Materials Science and Engineering
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Lecture - 21
TTT and CCT curves

Hello friends. Till now we have discussed about phase transformation. And in the last lecture we also discussed about the nucleation, so when a phase transformation from parent phase to new phase the product phase there is always going to be the process is also always going to be a nucleation and growth ok. So, it is not like that phase when it becomes unstable ok, it will spontaneously go into a new phase ok.

Like the whole thing changes without any other process just from one phase to another. For example, from austenite to ferrite it will not be a spontaneous the whole system is not going to go into a new phase suddenly , but it will be a process like where you have to nucleate first the product phase and then it will grow, so it takes time. So, there is a rate involved here a factor of time is involved here that it will take time though it is a though austenite is unstable let us say 700 degree Celsius ok.

But it is not going to be a spontaneous change in to ferrite ok. It will go through this process it is going to take time ok. So, that is what we understood from nucleation and growth rate and then we also saw a overall transformation rate from that. Now, there are very important technological application or technological importance of these ideas and that is in heat treatment processes.

So, before going to heat treatment processes we will under try to understand two very important ideas or two important concepts ok. One is called TTT curves that is time temperature transformation curve and another is CCT curve which is continuous cooling transformation curves ok. And these are technologically very important to know that what will be the time it is going to take for transformation first, what kind of treatment I will be giving to get a particular type of microstructure ok. So, it gives you over all idea and it actually helps in the in the design of the process if we have these curves with us ok.

So, before going to TTT, CCT curves just recap and may be some phases which we might not have discussed till now, ok. So, some microstructure which we will found find or phases which we will find in steel that we will see. So, one of them and you can see that I have written diffusional here, so that means, it is through diffusional transformation diffusion already we know the concept ok. So, this phase change will take place because of the diffusion of atoms ok.

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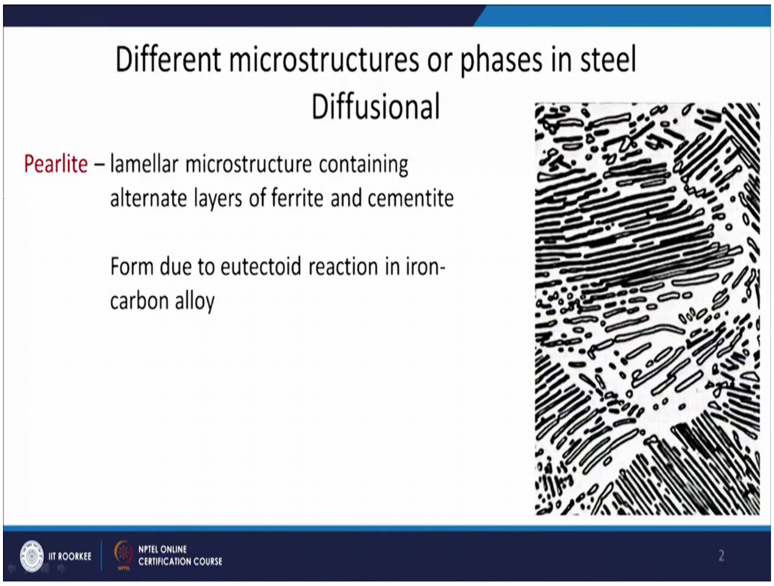

So, one of them is already we have seen pearlite which is a lamellar microstructure containing alternate layer of ferrite cementite, which forms due to eutectoid reaction in iron carbon alloys ok, from austenite to region where you get ferrite and cementite ok. And they form next to each other and we have also discussed that why they form next to each other because that is how they will be able to transport atoms between the two phases ok, depending upon their composition and that will be the easiest way to do that. So, first one is pearlite.

Couple of new phases microstructure which you will see one of them again diffusional, of course there are some debate about whether it is diffusional or not, but let us say it is diffusional.

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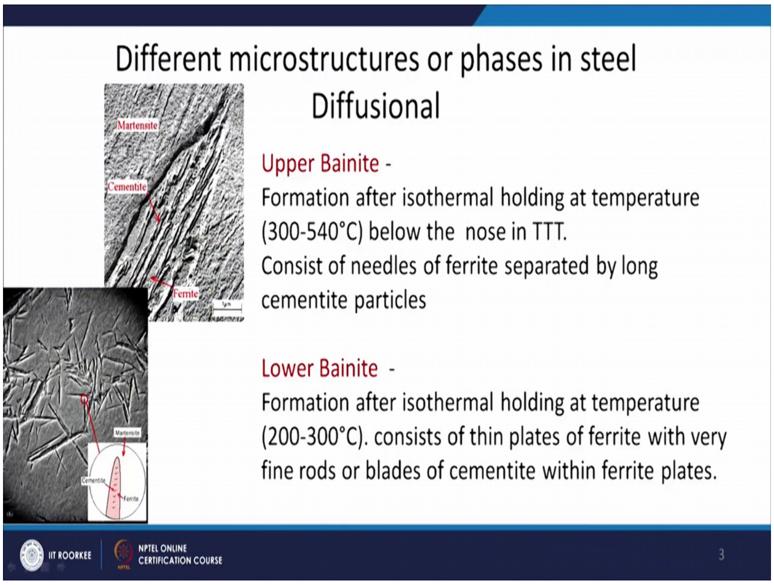

There you will see first phase which is called upper bainite ok. And it, or how it transform the formation after isothermal holding at temperatures at around 300 to 540 degree Celsius, below the nose in TTT curves. So, we will see what do we mean by these TTT curves. It consists of needles of ferrite separated by long cementite particles. So, this is a the type of microstructure you will see you are getting bainite of course, it is not very easy to see bainite in optical microscope , but one micrograph is shown here it is taken from book baikalister ok.

So, you can see the ferrite these are the ferrite plates long ferrite plates and in between these two ferrite plates is cementite as shown by arrow here ok. So, you get ferrite plates and in between them the cementite is formed. So, in pearlite what we saw? We saw ferrite pearlite ferrite pearlite morphology like that. In this case it is big ferrite plates are there and between two ferrite plates a thin cementite layer will be there ok. So, this is how the microstructure will look like.

If you go to another phase which is called lower bainite, in this formation after isothermal holding at temperature of 200 to 300 degree Celsius. So, for upper bainite it is around 300 to 540 degree Celsius for lower bainite it is around 200 to 300 degree Celsius. Consist of thin plates of ferrite again with very fine rods or blades of cementite within ferrites ok. So, in this case now, again ferrite will be like plates thin plates, but the cementite will not be between the two plates cementite will be within the ferrite plate itself as is shown in a schematic here. So, this will be a ferrite plate and then you have cementite which is within the ferrite plate ok. So, I think because of lower tire transformation temperature you do not get enough time for diffusion and that is why they nucleate within the ferrite plate ok. So, this is how the microstructure will look like for upper bainite and lower bainite, of course, very difficult to resolve them in an optical microscope ok.

Then one of the very important phase which you get in steel is called martensite it is a diffusion less transformation ok. In this case there is no confusion that it is diffusional or diffusion less it is going to be diffusion less ok.

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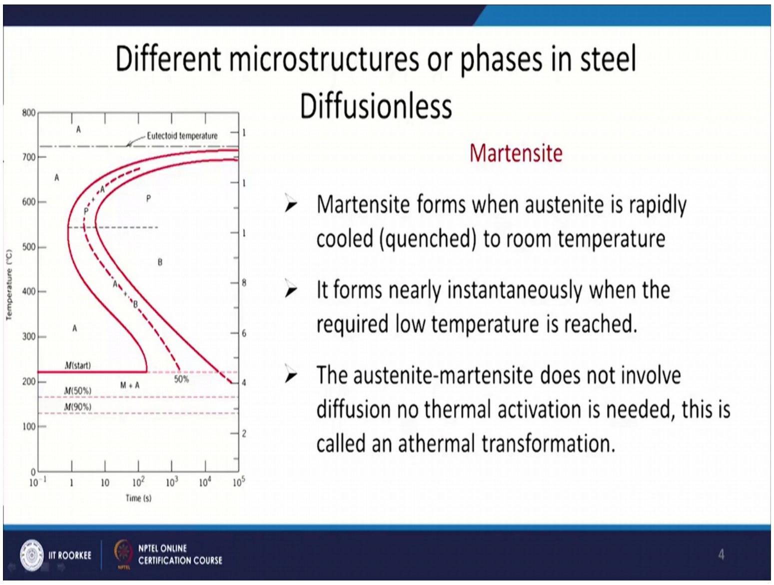

So, when it forms, martensite forms when austenite is rapidly cooled quenched to room temperature. So, if you do very fats cooling the austenite transforms to martensite. It forms nearly instantaneously when the required low temperature is reached ok.

So, this is how a TTT diagram will look like we will go again into detail of that I just wanted to show you that what martensite will be doing. So, you have to have a very high cooling rate as I have showing it here ok. This is the kind of cooling rate we will have ok. And can see that in this case there is no effect of time. For example, if I hold my material after crossing the m start. So, martensite will start forming when I cross a temperature of let us say here it is around 220 degree Celsius, so as soon as I cross that it will start forming. And suppose if I hold suppose I hold at some 200 degree Celsius for any amount of time the amount of martensite which has formed will remain same.

For example, if I go to a temperature of around let us say here it is 170 degree Celsius or. So, at which point I will have 50 percent martensite and if I hold at this temperature it is going to be 50 percent martensite without any effect of time. So, the martensite transformation how much martensite will be forming will depend only on at what temperature I am up to what temperature I am going ok. So, there is no effect of time here.

So, it does not require any diffusions. So, no thermal activation is need this called athermal transformation because there is no effect of time only you have temperature, at what temperature you have that decides the how much martensite will form. In a martensite when it forms each item displaces a small sub atomic distance to transform FCC gamma to martensite which has a body centered tetragonal structure or BCC it can be both ok.

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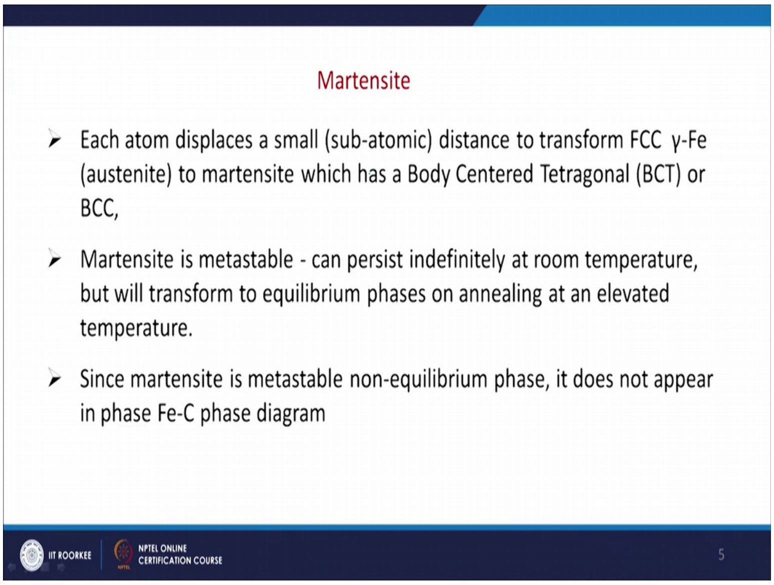

So, if carbon if trapped while transforming then you will get BCT if it is not there then you will get BCC ok, but martensite transformation involves only very small changes in the atomic positions ok. That is why because when we are doing at very fast cooling rate you do not have time for very large range diffusion only small changes in atom atomic local atomic location will give you martensite of course, they are not going into details of atomic mechanism here.

Martensite is metastable ok, it is not a stable phase and can persist in different in indefinitely at room temperature, but will transform to equilibrium phase on annealing at an elevated temperature. So, it is like diamond, in case of diamond we said that though it is not a stable phase of carbon, but it will remain in form of diamond. Similarly martensite is not a stable phase ok, but it will remain like that and, but it will if I take it to higher temperature it martensite will dissociate into the stable phases.

Since martensite is metastable now, non equilibrium phase does not appear in phase or phase diagram ok. In the phase diagram of iron carbon phase diagram we did not talk about martensite. We talked about austenite, we talked about delta ferrite, we talked about alpha ferrite, we talked about cementite, but we did not talk about martensite there ok, because phase diagrams are equilibrium phase diagrams and this is a non equilibrium phase it is not a stable phase ok. That is why it is not going to appear on the phase diagram.

So, this you should always remember some time non equilibrium phases are shown on the phase diagram by a dashed line ok. So, basically there are other phases also, but these are the 3 or 4 most important ones austenite and ferrite we have already seen in quite detail then you will get pearlite or you will get upper bainite lower bainite and martensite ok.

So, now, coming to time temperature time transformation diagrams ok. So, basically we have already seen that you get for transformation we get typical S curve the growth kinetics when we were looking at we said it has a typical S curve. So, first it is slow then it escalates go to maximum and then it again decelerates. So, from these S curves only you get this TTT curves ok. So, family of a S shaped curves at different temperature are used to construct a TTT diagram we will see one example here.

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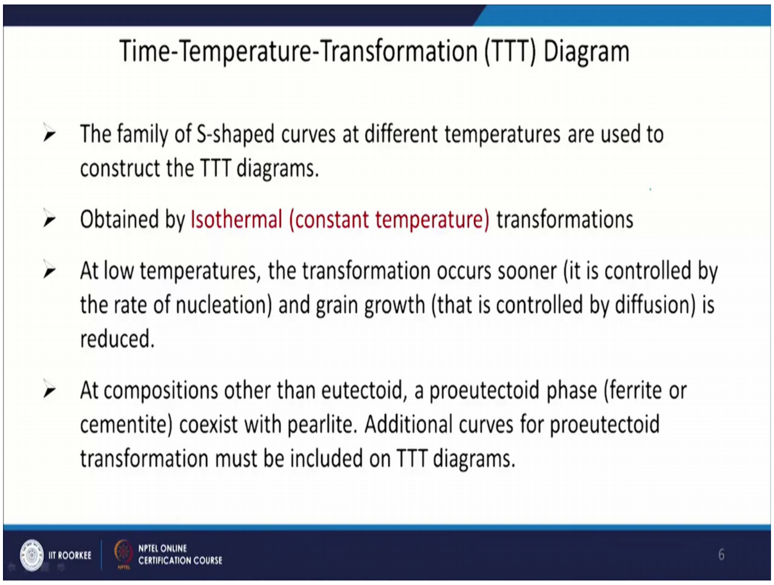

And how you get that? By doing a isothermal constant temperature transformation. So, from austenite phase you come to some temperature where austenite is not stable hold at that temperature for very long time and you will have a transformation during this process ok.

At low temperature transformation occurs sooner it is controlled by rate of nucleation and growing growth sorry, it should not be growing growth that is only growth of new phase that is controlled by diffusion is reduced I will just cross this here. So, at low temperature the transformation occurs sooner it is controlled by rate of nucleation. So, when you go to very low temperatures as we discussed during nucleation and growth that you are driving force increases. So, the overall transformation rate increases ok.

So, that is the reason why you have higher transformation rate as we go or we give a large under cooling or large super cooling ok. So, if you are at a temperature below the equilibrium temperature where this particular phase is not stable the growth rate the nucleation rate will be high. So, you will get very the micro structure which you are going to get will be very fine ok. And the growth will be of course, controlled by diffusion. So, growth also initially will increase and then it will decrease at composition other than eutectoid a proeutectoid phase is ferrite or cementite coexist with pearlite additional curve for proeutectoid transformation must be included on TTT diagrams ok.

So, if you have a any other phase also coming with pearlite for example, in this case then we have to have additional TTT curve for this another phase also ok.

Now, coming to how the transformation TTT curves are plotted ok.

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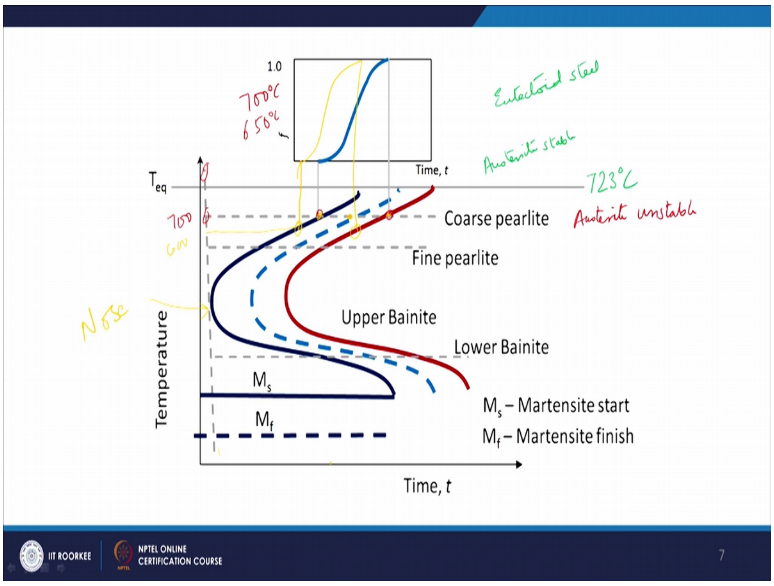

You can see that this is by a T equilibrium temperature. So, basically above this austenite is stable let me write it here that above this my austenite is stable, ok. So, let us say we are talking about eutectoid steel here ok. So, let us say around this must then b equal to 723 degree Celsius or so, ok. So, above this it will be stay austenite is stable and below that you will have formation of pearlite ok. Now, so, let us say I am at this temperature right. Now, and I have started cooling ok. So, I am just doing a kind of rapid cooling here ok, quickly I am going to any temperature I like.

For example, I come to this temperature here and then I am holding at this temperature. So, you can see that these are the isotherm and this is my time scale this is my temperature scale and I am not changing the temperature. So, from this temperature to this temperature I have come quickly and now, at any temperature below this seven twenty three austenite is not stable.

So, I say austenite unstable and I am holding it. If you look at the S curve which we discussed at after some waiting period in which you will have a the nucleation and so, on your growth starts and accelerates and decelerates. So, from 0 fraction you go to the 100 percent fraction of new phase which is forming ok. So, you can see at the start, where the start is taking place for the transformation that is you can say that let say I am doing this experiment at 700 degree Celsius ok. So, this S curve is plotted for 700 degree Celsius ok.

So, I found out that after this much time the transformation starts. So, I have plotted one point here and after this much duration the transformation is complete. So, I have plotted another point here ok. So, now, I have got two points on the TTT diagram ok. Right now, there is no TTT diagram only I have this two points let us say. Now, again I will do another experiment let us say I will do it. Now, at 650 degree Celsius and again may be I will get another type of S curve here.

For example, let us say, let us say I have will get another curve like something like this and I can again draw that where it is starts where it ends ok. So, this is my start point this is my end point ok. So, now, at 600 degree Celsius I have got another two points. So, now, like that I can keep getting points there where the phase transformation is started where it is completed and that is how you can if you get all the points here you will see that you are getting a curve here and this is a isothermal transformation curve TTT curve.

So you can see that. Now, I will be able to tell you that if you want coarse pearlite at what temperature you should hold the your material after cooling. If you want fine pearlite at what temperature you should hold it you can see that if I do large under cooling there will be more nucleation event. So, the micro structure will be fine. Then you will say at some point it becomes maximum transformation rate will be maximum and then it becomes again sluggish again it become slower and this is what we call as nose of TTT curve ok. So, this is my nose of the TTT curve and again it will start decreasing. So, I get another two type of micro structure here, one is upper bainite and second one is lower bainite.

So, if I do cooling such that I am not crossing the nose ok, then I will be even if I hold at temperature where lower bainite will be forming I will get lower bainite ok. So, these curve what they tell me is that where the transformation is going to start and where the transformation is going to complete ok. If I stop the, if I let say if I do something like this is I am holding my material at 700 degree Celsius up to this time I am not going up to the finish ok.

So, then I will get only 50 percent of pearlite here and suppose remaining material I just quench it then I will get the martensite here ok. So, you see for martensite there is no time scale here it is a constant two lines are at constant temperature. So, if I some how escape this nose and go below any temperature below the ms I will start forming the martensite ok, and if I cross this temperature I will finish the martensite transformation. So, in this case there is no effect of time. So, suppose I at 700 degree Celsius I do hold up to a time where 50 percent pearlite is formed and then I quench it, so the remaining austenite will be transforming to martensite ok.

So, by having or by manipulating this type of treatments you can see that you can get plethora of micro structures ok. So, this is how the time temperature transformation curves are made that is explained in the next slide also.

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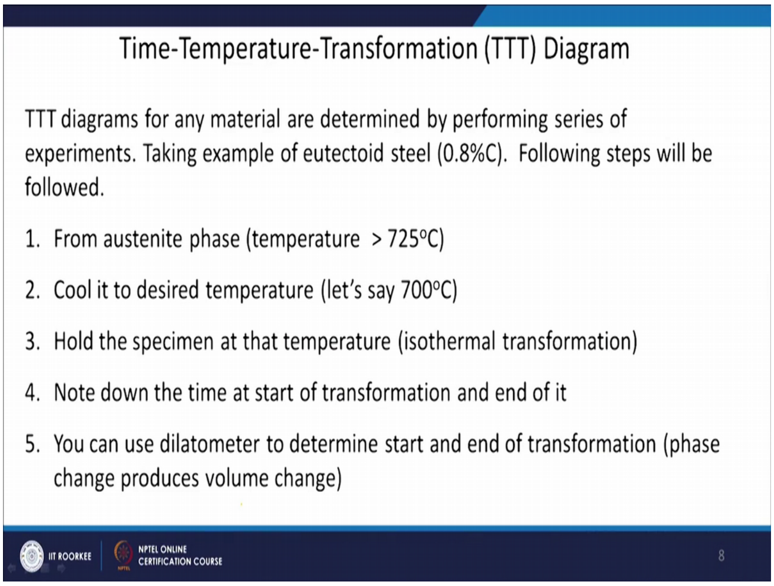

So, for TTT diagram of any material determined by performing series of experiments; taking example of eutectoid steel following steps will be followed.

From austenite phase temperature above 725 degree Celsius. Cool it to desired temperature let us say 700 degree Celsius. Hold the specimen at that temperature. So, you have doing you are doing isothermal transformation. Note down the time at start of transformation and end of it. You can use dilatometer to determine start and end of transformation ok, phase change produces volume change.

Dilatometer is a is a is a instrument to give you the change in the volume change in the dimension of the sample ok. So, when phase change occur you are going from FCC to BCC or from BCC to HCP whatever there is always a going to associated change in the size of the sample dimesion of the sample, volume of the sample. And this can be noted by instrument called dilatometer. So, this dilation in the size will be noted by instrument and that is how you can get that where that transformation is staring and where the transformation is completed ok. So, this is how you plot a time temperature transformation diagram.

Now, you will be able to appreciate that when we discussed over all transformation rate I said you can get TTT curve from that ok. And now, you will be able to notice the similarities between the overall transformation curve and the TTT curve here ok.

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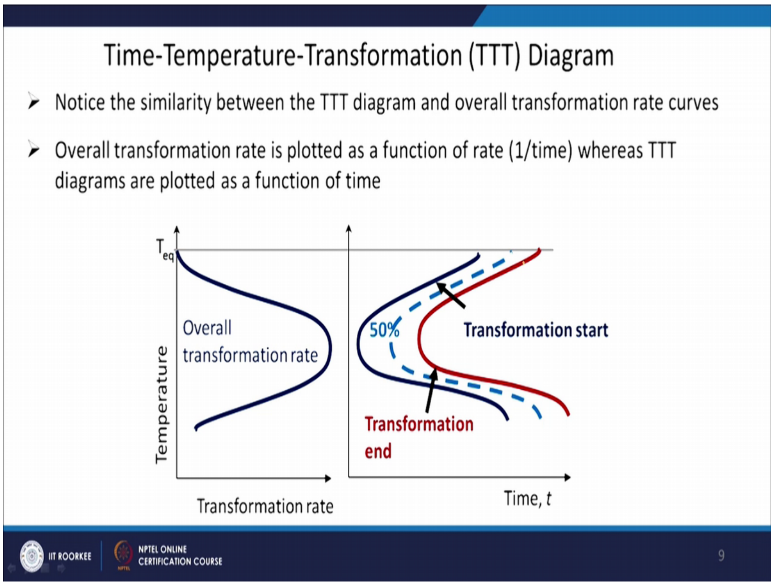

So, here in overall transformation rate what we plotted on y axis you had temperature on x axis I had rate transformation rate. So, I said the transformation rate will be slow or will be sluggish at a small under cooling, it will increase with under cooling and then it will again go become slow. If you see the overall transformation rate also it follows the similar train, but only difference is that instead of rate here I am plotting time here and you know rate and time here, iInverse relationship ok. So, as if we are saying that rate is highest here then on time scale I will say the time required to start the transformation will be lowest here ok. So, as you can see rate is high. So, the transformation time will be low ok.

So, this is how your transformation rate those nucleation growth ideas are related to your TTT diagram. And from TTT diagram you can actually appreciate that it is very important to understand to for getting a particular micro structure. Suppose a customer ask that I need a fine pearlite I know at what time temperature I should hold to get fine pearlite, if somebody ask me coarse pearlite of course, I will know at what temperature I have to hold to get coarse pearlite. And of course, for different steel these curves will be different because your composition changes. So, all your kinetics will change for different steel you have different type of curve.

Before coming to this I also said initially here in the first slide that if you have a composition other than eutectoid proeutectoid phase ferrite cementite also will have to come ok. So, just let me give you some idea about that. So, basically, I have temperature here and I have time here, one temperature we have already discussed ok.

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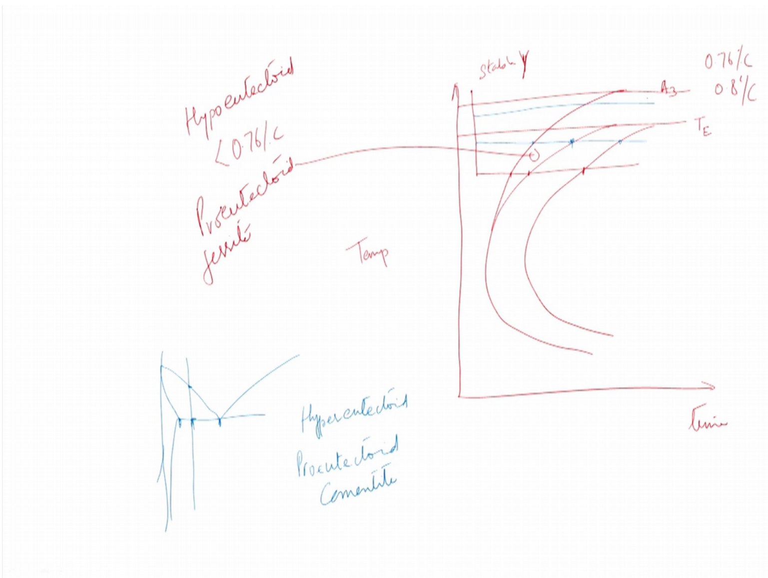

So, this is my let us say. Now, I will call it as temperature there eutectic reaction taking place ok. So, one curve I have already shown you that you will get something like this ok. Now, if you have this is for 0.76 percent carbon or 0.8 percent or some books you will see 0.8 percent in some books you will see 0.76 percent it is more or less around that composition where you get the eutectic reaction, ok

So now, as I told you that for a if it if it is a hypo eutectoid still for example so, my carbon percentage is lower than 0.76 percent carbon ok. So, it is hypo eutectoid if it is hypo eutectoid then I should get one phase forming before the eutectic, eutectoid reaction that would be proeutectoid ferrite, is no it. So, that will be forming before this ferritic reaction let us say for particular composition that temperature is this and I think this is your a 3 temperature on the phase diagram ok. So, from where the proeutectoid should start forming. So, I will get an additional curve now, which will be related to proeutectoid ferrite ok.

So, now, once I go from a stable austenite phase. So, this is stable austenite here I will write just gamma here ok. Suppose I start the isothermal I do a rapid cooling and then I am holding isothermally at this particular temperature now, ok. So, now, you can see that I will get some amount of proeutectoid ferrite ok. So, this is for this base for proeutectoid ferrite and some amount of pearlite which you can easily appreciate from the phase diagram according to the phase diagram it was supposed to be like this ok.

So, suppose I take any composition here. So, as soon as I cross this temperature the proeutectoid ferrite will form ok, and when I cross this temperature the remaining austenite will be transforming into eutectoid and how much pearlite will be forming I can get from the lever rule. So, this much will be the amount of pearlite divided by the total arm length and this much arm length divided by the total will be the proeutectoid ferrite ok.

So, I can get that how much will be the proeutectoid ferrite, how much will be the pearlite during the after the transformation. If I do at a any other temperature you will see that this much will be the this much will be the time required to proeutectoid transformation and this much will be the time required to have pearlitic transformation ok. If it is a hypoeutectoid steel then instead of proeutectoid ferrite you will get proeutectoid cementite, is not it.

So, if you have a composition where another phase is also coming there will be additional curve here for that particular phase. So, it can be either proeutectoid ferrite or proeutectoid cementite you will get additional one and then you will have a transformation like this. If you are not crossing the equilibrium temperature where this eutectoid temperature it will be you will get ferrite obviously, ok.

So, we discussed this one we also saw the procedure to get a TTT diagram we kind of showed the similarity between the transfer overall transformation rate and transformation TTT diagrams.

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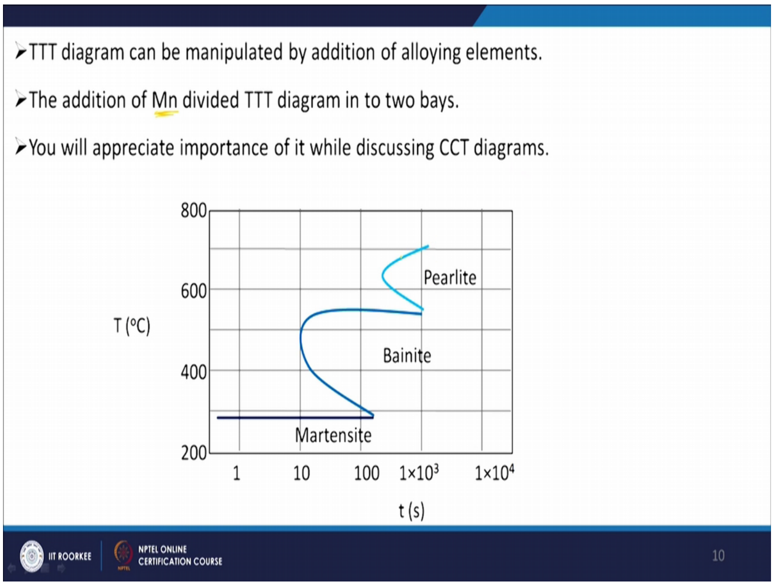

Now, TTT diagram can be manipulated by addition of alloying elements. For example, the addition of Mn here divided TTT diagram into two bays instead of one single curve like this in the, right now, I am also seeing two curves here, one is like this another one is like this. You will be able to appreciate the importance of this while when we discuss the CCT diagrams ok. We will see that why this is very important ok. And just before telling you that why this is important I will tell you one let will go to CCT curve first.

So, this is the continuous cooling transformation diagram. Why this is important? Why TTT curves are not going to be of much help to you? Because in industry you will not be able to do isothermal transformation ok. For a small sample taking it from austenite temperature quickly to a temperature where you are going to do isothermal transformation is easy it is a very small sample.

Suppose you have a component big component like this one ok. So, let say you are able to achieve uniform temperature throughout the section of this big product. Now, how we are going to do a isothermal transformation of this or how I am going to first quench this to a temperature, where I want to hold it for a isothermal transformation, for this much big body you must be knowing about heat transfer ok. First heat transfer will takes place from the surface. So, you will have lower temperature of at the surface, but inside temperature will be still high this heat will be conducted and it will be either radiated or you can take out from convection ok. So, it is not a easy job to cool this product to temperature where I want to hold it isothermally and then holding isothermally at that temperature require energy and time ok.

So, industrially TTT curve are not going to help you and we are not going to do isothermal transformation most of the time. So, in industry it is what we do is continuous cooling transformation. So, you will be continuously cooling the steel from the austenite temperature to room temperature without doing any holding of at particular temperature. So, this are called continuous cooling transformation diagram. So, whatever we have plotted for trans TTT diagram that will slightly change and what the change will be shown here you can see that this is a blue lines or the dark blue lines are shown for TTT curves and this dashed one is also shown here where the transformation will complete.

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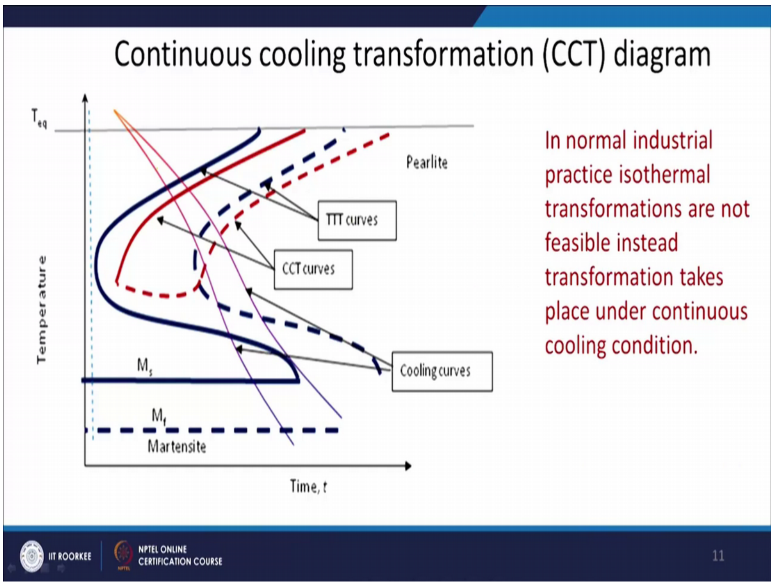

And the CCT curve are shifted towards the right and also shifted downwards. So, from when you transfer from TTT to CCT that curves will shift right and downwards ok, this is because your kinetics are changing because of continuous cooling ok.

So, the CCT curve is shown by this red line here. So, this is where the transformation will start and this where the transformation will end and you can see that we are not plotting anything below the nose as in TTT curve we said that you can go at a temperature below the nose temperature and again you will have bainitic transformation here, but in CCT we curve we are not showing anything below the nose why. If you see the TTT curves they are transformation is the cooling is curve is going like this which is super imposed on the TTT and CCT curve here. There are two cooling curves are shown here.

So, for any cooling whatever you do you are always going to cross the whether it is pearlite or ferrite or whatever phases are coming, you will always going to cross the one which are going to form at higher temperature first and then you will be going below the temperature will go below, below the nose ok. So, the transformation will always a start for pearlite or ferrite before it does for bainite ok.

Because I am always going to cross this boundary first ok, whereas in TTT actually what we did is we first skipped the any transformation high temperature transformation and came to this temperature and then we hold we did the isothermal holding at this temperature ok. Where as in this case now, you can see that I cannot do that it is always going to cross the boundary here the it will start the either ferrite or pearlite transformation ok, and it will end somewhere here where it crosses the end the transformation end curve. So, I cannot form bainite here ok.

So, in continuous cooling transformation you will not be able to form bainite and that where now, you will start appreciating that why you we wanted those two bays ok. So, in CCT curves I am not going to have anything below the nose because I will not be able to form anything ok. If I skip the nose also if I do a fast cooling I will go into the martensite region. I cannot be able to go to bainite region ok.

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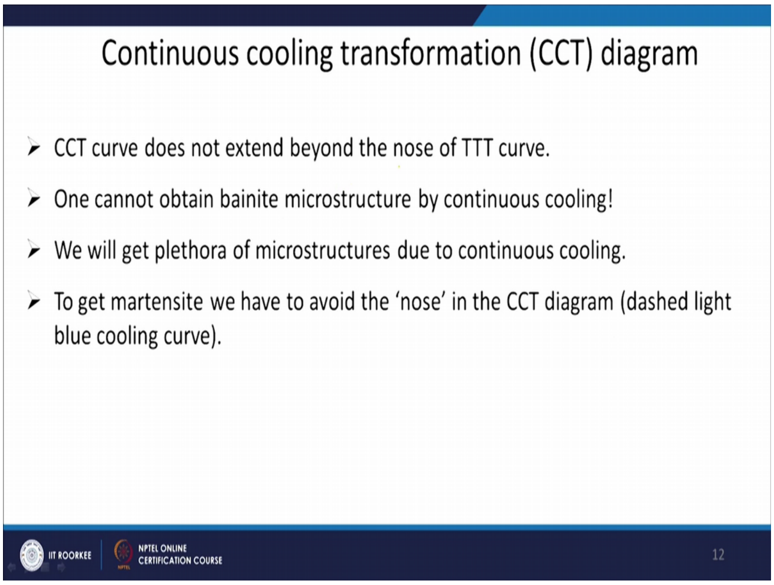

So, this is what is continuous cooling transformation curves. So, CCT curves does not extend beyond the nose of TTT curve as I told you one cannot obtain bainite microstructure by continuous cooling we will get plethora of microstructures due to continuous cooling. Now, you can also appreciate that in isothermal transformation I am sure that I am going to get coarse pearlite, fine pearlite or upper bainite or lower bainite because I am holding at that temperature where these phases are going to form or these microstructures are going to form.

In continuous transformation you will get actually may be a coarse pearlite also may be a fine pearlite also because different section of your product will be have will be having different cooling rates surface will be having very high cooling rate the interior of the product will be having low cooling rate. So, you will get plethora of microstructure within the sample. To get martensite we have to avoid the nose in the CCT diagram as we have already told ok.

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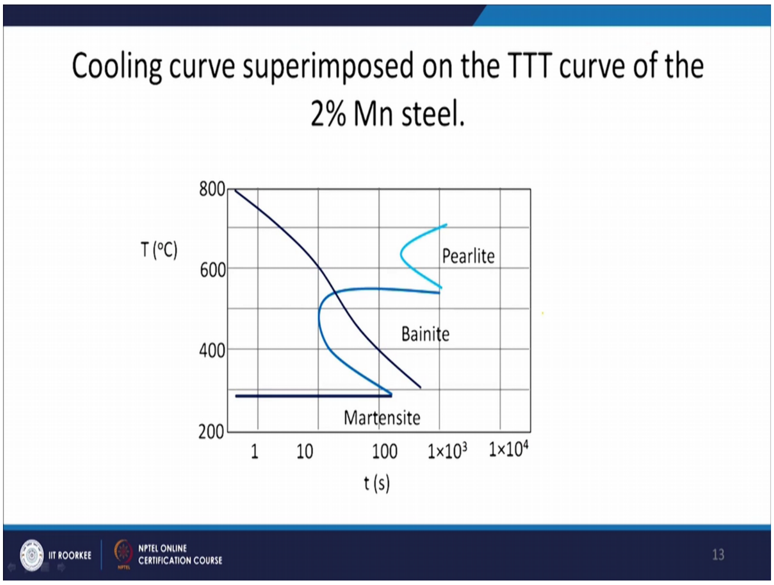

And now, you as I told you will be able to appreciate that why we need this two bays here. So, this is the 2 percent manganese steel ok, there you have one bay for pearlite another bay for bainite and now, you can see that with the continuous cooling curve also I am able to have bainetic transformation or bainite I am able to get bainite with continuous cooling also ok.

So, with this I like to thank you ok, and basically we have covered very important technological aspect of this material science and engineering that how we are going to have different type of transformations ok, and what different phases you will get at different temperature ok.

And alloying element, we just saw one alloying element there are large number of alloying element which are used in steels. They are going to affect your transformation rate and transformation start time and end time ok, and that is how you are going to get different type of microstructure and of course, each microstructure has their own properties ok.

So, with that I say thank you to you.