Introduction to Materials Science and Engineering
Prof. Rajesh Prasad
Department of Applied Mechanics
Indian Institute of Technology, Delhi

Lecture - 96
TTT diagram of Eutectoid Steels

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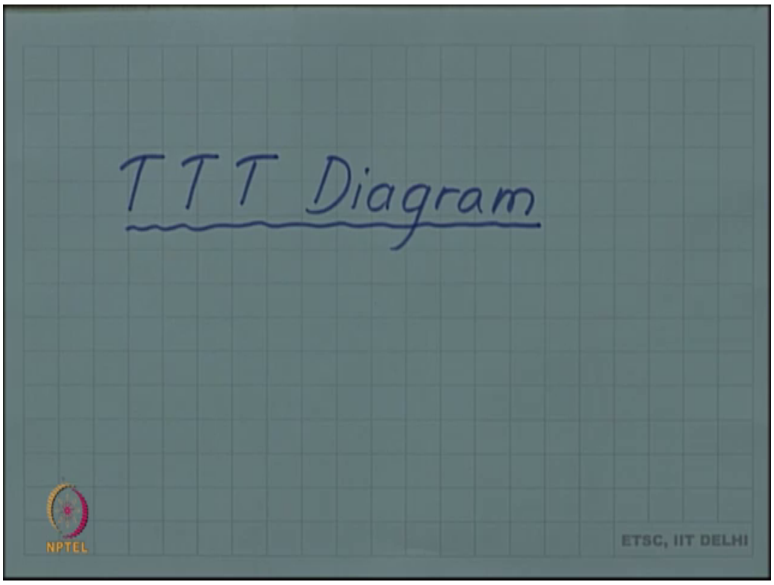

We looked at the fact that in the same steel of same composition the eutectoid steel of 0.8 weight percent carbon. We can develop different micro structure and different properties through various heat treatments, and we listed different heat treatments and we mentioned how they change the property. However, we cannot understand this difference why these differences are coming simply through the iron carbon diagram. Because, iron carbon diagram lacks one important scale and that is the time scale.

So, to include that time scale, we have something called time temperature transformation diagram. We have already met this diagram when talking about liquid to solid transformation, and we saw that how it was helpful in understanding in the coarse and fine grains, which can be formed on different cooling rates, and also the amorphous material.

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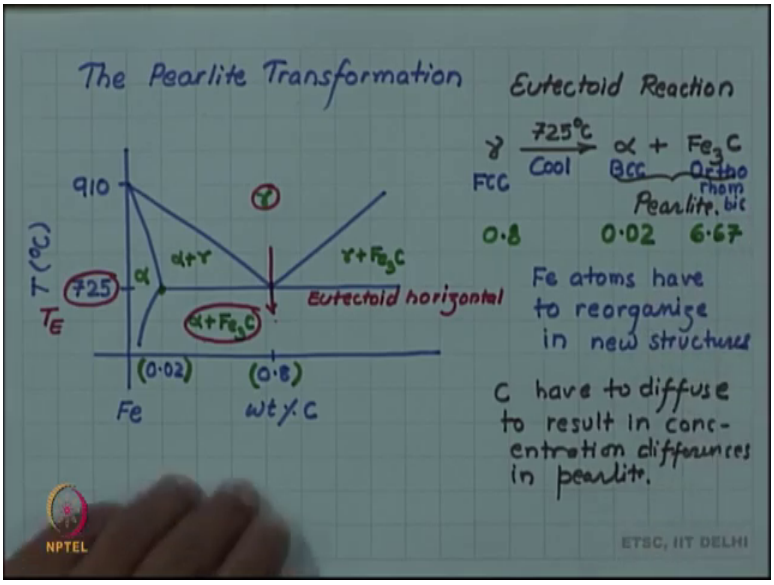

We have equivalent TTT diagram for iron carbon system, but before we go to that. Let us look at our familiar phase diagram the iron carbon diagram. In which we saw that this region which is austenite it will transform to alpha plus Fe 3 C, if we cool through 725 degrees Celsius which is the eutectoid temperature.

So, this is the eutectoid temperature T E, this horizontal if you remember is eutectoid horizontal. So, gamma transforming gamma is austenite, austenite transforming into alpha plus Fe 3 C the mixture which is called pearlite, is the pearlite transformation and it happens at 725 degrees Celsius, which is the eutectoid temperature this reaction is also known as eutectoid reaction or eutectoid transformation.

And the product of the eutectoid reaction of austenite is called pearlite; however, if you look at this transformation the phase diagram is telling us that the transformation will happen at 725 degrees Celsius. So, below 725 we should have alpha plus Fe 3 C.

However, the phase diagram is not telling us this transformation happens on cooling the phase diagram is not telling us, how much time the transformation will take place. So, at 725 degrees Celsius how long do I have to wait if I want to transform a given mass of austenite into pearlite because there is no time scale in this.

So, actually since this is a phase diagram which means an equilibrium diagram, it really tells us that if we wait for long enough time such a transformation should happen. So, in equilibrium this transformation will happen, but in a real industrial process time is important and we cannot wait for very long time.

So, we need to know, what is the time scale for the transformation. You can immediately see that this transformation cannot happen immediately because, gamma is face centred cubic, alpha is body centred cubic and Fe 3 C has some orthorhombic structure. So, crystal structure has to change and for this crystal structure change iron atoms have to move, they have to change from FCC to BCC and a new compound of iron atom with carbon has to form.

If you look at carbon concentration again you see that the carbon concentrations are very different, gamma which you started with was of the eutectoid composition 0.8, but alpha which forms is of this composition which is only 0.02.

So, alpha is 0.02 which is 40 times reduction in the carbon concentration and Fe 3 C is carbon concentration is 6.67. So, you can see that carbon which was initially uniform has to partition into a very low carbon region alpha and very high carbon region Fe 3 C. So, carbon diffusion has to take place.

So, both iron atoms have to move iron atoms have to reorganize in new structures. This requires movement of iron atom and carbon atoms have to diffuse to result in concentration differences in pearlite. So, both these atomic movements will be time dependent.

We have seen in diffusion the time is required for atoms to move and this will require time. So, this transformation will not happen instantaneously, it is not that as soon as we reach 725, the entire austenite will transform into pearlite. So, we have to wait for some time for the transformation to happen. How long we have to wait? This is the answer which comes from the time temperature transformation diagram.

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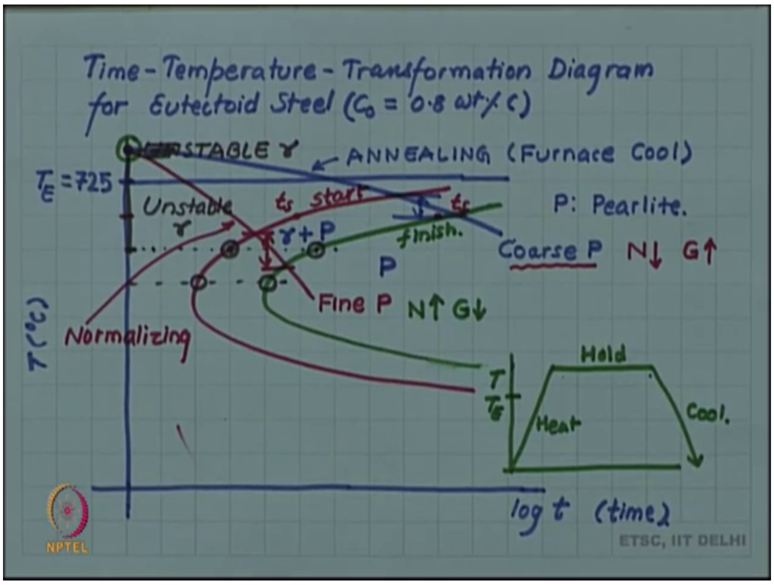

So, just like we created for liquid. Let us now try to create a time temperature transformation diagram for eutectoid steel that is the carbon concentration is 0.8 weight percent carbon. The TTT diagram for eutectoid steel is what we are going to draw now. So, the TTT diagram has a vertical axis which is the temperature axis.

So, we have temperature here and has a horizontal axis, which is the time axis, and to take care of both short and long times the time axis is usually in logarithmic scale. So, let us write this as log t, which is the time. On the temperature axis for eutectoid steel a critical temperature which is of relevance is the eutectoid temperature.

So, we mark that this is the eutectoid temperature which is 725 degrees celsius. So, let us start by drawing a horizontal line here because, this is an important temperature which. So, tell tells us about the stability above this temperature austenite is stable, below this temperature austenite is unstable and should transform into alpha plus Fe 3 C.

So, this line tells us that above this we should have unstable austenite. Let me write it unstable gamma and below this I am sorry I made a mistake. So, this is a stable above this austenite is a stable. So, that is a stable gamma below this, we will have unstable gamma. I am writing unstable gamma because, below this as we saw although we come below 725-degree celsius austenite will not immediately transform into pearlite. So, it will take some time.

So, before that time if we have austenite below 725 that austenite will be unstable then, just like we did for liquid solid transformation what we can do is that, at any temperature below 725, plot the time for the start of transformation and plot the time for finish of the transformation.

So, let us say t start and t finish and if we do this exercise for all different temperature and join the start times we get a C curve. So, this is the start time and this is the way it goes and we have seen the reason for the C curve, that close to the equilibrium temperature.

The driving force is very small notice that above 725 gamma is a stable. So, at 725 it just critically unstable and as we go below gamma becomes more and more unstable, more and more unstable means the driving force for the transformation is becoming more and more. So, as we go down in the temperature there is more and more driving force, which will try to make the transformation more probable and faster.

However, as we go down in the temperature, the atomic mobility becomes slower and slower. So, these 2 competing factors as we have also described in the case of liquid to solid transformation, it combines to give you a C curve. Because close to the equilibrium temperature the driving force is very small although atomic mobility is very high driving force is very small and that is why you require large time.

If you go to very low temperature driving force is quite significant, but then atomic mobility becomes slow and again you require a large time. In between there is a combination of these 2 factors such that, you have reasonable atomic mobility and reasonable driving force which gives you a fastest transformation or shortest time for transformation.

So, you get a C curve, which we call let us say the start C curve. Similarly, you will have another C curve is corresponding to the finish point and that also will have a similar shape. So, this will be the finish curve. So, essentially what it is a indicating that if I hold austenite somehow if I prepare my austenite stable austenite above 725, and let us say suddenly quench. This is how experimental the TTT diagram is determined. So, suddenly quenched at some temperature below the eutectoid temperature, and then you study the transformation of that austenite.

So, you will find that nothing is happening to austenite before it hits the start curve then, as the transformation begins you can mark the start time and then progressively more and more of austenite will transform. And finally, when all austenite has transformed you can mark the finish point.

And if you do this for different temperatures you will get the entire C curve for the start and for the finish. So, before they start as I have already marked before they start curve you have austenite, but that austenite is unstable because, it is below 725, austenite is stable only above 725. So, this unstable austenite wants to transform, but it requires so much time to transform and before that start it is an unstable austenite.

In between after start has happened you have started forming that transformation product, which in this case is pearlite. So, you have let me write this as gamma plus pearlite, P for pearlite and then once the transformation is complete you have 100-person pearlite.

Let us now, use this diagram to understand the difference between annealing and normalizing recall that we introduced 2 terms for 2 different heat treatments. If you if you form austenite at a higher temperature and then, so, that is above 725. So, if you heat if you heat your eutectoid steel at a temperature above 725 you will be in the austenite phase field. So, if you heat recall that all heat treatment were heating then holding and cooling. So, this heating I did not mention it in the previous video this heating for eutectoid steel, if you want to do a heat treatment has to be above the eutectoid temperature because you want to have your starting phase as austenite.

So, you have to hold it at a temperature above the eutectoid temperature such that austenite is a stable phase, and hold it for sufficient time that you have 100 percent austenite. Then, this austenite can be cooled as we saw yesterday well in the previous video that, this austenite if it is cooled in the furnace, if furnace is switched off it will be cooled very, very slowly.

And then it will form what is called Coarse pearlite. So, it forms pearlite, but it gives us coarse pearlite that is the alternate plates of ferrite and cementite are rather coarse they are thick. So, this was called the annealing. This process we call annealing, which was furnace cooling that we simply switched off the furnace and did not take the sample out.

So, the sample is cooling with the furnace. So, the cooling rate will be very, very slow, but if I cool faster that is if I take the sample out and put it in air then, that is a faster cooling and this is called normalizing let me write running out of a space. So, this is normalizing and this will give us fine pearlite. Now, this coarseness and fineness can be understood in terms of the range of transformation temperature. If you look at annealing and if you look at the transformation temperature, you can see the transformation temperature range is higher as compared to if you look at normalizing.

So, since you are cooling faster you hit the start curve at a lower temperature. So, the transformation starts at a lower temperature and finish at a lower temperature, when you are cooling slowly you hit the C curve at a higher temperature. So, transformation starts at higher temperature and finishes at higher temperature. And if you recall if the transformation is happening at high temperature we said that at a higher temperature growth is more dominant than nucleation. So, growth rate is higher nucleation rate is less. So, less number of pearlite or a ferrite and cementite plates will nucleate and they will grow faster. So, that will result in the coarse pearlite.

So, nucleation rate is low the growth rate is high due to higher temperature of transformation. In the fine pearlite the reverse is the case here the nucleation rate since, the transformation temperature has now come down at lower temperature nucleation dominates. So, the nucleation rate is high the growth rate is less and this will give us fine pearlite.

So, annealing and normalizing can be understood in terms of the TTT diagram, and the dependence of nucleation and growth rate with respect to the temperature. We will continue to use the transformation TTT diagram to understand other transformation other heat treatments which we discussed in future videos.