Phase Transformation in Materials
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Lecture – 44
Martensite (cont.) and T T T Curve

So students we are going to discuss further on martensitic transformations little bit before I move on to the transformation kinetics. As you know martensites are very classical features of steels. So, that is why discussion of detailed nature required. Martensite looks like a distorted plates or laths in the microstructure. By the why do they get distorted? And how the morphology actually develops? That requires little more discussion. As we have seen that any steel once it is quenched from the high temperature it forms martensitic plates.

And these plates are arranged in a any direction on the micro structure. That is what is observed in the optical as well as a cm micro structures. Now we can actually this see that they actually indeed looks like a plates that is what I have shown you earlier also. And they are faulted and basically faults lies both inside the plates as well as on the surfaces.

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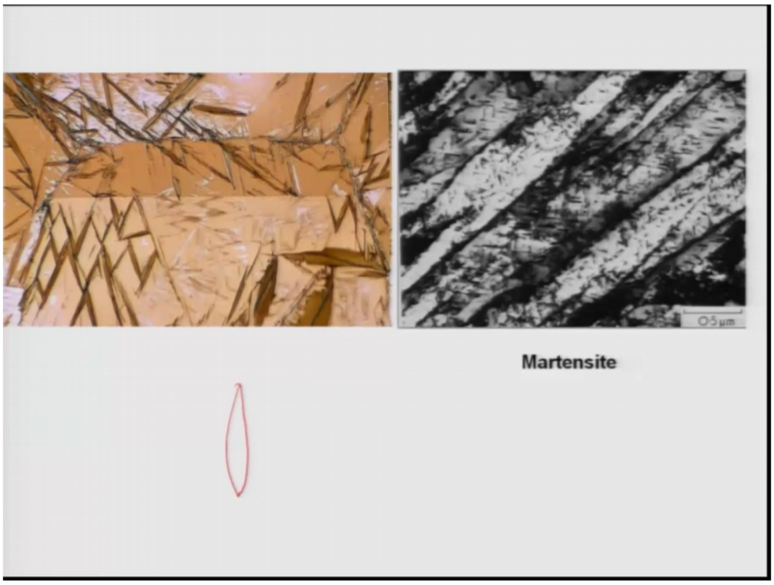

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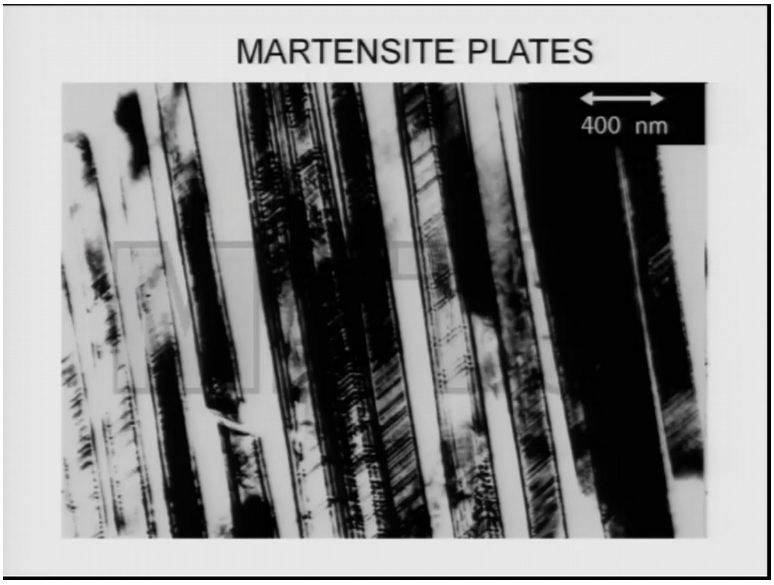

That is there on the plane between the austenite and the martensites, but mostly internal faults are more predominant in the microstructure. That is what I have shown you internal faults like twins very predominant in the martensitic plates.

Now, I came to know that these things can be easily discuss using nice analogy. And that analogy is there in the book of Professor A.K. Jena and Professor M.C. Chaturvedi and I am taking directly the example from this book. As you clearly see that before the transformation of martensites there are some scratches made on the surface.

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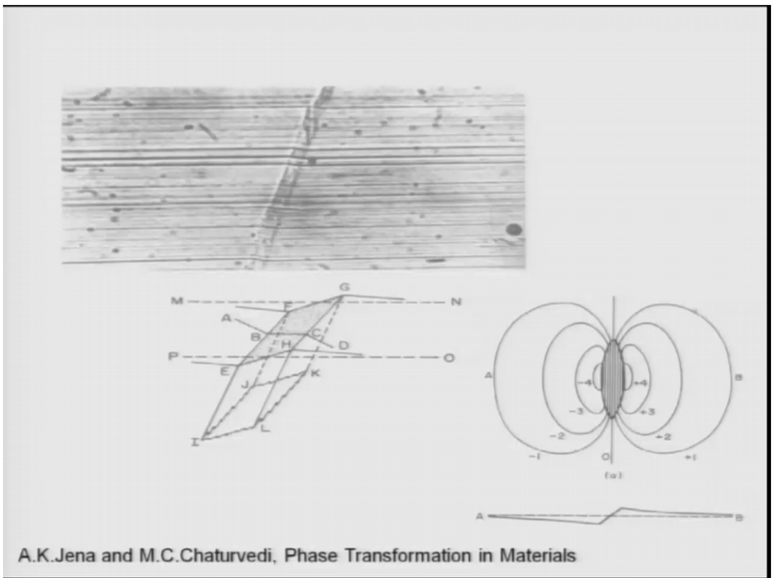

And then the steel was heated to high temperature and quench in water. So obviously, martensitic plates will form on the surface. And this will create this normally creates surface relief; that means, the distorted plane comes out from the surface and creates a surface relief. That is what is seen their; you can see there is a distorted region along these lines Let me just show it any way.

So, this is the distorted plane as you see here on this along this level these directions. Now one can actually look at the scratch the scratches were actually moving on the plane of the parent phase austenite, then it gets bend on the martensitic plates then subsequently they again remain flat on the surface. So, we can represent this whole situation in a schematic manner. That is what I have showing on this like a distorted plates. The MNOP is the undistorted plane of the austenite before the transformation.

And E F G H I J K L that is specifically is the distorted martensitic plates. As you clearly see the scratches were moving on the flat MNOP surface, then they get bent as to clearly see it was moving like that then N K bent along B C and then again moved out from these distorted martensitic plates. So therefore, but the scratches continuous, it has never been displaced from the parent to the martensitic plates it was continuous; that means, what that means, both the martensitic plates and the paranoid austenitic phase has a definite crystallographic orientation relationships, as well as they are maintaining the planes like E F I J and L K. Or a G H L K these planes which were in actually parallel to the paranoid austenite there maintaining those 2 planes same.

And it is very evident from these 2 planes, that is E F I J and G H L K they are the ones which are actually habit planes, because they have not undergone any kind of a distortion. Distortion happens along on the planes of E F G H and I J A I L K. The bottom and a top planes which has got distorted they got bent basically. On the other hand the planes which are lying on the sides of these plates those are in contact with the austenite paranoid austenite they are remain undistorted.

So, it is very interesting situations, because the same of the martensite is mainly because of the distortion very clear. Martensite forms plates are the laths because of the distortion. And this distortion is happening all the all uncertain planes the planes, which are remain attached remain parallel to the austenite they are actually not getting distorted. So, it is very evident if I plot or if we actually calculate the using tools the strain levels or strain actually induced both in a martensitic plates as well as in the austenites and can be plotted like that. As you see a stand for austenite and this is the martensitic plate inside it.

As very clear the strain in the martensitic plates. You can see here this is on the A B line, is remains flat before distortion where before formation martensites after for So, martensites these. This skating is elastically distorted in the austenite in the both sides. And inside the martensitic you know elliptical martensitic plates there is a huge parallel distortion and these leads to surface relief on the plane become you know bent, and that causes surface relief. It is evident that strain inside the martensitic plate is very large, that is obvious from this picture also.

But there are sufficient (Refer Time: 05:33) elastic strain in the austenite also. At the scene minus 4, minus 3, minus 2, minus 1, these are actually negative elastic strain. That is nothing but elastic strain in other way and this is plus on the B side. So, to in order to keep these 2 planes E F G I J and G H L K intact, there needs to be elastic distortion in the original parent phase. And that is required in otherwise these planes cannot be kept and distorted. And these 2 planes are known as habit plane that is why.

Now, this is all impossible this kind of situation is possible, once if you look at it in detail manner this is only possible once you have a shear. That is what is told in this book this is the only possible whenever simple shear strain this invariant planes which are kept their. What I call habit planes are only possible when there is a simple shear strain involved where the direction of the movement is parallel to the reference plane. Reference plane is here is basically these 2 planes which are habit planes.

So, the direction of the movements of the atoms that is seen there also see if you look at the orientation of the plane E F G H that is bent. In the directions same as the distortion of the crystal, so that is always happens; that means, the plane become plane distorted plane become ribbon plane and distorted direction even that direction even direction. Even in the parent crystal austenitic crystal as well as martensitic crystal they do not get changed.

So, that is only possible when they keep their initial relationship constant without distorting much. Now surprisingly there are lot of experiment has been done to measure these undistorted habit planes, in different martensites. And this I listed even in the tables of this book. If you look at it these planes are irrational planes like some of the planes of a indices given in this book as you know very 29 22 33 or maybe 2 to 5 in the steels actually. Or even in non ferrous atoms alloys like in titanium it is 8 9 12 h kale I am talking about it h kale is 8 9 12 is a very irrational odd planes.

So, these planes actually are remaining undistorted. And that is only possible all when you have a shear like deformations. So, what actually happens is that that is what is shown in the next picture which I have shown you earlier.

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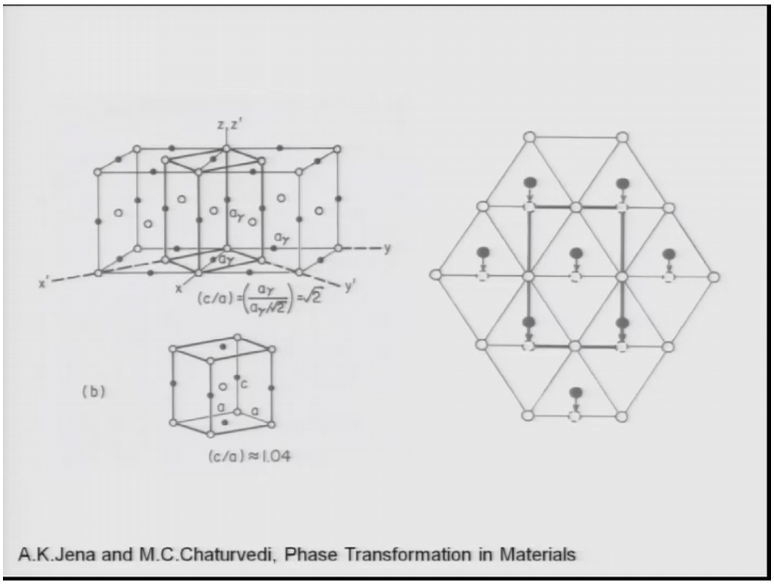

What actually happens in like this if I have continuous FCC austenite unit cells sitting in a manner atomically where these white circles or these open circles are actually correspond to iron atoms and the close black circles are correspond to carbon atoms. What we can do is basically that we can actually constitute an bct unit cell out of the 2 FCC unit cells. Just like the way it is shown in this picture. And the one which is taken out from the construction is shown here in picture B. You see c by a ratio is actually close to 1.04. That is a very, very small distortion or very small increase of the c as compared to the BCC unit cell of the corresponding alpha phase.

So that means what? These distortions which are happening can be again represented in terms of a atoms. Here these white sorry the open cycles actually iron atom sitting on the plane and this dotted open cycle actually are sitting on the in the below the plane and; obviously, the carbon atoms are actually sits on as a black close circles. As you see here that these positions which were there the carbon atoms actually move from this position to this positions very easily.

So, thus that whole distortion requires vertical movement of the carbon atoms. These carbon atoms which I am showing here these carbon atoms actually move vertically simply by application with shear forces like that like in this way and they cause the distortion in the martensitic plates. So, that is the basically idea. Now if you do this kind of distortion you generate strain lot of strain. And this strain can all be accommodated simply by creating twins. That is also can be seen in a simple picture.

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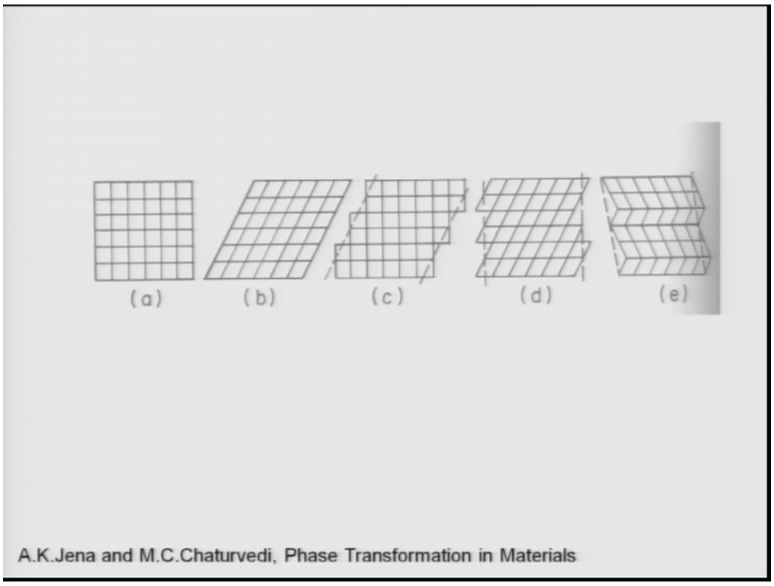

Suppose if I take a simple undistorted lattice as soon as a. And then started giving a shear strain, this is given a shear strain. So, one has bent one part of the crystal has become this bent with respect to the other. And again if you want to create invariant planes which will remain invariant in with respect to the matrix, then what is require is to give a slight distortion like that you see this is a slight plastic distortion given. So, at any place do get move.

And subsequently this plane should be arranged analytically favorably like that and this will lead to information. That is very evident in picture from CDE. So, thus twins in the martensitic plates are actually because of this heavy plastic distortion which is their required to keep this habit planes intact. That is why this is the shear process leading to that leads to twins in the martensites. I hope it is clear and evident from this picture details are actually there in the book chapter 10 and this will give you much little analogy of the how things actually done.

So, martensites actually are because of the strain martensites are very hard. As you see and because you have lot of plastic strain involved they brittle, because it has already been it has to it has already accommodate lot of strain, now if you want to deform them little bit it will simply crack or you know break into pieces. And that is where martensites even in non ferrous alloys also cannot be used directly, except in nickel titanium alloys where martensite transformation used for say memory.

So, most of the cases martensites needs to be treated separately, because brittleness that will not allow martensites we directly used in the applications, but there extremely hard so; that means, where is tense wise they are good, and so, why it can be applied for many applications. In fact, in many auto industries they use martensitic plates why are they rotated rotating or movement parts which are actually a relative movement each other are present. And this is mainly leads to wear and tear of the components.

So therefore, hardness can be used as a means to reduce the wear and improve is resistance for such a kind of wear and tear that is there now in. So therefore, we have seen all different kinds of transformations in the steels, like you have seen transformations because of the simple cooling from the austenite leading to pearlite, we have seen transformation leading to quenching leading to martensites and we have seen transformations which can lead to bainite formation. Pearlite is a purely diffusion transformations martensite is obviously, diffusion less transformation space here induced and there is no at what is called temperature dependence is there as far as transformation is concerned is all sample is to be quench to bypass the pearlite transformations.

Another benedict transformation is a combinations of both this diffusion as well as shear is still doubtable, but it can be said that both these features are presented benedict transformations. Now question is that if we know that steel undergoes all these kinds of transformations from the austenite, when it is a cool differently then can you use can you study the kinetics of the phase transformations and use them use these results. What is a means to you know get some information regarding their transformation? That is what is done in using a T T T curves that is what I will do use.

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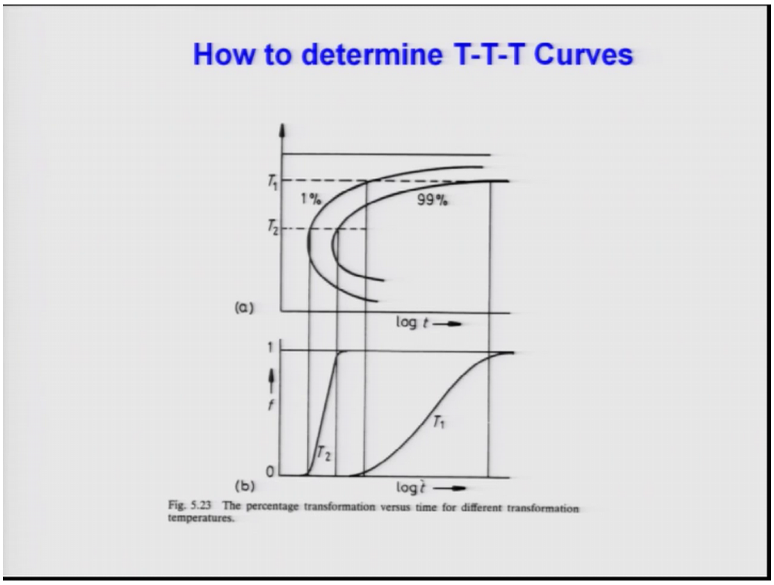

So, T T T curves first of all let us discuss how these T T T curves actually determine. You know as you know any diffusion or transformation has a time dependence because diffusion needs time. So, when austenite transform the pearlite carbon gets partition between ferrite and the cementite. So, that is requires a diffusion. So, how what is done? The obviously, transformation rate depends on nucleation rate also growth rate and even it depends on the overlap of the diffusion fields of the product phase a different phase not only that it also depends on the impeachment of these phases.

So, when they are going together because they are going separately. So, they do not know each other. So, they start impeaching each other then their growth will be hampered. So, all these factors in totality determines basically transformation kinetics, but important aspect to the nucleation. As you see here so therefore, if I measure the faction transformation as a function of the time, it will look like a such a kind of curve. It will look like a separate curve.

Obviously, the transformation at a temperature any temperature will start after certain time that is indeed the case for division transformations. Because it needs some time to start a transformation. Because diffusion requires time that is why actually that is the main reason and this time is shown here T 2 and T 1 these 2 temperatures, this time is known as incubation time the time after we the transformation actually begins. The ones transformation begins it increases initially slowly, and then increases fast and finally, reaches the maximum value closed faction transformation one.

So, this curve actually looks like a typical a snippet. Come now one can do it at different temperatures you can do it at T 1 and T 2 or even at any temperatures. So obviously, at T 1 the transformation starts at this temperature see here curve has started at this temperature. And transformation finishes at this time. The transformation has started at a time here. So, I can draw a line like these vertical lines and this correspond to my one percent transformation; that means; only one percent different phase has been transformed to a product phase.

Similarly, these points correspond to 99 percent transformation. So, if I draw a vertical line I can go into 99 transformations. At T 2 same thing can be done this is T 2 transformation rate is basically fast, because these see the time require is much lower than T 1. So, one percent correspond to these 99 percent correspond to that. So, in this way I can actually determine these s curves at all different temperatures starting with T 1 or even about T 1 little bit to ground to about much lower temperatures from these position.

So, once you have sufficient number of data then we can plot the time versus temperature sorry, time versus temperature plot and we can make these personal transformations as a curve to be shown. As you know this was faction transformation versus time, now we are actually changing from these 2 temperature versus time. So, that is why the curve nature gets change it becomes a c curve, and I have discussed you to in the last some class before how I it becomes c curve.

So, basically it looks like a c the transformation is very slow at high temperatures. A reaches a maximum value and it can get slow down. So, by this way we can actually denote one percent 50 percent 70 percent or 99 percent transform or curves. And these curves are actually known as T T T curves. In the literature the T T T curves actually tells you that how what are the different transformations can happen when you coolest shield differently. That is what will be shown in the next plot.

So, I hope you understand. Then the next curve is also to let you know how these things are done. Again what I can actually do it main inclusion to a as you see here this is faction transformation what is known as x ok.

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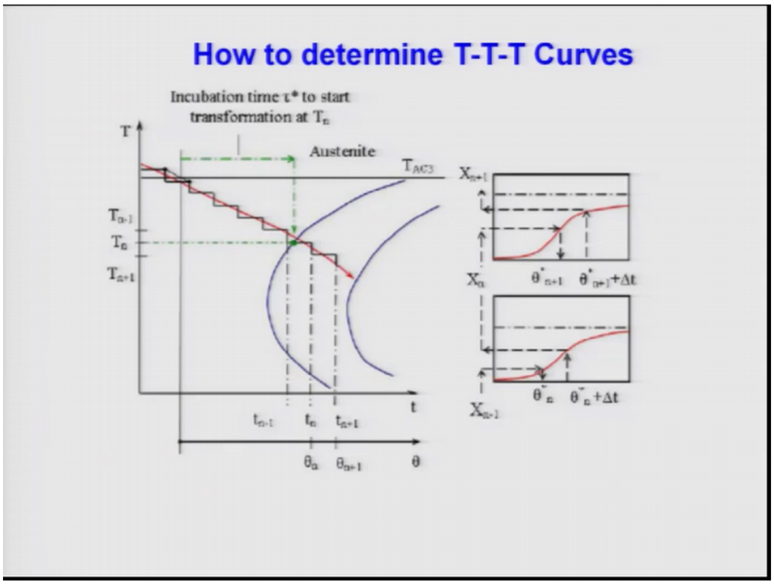

Passes time and you can actually see here at time theta n and at time theta n plus delta T we can actually determine the pass in a transformations differently. This is again a s curve here also s curve. So, one can determine different percentage of transformations, and then we can bring it there that is possible.

So, how we can use this T T T curve? That is what shown it here.

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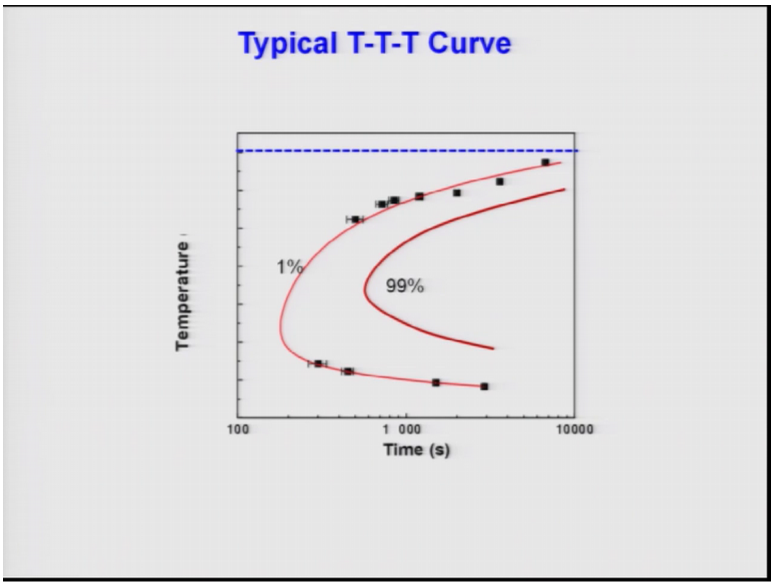

And this is basically one of the major T T T curves, as you see here this is the above which austenitic stable below which austenitic meta stable and these are the 2 curves at one percent and 99 percent transformations.

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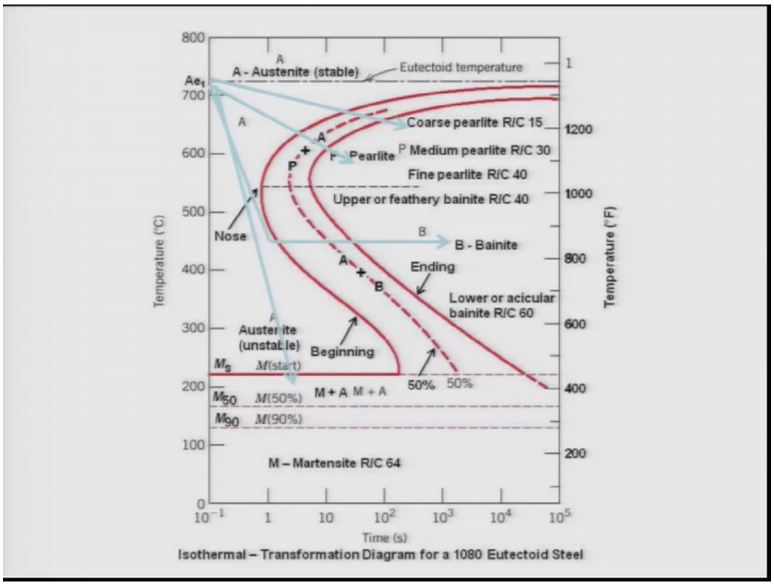

A typical T T T curve for 1080 steel or eutectoid steel is basically shown here. And as you see here these are the 2 curves which I just I shown you, but as you know martensite transformation does not depends on time. It is a basically a thermal transformation it depends on the temperature you quench.

See if you quench from to from the high temperature to 200 degree celsius temperature certain faction of martensitic immediately task form. That is certain faction of the austenite will immediately transfer to martensite, but if you cool it down to close to 100 degree celsius temperature more faction will be transformed to austenite to martensite.

So, this is just depends on the temperature to which it is quenched, and if it is quench even 0 degree celsius temperature it will transform more. So, slowly we can change the transformation faction transformation transform product, from the parent austenitic phase by quenching at different temperatures. Time has no role to play here, because transformation as I surely happen to the speed of sound that is 10 to the power 7 attended was 6 actually meter per second. So, that is quite high.

So, at that rate this has no temperature time has no effect. That is why these transformation lines as soon as a horizontal lines. It is a flat line as a particular temperature time has no effect. So, only the diffusion transformations that is pearlite and also bainites can be controlled or can be shown by such a kind of c curves. Now how we can use it? As you see first thing you should note is that a one temperature which is basically the temperature correspond to eutectoid temperature that is 727 degree celsius.

Above this temperature austenite is stable for the eutectoid steel, correct? Only below this transformation temperature austenite can undergo certain kind of a transformation, and leads to different products depending the cooling rate. See if I cool it is slowly the shown by this c curve see you see here this is this is sorry they curve this one the carbon which is stone here it is very slow cooling. Then it will lead to formation of coarse pearlite.

And coarse pearlite means lead to formation of pearlite first of all and coarse means internal was spacing will be very high. That is; what is the meaning of the coarse pearlite that is not understandable, why because the driving force when you cool down from the austenite temperature a one temperature to let us say about 600 degree 50 celsius temperature driving force is low. Under cooling is low as a driving force is slow therefore, the transformation rate is also slow.

And not only that diffusion is very fast here because it is high temperature. So, because of that the politic thicks that mean a internal spacing will be large. That is why it is called a coarse paralite it has a very low hardness rc corresponding to the c scale in the rockwell hardness, and that is very high low that is about 15. And then if you cool it little bit faster that is a second in the second line you see here, this pearlite will also form, but this will be fine pearlite. Why because you are cooling faster.

So, if you cool faster and temperatures reaches is also low about below 600 temperature driving force increases competitive previous 1 and that is well also the time given is small. So therefore, diffusion length scale also becomes shorter. And that is why the leads to reduction of inter lamellar spacing in the pearlite. And that is leads to formation of fine pearlite hardness can be jumped up from 15 to about 14 in the rockwell c scale. That is actually good.

So therefore, if you want to change the hardness of pearlite you can cool it faster, but not very fast, obviously. So, inside that you see this is written A plus B p is correspond to pearlite a correspond to the austenite which has not yet been transformed fully. Now in order to form bainite we know that the heat treatment cycle. We have to quench So, that pearlite transformation does not happen. So that means what? That means, say you see this is the nose of these c curve.

So, once you cross the nose of a c curve austenite will automatically transform to pearlite. So, only way to avoid the formation of pearlite is to bypass this nose. Therefore, you should know the critical cooling rate to bypass the nose of the austenite to pearlite transformation. That is not difficult once you have the diagram we can draw a line from the a one temperature which will be tangent to the c curve. And the tangent slope will provide you the critical cooling rate.

So therefore, to bypass the pearlite formation the cooling rate must be higher than these critical cooling rates. So, once the cooling rate is higher and the austenite will not transform to peralite, then if we keep it at about 450 degree celsius temperature basically from 350 to 450 reaches temperature for a long time. It is about let us say about 10 to the power 545 seconds, that is quite large time and then it will lead to formation of the upper bainite or lower bainite depending on the temperature upper bainite will form about 4 50 degree celsius temperature lower bainite forms are about 350 280 to 350 degree celsius temperature.

So, basically this tells us that the bainitic morphology can be changed depending on the holding temperature. Whatever the fact what I am the holding temperature the sample needs to be cooled rapidly enough to bypass the nose of these austenite to pearlite transformations. Another important aspect of that suppose if you cool it directly from the austenite temperature rapidly to the martensitic start temperatures ms then it will lead to formation of martensites.

Obviously this will lead to bypass of the both austenite to pearlite and austenite to bainitic transformations. And this is shown in this picture. As you see here clearly that the martensitic starts temperature is shown here this tells this actually tells you the start of martensitic transformation temperature below which martensites will form. And once it is cooled below the temperature martensite will automatically form it does not depend on time at all thus I told you.

So, the next lecture we will discuss little bit more about it, so that you understand also multi transformations and also the related issues.