Phase Diagrams in Material Science Engineering
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Lecture – 35
TTT curves for Steel

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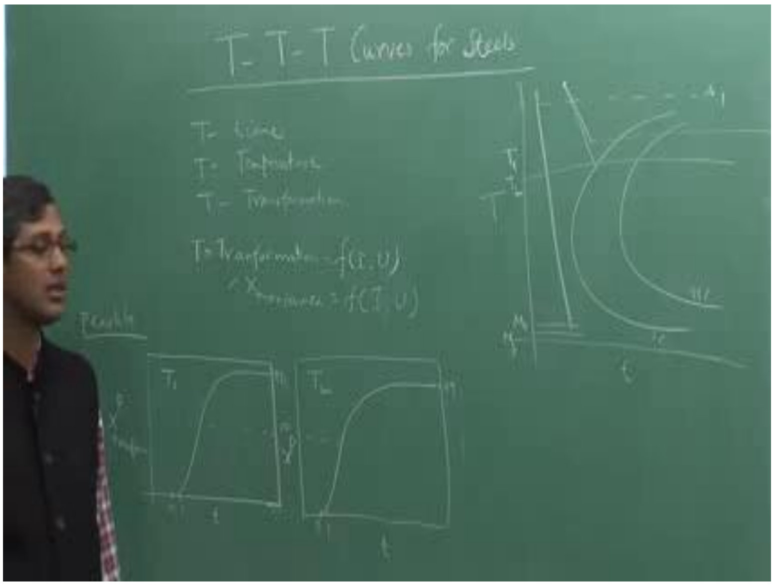

So, in this lecture, I am going to tell you about more about T-T-T curves; in the last class, I have just introduced this subject T-T-T. Let me again tell that there are three Ts in this; most of the times students when do not able to tell what are the meanings of each. First T stands for time, second T stands for temperature, and third T stands for stands for transformation. And the way we plot basically it should be three-dimensional plot, but we do not do that in material science or metallurgy. We plot two-dimensional plot between time and temperature. And this is suppose A 1 temperature then I plot inverted c curves. So, this is 1 percent transformation this is 99 percent transformation that is like that this is what it looks like. So, first I have to discuss how I get this curve then I will discuss what is the way to be understood, we can get out of it.

You know suppose let us consider I had you know transformation is basically depends on nucleation and growth as I told you. T transformation, it depends on nucleation or it is a function of nucleation and growth. What I transform nucleation rate and U transform transfer the growth rate; transformation or this can be as percentage trans x transformation is nothing but function of I and U correct, now, I we know that and I told you how it can happen in the last class. Now you know real experimental technique how do I determine. So, what is done let us consider for the case of pearlite then I can make you understand better way let us consider that I have a steel sample which is above this A 1 temperature here somewhere, A 1 is that pearlite transformation temperature or 727 degree Celsius for the plain carbon steel. So, if I cool this steel directly like this, some sort like this then only the I can start the transformation because transformation cannot happen at high temperatures high temperatures above A 1, it can only happen at temperature below that suppose I cool it like this very slowly and keep it at the temperature.

So, if I keep it at the temperature then what will happen, slowly austenite will transformed to pearlite. Now, this is my time and this is the transformation fraction transform x and this is suppose pearlite X P, I am plotting. As you know transformation for pearlite transformation will not start immediately it cannot start because it depends on nucleation, nucleation is will happen at a particular time. So, there is always inclusion period always inclusion period; immediately transformation can happen only for martensites. I have told you martensites transformation happens at a speed of sound, but both for pearlite and bainite transformation will not take start at the immediately at zero time you start at the finite time and this is what is known as inclusion period.

So, now as you keep it longer and longer and longer fraction transformation will increase and it will look like this correct; it will look like this, this just like a (Refer Time: 04:07) curve. So, initially, it will in fraction transformation, will increase slowly then it will increase faster then it will saturate. So, that is what happens if you keep it longer in this temperature long, long time, this is what will get. So, you may ask why like this well this is the typical feature of any diffusion transformation; any diffusion transformation which is happening because of the nucleation and growth this is what typically happens, and this has been documented in a literature. So, I do not have really time to why this nucleation and growth dominated transformation or the curve will look like this.

So, now I have done this is suppose a temperature T 1, I write that T 1. So, I can do it at temperature T 2; suppose, I cool it like this it is at T 2. So, obviously, at x pearlite versus time at T 2 will be happening it will start at much earlier because you pull it down my slot temperature (Refer Time: 05:16) portion will be larger, you have given more hardening the cooling. So, this will start and this will also be looking like this. So, what is the meaning of this curves, what I am getting this is 0 percentage, this is 1 percentage, and this is 99 percentage right; similarly, here also 0, 1, 99 percentage correct.

So, I can get at a particular temperature T 1 or at a particular temperature T 2, what at the time required for 0 percentage transformation, or what is the time required for start the transformation time required for 1 percent transformation, time required for maximum percentage. You can even tell I am required for 50 percentages, is possible. So, you know how it get this you know fraction transformation is basically done by optical microscopy, I take the sample you know at different time duration and observe under optical microscope and then calculate the volume fraction of pearlite phase form by point counting method.

Those of you who have no idea of point counting method which is nothing but a statistical point counting method, you have pointer which if it is hits the pearlite, you say pearlite is 1; if it is hits austenite, it you say austenite is 1, pearlite is 0, that is how, but it is like a point counting method 0 and 1. So, by that you can calculate that. Now, I can do this experiment for each temperature starting from this, T 1 lower temperatures. So, I will have a large number of data large, large numbers of data; at each temperature, I will have this time dependent curves for pearlite transformation.

Similarly, I need to do for bainite because bainite transformation will not happen at such a high temperatures; it will happen at lower temperature like 400, 350 or 200, 250 or 300 degree temperature. And obviously, I should also do for martensite; if I quench the steel directly from martensite temperature to this. So, martensite temperature will start at M s and it will end as M f, you can do that. So, I can actually do it for martensite transformation there is no time effect; time is not a factor because transformation happens thermally. So, I can only quench to different temperatures and then find out how much martensite is formed again by point counting method. So, these all are done everything is done for a particular steel compositions by doing this experiments, and then all the data are plotted in this plot which I will do it right now for you. And I will show you also. So, all these data are plotted on a particle time temperature plot.

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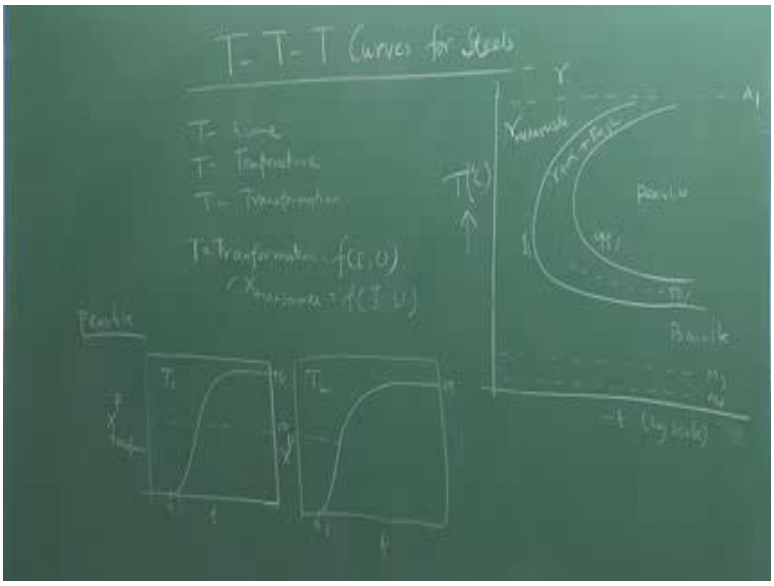

And this is suppose your A 1 temperature, this is your M S temperature, this is your M f temperature correct then you plot the way I have done correct. So, I think this is little wrong let me just reduce it otherwise I cannot show it bainite transformation. Now, this is 1 percent, this is 99 percent. And this is austenite, this is pearlite, austenite plus pearlite plus cementite; obviously, and this is pearlite, this is bainite. So, this is how it will be written and this will be austenite gamma oh I am sorry we should not I should use symbols gamma plus alpha plus cementite; gamma, martensite this is how the curve will look like. And this is log scale, but this is the temperature in degree Celsius, so all these data which I told you how to generate it or used to plot this diagram.

What this diagram has this diagram has different zones. So, suppose this is my A 1 temperature, this is my A 1 means the temperature above gamma is stable; at temperature below which gamma will transform into either pearlite or bainite or martensite depending on what are the way I possess the sample. And this is martensite region of gamma; that means, if I cool it down by below one gamma is should not exist right thermodynamically, but kinetically it will exist because transformation will leads to be very low at a little lower than a one temperature. And this is zone of pearlite when all the gamma will transformed into pearlite, this will come here and these are the two curves c separate curves there are two c separate curves one with 1 percent transformed cementite sorry pearlite, another one 99 percent transformed pearlite.

So, in between, we will have some amount of gamma will be retained that is why it is called gamma plus alpha plus F e C 3, this alpha plus F e C 3 is pearlite. So, in between it is bainite then here bainite retains because I know bainite transformation will happen if I cool quench the steel at about 350, 400 degree Celsius temperature and keep it long at a temperature then I can form bainite. And if I quench the steel below M s temperature it will be for martensites, martensite will start at M s start temperature and will end at M f end temperature. So, they are the different zones correct, sometimes we will find as a 50 percent line will also be plotted. So, you can do that this is the 50 percent, so that is how the diagram looks like and this is how to be read. So, now before I read this diagram, I will just go back to slides and show you some more things.

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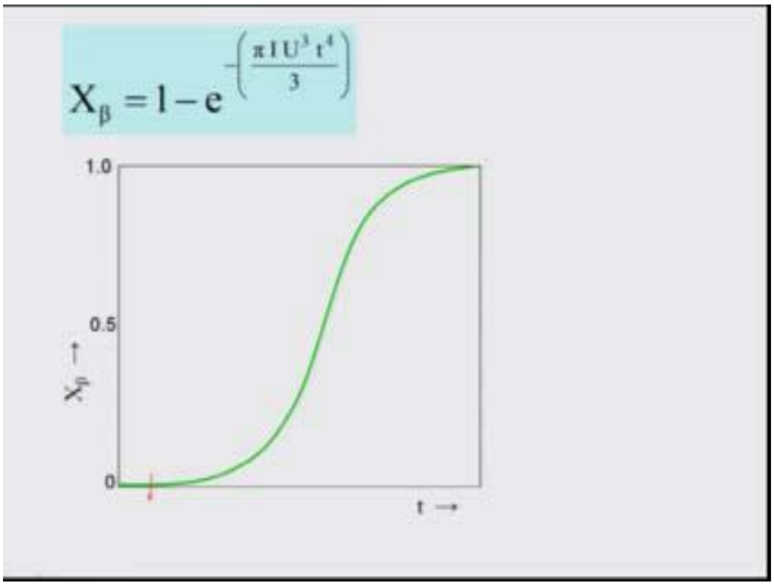

So, as you see here this is the plot on the things where I have made. So, you see here this is the incubation period right below which no transformation happened; and then it reaches 100 percent become a flat beyond certain time. In between you have a transformation that is how it is looks like; it is like a stipulated curve correct. So, that is the typical feature of any diffusional transformation pearlite, bainite to some extent my martensite will not follow this. Martensite transformation does not require time, it depends on the temperature.

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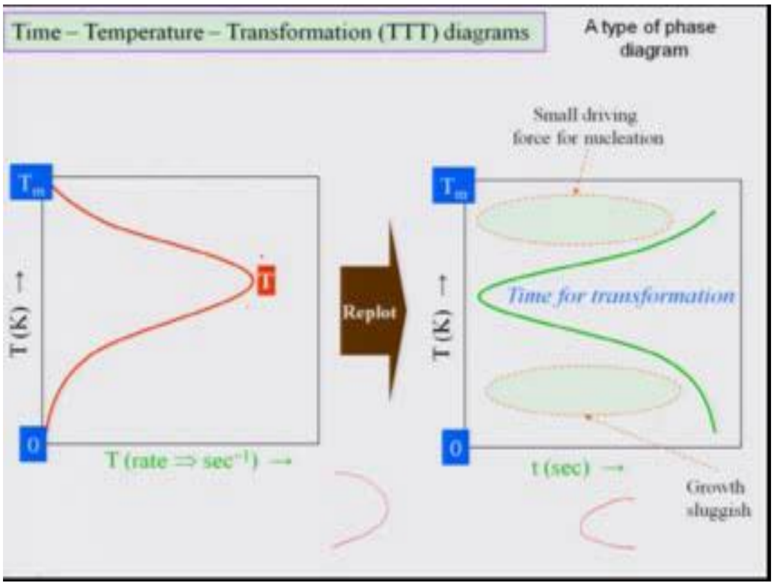

So, now as I told you the transformation rate T dot will be looking like this which I told you in the last class. And what is this? This is temperature versus rate; rate is per unit time. So, now, if I convert this diagram to you know temperature versus time that is what is done in this board. So, what will happen these curve will be inverted this is like C inverted c shape right, it is like inverted c it is just like this correct inverted c. So, this will be like this that is what happens that is exactly done in a TTT curve in the board I have shown.

So, if I know the nucleation and growth kinetics very well for pearlite transformations; then I know the transformation rate will be showing like this. So like at very high temperatures under a cooling is very low transformation will be slow because nucleation and growth rate will be low. At very low temperatures nucleus and under cooling is high, dying force is high nucleation will be probably high, but diffusion is slow. So, growth rate will be slow. All the at intermediate temperatures, both nucleation and growth rate will be very, very fast, or it will be quite substantial significant then only the transformation rate will be the maximum that is correct right for the pearlite transformation.

In pearlite transformation depends on the curve diffusion basically predominantly, and this carbon diffusion will be high at high temperatures lower low temperatures, but you know at high temperatures driving force will be low, this under cooling is low. So, therefore, transformation rate will be low. But at lower temperature, the driving force may be high, but diffusion is slow that is what intermediate temperature, the transformation it is maximum that is what is shown here. Transformation is little maximum at here. These curve when I re-plot that is what I have written re-plot temperatures versus time it will get converted that is what probably is shown in the next plot.

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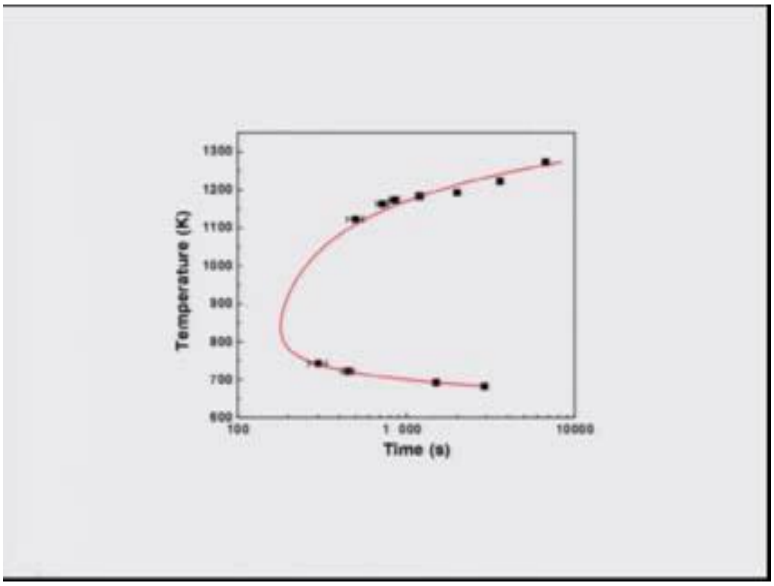

Yeah, correct this is what will be done. See, if I plot the transform temperature versus time yeah here it is correct.

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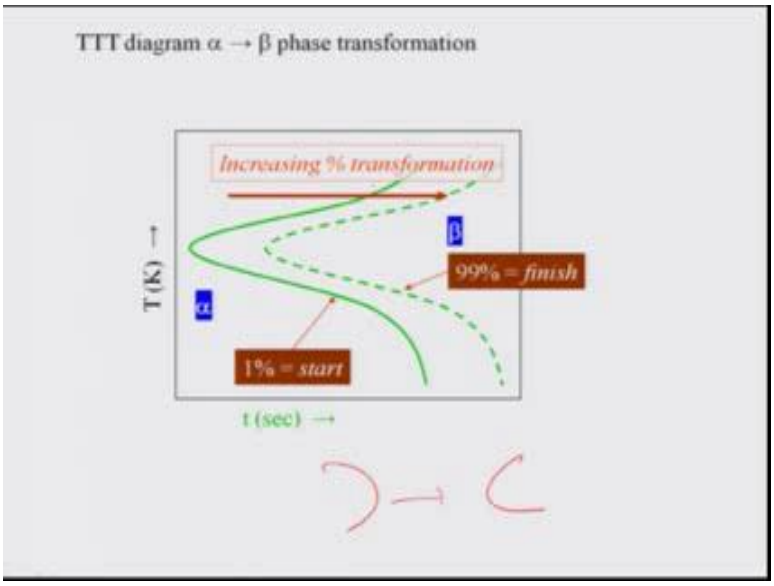

So, these plot will be converted into C separate curve converted from this to this if I change the x-axis; x-axis was in the transformation rate case it was second inverse one here it is second. So, that is how actually mathematically transformation can go. So, and we can always have a plot because the transformation depends on temperature and time. So, 1 percent they start and 99 percent they finish for a particular phase suppose beta or whatever cementite correct.

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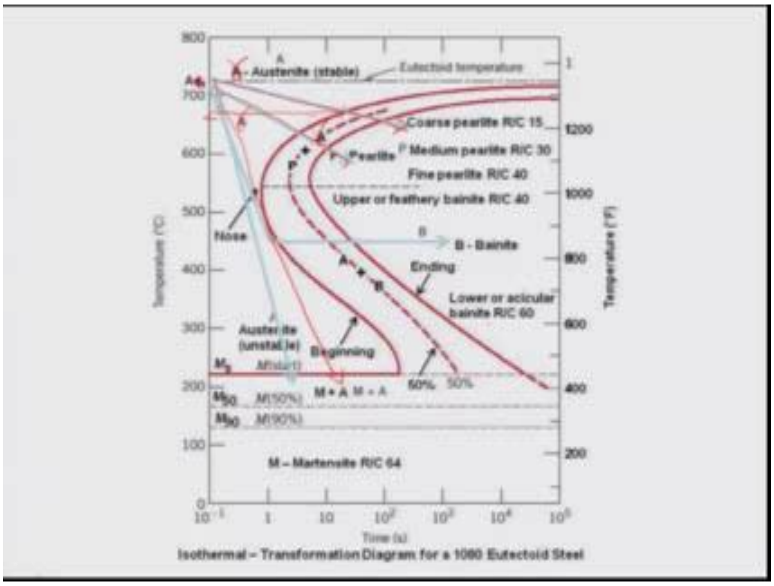

Now, let us discuss you know in detail about this curve I will give new sufficient introduction. So, whatever time I have I will discuss this particular thing. Well, so as you see here this is also first let us concentrate on the rate things as you see here this is temperature versus time and I have plotted A 1 temperature, A 1 here which is the eutectic transformation temperature M is start, M 50 is what 50 percent martensite, M 90 is 90 percent martensite. Sometime, you can do M f finish, but normally martensite transformation never gets finished as I told you because of the strain inside it retained austenite is present always that is what 90 percent of what most of the curves will see. And this is the temperature in the Fahrenheit Celsius scale. And these are the three curves one beginning, other one is end and 50 percent. As you see this A is basically transformed austenite or you can write gamma, this is pearlite and austenite, this is as you see.

Now, see this is what will get. Now, how we can use this curve. On this curve, we can impose the cooling rate how we can do that because this is temperature versus time curve. So, I can draw different lines and slope of each line will tell me the cooling rate, right. So, let us consider the first this one which I have drawn here very slow cooling rate. See, if I cool it very slow for above the A 1 or E 1 temperature, so above the A e 1 temperature, this is A e 1 and I am writing A 1 always. So, let us do that A 1 temperature. I cool it down very slowly. What will happen as the temperature as the sample is cooled, cooled, cooled only at this temperature about 650 you can see here this is 650. Transformation to pearlite will start because it will heat the beginning curve of pearlite and then it will further transform and at a little lower temperature 100 percent transformation of pearlite will takes place. As diffusion is faster at higher temperatures, pearlite will be coarse, and it will have a high you know low hardness RC scale hardness is given 15.

Similarly, if I have another cooling rate it will be faster I will have fine pearlites, because I am cooling faster correct. Now, this is what will happen for pearlite transformation you can have different cooling curves drawn on these things. If I cool it fast and by pass the nose of this one percent transformation curve by pass this nose of this one percent beginning curve what will happen pearlite transformation will not takes place. You have cooled faster after that diffusion transformation will not happen and then it will simply heat the M s start line and the martensite transformation will happen. So, you know I can always have a critical cooling rate calculated by the you know curve or by the line drawn which will just touch the nose of the beginning curve, it is just like this. The slope of this curve which I have drawn which is just touch the nose of this you know beginning curve is what is known as critical cooling rate as C c r very important because this is the cooling rate which is minimum cooling rate required to bypass the pearlite transformation.

So, you need cooling rate higher than these to form to form martensites that is the basic idea. So, now that is fine now to form bainite, what you do you just cool it faster now. So, that you bypass of the bainite transformations and hold it about 450 or 500 four degree Celsius temperature long, long time this is isothermal holding, I told you in a while when a bath high temperature bath. So, there if you keep it long, it will form bainite correct. So, as you know lower and upper bainite will have higher hardness; martensite will have much higher hardness it can have hardness of 64 even higher. So, that is how this diagram to be retrained about it. And it is very important that you have a hold on this diagram because unless and until you understand the diagram very nicely you cannot read it. For every steel in the world such a diagram is prepared and these diagrams are available in the book called making (Refer Time: 19:46) of steels by US Steel Corporation; in that all the physical metallurgy books will have this diagrams from many steels available.

So, you know many cases it is very difficult to form martensites at a slower cooling rate, because you need to have a cooling rate higher than the critical cooling rate. So, that critical cooling rate may be very high may be like quenching in water, but you know if you quench in water the steel sample the temperature goes down from 950 to room temperature and that leads to cracking in a sample because of thermal stress not only stress that have for martensite transformation, but because of thermal stress. So, in order to avoid that steels are alloyed, alloyed with some other alloying elements like carbon like mole titanium, aluminium, chromium, tungsten all kinds of things alloyed. The basic purpose of alloys is not only increases solid solutions strain, but also shift is nose to the right side. What will happen if the shift nose to the right side that is what is shown in this diagram?

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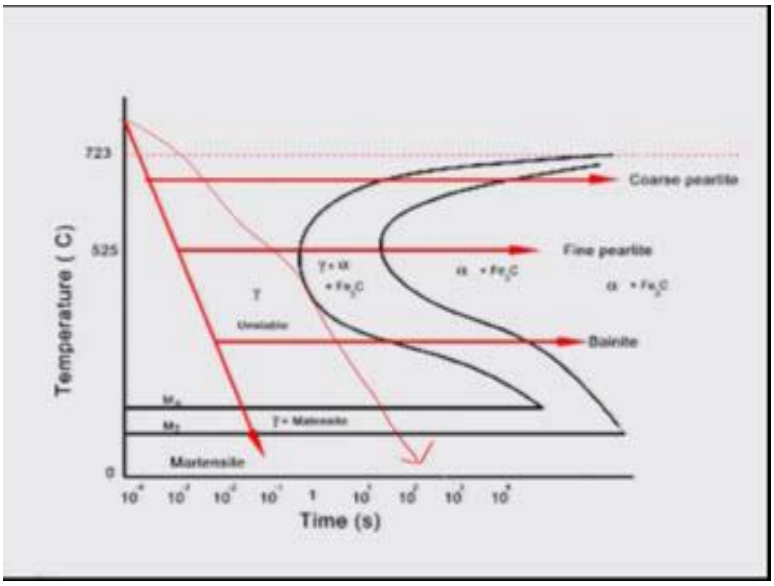

If you shift the nose to the right side, the critical cooling will to decrease this was the earlier critical cooling rate and this is now the critical cooling rate. You can decide which is slower and which is higher. Obviously, alloys steel will require lower critical cooling rate as you have seen here, so that is the basic idea of another idea of alloying you know. An idea of alloying is to form martensites at a lower critical cooling rate; and if I found martensites at lower critical cooling rate I can avoid the stress to the thermal effects cracking into the thermal effects can be avoided very easily.

And this is you know very critical that is why steels will contain manganese, steels will contain little bit of titanium, little bit of chromium, little bit of moly very small amount may be 0.5 or 0.2 percent manganese will be there in the steels because these are the elements which increase the higher availability to the steel higher availability means availability for martensite that is what normally observed in case of steels that this is why this is the reason that nose of the steel curves shifted to the right side or shift to the higher time.

In this curve, I have given the time scale you see time scale. If you see time scale start from 10 to the power minus 4 second to 10 to the power plus 4 second; the minis 4 second is nothing but a fraction even less than a millisecond but 10 to the power 4 is couple of hours 3600 is 1 hour that is (Refer Time: 22:21) seconds. So, 10,000 is about 3 hours or two and half an hours or so. So, you know you can cool it and you know this curve it is about 10 to the power of 3. So, you can cool it something like you know one hour time you can cool the sample. So, therefore, the sample which is containing alloy can be you know can be hidden or martensite can form by simply air cooling, put it into quenching water that is the message you can take it from me. So, the idea is that and this is the typical T-T-T diagram for 0.2 percent carbon steel again the things are similar.

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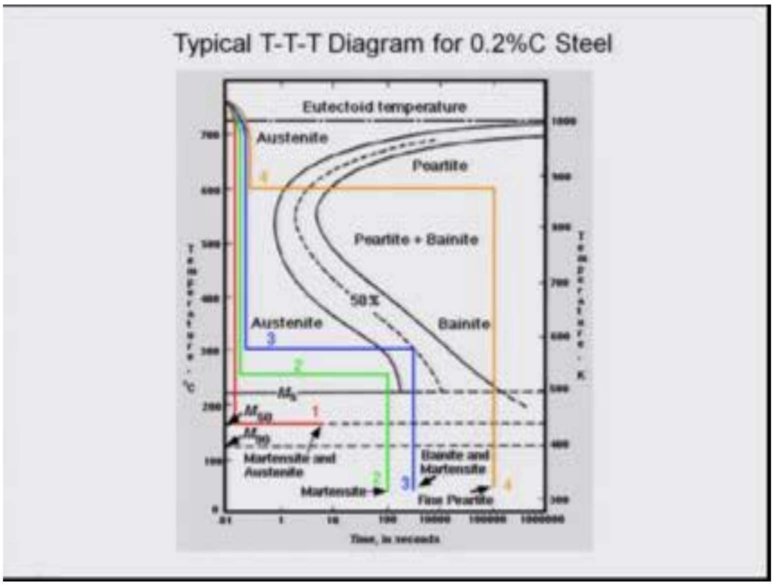

You see in the martensite, pearlite austenite everything is written. And now after my lecture you can go back to book you can go back to internet literature you can find out these curves and start reading start understanding these diagrams because this is very vital for you to understand and to read. So, although this course on phase diagram, but you know I am discussing all these things because this is very integral part of steel metallurgy in the country like India where lot of steels are produced. So, whatever is done by I will carry over whatever remaining for the steel diagram; and in the next lecture, I will start the cast iron which is also very important material and will have about three to four lectures on cast iron for detail discussions, different types of cast irons how they are formed what the way controlling that will discuss about that.

Thank you.