Phase Transformation in Materials
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Lecture - 40
Eutectoid Transformation in Steel (cont.)

Students we have been discussing about the eutectoid transformation in the steels. This is one of the important transformation, because most of the steels have the product of the eutectoid transformation as a pearlite. In the last class, I have shown you some pictures or some micrographs of pearlite and discussed you about how the transformation actually happens. Now, today I am going to discuss in detail about the transformation as it happens in the steels and also I will talk about whether, we can understand something about the growth of pearlite. So, any phase transformation in solid state or liquid state; obviously, we will have two stages nucleation of the phases and the growth.

So, first I will discuss little bit about nucleation so that we can make a complete picture of nucleation growth, connected together. Although I have discussed this in the last lecture, but let me just tell you again, there is nothing no harm in saying second time. So, as you know the pearlite has two phases one is alpha iron alpha actually, this contains very little amount of carbon in BCC iron and other one is a carbide that is known as cementite, the chemical composition cementite is Fe 3 C. It has orthorhombic crystal structure it is brittle and basically, it is an inter metallic with the compound, with iron and carbon and that is what makes the system consisting of one brittle phase and iron, because it is a BCC iron with very low carbon. So, therefore, it is a ductile phase.

So, in pearlite, we have a institute composite between a ductile phase and a brittle and hard phase and that is what gives the steel, the fascinating mechanical, physical properties. So, as you know the nucleation of the phases in, from the austenite or gamma phase can happen in many ways.

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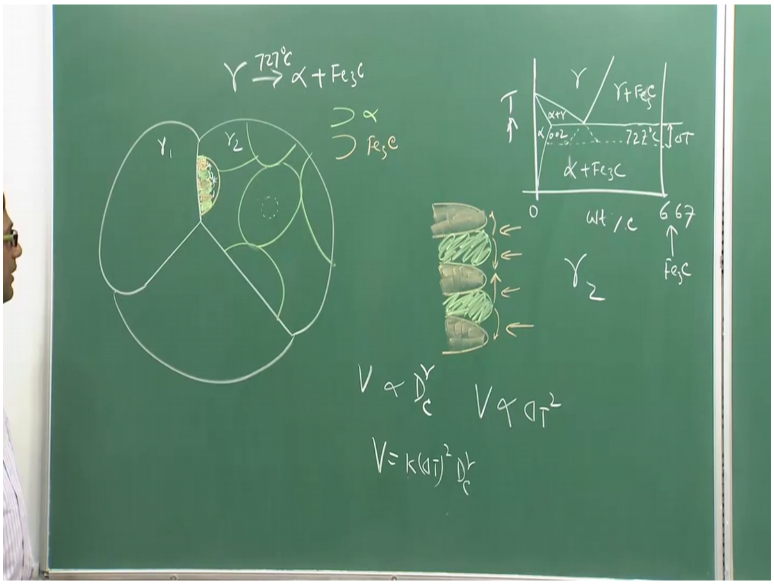

Actual transformation is gamma going to alpha plus Fe 3 C, as you cool down below 727 degree Celsius. Let me tell you this, temperature can be seen different in different books. It can start with 723 degree Celsius in some books and go away in more than 770 Celsius, in books that depends upon the purity of the gamma phase.

So, but does not matter the transformation happens, normally the temperature range of 720 to 730's and it leads to production of the two phases or formation of the 2 phases simultaneously, like alpha and Fe 3 C. Now, let us suppose; obviously, as I told you that the prior gamma grains will have boundaries before we transformed to pearlite. Let us, suppose, there are 3 gamma, grains with very well defined boundaries. So, it is very obvious as, we discussed the nucleation that, nucleation of these phases to start with, will always tend to happen, either along the grain boundaries or the gain corner or the edges of the grain boundaries. It can happen there, because the energy involved in getting the nucleation is much lower. In these you know sites, than inside the grains; that means the nucleation barrier is low.

So, let us suppose I have two grains, gamma 1 and gamma 2. Now, nucleation can happen any of these two phases. It does not matter, that it has to be starting with alpha or Fe 3 C tip. Normally, they with the steels having carbon constitution less than about 0.8 percentage. Alpha is easy to nucleate and on the other hand carbon concentration more than or 0.8, f e 3 is it a nucleate, but this is in general, you can always have nucleation of alpha or Fe 3 C, irrespective of the steel carbon concentration the steel.

So, let us suppose, I have a clean grain boundary like this between 2 gamma grains and first phase to nucleate is a cementite. So, I just put a nucleus in new cementite nucleus and; obviously, when the cementite nucleate, on these nucleates, on this boundary, it will try to keep one of these interfaces as a coherent. So, that, these boundary has a low energy. On the other hand, other interface will be incoherent. So, with the grain gamma 2, it as a incoherent boundary or semicolon boundaries. On the other hand, it with the grain gamma 1, it has a coherent boundaries; that means, this nucleus will have a specific orientation relationship, with the grains on left side, on the right side and these relationships are there in the books.

Let us now discuss about the complex crystallography, but these are described by various scientists, they as known as KJ relationship. Now, once it nucleates, then it will go into the gamma 2 grain, because it has incoherent or semicolon interface with a gamma 2 grain keeping this interface with a gamma 1, constant or same. So, at it is gross, because this is carbon reach, it has suppose 6.67 or 8 percent carbon, this growth of it require more carbon. Remember the carbon in these grains will not be as I has 6.67. Normally, the carbon will be pairing for 0.2 to form 1.1 percents of (Refer time: 05:57) carbon. So, therefore, different parts of this grain gamma carbon, will diffuse interstitially and reach this cementite nucleus and because of that cementite nucleus will grow like this.

So, on the cementite, grows the carbon concentration, nearby the cementite will be very low, because the carbon will diffuse to the cementite, because total carbon constants is fixed in the grain. So, therefore, if I somewhere, you have high carbon constitution near origins, will have low carbon concentration. This will lead to depletion with carbon in the nearby regions. On the both sides of these are in front of these also. So, therefore, this is the idle situation for the nucleation of the alpha and that is why alpha nucleus on the both sides of the cementite and it grows correct that is what it will happen.

Now, alpha is almost like a pure iron it has very little amount of carbon as I said you because it is very little amount of carbon, so; obviously, it is growth requires rejection of carbon into the nearby in this grain nearby regions of these gamma 2 grain. So, because of that again carbon concentration will be increasing on the both sides as well as in front of these alpha grains the alpha phase this is alpha and this is cementile it is write it down otherwise colors are like this. So, because of that the carbon concentration both side in front of the alpha will be more or increasing and this is will lead to basically, nucleation of these cementite on the both sides again and that is how these colonies forms as I discuss in the last class. This is similar, to eutectic transformation in from the liquid, exactly similar thing happens, when lamellar eutectic forms.

So, this will lead to a colony and this colony has slowly grow into the gamma grain and these colonies will appear on many places here or there or like that and that is what you have seen in the microstructure. These are the grains of the pearlite, remember each of these actually consisting of both the phases, cementite and alpha. So, that is the way transformation happens. So, the basic important aspect, here is that the most important things, which control, these transformation is the carbon diffusion as you know, carbon is interstitial species, because it is a small size atom in BCC, R N it goes into octal side and FCC is goes straighten sides. So, therefore, diffusion of carbon is relatively faster at the temperature below 727 degree Celsius temperature and that is actually, that is why these transformations are relatively faster as compared to the other transformation in the solid solution based alloys.

So, it is very clear, the carbon which is diffusing along these boundary basically; obviously, carbon a diffusing like these from alpha to FTC and also from the major part of the gamma grain, in front of it, to the F 3 C so; that means, the lateral diffusion of carbon is what is basically, playing the role. See if I have to draw it properly, if I draw it here, the whole thing lateral diffusion of carbon you see, if I draw these are the cementite (Refer time: 09:23) and in between if I draw the gamma, sorry alpha (Refer time: 09:26). So, this is alpha and this is also alpha and these are the cementite.

So, the diffusion of carbon like this lateral sides also diffusion of carbon from the front to these also important, because there is a gamma grain. Remember, this is gamma 2. So, that is the most important aspect. So, that was a growth rate V must be related to diffusivity of carbon in the gamma RN. That is must be, because this is what plays the important role very clear, what else can it determine these growth rate; obviously, the first thing which determine the growth rate is the under cooling off.

Remember this reaction, normally should start at 700 20 70 degree Celsius temperature, but it will never start, why; because the free energy available to do to stir, to drive, this reaction will be 0 at the reaction temperature that we know at any reaction temperature the free energy difference between gamma and the phase mixture of alpha and Fe 3 C, which basically is 0. So, therefore, it cannot start. So, to start the reaction, we need to under cool it. So, if I draw the relevant part of the phase diagram, here just look carefully, this is temperature, this is weight percent carbon right and i am not going to the full diagram that is 0 to 6.67 percent. A carbon, this corresponds to Fe 3 C, this corresponds to Fe 3 C.

So, if I draw all the relevant portions of phase diagram, this is what the relevant portion. So, this is alpha. Remember these point correspond to point 0 2 and this temperature is 727 degree Celsius. This is gamma, this is gamma plus Fe 3 C and this is alpha plus gamma and this is alpha plus Fe 3 C.

So; obviously, when you cool down the gamma phase below 727 degrees temperature to start a transformation, you need to under cool, we need to under cool by certain amount. Let us say, this under cooling is about delta T. So, therefore, if I clearly see that the concentration of the alpha metastable concentration of alpha and the Fe 3 C will be given by these 2 points. If we extend this lines, we will get that.

So, it is clear that this level of under cooling will provide further nucleation and the growth driving force and it has been seen that in actual experiments that V, the both velocity V, actually is proportional to delta T square the higher, the under cooling higher the driving force available, but in solid state reactions, actual under cooling can never be extremely high actual under cooling will be something like couple of few degrees it is not more than that why; because this nucleation is heterogeneous here and because nucleation heterogeneous. So, therefore, under cooling achievable is very low unlike in other cases.

So, that is one of the problem therefore, the (Refer time: 13:06) under cooling is not very high in these cases. So, therefore, one can write down the velocity of this thing of the of their pearlite lamel the colony is basically, K multiplied by delta T square into dC gamma where K is a constant, proportionally constant that depends on nature of the grain boundaries, nature of the, you know site where there nucleation growth happens and many other things, the very initial relationships. So, as you see here, these two are the most critical aspects. We determine the growth rate of the pearlite and they have a strong role to play in the nuclei in the growth of pearlite, that is a one important aspect to which you should must remember that, but not only that, it is very clear that these other than these factors there may be other factors which will also play a role.

Other factors like you know whether these pearlites can start inside grain bound again or it can start at the boundary or it can start at the edge will also play a role. It is very easy, if the pearalite nucleus at the grain boundary. So, that it can grow easily into one of the grains, but suppose, you have pearlite grows, starts growing inside a grain then it is much slower, even if the carbon supply is very high. Still if the growth will be very slow, because it has to grow from a inside a grain. So, therefore, nucleation requires higher legendre cooling, nucleation will take away a large part of the under cooling. So, available under cooling for the growth will be much lower, that is another one, the problem.

So, considerably nucleations majority whatever has been observe in the literature does happen on the grain boundaries that is one of the advantage of these solid state reactions. So, its very clear that diffusivity of carbon in gamma at the temperature close to about seven hundred degree Celsius temp degree is quite high compared to others. So, that is actually makes the paralytic growth very very fast. In fact, its growth rate should be couple of hundreds of micron per per seconds that is what has been observed and this allows us to actually discuss further much further. So, as you it is very clear that growth actually depends on diffusion of carbon.

Now, suppose, if I take this steel with a gamma structure, gamma R in structure and quench eternally into water. So, the simple corollary of these you know, equation is that as you quench from the high temperature to low temperature, high temperature to room temperature, directly the diffusion of carbon will not happen. ; because diffusion requests certain time all the diffusivities are higher for carbon in the gamma grains, but still it requires a finite time and if we do not provide the finite time at a higher temperatures close to 700 degree Celsius temperature. These transformation will not happen, this transformation is bound not to happen, because primarily, because for the, even if the nucleation of perlite or nucleation any of the grains happens either alpha or cementite, they cannot grow, because growth requires contribution of carbon, that if that is not allowed these colonies will never form and this is the reason.

So, when quench a steel, these all of you heard that, this is very simple at the very general term that, if you quench a steal from high temperature something like nine 900 d Celsius temperature, you will form a new phase called martensite, not pearlite and that transformation is actually does not depends on diffusion of carbon. So, that is why the transformation happens when you quench a steel, that is the one important aspect, first you have to be, it is very clear on looking at the paralytic transformations that if I quench steel from high temperature to room temperature by dropping in water or ice or whatever any media this poly transformation is not going to happen very clear, because it requires diffusion of carbon.

So, first thing which will be bifurcating, which will be bifurcating from these quench, from these transformations is martensite. I told you martensite is the first thing, which we can see to happen, if I quench a steel from 7 from 8 900 to room temperature.

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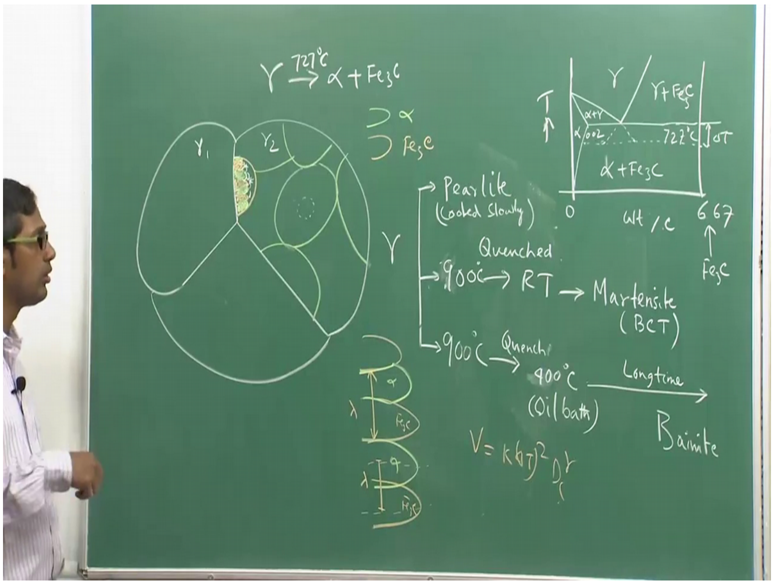

Simply you quench a steel it will lead to formation of martensite, that is another way of looking at a transforming gamma to some other product is that, if I take the steel from 900 degree Celsius temperature, 900 Celsius temperature quench into a oil bath quench. Let us say quench you have 200 degree Celsius temperature, it can be a oil bath or it can be some substance like some glass which can melt at about 200 degree Celsius temperature.

So, if it is quench and then it is kept here for a long time, pearalite will not also form, why; because at a lower temperature, when it cools down to 200 or 350 degree temperature, the diffusion of carbon is very slow. It is obvious, because iron (Refer time: 18:47) preserve 1,539 degree Celsius temperature and 350 is very low as compared to the milli temperature, because all diffusion diffusivity is actually scaled with melting temperatures.

So, therefore, at a lower temperature diffusion, although carbon is it interstitial species, still diffusion will happen very slowly. This is very generic thing happens in in the, even in steel also. So, if you do that, if I quench to coordination as temperature, we can also stop the polytic reaction, because this requires diffusion of carbon and a further keeping, the steel at lower temperature 400 degree Celsius temperature for long time will lead to a new product known as bainite again by the name of a famous scientist EC BENN, who described the martensitic transformation.

So, we can have actually three products as you see here starting from gamma if I start with gamma I can have three products one is simple pearlite, if I cool it slowly and if we cool it very fast, you can have a martensite and if you cool it intermediately, that is if you quench to about 400 degree Celsius temperature. Then keep it long time at a temperature, we are going to form bainites. So, that is the biggest advantage of steels depending on the type of treatment processes, transformation products can be changed. So, pearlite; obviously, is a lamellar structure of such a kind of thing, cementite plus alpha iron martensites a completely distinct, different product. It is basically, has a crystal structure of body centered, tetragonal bainite is again a product, consisting of both Fe alpha and Fe 3 C, but morphologically, this is distinctly different from the pearlite, they do not look like a lamellar structures.

So, I just wanted to tell you that these transformations indeed plays a very important role to for the steel metallurgy, because depending on the type of transformation, product properties to be change, like martensite is very hard and extremely brittle, pearlite and bainite is relatively softer. Pearlite is basically, much softer than bainite. So, that put pearlite and bainite will have sufficient, ductility marteniste will not have.

So, depending on whatever is our need on we can actually produce, this kind of structures by starting, which is the gamma at the beginning. So, martensites are very hard, therefore, they can be used in different application which requires a norm, which wide resistance and many other resistances. On the other hand, bainite and pearlite can be used in structural applications, where you need certain amount of ductility. So, depending on our need, we can change these phases and we can change the transformation products by simply doing different types of heat treatments.

So, that is the first thing which actually comes as a corollary of the polity transformation, because poly transformation is the basis of all these things, now, second important aspects of polity transformation is that, this transformation actually can be controlled by or the basically, mechanical property of pearlite can be controlled by controlling these inter lamellar spacing. So, let me just draw again, as you know like eutectic, we have also inter lamellar spacing between these grains between these products actually alpha and cementite.

So, we define this is alpha, this is alpha and these rest other things are Fe 3 C. So, we define this as a lambda or one can define other way, we can define like this, also it does not matter. So, is basically the width of the one alpha lammily and one cementite lammily that is, what is known as the inter lamellar spacing, similarly, you can also take from half of the alpha lammily center of the alpha lammily to the center cementite lammily that is also define as a lambda.

So, this lambda has a strong role in mechanical properties, smaller lambda is better. So, actually you can control this lambda by controlling the heat treatment temperature. Suppose, if I keep the reaction happening at 3 to 700 degree Celsius temperature. When the under cooling is low. So, these thickness of this lamella will be larger, they will not the smaller, because at higher temperature diffusion is very good diffusion can happen faster.

So, this lammily will be becoming fatter, but if you quench, if you actually have a not quench, if I give a much higher undercooling something like about you know, if you do the experiment at 650 to 680 degree Celsius temperature then this transformation lead to very final lamella, the lambda lamellar width, which will be much smaller and because at low temperature diffusion of carbon is slower. So, by simply controlling this transformation temperature, we can control the diffusivity of carbon as you see that V is proportional to basical to K. Delta T square multiplied by d c gamma. So, dc gamma can be reduced extensively, if you cool if you actually do the experiments at a lower temperature like 650 or 680 eighty Celsius temperature.

So, that is for it gives us another handle two for us to control the mechanical properties of pearlite. We can have fine pearlite, coarse pearlite depending on at temperature, at which, you are doing the heat treatment so; that means, we have nt number of choice a large number choices you, can have pearlite, different types of lamellar martensite when you quench bainites, there are different types of bainites also which, we discuss in the next lecture.

So, we can actually create large number of microstructure by simply changing our heat treatment conditions the understanding phase transformation allows you, to do that, that is the advantage of the phase transformation is steel. Therefore, we were going to take up these cases martensite and the bainite separately.

And finally, we will bring all the transformation, together I will show you that for a person which working in industry how he can control these reactions by simply controlling the heat treatment temperature and the time scale.