand the phase transformations in uncommon systems. The first diagram I am going to talk about is the time temperature transformation diagrams okay and in this diagram is these diagrams used to describe the phase transformation kinetics when you are holding isothermally at a temperature upon cooling from the austenite temperature.

Say this diagram shows the time temperature transformation diagram where we plot the various curves which I am going to explain in two accesses in Y and Y axis temperature and X-axis the time the of holding in this case so this diagram can explain say for example if you are cooling from the fully osmotic region rapidly and then hold it a particular temperature and we can identify the start on end off transformation okay.

So, at what time your transmission from austenite to pearlite begins and your austenite to pearlite ends right. And so we can cool it to various temperatures and hold it and identify this start of transmission and end of transmission so this is part of transmission and this end of transmission okay. But in this diagram so I see and the commercial application of this diagram is limited because in most of the applications in for example in welding our transmission is happening under continuous cooling right.

So, the sample is cool continuously from a austenitic temperature to room temperatures. So, we need to include the other parameters compared with this diagram which is known as continuous cooling transformation diagrams okay.

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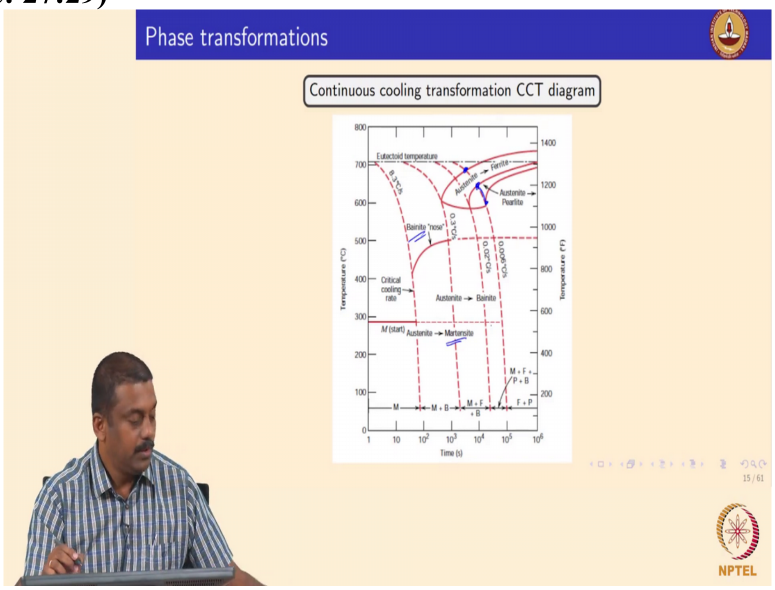

So, in the continuous cooling transformation diagrams where we identify the start and end of transmission when you are continuously cooling from high temperature to low temperatures okay and during this cooling process we identify the start and end of transformations for example in this case again what I explained here is the transmission of austenite to pearlite beginning transmission and end of austenite to pearlite transmission for an a hypo eutectoid steel.

And then the moment the pearlite and austenite information finishes then you would say have a paralytic information and this is pearlite start and pearlite end for this cooling rate. So, now if you look at these diagrams apart from this ferrite and pearlite transmission we also have a various other lines for example we have a bainite we have what you call the martensite and what are these, so we need to understand before going in detail about the CCT diagrams.

And we look at what are the other possible micro structural features that can form when you are cooling continuously the austenite to room temperatures okay.

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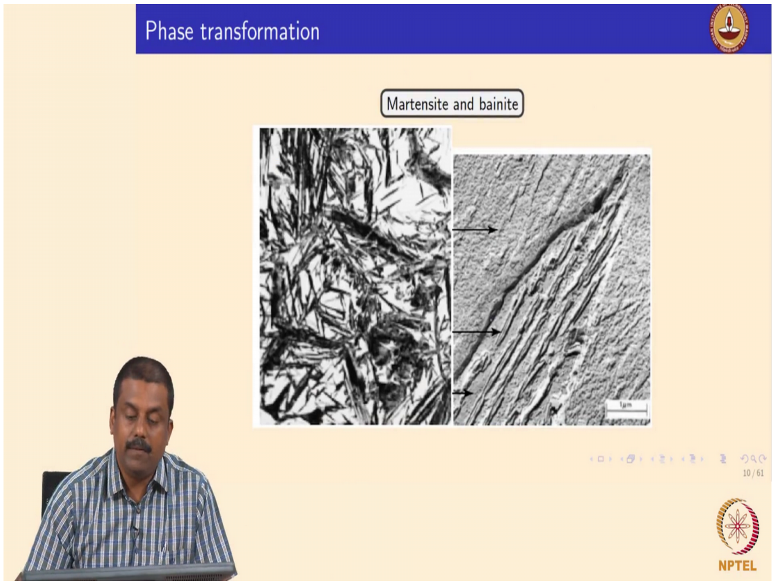

So, for that we will first look at the morphology of these two phases for example martensite, bainite. And this figure shows the other phases that may also form while cooling the austenite continuously to room temperature. So, this is a typical microstructure of what do you call martensite and this is a microstructure of bainite. Nobody see over here in the right hand side all right. So, the deformation mechanism of bainite and martensite is slightly different from the pearlite formation mechanism right.

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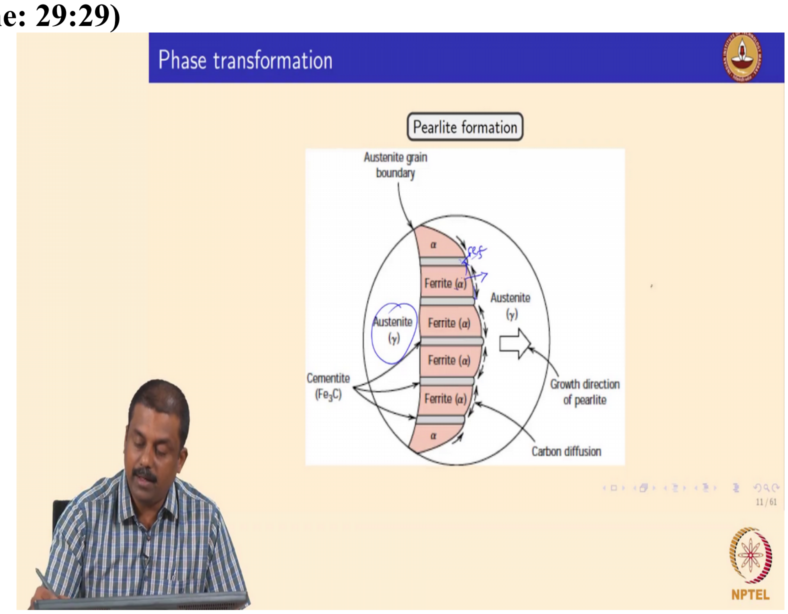

So, in pearlite formation mechanism so as I explained when austenite which has a carbon concentration less than protectoid less than eutectoid composition you would first nucleate ferrite and then ferrite once it forms it is not ejecting carbon to the altrans and austenite and that austenite transforms to pearlite upon reaching the eutectoid composition. So, in pearlite formation if you want to understand it is clearly you can refer this figure where we have the austenite when it cool or when it transforming to pearlite the ferrite first nucleates.

At the time boundaries as already explained the carbon concentration of ferrite is always less than the carbon concentration of austenite. So, the moment ferrite forms it has to eject carbon to the untransformed austenite adjoining to the ferrite. So, the carbon goes away from ferrite to austenite the moment you have a segregation of carbon sufficiently reached you would start precipitating austenite ok.

So subsequently this austenite can grow this ferrite can grow in by consuming austenite and during this process the ferrite rejects carbon and two adjoining regions and forming cementite lamellas ferrite cementite lamellas as I explained in this figure. And this happens is you know as you can say in then close to equilibrium when you do not have high cooling rates as well as not high alloying elements.

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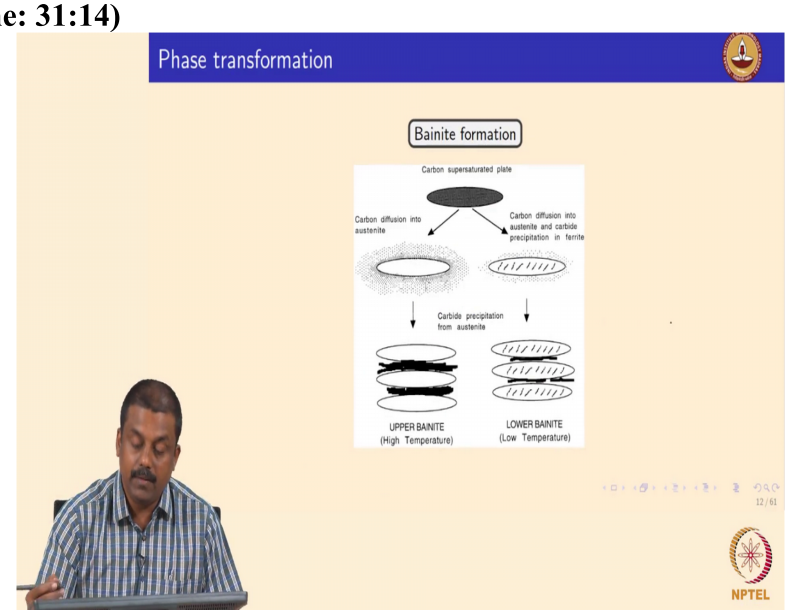

If you high amount of alloying elements for example manganese, chromium, silicon you may under with slightly increase in cooling rate then use it for a pearlite formation the morphology of the ferrite lambdas that you form in pearlite changes into somewhat ocsicullar, ocsicullar means nothing but shape over this is actually shown over here. The actual information mechanism is similar to pearlite mechanisms driven by the carbon diffusion.

Here what you see over here is the explanation about the bainite formation. So, you have supersaturated the austenite okay so when you cool this austenite to room temperature you are the carbon atom migrates from the pearlite to the adjoining austenite upon enrichment you form a cementite at the inter ferrite regions the; as I will explained the mechanism is similar to pearlite formation mechanism.

So, only thing is in this case the shape of the ferrite that form they are not as uniform as you see oven and pearlite formation and you will have a ocsicullar structure. So, when the temperature is decreased even further the carbon migration from ferrite is retarded because of the low diffusion of diffusion rate of carbon from the ferric austenite you may end up trapping some carbon atoms in the ferrite itself.

And ultimately this ferrite upon segregation can also precipitate iron carbide cementite in the ferrite log itself okay. And based on these formation mechanisms and we can form 2 type of bainites either what you call as an upper bainite where you have a partitioning of carbon completely from formed ferrite into cementite into the other joining the austenite and end up nucleating cementite between the two inter-lath ferrite or you may also end up precipitating the iron carbides inside the lot itself and some moment of the inter-lath ferrite as well.

And based on the morphology so the term the structure is an upper bainite or a lower bainite generally upper bainite form slightly higher temperatures and then below it bainite and because of these temperature difference we are also suppressing the carbon partitioning complete carbon partitioning from the form of ferrite to the adjoining regions okay. So, with that and we like to summarize so what you have learned so far.

So, we looked at the basic iron carbon system so what are the importance of the various lines you see in the phase diagram. So, we looked at the regions that are interesting for us in this course we looked at the eutectoid compositions the covered austenite and covering ferrite lines okay. So, what are the possible phases that can form in under equilibrium conditions when you cool when you are transforming austenite to room temperatures?

And so we looked at the continuous cooling transformation diagrams. We looked at the formation of pearlite from austenite how the carbon diffusion from a ferrite to austenite drives the transmission of pearlite. And upon adding other alloying elements and the increasing cooling rates in the; you also change the morphology of weight loss that are forming which actually lead to the formation of bainite.

And bainite can form in to this one by a complete diffusion of carbon from the ferrite lath and forming inter lath cementite or iron carbide which is known as upper bainite in the lower bainite you also nucleate a cementite inside ferrite laths thereby we have the structural changes from a complete inter-lath cementite and for its structure into cementite inside different laths as well as someone tough cementite right in between logs as well and this structure is all bainite.