Phase Diagrams in Material Science and Engineering

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Lecture – 30
Pearlite Transformation

In the last two lectures I have discussed you about the pearlite transformation iron carbon system. As you know there are three different transformations which need to be discussed as a part of the iron carbon phase diagram - first one is the diffusion control pearlitic transformation in which gamma transforms to pearlite below 723 degree Celsius temperature or what is known as A 1 temperature. As well as when you quench steel from high temperature gamma can transform to martensite by diffusion less transformations and third one is the transformation of gamma to bainite.

In today's lecture, I am going to finish of the portions which I could not do in the last lecture that is the transformation of for hyper eutectoid steels. And then I will finally, discuss little bit of about pearlitic transformation rate, how the transformations will happens and in the time permits I will move in to the martensites otherwise I will discuss martensite in the next class. So, as you know a (Refer Time: 01:22) to pearlitis transformation is basically a diffusion control transformation in which the single phase fcc (Refer Time: 01:30) undergoes a transformation leading to the formation of alpha ferrite and cementite in the lamellar morphology and that is what is known as pearlite. This transformation is predominantly controlled by diffusion of carbon and it happens temperature is below a one, specifically for plane carbon 0.8 percent carbon steel this happens at a temperature of 727 degree Celsius temperature.

So, I discussed you to about this transformation in it is pearlite forms and how the transformation actually happens and followed by a discuss (Refer Time: 02:09) you about the transformation is hypo eutectoid steels; that means, steels which carbon concentration is less than 0.8 and I was supposed to discuss hyper eutectoid steels that is steels which causes more than 0.8.

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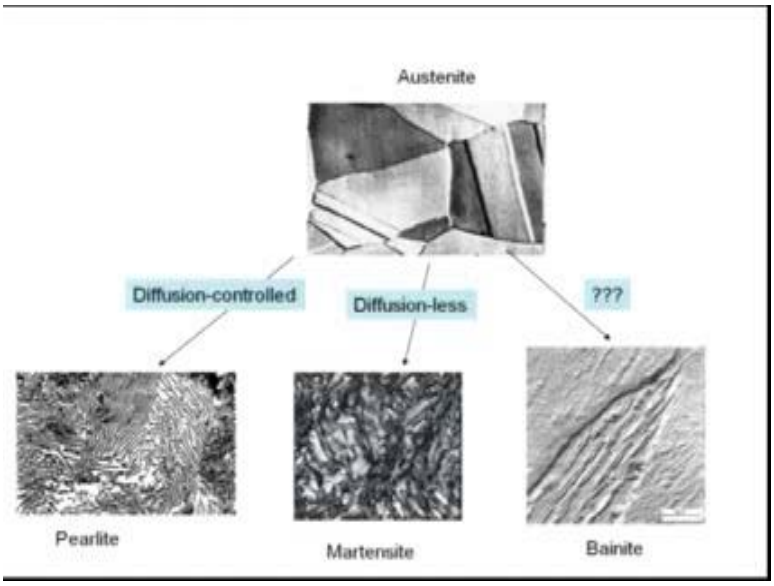

So, for the hyper eutectoid steels the phase which form from the gamma first is the alpha that is what is shown in this picture. I am going to discuss with from the phase diagram because that is my base.

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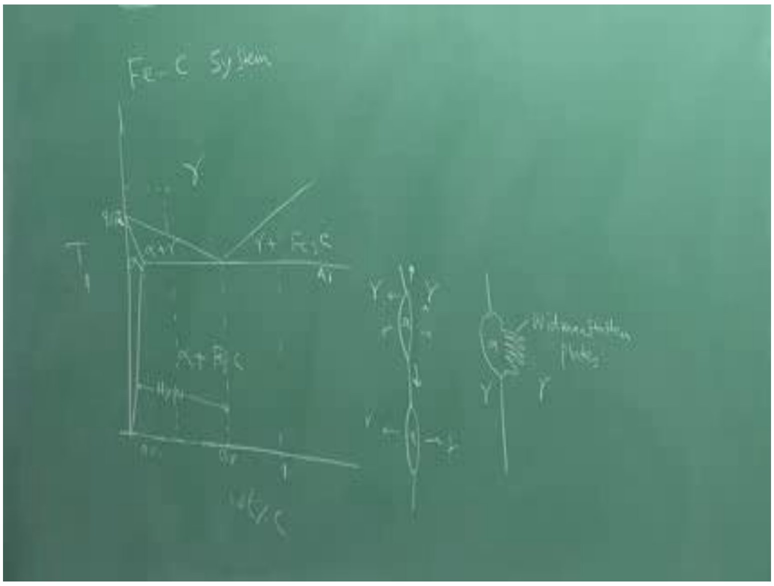

So, as you see here, this is the hypo eutectoid steel composition, but I write hypo. So, any in steel uses composition or carbon concentration less than 0.8 is known has hypo eutectoid steel. So, therefore, if I take a steel composition like this and start cooling from gamma region, which is about 950 degree Celsius temperatures, suppose here because this is 910. So, if I cool it down from a 950 degree Celcius temperature first phase will form a gamma is a alpha and alpha you know is a very very low carbon containing phase is almost a very low or zero carbon concentration at room temperature.

And finally, if you cool it down below 727 or A 1 temperature this will remaining gamma will transform to pearlite. Alpha which forms first from the gamma will there are different morphologies, I discussed with most important morphology a grain boundary electro mop and it looks like this (Refer Time: 03:45) like this (Refer Time: 03:45) particle which is forming between two gamma grains this is known as grain boundary electro mop. And it can also be having the plate 7 morphology known has (Refer Time: 03:55) certain pattern morphology.

So, when the alpha actually the reason alpha predominantly forms in grain boundaries because grain boundaries are the regions where the carbon diffusion can happen very easily. So, as you know alphas contains very low carbon, but (Refer Time: 04:11) contains quite large amount of carbon. So, carbon needs to be diffused out when the alpha grows, that diffusion process of carbon can be very fast if alpha forms grain boundaries because grain boundaries are sinks of carbon or the fast of fast diffusion normally it is with the grain boundaries. So, as soon as the alpha forms it rejects carbon in the nearby gamma region, nearby gamma grains and therefore, the growth of alpha is predominately depend upon how fast it can reject a gamma and because of that alpha grows initially length wise direction in the another grain boundaries.

Initially grows these two arrow direction as I showed you in this picture and when it becomes very long and or if the another alpha which is going here the diffusion field of this alpha and this alpha they merge then only it starts elongating in the inside the grains of gamma correct. That is why it will happen. Initially they will elongate along the grain boundaries because of the fast diffusion and when the diffusion pass of these two neighboring alpha will intersect or will have no carbon available (Refer Time: 05:28) the situation a grain they will try to move into the two gamma grains. That is why the two alpha forms along the grain boundaries, and it can also be like a widmanstatten morphology plates which I have discussed like this, this are widmanstatten plates. They can grow inside the grain of gamma very easily, very easily it can grow inside gamma and predominantly this morphology is observed in the steel samples for the hyper eutectoid steels.

So, that is about the alpha and ones the alpha forms and alpha will reject carbon. So, therefore, remaining gamma will be induced in carbon and once this gamma will be having a carbon concentration of 0.8 and the temperature you will reach below A 1 the gamma will transforms to pearlite. So, that is how this whole transformation of the hyper hypo eutectoid steel will happen. So, now, let us consider what will happen for the hyper eutectoid steel.

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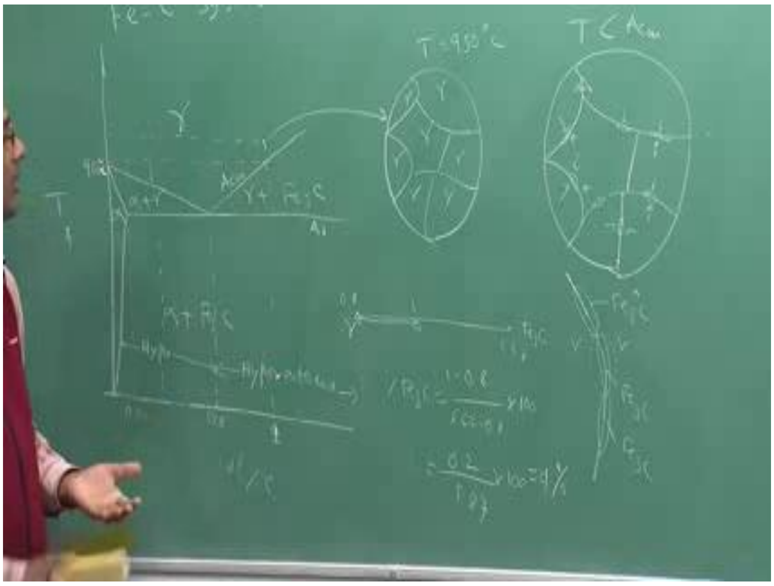

So, the hyper eutectoid steel I mark the steel composition of point of one atom weight percent of carbon. So, any steel composition beyond 0.8 for a plane carbon steel is known as hyper eutectoid steel. In steel it can 0.9, 1, I was taking one example which is point which is 1 percent carbon. So, what is going to happen here? Again if I steel take a steel sample at about 950 degree Celsius temperature, suppose somewhere here it will have a single phase gamma microstructure; that means all the grains will be gamma. So, at this temperature all the grains will be gamma, large grains of gamma as you see here these are the gamma grains nothing will happen above this temperature which this is temperature at which this is called Acm line that is the line a curve which (Refer Time: 07:38) phase stability between gamma and the cementite that is why it is called Acm, cm stand for cementite. So, below Acm cementite will form this cementite is again primary cementite like alpha primary alpha which forms here.

So, again this cementite, if I say this T equals to 950 degree Celsius temperature and if I draw the same picture T below Acm, what will happen? This gamma grains will remain and this gamma grains will remain whereas, the cementite will nucleate along the gamma grains boundaries because grain boundaries are the regions is where diffusion where carbon will happens fast. As you know if the alloy composition is 100 percent carbon; that means, each of this gamma grains will have 100 percent carbon. On the other hand cementite contains 6.67 weight percent of carbon. So, from 1 to 6.67 percent of carbon is defines it very large. So, therefore, if you want to form this cementite containing about 6.67 percent carbon you need carbon diffusing from gamma grains to these places.

I want to defuse and reach these places for cementite to grow. So, if the carbon normally diffuses very fast at the grain boundaries any pieces will defuse (Refer Time: 09:09) second boundaries is because grain boundaries is a region of defective. There are lot of defects in the grain boundaries, when the two gains mix there will be mini vacant sides, there will be dislocations, (Refer Time: 09:23) falling in grain boundaries is nothing but a row of dislocations. So, did you saw the reasons why the diffusion of carbon can be happen very fast or in the grain boundaries and that is why the cementite nucleates only prior gamma grain boundaries and then the cementite lamely will grow along the grain boundaries; that means, again they will lengthen along the grain gamma grain boundaries this cementite because of the faster diffusion path.

Finally, these lengthening will stop wherein another cementite lamely will intersect or meet the center cementite lamely. So, this one was going along the length of gamma grain boundary, this lengthening along the grain boundary will stop when these top one or the bottom one will hit the boundaries here that is what will happen. You know again if you allows more time or more diffusion to happen the cementite lamely cementite sorry this cementite grains will again grow into the gamma grain inside it. And normally we do not see it happening, why? That is because the amount of primary cementite will form is very low very low percentage, why? That is can be calculated. So, let us do the calculation using the (Refer Time: 10:52) rule my alloy composition is one percent carbonite. So, my (Refer Time: 10:56) will be at 1 percent carbon and this is 0.8 at the pearlite forms and cementite composition is 6.67 that is cementite right. So, this is gamma.

So, I am calculating the percentage of cementite about A1 temperature and that cementite is my final cementite which will form in the grain boundaries. So, what is the percentage of cementite? Very easy, you can do yourself. This is this, this is 0.8, and this sum divided by this sum what is that, so 1 minus 0.8 divided by. So, I am taking this sum, this sum divided by the whole sum 6.67 minus 0.8 into 100. So, this is point two divide by, this one is 7, so 5.87 into 100. So, it will come like about 11 percentage very small, very very small.

So, (Refer Time: 12:01) 20, 20 divided by 5.87 this will tell about 4 percent that is all very low. So, as you see here if the total volume percentage of this parallel cementite is four percentage so; that means, these stages will be lying along the grain boundary. They will not along they will not become fatter, or they will not grow along the inside these gamma grains because that much of cementite will not form in the micro structure. So, by simple using your rule you can clearly show that cementite (Refer Time: 12:37) is much lower on the other hand I have also done the calculation for the primary alpha which will form if you cool down from this temperature to this A 1 temperature that is very large. That can be 25 percent or even 30 percent or 50 percent not 4 percent. So, because if the total (Refer Time: 12:53) cementite forming at 1 percent of 100 percent of the carbon concentration is alloy is only 4 percentage. So, there will be only line on the grain boundaries. So, that is what will happen below Acm temperature.

Now at temperature, therefore, as the cementite forms what will happen? This is if you look at it although gamma grains all are having 1 percent carbon concentration, cementite having larger amount of carbon concentration will take away the carbon from the gamma grains that I have shown by arrows. The carbon will diffuse from the cementite from the gamma grains into cementites, you see here that is what will happen. So, because of the diffusion of carbon these gamma grains will be having lesser and lesser amount of carbon will become leading carbon concentration or rather I can say the gamma a carbon concentration gamma will follow this line, Acm line as you lower the temperature as you lower the temperature slowly the gamma concentration, gamma grain will drop along it drop along this line which can be followed by this line Acm on the phase diagram.

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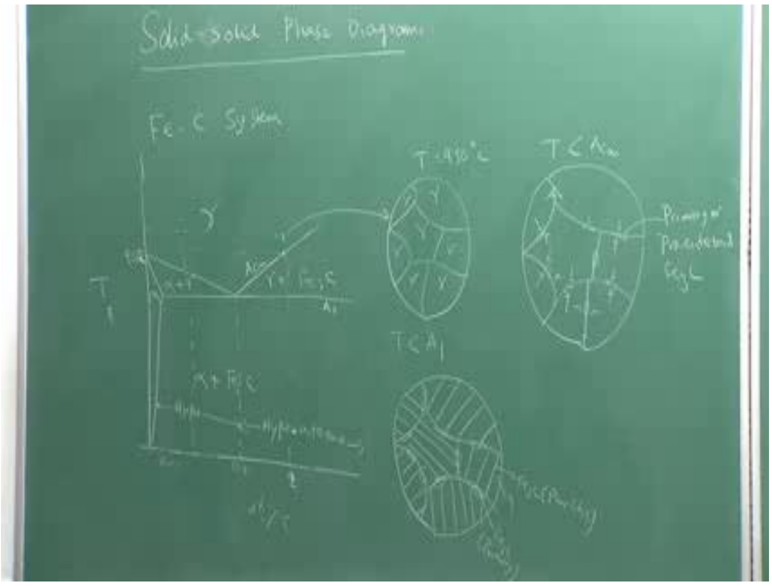

So, finally, add a temperature below A 1 whatever gamma grains will remain those gamma grains will transform to pearlite write. So, these are all the cementite, which these are all cementite which are grown along these boundaries it is very small, and these grains will then transform into pearlite, that is what is the micro structure you will get for the hypo eutectoid hyper eutectoid steel. So, this is alpha this is F e 3 c this is also F e 3 c, but we will call this has a primary or pro eutectoid. So, this F e 3 c is primary or pro eutectoid cementite, why it is called pro eutectoid? Because it is formed before the eutectoid reaction, eutectoid reaction happens at the below A 1 temperatures. So, anything forming above or temperature above this eutectoid transformation temperature is called pro eutectoid. So, that is why it is called pro eutectoid cementite. And this cementite which is inside in pearlite lamely is known as pearlite cementite or because it forms g 2 pearlite transformations. So, you have to you must know this difference between these this has formed by different mechanism then this one.

So, this cementite which I have marked as a primary they form by nucleation in growth on the grain boundaries of gamma at the temperature above A 1, but these forms by eutectoid transformations (Refer Time: 16:10), but eutectoid transformation which is (Refer Time: 16:13) type from the gamma to form both cementite and alpha. So, that is exactly how the cementites lamely will form. Now I have given you the whole picture let me just show you some micro structures, so here and also u 3 microstructures which I have shown you earlier.

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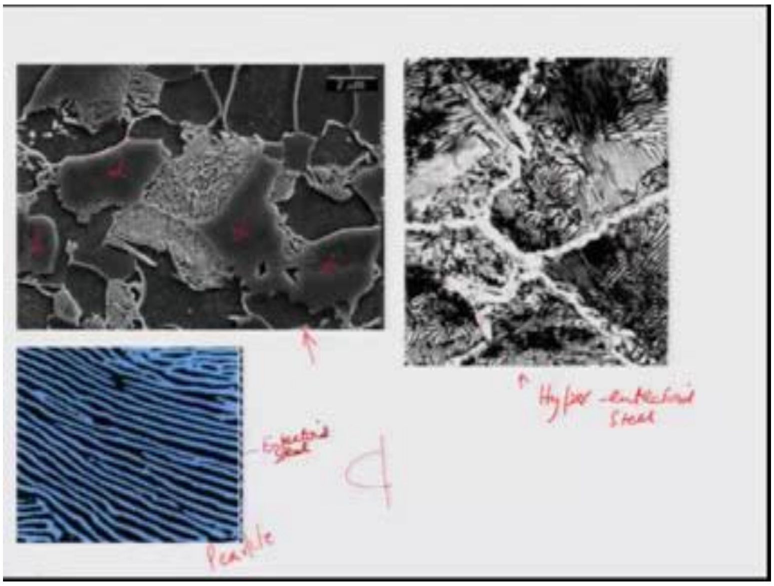

This is the pearlite as you see here, this is for the eutectoid steel pearlite, for the eutectoid composition that is 0.8, the left this picture is for the hypo eutectoid steel where you can see large amount of the primary alpha and the pearlite, pearlite is very easily designable from the microstructure and the right side you have hypereutectoid steel in which primary cementite has formed as another grain boundaries very small volume percentage. You see here only other grain boundaries it has formed, and within the grains of prior gamma grains what do you have as a pearlite, typical lamellar microstructure that is what you see in these grains, correct.

So, the major difference between hyper eutectoid steel and hypo eutectoid steel is that in hyper eutectoid steel you will use large big alpha grains primary alpha grains. On the hypereutectoid steels uses a small amount of the cementite, primary cementite forming around the grain boundaries of gamma these alpha also started forming on the grain boundaries of gamma, but they have grown and because their volume percentage according to the phase diagram calculation is very large. So, that is what you see large grain of the gamma. So, this you must keep in mind because this is very important.

Remember, majority of the steels in this world actually hyper eutectoid steels, 0.3 0.4 0.5 percent of carbon or even less 0.1, but very small amount of the steels which use a hypereutectoid steels. Because in the hyper eutectoid steels you have a primary cementite present this steels are brittle or are very strong all our knives (Refer Time: 18:16) even blades they are made of hypereutectoid steel, the shaving blades which are having very thin edge are made of hypereutectoid steels. So, that is the important thing about the hypereutectoid steels. Hypereutectoid steels are not used in large quantities, but they are used for specific applications and this applications demand high strength, ductility very poor, but high strength you want to create a knife edge should be very sharp. So, to keep a large sharp edge on the knife you need a strong material, hard material so that it should not bend it should not get deform when you are cutting something. So, that is why actually this micro system becomes very important.

So, the properties of this steels actually completely depends on the micro structure diagram and micro structure depends on the phase diagram also possessing conditions, but here it is completely depend on the phase diagram. So, I told you that how actually the hypereutectoid steel transformations happen. Now, another 5-6 minutes what I have I just want to discuss with you the way the pearlitic transformation rate changes. As you know pearlitic transformations, what is happening inside this grains it depends on the carbon concentrations; it depends on the carbon concentration in the sorry carbon diffusion in the steel; a diffusion of carbon along the gamma in the transformations.

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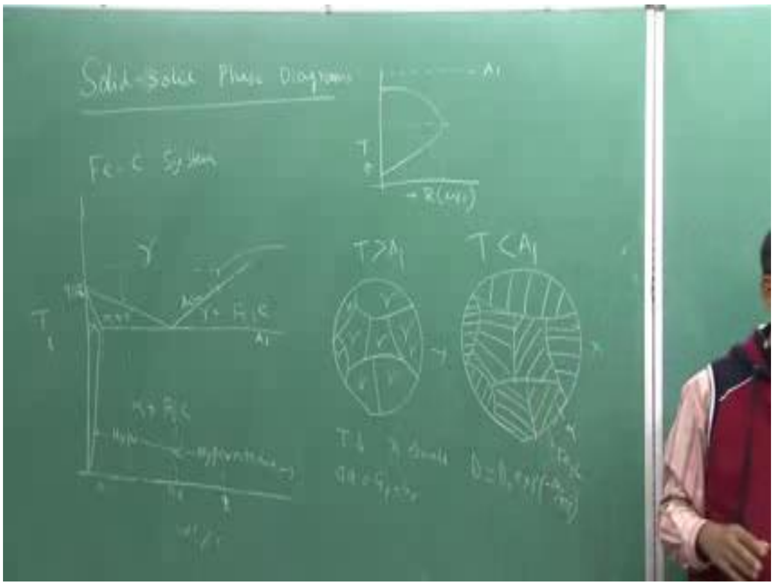

So, pearlite which actually happens for 0.8 carbon concentration steel, if I take a 0.8 carbon concentration steel; and temperature above T 1, above A 1 they will have all gamma grains and as soon as you cool below A 1 temperature these gamma grains will transform into pearlite and this is the way you show (Refer Time: 20:24) pearlite lamellar micro morphology and I show the orientation of this lamellar deferred in different grains, just is to make sure that they are forming in a different way.

So, my question is this when these transform to pearlite gamma, what is the way that each transformation happens? Normally the rate of the transformation depends on two things - one is the kinetic factor, second one is the thermodynamic factor. What is the kinetic factor? Kinetic factor is a diffusion of carbon, why you need to diffusion of carbon; you remember these gamma grains contain all 0.8 percent carbon. Now from these I am forming two phases - one is cementite which is carbon rich other one is alpha which is carbon lean alpha do not contain any carbon at room temperature, high temperature it contains about 0.02 percentage of carbon. So, therefore, on the other hand cementite contains 6.67 percent carbon. So, this large difference of the carbon concentration in gamma in cementite is only possible when there is diffusion. So, whole transformations form single phase gamma to two phases you know cementite plus alpha is basically dominated by carbon diffusion. And as you know diffusion is low at (Refer Time: 21:57) temperature.

So, if you cool a sample (Refer Time: 22:00) suppose much more than A 1 temperature diffusion is very very low. So, when the diffusion is low the thickness of this lamely will also be low (Refer Time: 22:10). So, we have because the carbon cannot diffuse longer distances. So, if carbon cannot diffuse longer distances thickness of this lamely will be smaller or on the other hand the distance between the two lamely will be the smaller that is what is the internal lamely spacing u lambda. So, lambda will be small or the diffusion temperature is low the temperature is low lambda will be small, because you know the diffusivity depends on temperature how D o into exponential minus Q by R T, why d g o is (Refer Time: 22:43) exponential constant and Q is a basically a activation barrier height and T is a temperature. So, as you increase the temperature D will be high as you decrease the temperature D will be low. So, therefore, when T will be low diffusion is low the diffusion is low the thickness of the lamely are also low and therefore, lambda is 1. So, this is the effect of kinetics, that is a effect of diffusion.

Now as you know as you under cool the things lower, you see the temperature is lower the driving force is low high, driving force will be high why because driving force depends upon lamellar cooling as you increase the lamellar cooling driving force will increase driving force is what driving force is nothing but delta G; that is G of product size that is here is pearlite minus G of gamma there is a driving force. So, this time force is summation of driving force of cementite and the alpha. So, if temperature is low this is high, if this is high that means, the rate of transformation is also very high correct; that is what is the opposite factor. So, as soon the temperature is lower means diffusion is low, but temperature is lower means driving force is high. On the other hand if the temperature is high diffusion will be in the higher, but the driving force will be lower.

So, these two factors actually act in a very different way in a opposite direction. So, that is why if you want to really plot the rate of transformation as a cost of temperature, suppose this is my temperature and this is a transformation rate R, so this will be like this why? As you are at the high temperature this is suppose somewhat A 1 temperature; obviously, very close to (Refer Time: 24:25) there is remote transformation happening why because there is no driving force available and your temperature is very low there will no transformation happening because diffusion cannot happen. So, (Refer Time: 24:36) can only happen if the temperature range from this to this. At up to which in which the transformation as you decrease the temperature from this to this, the transformation will keep on increasing it will increase very fast, why? Because this is the temperature domain in which both efficient is also good and driving force is available.

On the other hand, if you reduce the temperature further below driving force will be high, but diffusion is slow. So, therefore, the transformation rate will be decrease this is like inverse curve, you understand that the inverse curve. Only the inverse curve because of this opposite two factors - one is the temperature other one is the driving force. So, diffusion is lower as you decrease the temperature by driving force is higher.

Therefore, this higher driving force at lower temperature is basically used to create more of these interfaces as you decrease the lambda more number of interface will be created. So, more and over interfaces can be only balanced all can be balanced by providing more driving force. So, at higher temperature which is close to this temperature the pearlitic lamely will be very lamely means lambda will be very large. On the other hand the lower temperature lambda will be low, but the reason is diffusion when is this diffusion. So, you please keep understanding that this curve, transformation curve for pearlite is a function of r is a rate. So, you can say centimeter per second or micron per second. And this temperature these look like a inverse curve.

So, if I plot it in other way; that means, if I plot it you know time verses temperature it will like this curve. It will be opposite to that because here it is rate. So, you inverse it, take the time up it will be opposite that will come back to this we will discuss about (Refer Time: 26:26) diagrams.

With this I just I have given you a small introduction of this rate because this is the part of the phase transformation of a material. So, I do not have time or I cannot go detail of this of the transformation, but I told you the certain features that how the transformation pearlite transformation happen or the rate it depends on. Now question is that if I take a hypereutectoid steel or hypereutectoid steel the transformation rate will also be depending on how this primary alpha or pro eutectoid alpha or pro eutectoid cementite will form, so that means, if I want to really discuss about the of hypo and hyper reutectoid steel transformation rates, I should also be talking about two different transformation rate one at the temperature above A 1, and at temperature below A 1.

The below A 1 this will follow this because below one only pearlite transformation will happen, above A 1 transformation rate of alpha orcementite which is forming above the A 1 temperature will be different definitely. So, that if the time permitts I will discuss. So, I had given you a good idea about how hypereutectoid and hypoeutectoid steel, micro structure develop as a function of temperature. And I have also told you what is the way pearlite transformation rate depends on what are the factors which it controls. So, normally lambda just to give mathematical formula, lambda let me see I have written somewhere; lambda actually depends on these factors.

Let me just write it down because this formula is also very important. Lambda actually depends on following factors.

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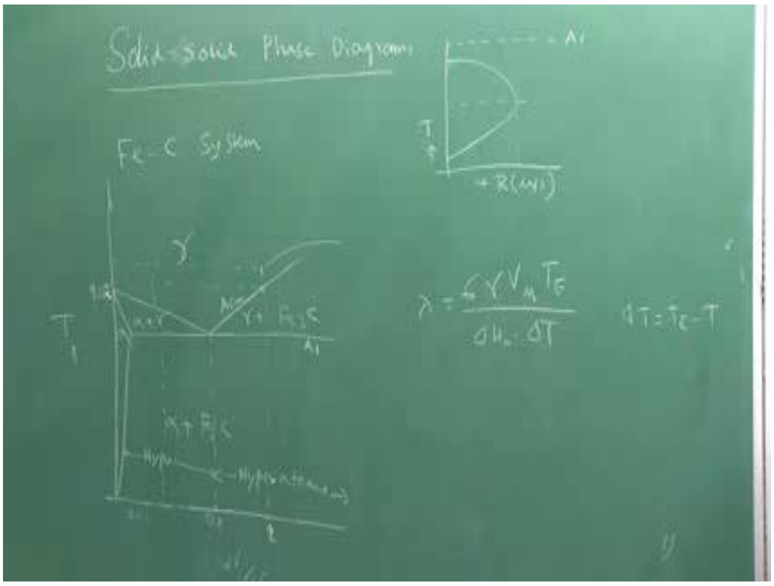

What are the factors? Is written as like this 6 gamma V m T E divide by delta H m into delta T. So, 6 is the numerical gamma is the interface (Refer Time: 28:23) between alpha and cementite, V is the molar volume - volume per density and (Refer Time: 28:30) must T e is the eutectoid temperature that is the A 1 temperature. Delta H is the heat of evolution rate transformations and delta T is the most important factor that is the under cooling that is the temperature below which you have to cool, below A 1 you have to cool to start the transformation that is what is the delta T. So, as you see here, as the delta T increases - lambda will decrease that is very clear, as you decrease the temperature lambda will decrease as you increase the temperature lambda will increase and delta T is nothing but T E minus T, T is the delta T temperature. So, that is all for the pearlitic transformation.

In the next class we are going to discuss about the martensites, I start discussion on martensite.