Phase Transformation in Materials
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Lecture - 45
T T T Diagram (cont.)

Well, let us continue our discussion on the T T T diagrams. So, I have shown you that the cooling rate determines the transformation and also the product. As you cool slowly you can form coarse pearlite or fine pearlite, and once it is cooled fast enough to bypassing nose of the c curve and kept at a as thermal holding temperature something that from 2 180 to 450 degree Celsius temperature, bainite transformations happen. And the type of product will depend upon the holding temperature for bainies. And lastly I told you that if I cooled it fast to by passing nose of the c curve. And to a temperature below martensitic stat temperature martensitic start martenstics will form. So that means, if you see it was cooled rapidly enough to bypass both the pearlite and the port ousted martenstic sorry bainitic transformations.

Then the third product martensites will form. And these formation of martensite is completely independent of it temp time. It depends only on the temperature to which it is cooled.

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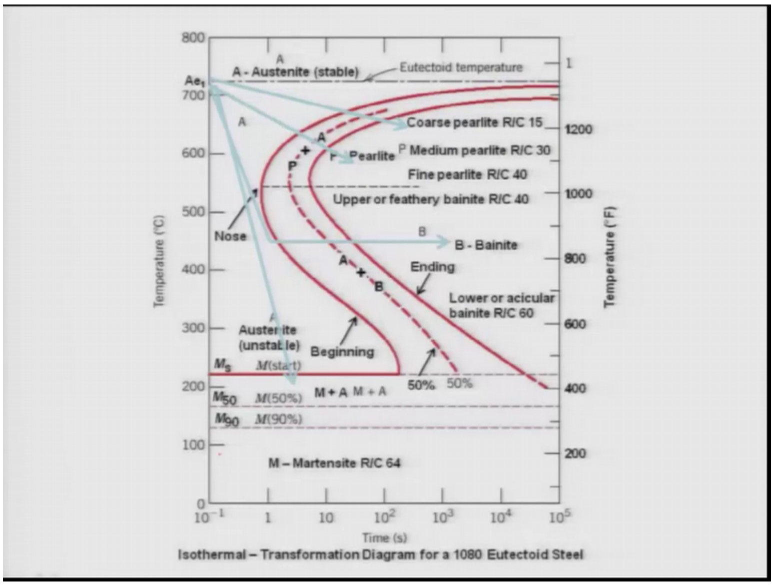

As you see there are 3 lines here. M s that is the martenstic start m 50 where the 50 percent martensite forms n 95 19 percent maternsites forms. Remember matenstic deformation leads to lot of strain in the matrix. And this strain as in the matrix; obviously, elastic strain and plastic stone in the matensites these are actually leads to a increase of the energy resistant. And therefore, the transformation from austenite to martensite should never been complete because the strain energy which is this positive part of the energy will be will be consuming part of the chemical free energy available for the transformation.

And so once the strain energy is large enough to take over the whole chemical free energy available for the transformation, well you know for the transformation possible. That is why matensite transformation is never complete. And so, these 3 temperature lines tell you for the quandaries shield that the how much percentage of the martensites you can form. And then remaining will be written austenite; obviously, written austenite is not a good phase along with martensite. And that needs to be transformed later way.

So that means what? Depending on the temperature to which I can cool if I quench to a hot oil which is kept at about 200 degree Celsius temperature, only 20 percent or 25 percent martensite will form. If we quench to a oil at temperature of 150 degree Celsius temperature, then it will lead to 50 percent to 60 percent martensites. And once it is quenched below 100 degree Celsius temperature, that is suppose at room temperature 30 degree Celsius then almost 98 percent 97 percent martensites will form.

So, that is why in the industries oil quenching, water quenching, polymer quenching all different kinds of quenching are used. Oil quenching can be used to basically to create martensites, different percentage, again the temper it both, because as you know tempering starts about 150 degree Celsius temperature. So, if we quench the steel to a oil bath kept a 200 degree Celsius temperature; obviously, austenite will transform to martensite certain fraction of it, and those martensites can begin tempered by keeping it oil quenching. So, oil quenching has both these advantages of making the certain fraction of martensitic formation and as well as tempering. Similarly a quenching which is done at room temperature or brine, which is sub 0 temperature or liquid nitrogen quenching will be only to form more martensites you can be used.

So, that is why whenever more amount of martensite are required, we always use these polymer quenching is more advantageous that way. Because polymer as you know one the steel is quenching polym any polymer of water polymer containing water polymer actually high temperature heat all these bunch molecules open up it behaves like water. So, it will take a more heat and once the temperature goes down the temperature of a sample goes down it will behave like a polymer. So, it will be become viscous sea transport will be slower. So, that sense that advantage is sense that polymer quenching can control the martensitic formation, much better way than the water quenching. That is why nowadays in the industries polymer crunching is more extensively used ok.

Because, once the steel is drop in the water it is at hot high temperature. There is a quench from high temperature. So, it will it will behave like a water. So, all the heat will be taken a water has higher heat capacity, and it will and it is behave like a fluid water. So therefore, heat will be transported transport fast the boiling will not happen much and near the sample. And the water and the ones the sample temperature will cool down. It will become like behave like a polymer it will not take over a heat so fast. So, that is why the different kinds of quenching techniques are used from 4 to form different marten sites. This is the main reason because it is an a thermal transformation depends only on the temperature to which it is cooled it does not depend the time at all.

So there are many other features which are important to be discussed. And that feature is that you know for martensite transformation important thing is the critical cooling rate what is literally known as ccr in the literature. The critical cooling rate has to be sufficiently low to be achievable. If it is very, very high, it can be achieved even quenching in the water remember one thing very clearly.

Once a hot sample is quench in water this will temperature dig drop is something like about thousand degrees. So, such a large temperature decrease will leave a distortion of the sample, because of thermal stress. So therefore, the quenching rate has us show lot of role to play to retain the sample shape. Mattensite formation also will lead to relief on the surface, but on the top of which you have a thermal stress because of the temperature drop. And this can distort the samples extensively. That is why the critical cooling rate is very important.

And normally plain carbon steel like 1080 steel has a large critical cooling rate. And that is why to increase decrease the critical cooling rate alloying is done. Remember alloying leads to alloying means putting different alloying element like martens manganese, manganese leads to shifting of the nose to the right side.

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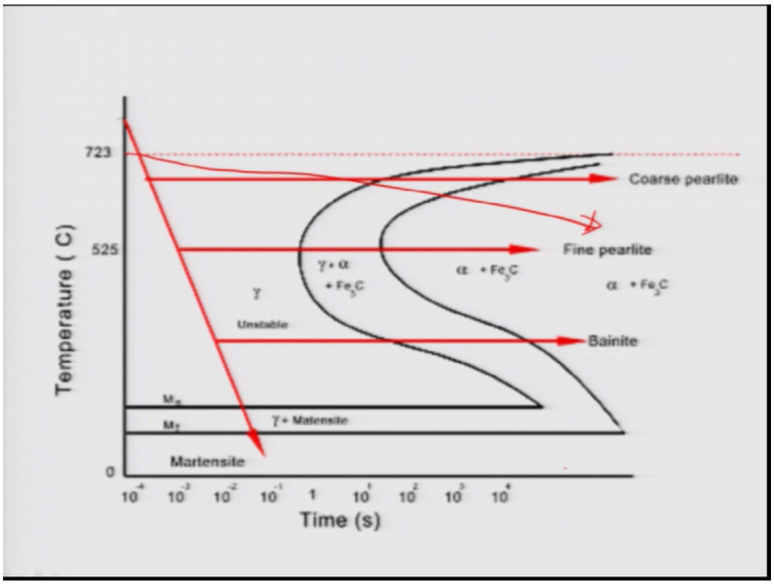

That is why it is shown here. So, nose of this c curve has been shifted extends to the right side. So therefore, critical cooling rate which is given by these line now, this is ccr. That is much, much lower. So, only when I cool it faster than that is this one, then only I can achieve martins reformations. So, that is possible. So, these cooling rate which is earlier one I have used in earlier plot is no longer required I can cool it this much or I can cool it even much lower than that I can form martensites that is possible.

So, one of the way of attaining lower cooling rate for to form martensites is to alloy. To make the steel you containing more alloys elements like manganese, or even chromium can we can be used in the steel. So, this is widely used in the literature. So therefore, if you clearly see that when you shift a nose show right side it also gives you a lot of advantage, let me first remove these lines. And then show you it also gives you another advantage what is the advantage? If you cool the steel if you cool the steel very, very slowly it is, just like a cooling one degree per hour such a slope very, very slope because the slope of this curve is very low that is what see here you can still from pearlite.

That is another point. That means what? Even when I take out the sample from the furnace and keep it outside just by keeping on a some hot plate pearlite can be formed you know and do not need to cool it fast. So, that is why alloy steel has more advantage in terms of the hardening, or in terms of d basically these transformations are concerned. Similarly if you if you cool it intermittently and keep it long time benefits will form, but bainetic formation here requires more time.

You see at this requires about 10 to the power 7 seconds that is quite large. So, that way we do not again much, because we do not want to keep it such a long time in the industry it will might because industry time is money. So therefore, the temperature times to reach these samples are kept. It should be could not be so large. So, for alloying additions the bainitic form bainitic transformation is not good for alloying additions. Sometimes it is can be costly also.

But for martensites is very good martensite formation can be done basically ok.

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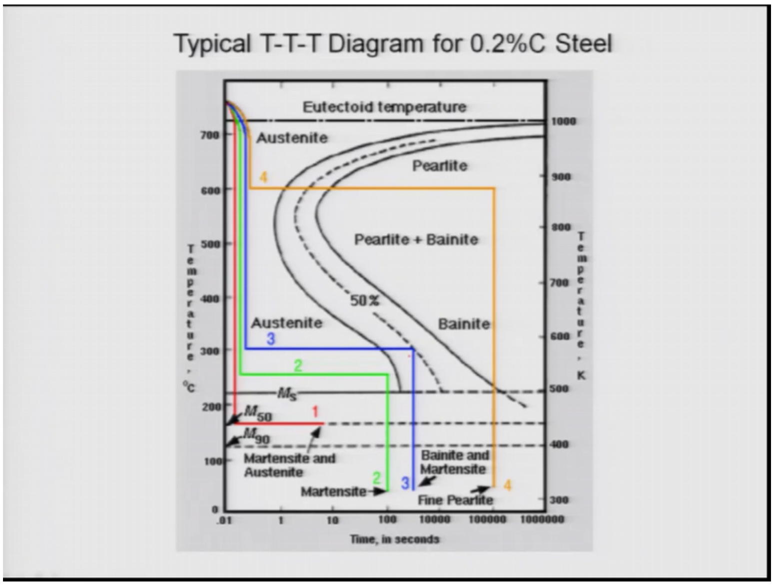

Again I am showing you this is T T T diagram for the 2.2 percent steel. That was initially fist one as 0.8 then that was near intermediate one was how identifying I had alloys and this one is for the 0.2 percent steel. These diagrams are has to be used routinely in the industries to understand the equity can to the transformations. Here again it has 2 curves officially 3 curves one percent na 50 percent 99 percent. And a may say 50 m and 90 are shown. And on these then there is a dotted line here which shows you the 727 degree

Celsius temperature, that is you take the toughens in temperatures and they have a defined cooling there. So, shown one 2 3 4 as you see here. So, one will lead 2 martensites 50 percent martensites. 2 will lead to martensites plus, you know 2 is basically in if interesting cooling.

You quench it to about 250 degree Celsius temperature and keep it there and, but do not go beyond these one percent poly transformation line, but this will lead to pearlites them remember then you quench it. But the advantage is this if once you do that you reduce the distortion of the sample. Because once it quenched (Refer Time: ten:49) it from 727 to about 30 degree celsious temperature leaves lot of quenching. So, what is done is a much easier you quench it to intermediate temperature, such way that it does not need to bainitic formations, and keep it there hold it So, that temperature becomes uniform in the sample surface distortion is less than you quench into room temperature. That can lead to martensite of transformations also, but without any distortion.

And 3 is basically bainites from martensites. That is also very interesting. You quench it to about 300 degree Celsius a temperature keep it long. So, that baintes bainites from lower bainaites will form, and you probably about certain percentage of the austenite to bainite and then. So, it remaining austenite which will be retained there. If you quench from 300 to about room temperature this will lead to matensites. So, you can actually have a micro structure consisting of bainites plus martensites together that is possible, because there are different requirements. As you know the properties of the material depends upon the phases as well as. So, they are volume factions in the microstructure. So, these cooling this T T T diagram still can allow you to control that. Both the type of phases and also the volume fractions this is one such.

So, one can also have a diagram like that you can cool it like these keep it little longer and quench it. So, by doing that this I mark 5 I can actually transform more austenite or transform austenite to more bainites and then remaining whatever may be certain fraction 10 or 15 percent will be transformed to marternsites by cooling that, that is the one other way. And now you can actually do different kinds of bainites you can actually cool it and do that this will lead to upper bainite or you can cool it, and keep it this and quench to water the upper bainite plus martrnsites. And 3 or 5 will lead to lower bainites to martensites the different kinds of morphology can be built in into the microstructure. And the 4 which is shown here is basically leads to pearlite; obviously, because you are cooling down and keeping it at a high temperature 600 temperature a long time.

So, as you will cross these nose you will form pearlite as I told you earlier also. So, the moment you cross these curves pearlite is going to mount to form, because that is the most stable product in these systems and then once the pearlite forms. So, sample can be easily cooled, because once completely transformation complete transformation austenite and pearlite happens nothing else can happen, whether you quench it are you cool it slowly does not matter.

But normally it is quenched because to are basically cooled rapidly to show that the pearlite which is form at high temperature does not get changed at when it is investigated further. So that, that means what this you know this is temperature was time each of these curves. Actually a cooling curves simply by changing the cooling curves one can actually change all kinds of different kind of microstructure. So, that is what actually important you need to understand. So, real kinetics of these transformations will be discussed later.

Because a kinetics means how actually mathematically the transformation, happens how the nucleation and growth effects. That is will be discussed separately as the kinetics of the phase transformations because the diffusional transformations are different types we have seen precipitation we have seen the eutectoid transformations. And we are going to see some more. So, once all the diffusional transformations are dealt with we will discuss about the kinetics of transformations separately.

Now as I told you that these 3 transformations peralite, bainite and martensites are very common in the steels. And I discussed with you how these transformations do happen in the process of heat treatment of steels. But this is very difficult to explain to these people who are working on a soft floor.

So, only way or representing them is using a T T T diagram, what is known as time temperature transformation diagram and steels, correct?

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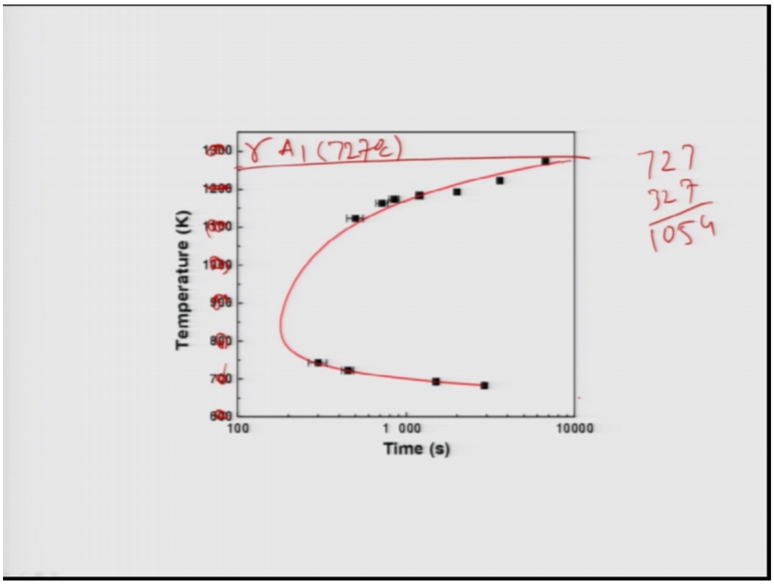

How these are actually used effectively in a in the actual applications; which I will be discussing in the next class, but I will tell you how this actually done? Remember that these transformations which are happening like perlite or bainite or martensite by using different heat treatments right. Pearlite will cooling it very slow bainite were quenching intimate temperature and keeping it longer there matensite to quench it room temperature or lower temperatures from high temperature. So, we are actually using different cooling rates. And these can be represented in a time temperature plots, correct, because temperature versus time will give you cooling rates.

If you draw different lines this has slope of the each line will give you the cooling rates. So therefore, we can actually use this cooling rate as a means of representing these phase transformations, but remember these transformations will percentage or how much transformation will happen from the gamma T p each of these phase will depends on how actually these transformation process takes place. For a typical paralytic transformations which is nothing but a diffusion control transformations it involves both nucleation and growth with the listing steps, the transformational look like a c curve, why? They easy to understand why looks like a c curve. Remember the temperature scale the temperature scale is little bit odd here.

So, if I draw 727 plus 327 this become 1054 degree Celsius temperature. So but it is showing something high here slowly if I let us put this as a thousand this is as a one temperature, I remove this temperature because they will be confusing to you. And there is a time scaling logarithm scale. So, as you see this is what is these 727 temperature for these steels. Now I have 70 degree Celsius temperature is gamma always, only a lower temperature it transform to some many products. So, for the pearlite when it is close to 727 as temperature the other cooling is low. So therefore, nucleation and growth is very slow, correct? But remember diffusion is also very fast at a high temperature. So therefore, what will happen you will have low less number of paralytic and less number of lamellas lamely present in the microstructure, but lamellar will be thick because diffusion of carbon is good or high at high temperature.

At low temperature under cooling is high; that means, that when you cool it down to very low temperature under cooling is very high. So therefore, nucleation and growth both are actually sufficiently easily can happen, but diffusion is low. So therefore, the pearlitic lamely will be thinner in size, but the number will be high, because under cooling rates and nucleation rate is high. So, in between the temperature somewhere high or low there will be optimum balance of nucleation rate.

And the growth obviously, because growth depends on diffusion nucleus depends on the under cooling growth also depends under cooling, but on the top of under cooling it depends on the diffusion as the diffusion is optimum at intermediate temperature that is why the transformation rate will be very high at intermediate temperature. That is why you have a c separate curve it is low slowly increases and this is a maximum then it again decreases because of a diffusional problem.

Because I told you 2 factors one is the under cooling other is the diffusion. So, these 2 factors act in opposition and that is why you have c separate curves. So, I can actually make we can actually make different c separate curves. And then represent in the transformations in different ways. Just that is what is shown in the next wave graph; I show yes you can see here that c separate curves. There are 3 c separate curves to a solid one is a dotted line and this is what is the A 1 temperature or some (Refer Time: 19:15) Ae 1 or Ar 1, but it let us take it is a one temperature above which austenite, which is dependent by a stable below. This austenite is also stable by matern stab ally, and you see here the c curves goes as a nose. And then there is a n to it and let us now discuss what happens our lower temperature right now.

So therefore, we have a c separate curves going like this. And there is another c separate curve going like this in between there is a dotted line. So, we can say this is beginning of the transformation is nam transformations. If only things to change is basically time, temperature is remaining same whether it is end or beginning it does not depends on massive temperature. It depends to the time it starts at a time of about 10 the power 2 seconds a lower temperature, but one second at intimate temperature and at about 10 to the 5 seconds at a very high temperature. It ends also a 10 to the power 2 temperatures the 10 to the power 2 at a lower temperature sorry, it ends or 10 to the power about 10 to the 5 seconds again at lower temperature. So, that is about intimate temperature it ends at a 10 second you see here.

So that means, at intimate temperature transformation reduced very, very high. And that is true because intimate temperature you have a optimum balance of under cooling and the diffusion. That is why I dictates the polity transformations. On the other hand as you look at bluer as you look at lower temperature you have parallel lines telling m 50 m 90. This is a actually martensitic temperature there is something known as M s remember if I quench steel. It will transform to martensite below certain temperatures it will not transform at a higher temperature because martensitic diving force, I will require to transfer martensite is has to be present sufficient amount of diving force.

So, M s is the (Refer Time: 21:07) m transform transformation at temperature, and then 50 percent and 90 percent transformation lines are given, because martensite happens in a very fast that is why there is no time dependent on that. It only depends on the temperature, if you quench below this certain temperatures only 50 percent 90 percent transformations will happen, but it will happen like a bust. Like a immediate kind of step it happens actually speed of sound in the steels. That is why these lines are drawn like that.

Now I will stop here we will discuss about different things here different cooling rates pearlite bainites and other things. In the next lecture and show you how this can be used for the steels to predict different microstructures for different properties, which is also shown on the right side of this table.