Heat Treatment and Surface Hardening (Part–1)

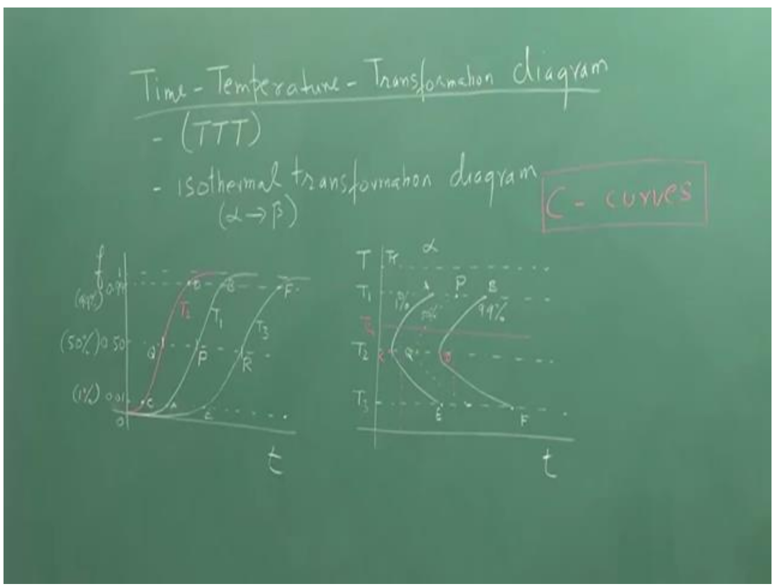
Professor Kallol Mondal
Professor Sandeep Sangal
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture Number 35

Time-Temperature-Transformation (TTT) diagram

Ok so we are we have been discussing the kinetics of phase transformation and in this context one very important concept which has great practical utility is what is called as the Time Temperature Transformation Diagram.

(Refer Slide Time: 00:40)



In short this is called as the (TTT) diagram. This diagram is also called as isothermal diagram, isothermal transformation diagram. Now what is this isothermal transformation diagram or the TTT diagram.

Well in this diagram very neatly given conditions of temperature of transformation it can tell us at different times how much what is the fraction of the transformed product. In order to construct this diagram once starts let us start with the Avrami function or the Avrami plot of f versus t, fraction transformed versus time which we saw in the last lecture is a sigmoidal curve something like this.

Let us say that I have plotted this particular diagram or this particular curve or this particular set of data points from an experiment. At a temperature t1, so let us say this one this particular curve is plotted at temperature T1. Let me set the start and the end of the transformation well we cannot really set start of the transformation at 0 it is not it is very difficult or almost impossible to measure the start of a transformation but one can decide on a small number as the start of the transformation let us say we say that when the fraction transformed is 0.01 or simply 1 percent fraction transform.

Let us consider that as the beginning of the transformation and let us consider the end of the transformation as the (frac) where the fraction transform becomes 0.99 or simply 99 percent of the transformation has taken place. So on this sigmoidal curve I have two points the start of the transformation, let me call that as point A and end of the transformation the point on the curve let me call that as point B.

Now what I do is side by side let me draw this time temperature transformation diagram. So vertical axis is temperature, the horizontal axis is time. In this let us select, let me first put down on this the temperature Tr. So let us say we are looking at a phase transformation of alpha going to the beta phase. So (the) Tr is the transformation temperature so temperature above this transformation temperature we have only alpha is only when the temperature goes below the transformation temperature that beta will start to form.

Now on this curve I want to plot these points A and B. So let us say this is by temperature T1 and on this let us say point A is whatever time that is here so what same time I plot I make make this point A here. Let I call this point as A then on the same temperature T1 line I will have another point B so what these two points are telling me is that if I keep the temperature transformation temperature is T1 the transformation is 1 percent complete when it this much time elapses and then when further this much time elapses the transformation is 99 percent complete.

Now let me consider another we go down in temperature. As we go down in temperature as we have already seen initially when we are this temperature T1 is quite close to the transformation temperature so the kinetics will be slow because the nucleation rate will be low the growth rate would be low. But both of the nucleation as well as growth go through a peak as the undercooling goes up and let us consider another temperature T2 where the kinetics have now are at a peak.

As a result I will have a second curve showing much faster kinetics at this is at temperature T2. Again I can mark two points that this much time is required for 1 percent transformation to complete and this much time is required for 99 percent transformation to be complete. So here let us say the temperature T2 is somewhere here and I make a plot I make copy these two points on this diagram.

Let me call these points as point C and point D. So point C will ofcourse be somewhere here and so let me call this as point C and point D would be at a time earlier than point B but greater than point A. So that point may be somewhere here so let us say this is points these are points C and D. Now let us choose a third temperature where the undercooling is very large as a result again the kinetics slows down and the transformation curve at a third temperature T3 looks something like this.

So this is now at temperature T3. So I have again two points for 1 percent transformation complete and 99 percent transformation complete. I will mark them as points E and points F. So I have now points E and F correspondingly on this diagram I note this T3 as the (temp) transformation temperature. And point E let us say may be somewhere here at point F is let us say somewhere here.

So I have these points plotted at the at this session of this diagram. Now imagine that I can repeat this exercise for many other temperatures between T1 and T3. So I will have a set of points and I can join all those points so I can join points A, C and E because they all correspond to 1 percent transformation complete and I can join points B, D and F to indicate 99 percent complete.

So this is one percent transformation complete, this is 99 percent transformation complete. So all the points on this curve are for 1 percent, all the points on this curve are for 99 percent of the transformation getting completed. Similarly I can choose other fractions for example I can choose 50 percent complete. So point 50 on this curve, so I have 3 points to be plotted there P, Q and R.

So point P is for temperature T1, so point P will be here. Point Q is for temperature T2, so point Q will fall somewhere here and point R would fall on the temperature T3 line. And one can join these three points as well and I will get on this diagram the 50 percent transformation complete line similarly one can have lines for other percentages of transformation. This constitutes what is called as the time temperature transformation diagram.

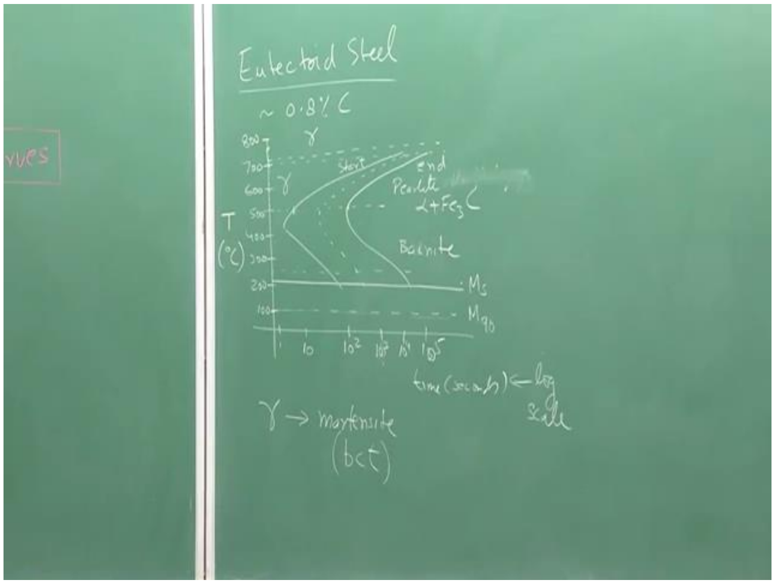
Because in one single diagram I have very neatly put down amount of transformed product given a temperature of transformation and given a time. So for example if I want to find out at now a temperature, let us say at temperature T4 what is the situation well the situation is that it will take this much time for the transformation to get completed or only 1 percent transformation to take place.

And it will take this much time for 99 percent of the transformation to be over. Similarly one can find from this diagram for other temperatures what is the rate at which the transformation is taking place. Note from this curve that the both all the curves that are drawn are in the shape of a C.

So many times such diagrams are also called as C curves. And the reason for the shape of the curve being a in a C shape should be clear that for small undercoolings the transformation rates are slow so it takes much longer time for transformation to start and end at very high undercoolings or at very low temperatures again the kinetics is slow at intermediate temperature the kinetics is fast and at temperature T2 the way I have drawn this the kinetics is the fastest or there is a peak in the kinetics.

Now I will a similar kind of now these kinds of curves can be drawn for different transformations in different material system. Suppose we take the example of a eutectoid steel.

(Refer Slide Time: 13:30)



So taking the example of a eutectoid steel that is roughly 0.8 percent carbon and let me sketch the diagram for the TTT diagram for the eutectoid steel. That is I will put down the vertical access as temperature access, somewhere here is the 723 degree centigrade line or the eutectoid temperature line above this temperature we have all austenite in the steel and below this we would have ferrite and cementite.

The C curve for this I will just roughly sketch it, so let me put time here. See this is a very rough sketch I have drawn so this represents the start line of the transformation, this represents the end line, end of transformation somewhere here would be the 50 percent line. So out here is austenite gamma and out here is alpha plus Fe3C, ferrite plus cementite. For many systems this diagram would be sufficient but in the case of steel we have some more points on this diagram.

Suppose I want to cool from austenite, so if I cool down let us say to 500 degree centigrade rapidly and then hold it here then the austenite will start to transform to ferrite plus cementite in pearlitic morphology and end of transformation in about let us say about 100 seconds or so at 500 degrees centigrade and the transformation starts just in a few seconds. If I am somewhere at 700 you can very clearly see that this transformation will take a much longer time to start and a much longer time to end.

Similarly if I go down to about let us say 250 degree centigrade again the transformation will take a much longer time to start and end. What would happen if I just continue to cool down without touching the C curves? Then in this (ca) in the case of steel austenite (ga) gamma transforms to what is called as marten side which is a meta stable phase and its crystal structure is body centered tetragonal.

This transformation is a diffusion less transformation and it takes place through a shear mode. However this particular transformation will not be discussed in this course it is beyond the scope of the of this particular course. But on the diagram we would have a marten side start line is called as MS and we would have a marten side M line or let us say M90 line, that when it reaches the 90 percent of the marten side would have formed and the other thing to note is incidentally I should write also vertical access temperature is in degrees centigrade.

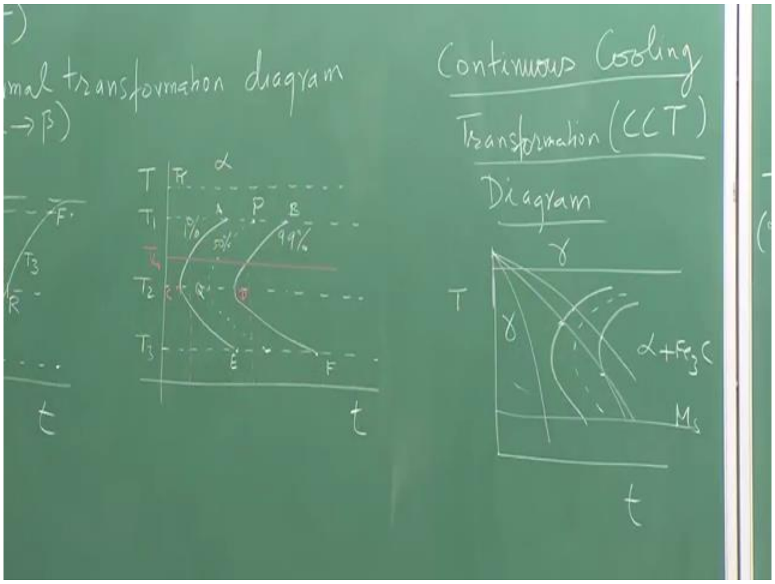
The access is time in seconds and it is log scale, that you can make out where the way I have I have put the times on the horizontal access. So you can see from here that for if you want to design a heat treatment from this diagram will tell be that at different temperatures how long it takes for the transformation to start and end.

Other thing that I have not pointed out here and such a little bit of out of the scope is that at the upper part of the C curve in this particular case we get pearlite morphology or simply pearlite which is alternating layers of ferrite and cementite. The lower part of the this particular C curve we get bainite morphology or simply called as bainite which is again consisting of ferrite and cementite.

However the mechanism of transformation of pearlite is different from the mechanism of transformation of bainite. However we will not be discussing these mechanisms here. Now the TTT diagram as such you see is also called as an isothermal transformation diagram which means that the transformations are done at a constant temperature. However for many practical applications we have transformations taking place as the temperature is continuously cooling.

In that case the TTT diagram directly will not be able to tell us when the transformation will start or the kinetics of the transformation in that case, where things are being continuously cooled. And in large number of practical cases that would be the situation where the cooling is taking place continuously however in many many cases we also so isothermal transformations in the industry. So we also have something similar to the TTT diagram to take care of the continuously cooled material.

(Refer Slide Time: 21:20)



In the case of the continuously cooled material we have what is called as continuous cooling transformation diagram or simply (CCT) diagram. So what is the continuously cooling transformation diagram again you will see it will be in the form of a C curve.

This is temperature access this is the time access, however to read such a diagram. Suppose I cool continuously my cooling curve may be something like this, so this point now will tell me the start of the transformation and this point tells me the end of the transformation. Similarly if my cooling goes something like this then again it is telling me the kinetics of the transformation.

Or if I cool so fast that I go down then no transformation will take place and if it is a eutectoid steel or any other steel then we may end up getting marten side if this is austenite here then out here would be alpha plus Fe3C. Out here is austenite and then you will have the marten site start line over here. And you will get marten site if the cooling continuously cooled material does not touch the C curve.

And this diagram can be derived from the TTT diagram but however we will not be doing this in this course, with this I stop here.