Introduction to Materials Science and Engineering
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Lecture – 97
Quenching and martensite

Let us discuss another heat treatment called quenching. Now, quenching produces particular structure called martensite, and we will discuss that also.

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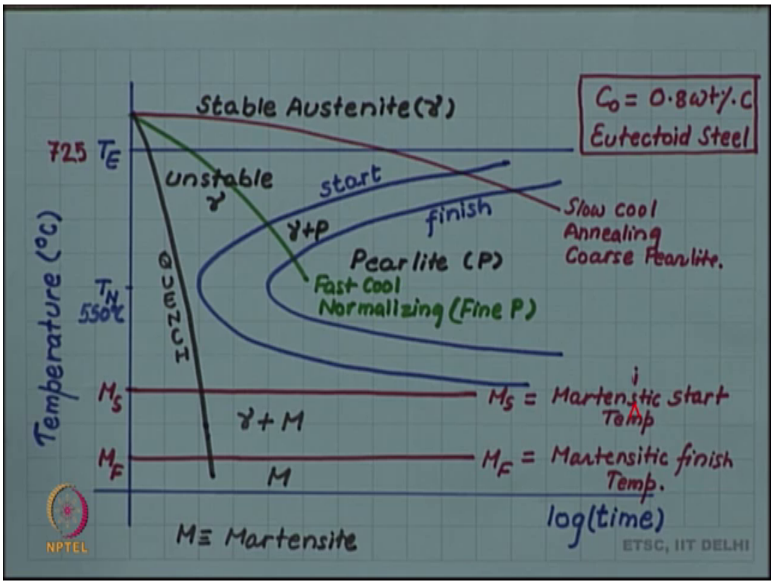

So, let us look at the TTT diagram we came across this last time when discussing annealing and normalizing. So, we have 2 C curves the start curve and the finish curve, which indicate the start of transformation of unstable austenite into stable phases which in this case was pearlite.

So, we have a start C curve and a finish C curve we have the eutectoid temperature marked here as T E, above the eutectoid temperature you have a stable austenite we have then advantage over phase diagram that, we have the time axis in the phase diagram the time axis is not there, but then at the same time the price which we pay for having the time axis is that we have lost the composition axis. So, this whole diagram is drawn only for one particular composition.

So, in this case we have drawn this for the eutectoid composition that is C O is the carbon concentration is 0.8 weight percent carbon and this is what we call the eutectoid steel. So, if you have a different carbon concentration, then you will have a different ttt diagram. So, every ttt diagram is for a particular given composition. So, this has to be kept in mind because, we have lost the composition axis the x-axis of the phase diagram.

So, this eutectoid temperature T E is the transformation temperature for the eutectoid steel and that we know is 725’C. So, that is the eutectoid temperature above which you have stable austenite as soon as we cool it below that, austenite will become unstable and will start transforming. We saw 2 curves in the last video one was for slow cooling which was annealing. So, this we call annealing and this produced coarse pearlite.

We had another curve the faster curve let us call that fast cool which was normalizing and it produced fine pearlite for us. The question now is, if we cool extremely fast. So, fast that we miss the nose this is called the nose of the C curve, where you have the fastest transformation rate the temperature corresponding to that I have marked as T N that temperature is about 550’C. If you start cooling faster and faster then you may achieve a cooling rate an extremely fast cooling rate let us say, now represented by this line that I miss the nose of the C curve extremely fast cool this is what is called this kind of treatment, which gives you extremely fast cooling is called quenching. So, I am quenching the steel now.

So, if you quench the steel if you cool it very fast like, if you take it out from the furnace and drop it in water cold water kept at room temperature. So, then the cooling is very effective in water and you have a very fast cooling rate and that is called quenching. So, what would happen, what will be the fate of this austenite which is being cooled so, fast that you are missing even the start curve so; obviously, there will be no pearlite formation in this umm this cooling rate because, you are not even hitting the start curve for the pearlite transformation.

Recall, we had a similar situation in liquid to solid transformation where we had C curves for start of crystallization and finish of crystallization. So, there also if we cooled slowly we got coarse grains and we cooled faster we got fine grains. So, these situations are analogous to the liquid to solid transformation. And there when we quenched so, fast if we cool the liquid so, fast that it missed the nose of the C curve in the liquid to solid transformation. Then, we retained the liquid structure right down to the room temperature and that was super cooled liquid or glass.

So, one possibility was that if we cool with austenite very fast do we retain this high temperature phase? Do we retain this austenite down to room temperature down to low temperatures? ; however, in the case of austenite this does not happen nature throws another surprise at us and that is what is called the martensitic transformation. So, what really happens here is that at some transformation at some temperature let me label it M S, when I draw a horizontal line here a new transformation begins and that is called a martensitic transformation.

So, M S the start of the martensitic transformation M S martensitic start let me call it. This is a temperature at which martensitic transformation begins and then, there is another temperature below that and I draw another horizontal line there which is M F, which is finished of the martensitic transformation. So, martensitic start temperature and martensitic finish temperature.

So, as the steel is being quenched as we cool below T E it will change from being stable to unstable austenite, that unstable austenite will is being cooled and is never able to transform to pearlite. Because you are missing the start of the pearlite transformation, and then it is becoming more and more unstable and finally, when it crosses M S it starts transforming into a new phase called martensite. So, we can write here, the fail as austenite plus martensite I am using M for martensite and then below M F you will have martensite.

One difference you are immediately seen between the pearlite transformation and the martensite transformation, and that difference is that although for polite transformation I was having C curve for martensite transformation I am having horizontal line. This is because, in martensitic transformation the amount transformed is independent of time. Now, although our x-axis is time time plays no role in the transformation of martensite. So, amount of martensite transformed depends only on temperature. So, at M S the transformation has just begin. So, a very small amount of austenite has transformed into martensite.

As we cooled further more and more amount will transform and finally, at mf we will have 100 percent martensite. So, in between MS and MF we can think of let us say at some temperature we will have 50 percent martensite. So, gradually the amount of martensite will change as we lower the temperature, but the transformation rate itself is very, very fast such that as soon as we reach those temperatures within no time the transformation is completed to martensite. And if we hold at that temperature in between temperature let us say at 50 percent martensite if we allow more time then, the amount of martensite is not going to increase. It is going to remain 50 percent as the time passes.

So, the role of time disappears in the transformation of martensite. It is a very fast transformation and the amount transform depends only on the temperature. Let us look at this martensite phase although we are saying that a martensite phase has formed we have not described what this phase is. So, let us look at what this martensite phase means.

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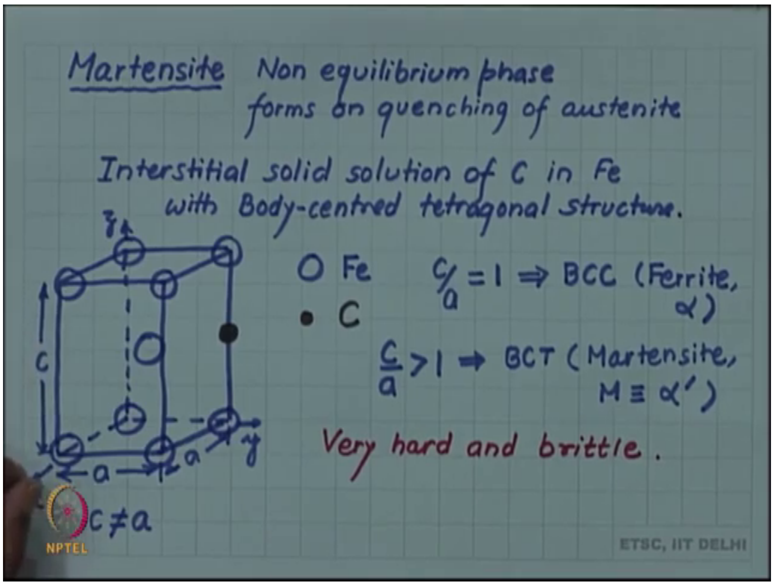

So, this phase we have not seen in the iron carbon equilibrium diagram. So, first of all it is a non-equilibrium phase and is formed on extremely fast cooling of austenite quenching of austenite or extremely fast cooling. We can define martensite as an interstitial interstitial solid solution of carbon in iron. So, this is same as austenite or ferrite only the crystal structure now is different. So, the interstitial solid solution of carbon in iron with body centered tetragonal. So, both ferrite and austenite were cubic phases, but now we have a tetragonal structure. So, body centered tetragonal structure or crystal structure that is what is martensite for us.

You recall by body centered tetragonal, we mean the unit cell of body centered tetragonal will be like body centered cubic. Only thing is that one of the axis the c-axis will be longer than the other 2 edges of the unit cell. So, this length along x and y these are a, but this length along the z-axis is c. And C is not equal to a, if c was equal to a it will be cubic c not equal to a gives us tetragonal.

The iron sets at the corners and the body center because, this is body centered cubic and carbon finds it is location in the middle of the edges of the c-axis. This is iron and this is carbon and the c by a ratio is not very high. So, remember that if c by a becomes equal to 1. If c by a equals to 1 it is no more tetragonal, it becomes body centered cubic. So, that is what is your ferrite.

You use the symbol alpha for ferrite, but if c by a is greater than 1, then it is body centered tetragonal and that is what is our martensite. I gave the symbol M for this, but because of it is relation to ferrite you can see it is a slight distortion of ferrite which will give you martensite. So, sometimes it is also have a designation alpha prime.

So, alpha is BCC. Alpha prime is body centered tetragonal and this phage this crystal structure is very hard and brittle. So, it is importance in terms of it is property is that it is very hard which is a good news, but it is also brittle which is a bad news. So, very hard and brittle we already talked about some differences in the way austenite transforms to martensite. So, let us note those differences. So, this is a very these differences are very important so much. So, that all such transformations are labeled as martensitic transformation.

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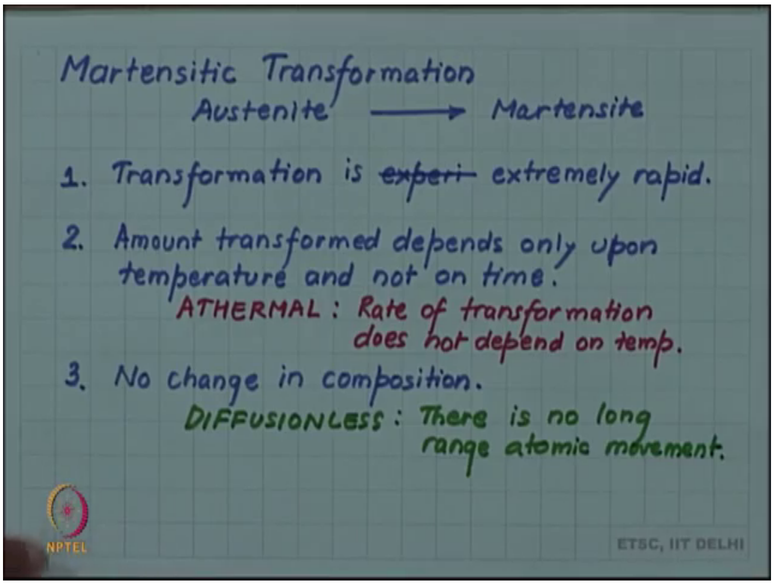

Martensitic transformation of which the transformation of austenite to martensite is a prototype so, austenite transforming to martensite is known as martensitic transformation, but it has several characteristics and any transformation which shares those characteristics will also be called martensitic transformation. So, what are those characteristics of martensitic transformation?

First of all, the transformation is extremely rapid, and that is why it is possible to have the transformation even on rapid quenching, which is not giving much time for transformation to happen. So, the transformation itself is extremely rapid extremely rapid it completes in no time. So, and since it completes in no time we see that the rate of transformation does not depend upon temperature. So, amount transformed as I indicated to you here, amount transformed only depends upon the temperature at which you have reached. So, at M S the transformation has just begin and then gradually it increases and at M F it completes.

So, amount transformed depends only upon temperature not on time. To emphasize this sometimes a phrase a thermal is used and such transformation are called Athermal. And Athermal we mean it is little confusing term to use because you see amount transform depends on temperature, but not on time. And we are using the term Athermal which means that it is independent of thermal effect, but what is independent is the rate of transformation? So, rate of transformation does not depend on temperature, and that is why you did not have the C curve. In the case of C curve, you can see the very existence of C curve is indicating that the rate of transformation are a strong function of temperature.

So, just below T E the time required for transformation to pearlite is very high the rate is very slow, but close to the nose the rate is very high and the transformation to pearlite is very rapid. So, the C curve is an indicator that the rate depends upon temperature, but here the horizontal lines for M F and M F are indicating, and the absence of C curve is indicating the rate does not depend upon temperature. So, this is called an Athermal transformation.

Another important characteristic of the transformation is that the composition is not changing. So, if we had eutectoid steel and if we are cooling it very fast there is no time for composition to change. So, in perlite when perlite form remember although we started with 0.8 weight percent carbon, and the pearlite is consisting of ferrite which has very low carbon 0.02 weight percent carbon and cementite which had very high carbon 6.67. So, enormous composition change happened when austenite transform to pearlite no such thing happens in martensite.

So, no change in composition this is linked to the fact that transformation is very rapid, since composition change is not required transformation can happen very fast. If composition change is required diffusion will be required and time will be required. And diffusion rate rates are dependent on temperature. So, the rates will depend upon temperature. So, these facts are not all really independent, but are interlinked. So, there is no change in composition sometimes this fact is also stated as by seeing that the transformation is diffusion less.

When we say diffusion less, you can see that the transformation is requiring a changing change in crystal structure, but when we are saying that the transformation is diffusion less the for crystal structure to change atoms have to move, but atoms move very little and we will show how that is possible. So, very little movement of atom, less than one complete atomic jump let us say, will lead to the transformation, where as diffusion less we mean in diffusion we mean long range atomic transport. So, by this diffusion less we mean that there is no long-range diffusion atomic movement.