Introduction to Materials Science and Engineering
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Lecture - 93
Time-temperature-transformation (TTT) diagram

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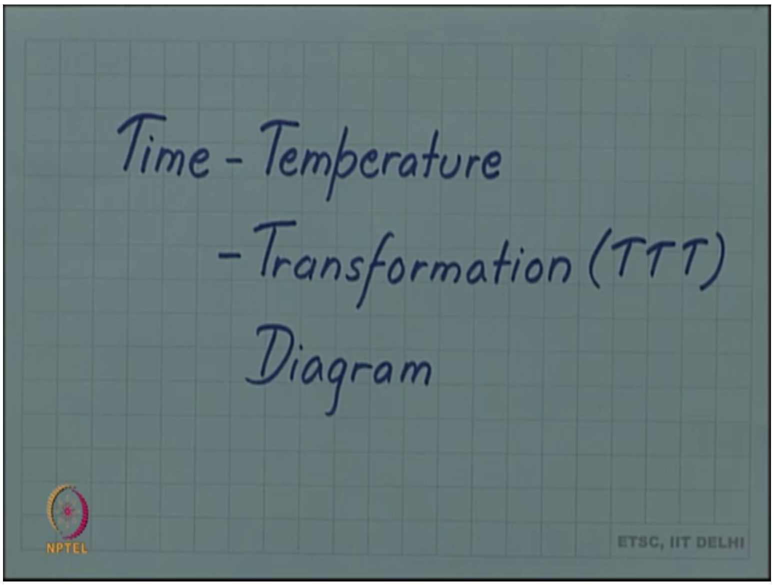

Let us look at an important transformation diagram known as time temperature transformation diagram. This kind of diagram is very important in phase a study of phase transformation; so, we have already looked at. So, let us make the time temperature transformation diagram has temperature axis.

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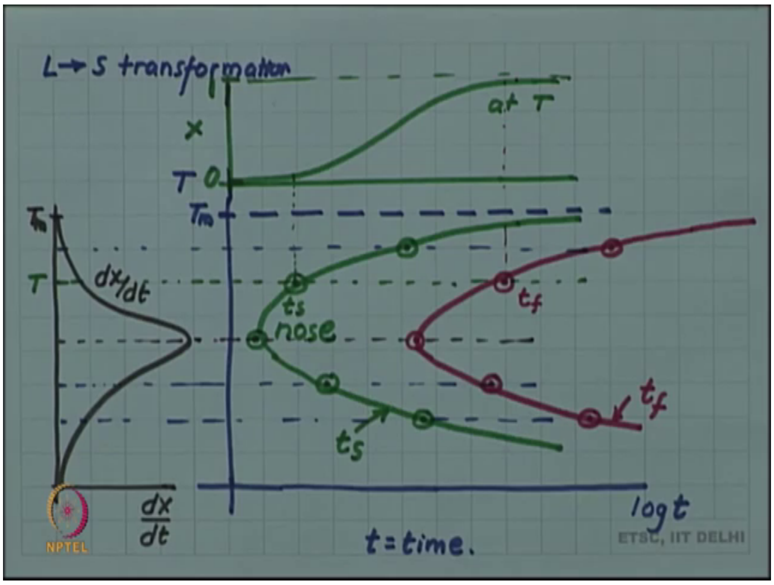

The y axis is the temperature axis and the x axis is the time axis. And generally, the time is given in logarithmic scale, we have log t. And here we have temperature, again let us looked at as an example liquid to solid transformation.

So, we have critical temperature which is the melting temperature, above which no transformation will happen. So, we can draw that line, and we have already seen that how the transformation rates change as a function of temperature. So, we can build that diagram here, and recall that we saw that at melting as a function of temperature. The overall transformation rate goes through a maximum. It goes through a maximum at some temperature, where this is the overall transformation rate d x by d t

Also, at any given temperature, we have seen that the transformed fraction x transformed between 0 to 1 as a function of time and has some sort of s curve. Let us say that we have drawn this s curve at this temperature. Because this s curve will; obviously, change at different temperatures. So, at this temperature what I can do is to plot the time for the start of the curve the start of the transformation. So, you can see here initially the transformation volume fraction transformed was very negligible and will not be detectable.

At the point where it reaches some sort of detectable level, that will be our start time. So, we mark that as our start time Ts. And after some time, the transformation will reach very close to transformed fraction of 1 so, that time we can call as time for finish. And obviously, at the maximum temperature at at the temperature at which you have the maximum rate, both the start time and the finish time will be shorter.

The start time will be here, and the finish time because the transformation rate is fastest. So, the transformation will complete in the shortest possible time, it will start in the shortest possible time, and finish also at a shortest possible time. But if we go lower than this temperature, if we lower the temperature further, then the time to start and finish will again start increasing.

And if we go to a still lower temperature, so, the rate for transformation this is the transformation rate is still smaller. So, the time to take into transform will keep increasing. And similarly, at high temperature you can see, that as you try to reach closer and closer to the melting temperature, the reaction is becoming slower and slower the transformation rate is becoming slower and slower. So, you will take more and more time to start and finish the transformation.

So, if we now in this diagram connect all the start times. So, these green points are a start time by a single curve, we get what is called a c curve, you can see the shape of the c curve, and this is the start curve. So, I label this as time for a start or ts. And if I connect all these red dots which were representing the finish time, then I get another curve and this is the time for finish.

So, both these are called c curves, and both will approach at the higher temperature side both will approach asymptotically the melting point, they cannot cross the melting point, because there is no transformation above the melting point, but they will reach asymptotically the melting point. And at a point where at the temperature at which the maximum transformation rate was there, they will show a minimum time and that is usually called in the nose of the curve.

So, this is the nose and above and below the nose you have longer time, than corresponding to the nose. Now from this diagram, we can interpret how the transformation is happening.

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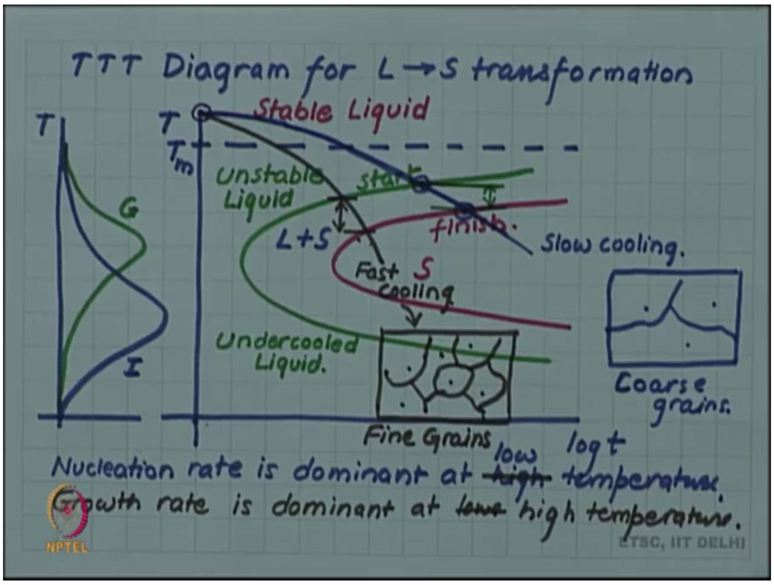

So, we are drawing TTT diagram time temperature transformation diagram, you can see it has a time axis it has a temperature axis, and it is representing the transformation a start time for the transformation and finish time for the transformation in the diagram. So, that is why we call it with 3 t time temperature transformation diagram.

The time temperature transformation diagram for liquid to solid transformation; these are the 2 axis of the time axis in logarithmic scale, you have the temperature axis and temperature axis the critical temperature is the melting point, above which nothing happens. And then we saw that there were 2 t c curves one for the start time and one for the finish time.

This is a start, and this is finish, now we can superimpose on these curves, the cooling curve for the alloy so, cooling curve for the liquid. So, as the liquid is cooling so, let us start with a liquid at a temperature higher than the freezing temperature Tm, and then from there we gradually cool this. So, you can see that if I am cooling it, at some point it will hit the start curve, and the crystallization will begin, and at some point, it will cross the finish curve and the crystallization will finish.

Although the way we had drawn this diagram was for isothermal transformation so, it will not be directly applicable for such cooling curves, but approximately we can take these temperature as the temperature for start and finish for this continuous cooling diagram also.

So, before you can see before the start curve so, let us first label the phases. So, before the start above the melting point you have liquid and that is a stable liquid that that is a happy liquid it is it does not want to transform. So, we have a stable liquid. Below the melting point liquid so, transform, but before the green curve the transformation has not started. So, you have a liquid which wants to transform, but has not yet transformed. So, that is an unstable liquid.

So, below this here you have unstable liquid or are also called under cool liquid because this is a liquid below the melting point so, we can call it under cooled liquid. Then beyond green line the transformation has started, so, you have liquid as well as solid. So, some liquid has transformed into solid, but some liquid is remaining. Beyond the red curve the transformation has completed so, you have only solid.

. So, if we now follow this blue line, if we now follow this blue line so, the transformation begins here and then completes here. So, finally, from a stable liquid it goes into under cooled liquid, and then it starts transforming into solid and completes the solidification. The temperature range over which this transformation happens can be seen as this range. And let me label this, this line as a slow cooling. In comparison with another line which I am going to draw now which will represent a faster cooling. Because you can see that the temperature is now falling much more rapidly compared to this blue line.

And if you now compare the temperature range over which this transformation is happening is this. So, on faster cooling the temperature range over which the transformation happens is lower than in slower cooling. This you can then relate with your nucleation and growth rates. So, remember, that there was a nucleation rate maximum, and there was a growth rate maximum. So, at on the higher temperature side, growth rate is dominant compared to the nucleation rate.

On the lower temperature side, the nucleation rate is dominant compared to the growth rate, let us note that. Nucleation rate is dominant at high temperature, growth rate is dominant, sorry I just made a mistake nucleation rate is dominant at low temperature you can see from the diagram here, growth rate is dominant at high temperature.

Now, you can imagine what is happening in your liquid. So, if you have a liquid, and in slow cooling the transformation temperature was higher. So, the growth rate is higher and growth rate is more dominant than the nucleation rate. Which means few nuclei will form, but they will grow very fast. So, few nuclei form and they grow very rapidly. So, you will end up with large grains or coarse grains.

Whereas, imagine what will happen in the faster cooling, now in the faster cooling the transformation temperature is lower on the lower side nucleation rate is more dominant than the growth rate. So, faster nucleation gives you many nucleation centre, and the growth rate is slow. So, they grow at a slower rate and in so that provides even more time for further nucleation events to happen. So, in the end you will end up with many grains, because each nucleation event leads to fine in the final structure one grain.

So, the nucleation rate is high you will end up with more grains, and since the total volume of the transforming material is the same, you will have a smaller grain size so, we have finer grains. So, this is a normal observation in a cooling of a liquid that if you cool it slowly, then you have coarse grain, if you cool faster then you have fine grains. We will end up this with one more interesting case.

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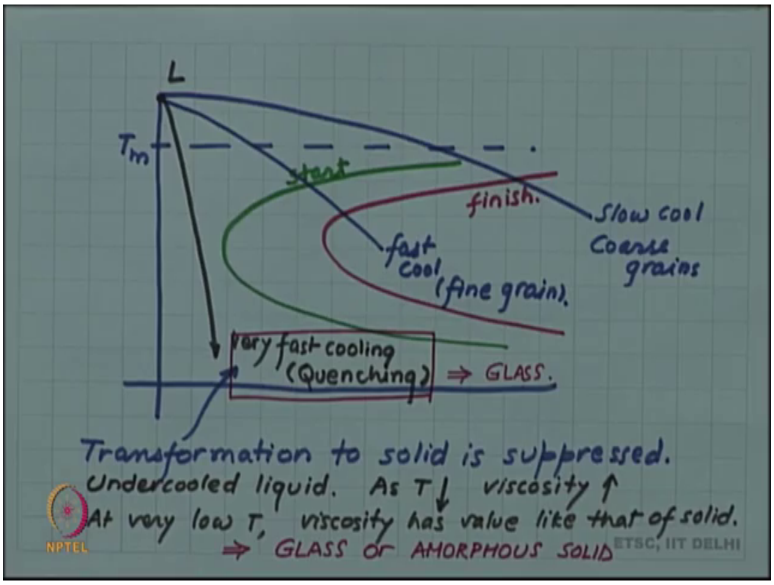

Start c curve, and our finish c curve; so, we saw that a slow cooling gave us coarse grain, and a faster cooling gave us fine grain. But what will happen to a liquid which is cooled this fast? Very fast cooling; let us call this so, here the cooling is so fast, sometimes this is what is called quenching. So, if you cool something very fast, you are quenching the material.

So, if the liquid is quenched so fast, that it even misses the nose of the start curve. So, the solidification is never starting in this liquid. So, what will happen? What will be the end product? So, obviously, since it is started with liquid, to start it in the liquid phase and it is never transforming to the solid phase that liquid continues to remain at lower and lower temperature. So, essentially what you have is an under cooled liquid here? But then, this like although it is not transforming into solid, it is physical property keeps changing. And one of the physical property is the viscosity.

So, let us note this so, transformation to a solid is suppressed, will be suppressed. So, you end up end up with under cool liquid; however, as temperature falls as temperature falls, viscosity increases, this will mean that this liquid will become more and more viscous as the temperature is falling. So, below a certain temperature the liquid will be so viscous that will appear like a solid.

So, at very low temperature viscosity has a value like that of solid. And such under cool liquid which appear to be solid in terms of their viscosity in terms of their flow property is what we call glass, essentially, we have formed a glass, which cannot which is also called amorphous solid. So, very fast cooling or quenching such that the solidification curve is avoided, it never hits the start curve will, then result in the formation of glass. So, the TTT diagram for liquid to solid transformation also helps in understanding why very fast cooling can give us glass instead of a crystalline solid.