Phase Diagrams in Material Science Engineering
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Lecture – 27
Eutectoid transformation in Iron-Carbon phase diagram

Dear students we have started our discussion on iron-carbon phase diagrams and basically, on steels. So, we are going to discuss in detailed manner about the eutectoid transformations in the steel.

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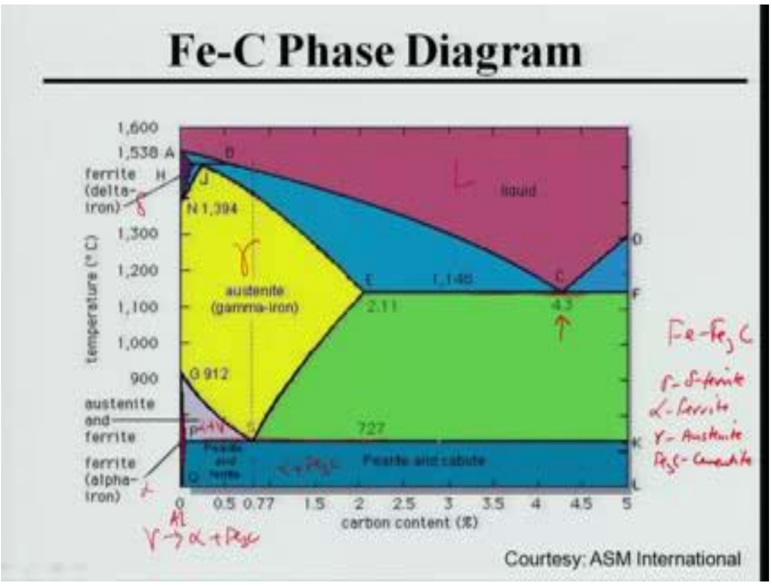

Just to remind you, that iron-carbon phase diagram is basically, in metallurgy represented as iron-iron carbide phase diagram and the, white, what does it mean? That means, phase diagram basically starts with 0 percent carbon and its ends at 6.628 percent carbon, and why it is so? Because, it is a phase diagram between and iron and iron carbide or Fe and Fe 3 C; in Fe 3 C, the carbon concentration is 6.628 percentage, so that is why, the phase diagram is always represented from 0 to 6.628 percent carbon. And this is a partial phase diagram and I also told you, that this, any part of the phase diagram beyond 6.628 percent, 6.628 percent of carbon is not of any importance to us, so we are not going to discuss.

So, what are the different important aspect I discussed? In this phase diagram there are basically 3, 4 solid phases starting with alpha iron solid solution, gamma and solid solution, delta and solid solution. I mentioned alpha, gamma, delta on the phase diagram and then you have Fe 3 C as a intermediate phase. So, there are 4 solid phases present and other than that you have liquid phase also. So, the regions, which are important to us are marked here, gamma, alpha, alpha plus gamma, delta and this is alpha plus Fe 3 C. Alpha is known as ferrite, alpha is always written as ferrite, gamma is written as austenite and Fe 3 C is known as cementite.

Please remember these names and delta is known as delta ferrite. So, please do not get confused with alpha and delta, both are BCC. Alpha is a room temperature phase, whereas delta is high temperature phase. Normally, solid state reactions, alpha, delta, does not make much importance, but in only for low carbon concentration steel delta makes any difference.

So, now the reaction, as you know, there are three important reactions in this phase diagram. The first one is the eutectic reaction, which takes place at about 1146 degree Celsius temperature marked here, the carbon concentration of 6, 4.38 percent carbon and that is basically important for cast iron families. So, we are going to discuss importance of this reaction when you talk about cast irons. Then, you have, this is, you see this is the horizontal line at 1146. So, every horizontal line in a phase diagram represents a reaction.

So, now there is another horizontal line here which corresponds to peritectic reaction between liquid and the delta giving rise to gamma. I discussed about peritectic phase diagrams a lot, so I am not going to discuss now the detail of this, only when you talk about stainless steel we are going to bring this reaction into the discussion. Important thing which is happening here is this reaction which is at 727 degree Celsius temperature is known as eutectoid reactions. And as I told you, eutectoid reaction is gamma going to alpha plus Fe 3 C. It happens at A1 temperature and I told you why you say A1 because 727 is only for iron-carbon system, it can vary depending on steel compositions. You have manganese, phosphorous, Sulphur, copper, iron, cobalt and then, you have nickel, chromium, depending on the elements present this temperature can change, that is why it is always used, better to use a temperature called A1. So, A1 is this temperature which this eutectic transformation happens, correct.

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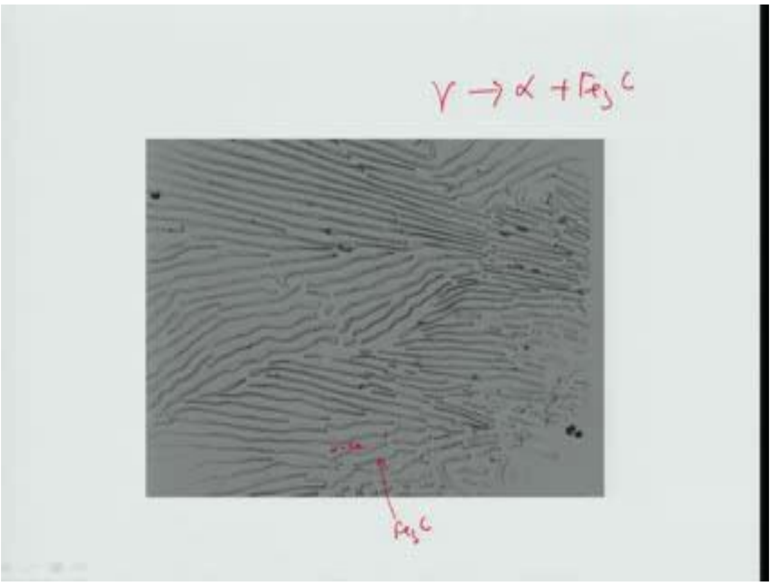

How this eutectic transformation is manifested in the microstructures? Okay, now let us now look at it that. I will going to show you this is manifested by a mixture of alpha and cementite where I told you this is the alpha iron, the white one and this lamellas which you see is black, is cementite. So, therefore when gamma transformed into alpha plus Fe 3 C by eutectoid reaction, this is the kind of microstate forms.

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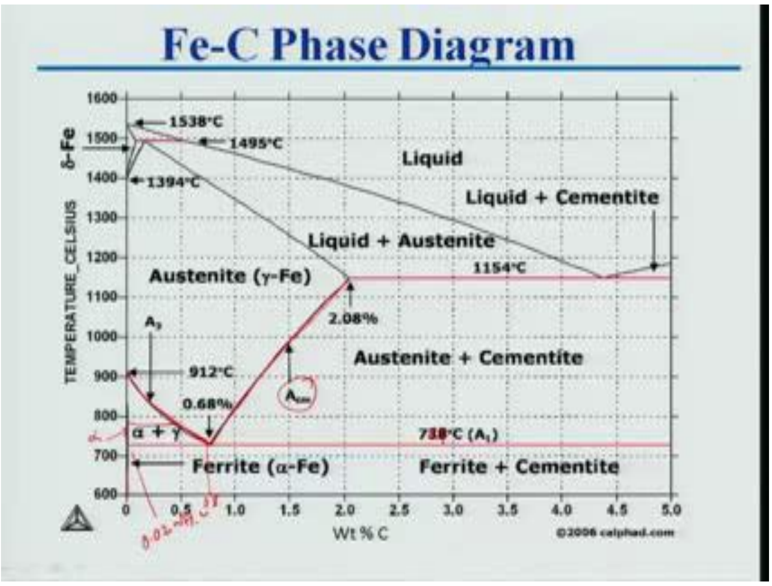

And I told you, that alpha is very, very ductile because it is a BCC structure with very low carbon concentrations. What is the carbon concentration in alpha iron let us look at it. You can see here, this is the alpha, this is the alpha in a big phase diagram starting from 0 to 5, even we have removed 6, from 5 to 6.7 percent also, still here you can see alpha is seen only a line.

So, therefore the maximum concentration of carbon and alpha at around 727 degree Celsius temperature, 727 degree Celsius temperature is 0.02, 0.02 8 percent carbon, at room temperature it is virtually 0. So, that is why, alpha is basically almost like a pure iron, very little amount of carbon. And where does this carbon go? They go to the interstitial sites of alpha, whether octahedral or tetrahedral points.

So, now this is the A1 temperature written, you see here in this phase diagram, all the infinite reactions are given by red line, A1 temperature and then, this is A3 temperature. A3 is what? A3 is, as you add carbon into iron, the stability of gamma phase decreases as a function of carbon concentration and it is just a minimum value at 0.8 percent carbon, 8 percent carbon that is what eutectoid carbon concentration, correct. So, and then this is alpha plus gamma zone because between two solid single phase zone. There has to be a two phase zone and this temperature, this one is the line is known as ACM. ACM stands for a cementite. This is the basically cementite, you know, composition line as in the, in the, when it, when it, it, you know, it is in contact with the austenite, that is, what the cementite concentration, a carbon concentration cementite will vary, okay. Although we say cementite concentration was 6.61 percent carbon, but it can have a window, anyway.

So, these are three lines, A1, A3 and ACM. A2 is a temperature where the, it is about 763 degree Celsius temperature. 763 is somewhere there, this is the (Refer Time: 07:19) parametric transition temperature for the alpha phase, correct. So, before I discuss on this diagram; let me just go to the board and tell you how it can be further clarified, okay.

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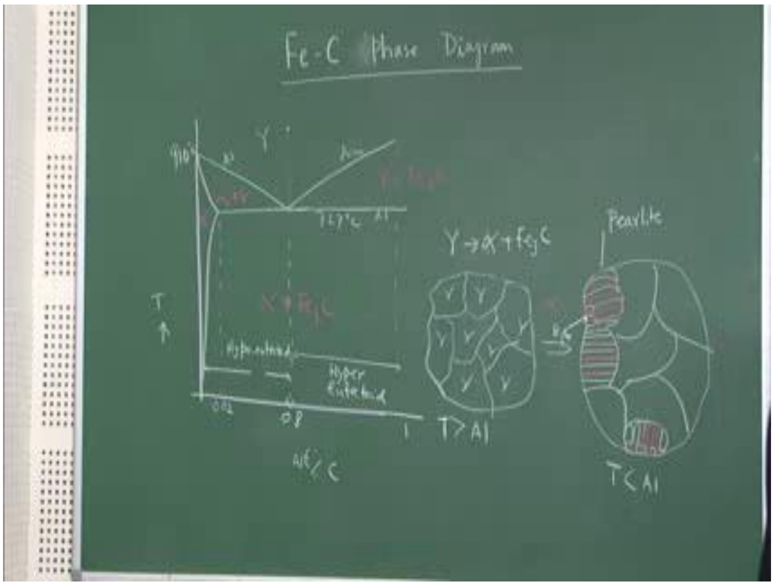

So, I have drawn here the, and the, on this diagram I have drawn here only the important part of the phase diagram, what is that. That is, these starting from 0 to 910 degree Celsius, carbon concentrations is about, about 1 percentage, maximum, 1 weight percentage. So, what are the phase fields here? This is the gamma, this is the alpha and this is basically, alpha plus cementite and this is alpha plus gamma. Similarly, this will be gamma plus Fe 3 C, cementite. Please remember this, these phase fields are very important.

And what are these lines? This is A1 temperature line, this is A3 line and this is ACM line or curves, fine. So, now question is this, this is my eutectoid composition and this let me just write down properly, this is 0.8 weight percentage of carbon and this one is .02. So, this is not in scale, I have just wanted to show you in detailed manner, that is why I have done that.

Now, if i take a steel of composition 0.8 percentage and heat it beyond 727 degree Celsius temperature or beyond, say, let us say about A1 temperature and let us say, I heat it about 956 degree Celsius temperature at this (Refer Time: 09:08) point. So, everything else will be in gamma. If everything is gamma, so what will happen? I cool down; as I cool down this, let me just draw this line, through that you can get a better understanding of these features. So, I have a steel composition steel appointed composition at about 956 degree Celsius temperature, I am cooling it down, I cool it down. So, nothing will happen till it reach the A1 line, nothing will happen, only thing will happen is, that gamma grains should continuously, I know as you cool it down it will, it will have carbon enriched in gamma, okay.

Now, below 727 degree Celsius temperature you are going to have, you cannot have gamma any more, gamma has to transform eutectoidically to this phase mixture between alpha and Fe 3 C. How does this happen? So, let us draw several pictures to show you that. This is suppose gamma grains, single phase gamma grains, this is all gamma above 700 to temperature above A1 or here 720 degree Celsius temperature. Now, as I cool it down what will happen? If I cool it down below 900, below A1 temperature and when it reaches below A1, this grain will transforms into a phase mixture of alpha plus cementite.

How this will happen? Well, to understand these let us draw one of the grains, I will do others, okay. Suppose this now this grain has uniform carbon concentration of a 0.8 weight percentage. Now, by suppose, by some means, we will discuss how some means, suppose cementite nucleates, cementite nucleates some part, cementite will form, Fe 3 C will nucleate and then it will grow. Basically, every (Refer Time: 11:13) phase transformation starts with nucleation.

So, therefore, if the cementite nucleates here, cementite is lot of carbon, huge amount of carbon, it contains 6.61 percent carbon, remember my each grain contains about 0.8 percent carbon and if I want to nucleate cementite, I need 6.67 weight percent carbon, that is a lot, lot of carbon. So, it will do one thing, it will take all the carbon from nearby region it will draw all the carbon from nearby region, why? Because for each to grow from nucleation, it requires more and more carbon; carbon is differ, important species. Iron is abundantly available, in each of these grains iron is not a problem only carbon is, is a problem. So, carbon will, will be required for its growth of cementite.

As it grows, nearby regions, that means, the regions which are in front of it and side of it will be depleted of carbon because it requires carbon. So, as it is getting depleted of carbon, carbon concentration will reach very low. Very low means, it will reach even 0.02 or even less than that. When it happens this will lead to nucleation of alpha phase on the both sides of these. So, this is my cementite, this green color thing is cementite and red color one, this is cementite, Fe 3 C and red color ones, this red color thing is alpha, iron alpha phase. So, now, so that means what? This is the way I can actually nucleate alpha on the both sides, of this both sides of the cementite.

Now, as alpha, alpha contains very, very low amount of carbon, as you see from the phase diagram it contains maximum 0.02 percentage carbon, whereas my green, green has higher carbon concentration than alpha. So, as the alpha grows into it, there on the both sides of alpha and in front of the alpha, there will be huge carbon buildup because it will reject all the carbon. It does not need carbon; it need only iron because it has more amount of more carbon, less carbon than the alloy compositions or the grain compositions, no at much, much lower than this cementite compositions because it does not need carbon. So, it will go very easily without requirement of carbon or by rejecting carbon into the nearby regions. So, all the nearby regions or in front of it will be, you know, the carbon will be enriched and when the carbon concentration reach very high, then cementite will nucleate and it will grow.

And this process will continue, as I told you, this process will continue and that is how a grain, a colony will form and when this colony will grow like this, this will grow like this, it will form fully pearlite structure. That is what you have seen the image, I am going to show you again, when it grows it will become fully pearlitic structure. So, that is the structure of a pearlite.

Similarly, any other grain in that will have, alpha can nucleate at the beginning and if the alpha nucleates and grow alpha has very low amount of carbon. So, as alpha grows, it will reject carbon into nearby regions on the sides and the front and when the carbon concentration in nearby region will be very high, it will form cementite. So, similarly when a cementite requires more carbon, alpha will grow and these things will follow like this. So, and then you have a colony of cementite formation happening, cementite formation will happen, something is wrong, no, it is okay. So, (Refer Time: 15:35) this is the way the colonies will form.

So, all the grains will have this colonies, I am not drawing it, red and green color stuff, this is red. So, red and green, red and green, everywhere it will be like this. I am not going to draw all of them, but this is how things will happen. So, that is the way the eutectoid transformation will, will actually occur or this is the mechanism eutectoid of transformation.

So, basically, that this transformation is aided by diffusion of carbon. As the carbon diffuses carbon diffuses is the predominant factor and you know, carbon is interstitial elements in this alloys, why? Because carbon goes to the interstitial positions of iron as it, it is interstitial species; diffusion of carbon is very, very fast as compared to the iron. Why it is very, very fast? See, for diffusion of carbon it requires more number of interstitial positions and in a system like BCC or FCC iron, basically in BCC iron, it is easy for carbon to move from one interstitial pieces to other interstitial pieces because the sites will remain vacant, because if we are adding very little amount of carbon, but interstitial pieces, the amount of, the amount of interstitial positions will be very large.

Therefore the vacant sites are also very large. So, therefore diffusion of carbon is very fast and at the high temperature, close to 700, 800, 900 degree Celsius temperature, diffusion of carbon is very, very high. So, that is why, the whole transformation is basically controlled by the diffusion of carbon ahead of this lamellae what I have drawn, the way I have shown you.

So, this, this is what is the main mechanism of formation of the pearlitic colonies and these are known as pearlite. As I told you, this whole thing, this is known as pearlite. Why it is known as pearlite? Because if you see this, this kind of sample (Refer Time: 17:46) and optical microscope, the luster or color of these will be like a pearlite or like a pearl, like a pearl, p, e, a, r, l, pearl, and pearlite means small pearl, that is why, because this is a micron scale, that is why, it is called pearlite. So, now this is for the eutectoid composition steel.

On the other hand, you also have as eutectic alloys, you also have the hyper eutectoid, hyper eutectoid steels and hypo eutectoid steels also, we need to discuss them, also how this transformation will happen and they are very important. Remember, both of the steels in the world, almost like 1000 million tons is produced having composition between 0.2 to 0.5 percentage of carbon and very less amount of steel is produced which are having hyper eutectoid steel. Mostly steels, which are used for knives, cutleries and very hard objects, are like blades for razors, they are actually have compositions close to 1 percent or 0.8 percent of carbon.

But all the steels, which are used for structural applications, like bridge, house or any building or any other purposes or ship building or whatever, it is, it basically falls in the hypo eutectoid range. In the hypo eutectoid range, hypo eutectoid range, the compositions of the alloys will dictate what is the properties will have. But before I do that let me just go back to the slides and show you the, the, now the microstructure with understanding of this you can now able to get a better idea of, of the things.

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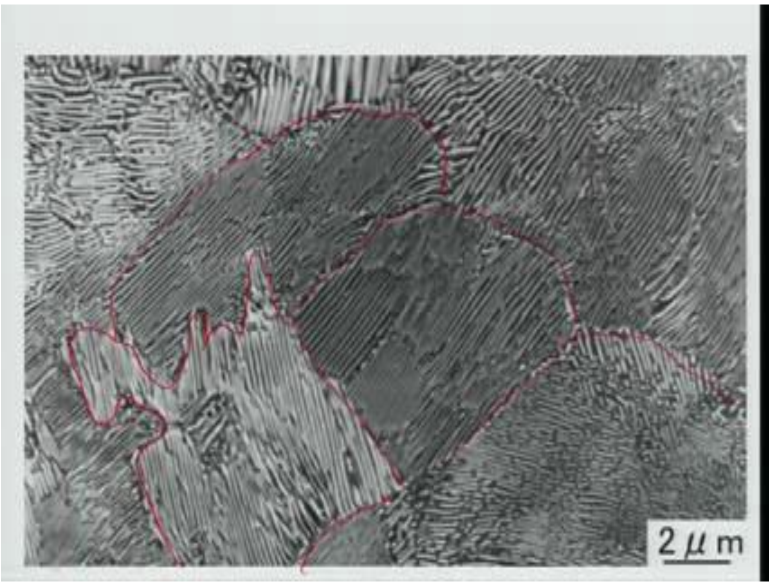

So, this is what I shown you lamella structure, now let us see a better picture of this, yes. Sorry, what is that, this is the better picture of this? You can see, that there are grains of austenite, this was grains of austenite, I am drawing few of them. This is the grains of austenite and each of this grain has, then you know, undergone these eutectoid transformations. Because of these you have formed colonies, large colonies and each colony has black and white regions.

So, these black and white regions are what? Black ones are basically cementite and white ones are basically pearlite or say, ferrite. And this black and white thing happens because of what? Because of (Refer Time: 20:19) we use, we normally use nitrol, which is nothing but a nitric acid, to (Refer Time: 20:24) it and nitrol paper as soon as reacts with cementite and cementite regions goes away and that is why you form the black regions.

So, that is the way, that is the normal microstructure of the hyper, hypereutectoid, sorry, eutectoids steels or 0.8 percent carbon, plain carbon steels.

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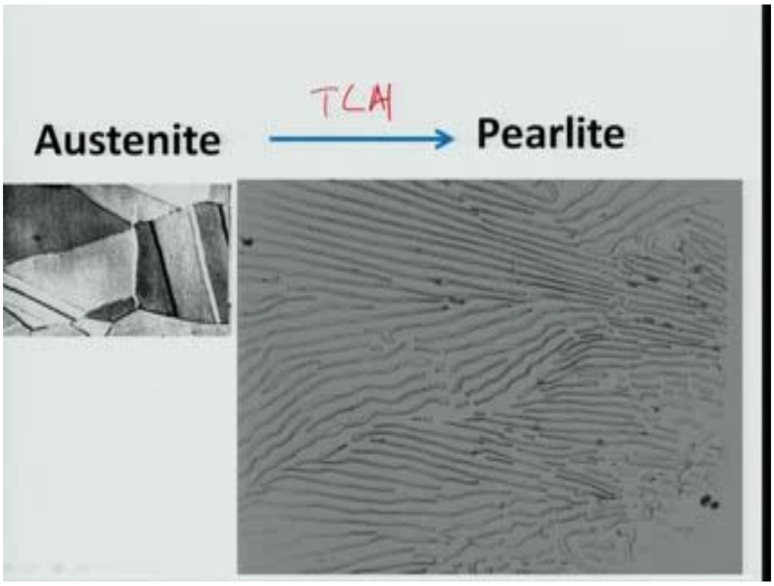

So, now let me just go back and so, therefore in a nutshell, this is austenite and if you cool it down below T1A1 temperature, it becomes a pearlite. At this time, this is a very important thing, I told you, in pearlite cementite is a very hard phase and whereas, ferrite is a soft phase. Because of these, because of these mixture of a hard phase in a soft matrix, because ferrite is the phenomenally large ideas consisting of ferrite, that is why it is called matrix and this cementites are very small fraction of the, of the pieces present in the microstructure. This is, has a wonderful, both mechanical and physical properties, because of the, this in-situ composite, which is PPR during this reaction and which is unique in the world. No other systems can show this kind of microstructures, that is why steel is so widely used in the in the applications.

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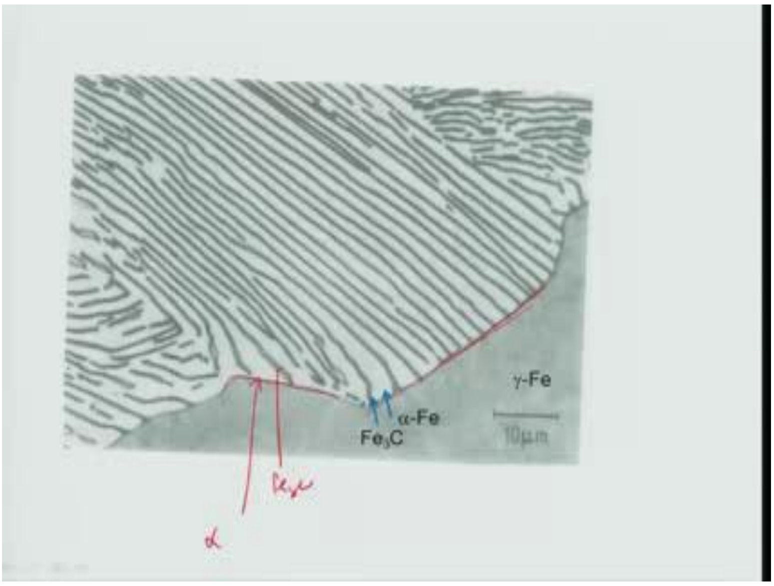

So, now I just want to, yeah, I just want to show you this picture. This is taken form a book called, Making, shaping and treating of steel by US Steel Corporations, very important book, very big book. Is there any steel plants you can access, that it will talk about starting from making to the, this is shaping and treating of the steels also. So, this is a picture in which you can see, this is the colony of pearlite and in front of which you have a gamma iron, correct. And the interface looks like a very, very curvy one, very curve interface, you can see here. And you can see these, these black ones are cementite, as I marked you, these black ones are cementite and white ones is alpha, alpha, alpha Fe.

So, this basically the idea is that to show you, that this interface between the gamma iron and the pearlite is a very mobile interface and its movement depends on the carbon diffusion acquisition phase. And this reaction is exactly similar, same like eutectic reaction. In the reaction you have eutectic phase on this side and have liquid on the other side, instead of that, instead of liquid you have gamma iron in this sides.

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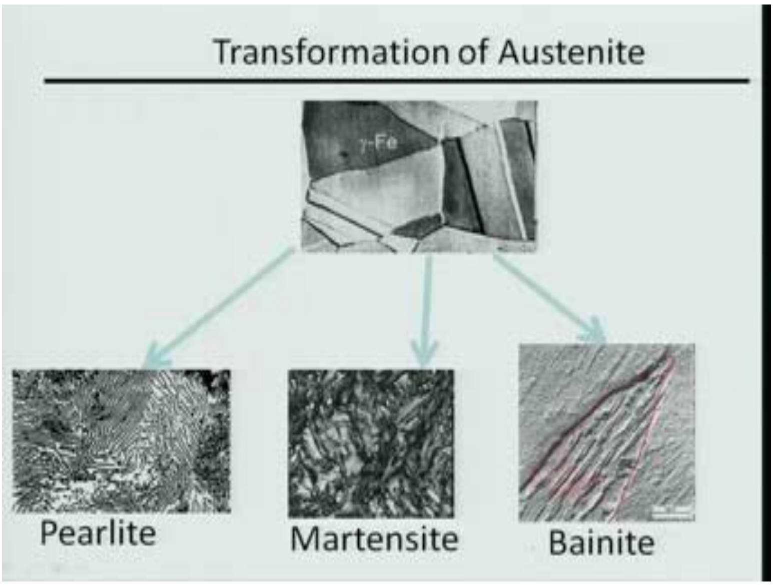

So, now I go back to this, go to this. So, therefore the one of the way of transforming austenite is by forming pearlite. Pearlite is, is basically a deficient control transformation process, pearlitic formation transformations from the austenite, but and this happens in a very slow cooling rate; slow means, it is a very pretty slow cooling rate. But if you cool it very fast, right, like take the sample in austenitic stage, that I heat the sample at 950 degree Celsius temperature and then, you directly quench in water. As I mentioned in the last class, it will form martensite.

And martensite, this is different, completely different phase. It is a body centered tetragonal structure, is very hard and very, very (Refer Time: 23:43) micro phase, but very, not very tough. On the other hand, if you do a completely different kind of things, that is, you cool it from the austenite to about 350 to 400 degree Celsius temperature and keep it at the temperature for long time, let us say, about 12 to 24 hours in a oil bath at about 400 degree Celsius temperature, what you form is a bainite. And bainite is also consisting of cementite and ferrite like pearlite, but the morphology is different. This is the bainite where you see like little tree leaves, inside the leaves you have this cementite and ferrite mixture presents.

So, in the next class, that is, what I am going to do. I am going to first discuss about the hyper and hypereutectoid steel transformations and then, I will go on to the, on martensites and bainites one by one.