Phase Diagrams in Material Science Engineering
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Lecture – 26
Introduction to Iron-Carbon phase diagram

Now, we are going to start with the classic iron carbon phase diagram. Basic idea is to discuss both steels and the cast iron, because they are the two important materials wall produces. I would like to tell you that steel is the second largest material we used in the world, after concrete, and cast iron being the from the same family as iron carbon alloy has the line (Refer Time: 00:44) in automobile industry. So, therefore, it is very important that you know about these materials, but before you know the materials, the basic aspect of these alloys both steel and the cast iron, is related to the iron carbon phase diagram. In our iron carbon phase diagram has normally presented as incomplete phase diagram, and that is what I am going to discuss first to you.

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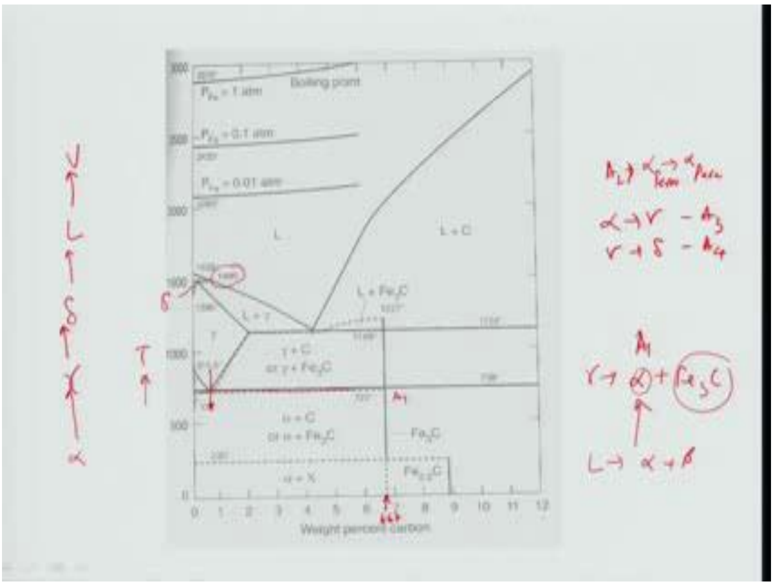

So, let me just take you through your tour of iron carbon phase diagram. So, as you see here, this is the whole iron carbon phase diagram which you have never seen in your life probably, what is their here. As you know iron has three phases in the room normal pressure; first one is alpha phase which is stable up to 911 degrees Celsius temperature, specifically 911.5 degree Celsius temperature. The next one is the gamma phase which is stable up to 1394 degrees Celsius temperature. Then you have a delta phase here which is not shown delta phase. Which is not shown here, this is what is your delta phase not shown here. Delta is a bcc structure; alpha also has a bcc structure.

So, alpha gamma delta then it is form liquid, then it form vapor that show thing happens for iron as youincrease temperature. So, at room temperature alpha is magnetic, and you know that alpha which is a basically raise stable for the room temperature at normal pressure, can undergo (Refer Time: 02:32) to parameter transitions, and the (Refer Time: 02:34) temperature is something like 768 degrees Celsius temperature, and this temperature can vary as a function of compositions of iron.

So, therefore, this temperature is known as a 2 point, a 2 is the magnetic to (Refer Time: 02:51) to parameter transition of alpha. So, I can write down alpha phase a 2 is basically alpha to alpha, this is fero to para magnetic. This is a two temperature point. Why we use these symbols a 1 a 2 a 3 a 4 or a c m, because the temperature may change based on the composition of the material. Now, alpha to gamma transformation also depends on temporary composition of carbon that will see later. So, that is abnormally given as a 3 point. So, alpha to gamma transformation is known as a 3, and gamma to delta this transformation is also known as a 4 point. So, a two a three a four, there is another temperature called a c m which you will see later. So, as you understand the, basically three solid phases alpha gamma and delta and liquid and vapor phase, and these things are actually the vapor phase diagram of iron and carbon; that is one atmospheric pressure point one atmospheric pressure 0.01 atmospheric pressure, and this all happens at a very high temperature.

So, these are not important to us. What is important to us is this part. Now not only that you know iron carbon phase diagram is plotted always first temperature versus, this is temperature axis temperature versus comp weight percent of carbon normally. And it can go up to maximum 6.67 percentage carbon, this is the point for 6.67 percentage weight percent carbon; why, because there is a compound which forms if you add carbon into iron, and the compound is known as f e 3 c all cementite, and this compound contains about 6.67 percent of carbon, beyond which whatever happened to the phase diagram is not important for any metallurgist. This is all important for (Refer Time: 04:47), but not for any metallurgist, or material science, because that particular domain of phases which forms there, is not at all used in the real applications, because they are extremely brittle.

So, therefore, all our concentrations will be carbon concentration from 0 to 6.6 weight percentage.

Specifically our concentration will be 0 to 4.5 weight percent of carbon, not even more than that. So, what is there; that is what you should know. Now for any phase diagram I told you, first of all you should know the phases presents that I have discussed. So, you have alpha gamma delta iron three solid solution phases are presents, and then you have a compound called f e 3 c present. So, there four phases present, let us keep it keep remembering these things and then; obviously, of liquid phase which is universally present any phase diagrams. So, what as we are discussing with solid state the actions, liquid is not important to us, solid phase is important to us. So, these are the solid four solid phase alpha gamma delta and f e 3 c. Second important thing is the reactions, any phase diagram where reaction can be registered by looking at a horizontal line, or a line which is parallel to the composition axis. As you see the two three horizontal lines here; one is here, one is there, and third one is there.

Each one of these correspond to a reaction, why do you know that these two lines the high temperature they corresponding to reactions involve a liquid phase, like this reaction I only discussed it to you this is a interactive reactions. The only information of gamma plus the graphite, or gamma plus cementite, depending on what kind of cast iron we are going to use, which we will discuss when you come back to the cast iron family. This one which is the pay tactic reactions, happens at about 1495 degree Celsius temperature, and in this reaction delta and liquid reacts and form gamma iron, this is only important for stainless steels, or steels (Refer Time: 06:55) steels which contains very low amount of carbon. So, sometimes after few classes I will concentrate on that and tell you what are the issues of that. The important reactions which you must consider and discuss is this last line at seven hundred and twenty seven degree Celsius temperature, what is known as a one temperature, which I am not discussed, this a one temperature line.

And this is the reaction which is the eutectoid reaction I told you in the last class gamma going to alpha plus f e three c. this is what happens if you cool it down, at below 727 degree Celsius temperature per gamma iron. This (Refer Time: 07:39) temperature is also function of compositions. So, therefore, we always use a one temperature, a one as a symbol to detect this temperature. this can vary depending on the concepts of the (Refer

Time: 07:52) elements and many other stuffs. So, therefore, this is the reaction should concentrate. And as I told you this is a eutectic reactions and eutectic reaction is basically as similar to eutectoid reactions. Eutectoid reaction is l going to alpha plus gamma beta. So, one two solid phases from (Refer Time: 08:15) from one liquid phase. So, similarly in eutectic reactions, gamma phase which is solid phase transforms to two solid phases. So, two solid phases (Refer Time: 08:23) transforms a single solid phase, and this is the important things in steels, because of this reactions we will form a particular p c s known as perlite, and the perlite gives (Refer Time: 08:38).

So, let me tell take you through the perlite after. So, you probably understood the different parts of the phase diagrams. As you see at other than that this is a two phased field region, which is alpha plus f e 3 c, this is a two (Refer Time: 08:51) gamma plus f e 3 c l plus gamma l plus f e 3 c, and then the gamma plus delta one region will be there. So, there are four two phased field regions, and there are after plus gamma also, five two phased field regions remember sorry, and then you have alpha gamma and delta and liquid four single phased regions; that is all. In addition to that I have given you alpha plus c gamma plus c l plus c and also dotted lines in these diagrams. Please understand that f e three c in iron carbon system is a metastable phase. Metastable phase means it is not the analytically most stable phase. It has higher (Refer Time: 09:36) energy, then the stable phase and what is stable phase, is a graphite.

If you add carbon in large quantity, and cool it slowly, you are going to form f graphite or carbon duly form the liquid or from the solid gamma also, because of the problems in nucleate nucleation and the growth of f e 3 c, when you have certain conditions satisfied. So, that is why these dotted lines corresponding to that gamma equilibrium. The equilibrium between carbon and iron, pure carbon means graphite and iron, and the solid lines corresponding to equilibrium between iron and f e 3 c. So, if you consider carbon then this phase diagrams will extent up to 100 percent carbon; not stop at 6.67 percent carbon, but it is not interesting beyond 6.67 percent carbon, when you consider equilibrium between iron and graphite, even if we can consider that, so basically all the important ingredients I told you at there, and I just want to tell you as a metallurgist or as a materials engineer, you must remember this phase diagram. Even if you forget most of things of the course, but this phase diagram should be at your tips.

You must be able to draw it, which I will do the next class, and also you must be able to explain different zones of the phase diagram that way I told you, we are discussed with you. So, as I told you let us first discuss this transformation saw which is known as eutectic transformations, but you know alpha is a bcc structure, gamma is fcc structure very simple, but cementite has a orthorhombic structure, it is a complex structure. I do not want to scare you, but please remember that, this is the orthorhombic structure is a complex structure.

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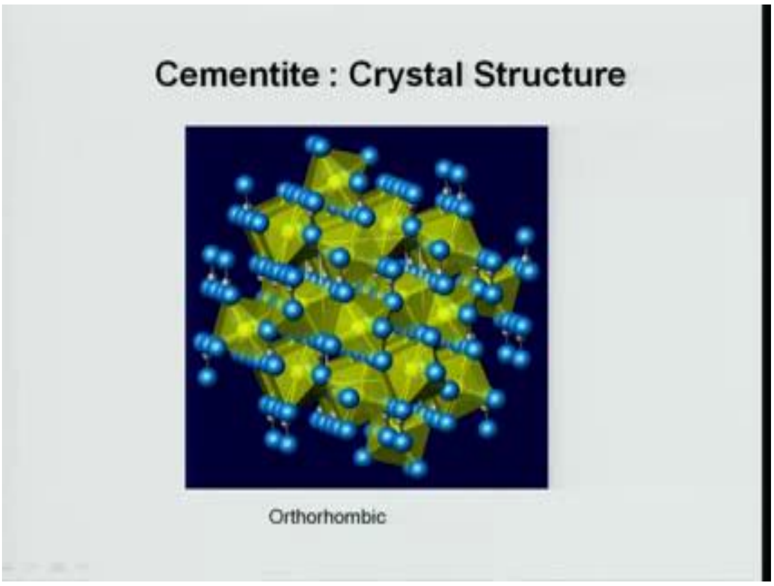

Here you can see these blue items are iron atoms, and these yellow atoms are carbon atoms and their tetrahedral octahedral or bond it. You can see the octahedral. So, inside the octahedral some carbon atoms are gone, and each at corners of the octahedral are actually you have iron atoms, but this is what the structure of cementite. In fact, because of these complex structures cementite is very hard and brittle phase. Now, let us look at the (Refer Time: 12:01) first, perlite which you probably hard perlite, perlite what comes from the thing known as pearl.

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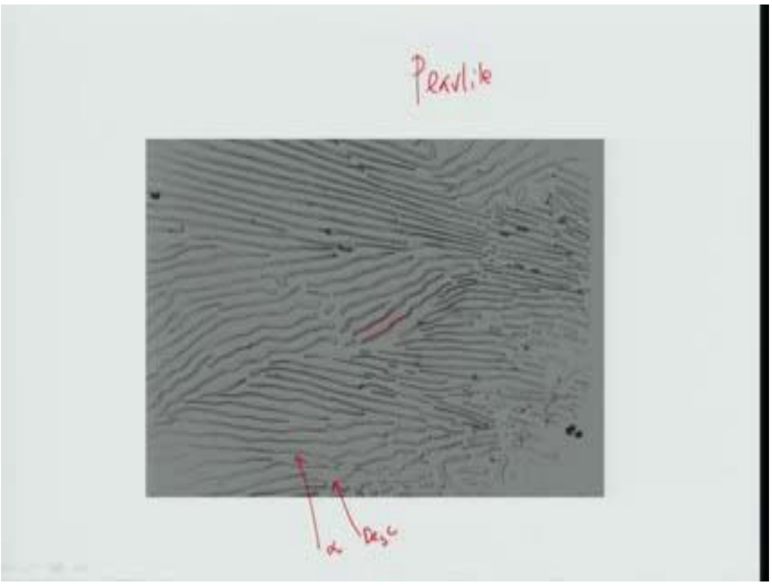

Pearl which we use, we normally grow from the oyster cells, and the pearlite can be used as jewelry. So, these microstructures are looks like a pearl that is why it is called pearlite like. in long back in England when this was studied they saw this microstructure optical microscope, and they saw this is a pearlitic lusture or a pearlatic color, basically looks like a perlite, or looks like a pearl; that is why this is known as pearlite, lite means small. So, pearlite consists of two phases as I told you, gamma sorry alpha and f e three c. So, this wide regions are basically alpha and this is f e 3 c remember, alpha is not a pure iron alpha is a solid solution of carbon in iron, and what is this type of solid solution it is. It is a (Refer Time: 13:01) solution, in which carbon atom goes to (Refer Time: 13:06) places in the alpha. So, alpha is a bcc structure. So, there are two types of interstitial sites; one is octahedral and other one is tetrahedral.

So, carbon can go into one of this sides, or both depends on what kind of crystal structure it has for the size of carbon atoms, and forms a solid solution, but alpha contains very low amount of carbon. You know at seven hundred and twenty seven degree Celsius temperature carbon constitutional alpha is very low 0.02 percentage carbon, or 0.025 weight percent of carbon room temperature alpha is virtually free of carbon very little amount of carbon is present you can say (Refer Time: 13:46) level of carbon is present. So, that is why alpha is most the time confused to be a pure iron or solid solution, (Refer Time: 13:55) alpha here is solid solution of carbon in alpha bcc iron at room temperature normally, and f e 3 c is a intermetallic phase an intermediate phase, or a compound the fixed (Refer Time: 14:10) three is to one, or it contains about six point six one percent carbon and rest of the thing is iron. So, real microstructure will be like this, it looks like exactly like a eutectic microstructure eutectic microstructure will have lamely of alpha and beta phases.

Similarly these are called alpha lamellar and band the f e 3 c lamely. All these dark colored things which are like this I am drawing at the f e three c white thing is alpha. This is actually a mixture of very hard phase f e 3 c, within a, with alpha which is a ductile phase, and because of this mixture which is known as a composite (Refer Time: 14:51) composite, steel has wonderful mechanical physical properties, and that is why steel is better than none. So, better than everything sorry, better than everything any of the material you see in the real picture, steel is better than anything you see in the world (Refer Time: 15:10) world, and this reason because this structure is so important now one can actually control the spacing of these two lamely very easily, and control the mechanical properties by different processing. Now, in t e m transmission electron microscope, this lamely can be seen very nicely.

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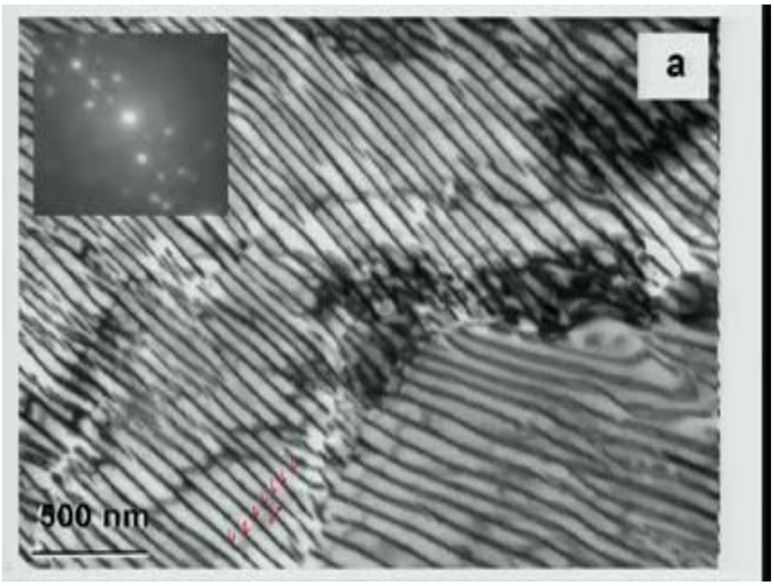

You can see here this thicker one's are alpha, this are alpha phase. The black one which I am drawing by arrows are basically f e 3 c, and this dimension 500 nanometers. So; that means, the distance between alpha to alpha, is about a couple of hundred nanometers, and you can control the distance. By controlling the distance you can control the mechanical properties; that is the beauty of this.

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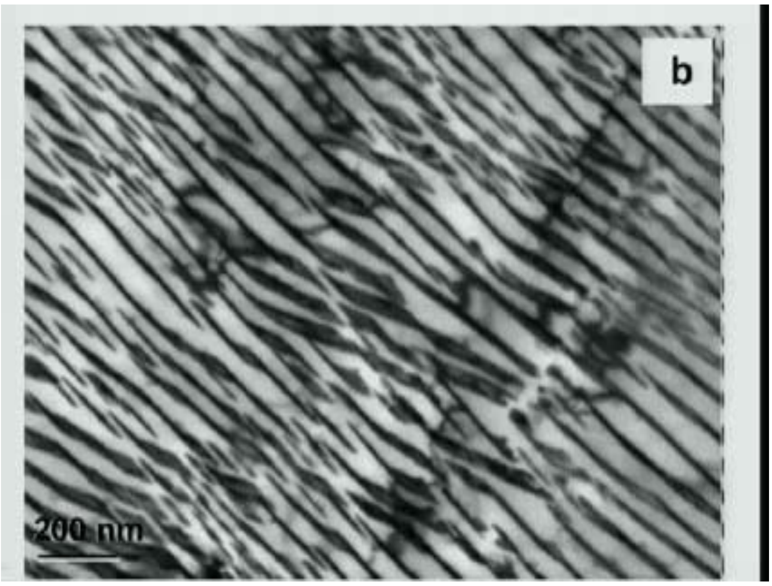

And I will show you many other pictures, because this is just like eutectic morphology in solid state.

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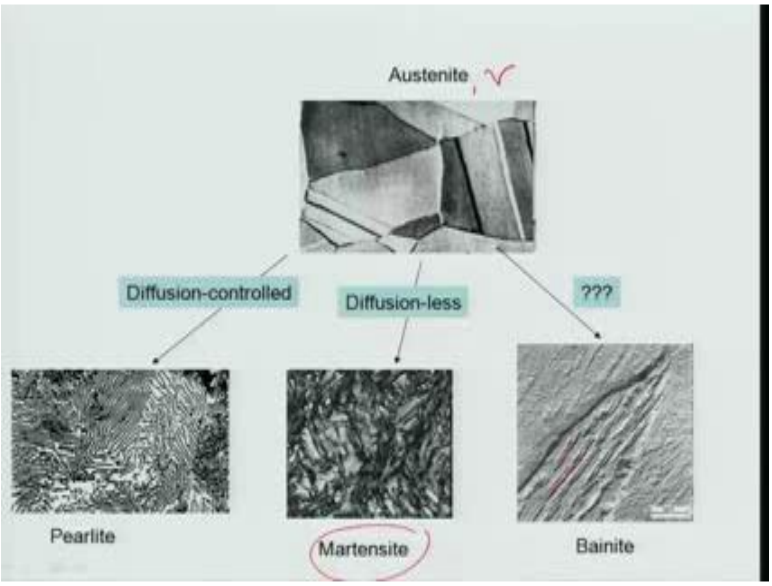

Now, you know while discussing these things I must bring to a point that, in the eutectoid transformations, the most important thing is the gamma phase; austenite. After giving you a description of phase diagram, and also little bit of microstructure features of pearlite I just wanted to go back and tell you, how one of the host of microstructure we can obtain in a steel, and how we can do that; that is the basic purpose of this slide. So, our base microstructure is austenite, which is gamma phase.

We call it austenite, basically coming from a name of a scientist. So, austenite is a gamma phase, you can see here these are the austenite grain single phase, and if you cool it very slowly, though the eutectic transformation temperature, you can form pearlite. Pearlite is what? Pearlite is a lamellar morphology, having a lamellar morphology consisting of alpha solid solution and f e three c, white color thing is alpha, black color thing is f e 3 c. Now, this will happen if you cool it very slowly, or cool normally.

Suppose if you take a sample gamma, which is austenite, and from that austenitic phase you drop it into a bucket full of water. It will get quenched, like you get you quenched your thirst in summer day hot day. So, similarly this sample also will get quenched in water. What the meaning of quenching. Meaning of quenching is that gamma phase with all of a sudden get cool down to room temperature, from high temperature. Whereas, you know gamma is stable only above 727 degree Celsius temperature for carbon concentration higher than zero, also have carbon concentration higher than point 0.8 actually weight percent carbon, but normal it is high temperature phase. So, if you quench from 727 or higher than that temperature to the room temperature, by dropping in the water that is what is known as quenching, and if we do that, we will get a different product what is known as martensite. Martensite is a single phase structure unlike pearlite, but it consisting of needles of martensite.

So, you can see here the same structure can be bypassed by quenching or cooling rapidly, and it can obtain a different kind of structure called as martensite. Martensite is accidental discover we should discuss in detail when we talk about it. It was discovered by Martin's, R Martin’s in Germany long back accidentally. Martensite is a very hard and brittle phase, and it forms by quenching. So, therefore, it will have a lot of phase in quenching. Now third thing which is important, which is coming to (Refer Time: 19:11) very important to steel metrology is known as bainite.

So, now, question is that even if you cool slowly you will form pearlite by slow cooling, which is a mostly diffusion control phase transformations, where gamma transfer into f e 3 c and alpha by diffusion process. And if you quench fast there will be no diffusion in from martensite. In between suppose you cool the gamma fast enough, and keep it at 400 500 degree Celsius temperature 0.350 point degree Celsius temperature for longtime, just like a (Refer Time: 19:46) you cool it from 995 Celsius temperature gamma is stable, directly to 350 degree Celsius temperature, and keep it there for a long time.

What you will get is known as bainite, and bainite here I am showing is a (Refer Time: 20:01) like structure is like a leaf tree leaf in which you can see tree leaf is consisting of alpha and f e 3 c. So, difference between this pearlite and bainite is that, in pearlite you have basically this lamellate structure, and in bainite you have this tree like structure or the other structure possibilities (Refer Time: 20:20) it is. So, far not clear how the structure forms, what are the basic mechanical information of this structure; that is why I put this point of interrogation here. So, what you understand from this slide. You understand that in steel I can take austenite and just varying the process parameters little bit from left and right I can create three different types of structures, and each of these structure will have different physical and mechanical properties. This is the beauty of metallurgy. You can take same phase cool it differently, and create three different microstructures; that is why it is so interesting. Steel is so important and interesting aspect of things.

So, I just go back now to the phase diagram. Now you know the important thing which we should understand, which I am going to do in the next class in detail manner, how this eutectic transformation happens, but before that whatever time I have in this class, I would like to tell you the important aspects. As you know these eutectoid reactions, which I have written as alpha plus f e 3 c, in which two solid phases form duly from one solid phase, as I told you repeatedly; one of the solid phases is, a very soft alpha iron, and other one is a very hard compound f e 3 c. So, therefore, this is nothing, but (Refer Time: 21:42) composite between a soft phase and a hard phase.

Composite means what, bamboo is a composite it has fires and soft (Refer Time: 21:51) phase. So, that is a very hard and tough material. So, because of presence of these two phases; one is hard and brittle, and very high strength and other ones soft alpha, and because of well mixture, very nice mixture of these two we get interesting physical and mechanical properties of steel, and that is why steel can be used for many applications.

Now, as I told you that this reaction is basically governed by diffusion of carbon, this is a diffusion control reaction as you see. So, we can control the reaction by controlling the diffusion of carbon. So; that means, we can change this pearlitic lamellas distance by changing the diffusion, by controlling the processes such that diffusion of carbon can be control. And by doing that we can clearly, we can actually control the mechanical properties, because strength of these particular mixture, depends on the distance between these two, basically experimental call inter lamellar spacing in eutector eutectic transformation distance from one center of the lamellate to other center of the lamelle. So, that way I have drawn a (Refer Time: 23:00). So, this will be like this; suppose if I trick center of this lamelle center of this lamelle this is what is lambda. So, by controlling or other I can tell you have center of this lamelle f e 3 c a center of the alpha and this distance, is known as lambda.

So, by controlling this lambda we can actually control its mechanical properties; that is another beauty of pearlatic microstructure. So, with this I just, I would want to tell you do that I have given you very you know brief and salient description of the iron carbon phase diagram, which is important for you to understand. We will come back and forth for this phase diagram, because we need to discuss many important issues, but what you should take away from the lecture is that the five phase diagram, is very important for controlling the (Refer Time: 23:52) of steel you must not forget. So, therefore, it is for your own interest that you understand that phase diagram very nicely and obviously related to the different reaction.