Materials Science and Engineering

Dr. Vivek Pancholi
Department of Metallurgical & Materials Engineering
Indian Institute of Technology, Roorkee

Lecture - 19
Iron-carbon phase diagram

Hello friends, so in the previous lectures we discussed about equilibrium and non equilibrium cooling in isomorphous system, then we discussed about equilibrium cooling in eutectic systems and by that we were trying to understand that what kind of different microstructure or how different phases form and how they are kind of where they will form and what will be the fraction and their composition and so on ok.

So, now we will take one very important phase diagram for any engineer and that is iron carbon phase diagram. Again iron carbon phase diagram is a misnomer here because, it actually what we study is the phase diagram between iron and cementite, that is one of the phase which form between iron and carbon ok. So, only we see the phase diagram up to there the cementite forms we do not go up to a 100 percent carbon. So, it is this phase diagram is not between 100 percent iron and 100 percent carbon the phase diagram is between 100 percent carbon 100 percent iron and 100 percent cementite.

So, the phase diagram is between iron and cementite. So, please keep that in mind and this was of course, one of the most important system to understand ok. So, that is why I have taken it right now, later on we will see a few more things which are related to phase diagram and basically transformation and how transformation gives you different type of micro structures.

So, first we will understand the iron carbon phase diagram at this stage, now before going into phase diagram let me give you a classification scheme which you will find in books and in a lot of discussion for iron carbon system basically, that what type of composition we will classify their composition in which category.

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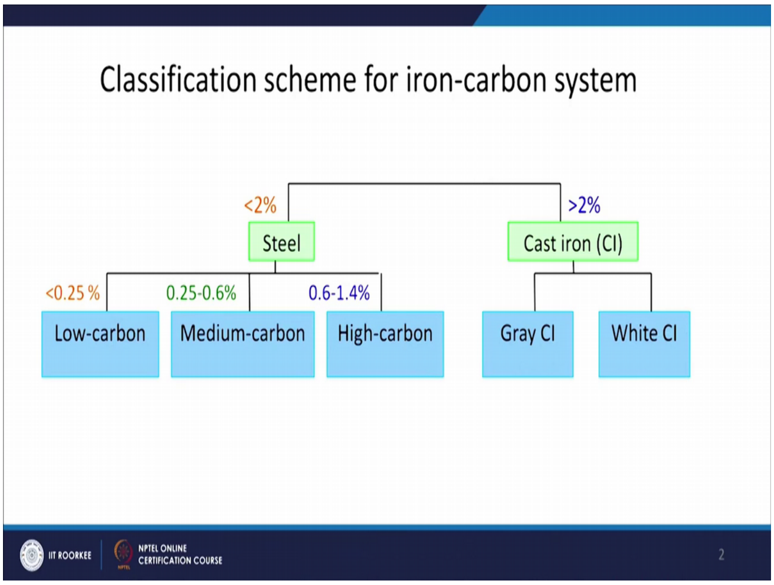

So, as you can see here that our iron which as carbon percentage less than 2 percent ok, that we call as steam and iron carbon system which contains more than 2 percent carbon is called cast iron. So, you have a steel and cast iron, cast iron at 1 are widely used nowadays the applications are very limited, whereas, the steel is 1 of the widely used material in structural applications.

So, in steel also I can divide it into different categories for example, lower than 0.25 percent I can call it as low carbon steel, 0.25 to 0.6 percent I can call it as medium carbon steel and 0.6 to 1.4 percent I can call it as high carbon steel. Similarly cast iron also we can classified it into gray cast iron or white cast iron 2 categories of cast irons are there ok.

So, this is a roughly scheme now there are more addition to these also. For example, there is 1 class of steel which is called interstitial free steels ok; that means, you have taken out all the atoms whichever there in interstitial positions out of those interstitial position.

So, you do not have any atom which is occupying interstitial positions or these are called interstitial free steels. So, if is steel more popular is known a IFS team. So, there are different categories which can keep on adding into there ok, but from overall understanding right now.

This much is enough for us that we can classify steel into different categories, now this is by a iron carbon phase diagram, of course it looks intimidating right.

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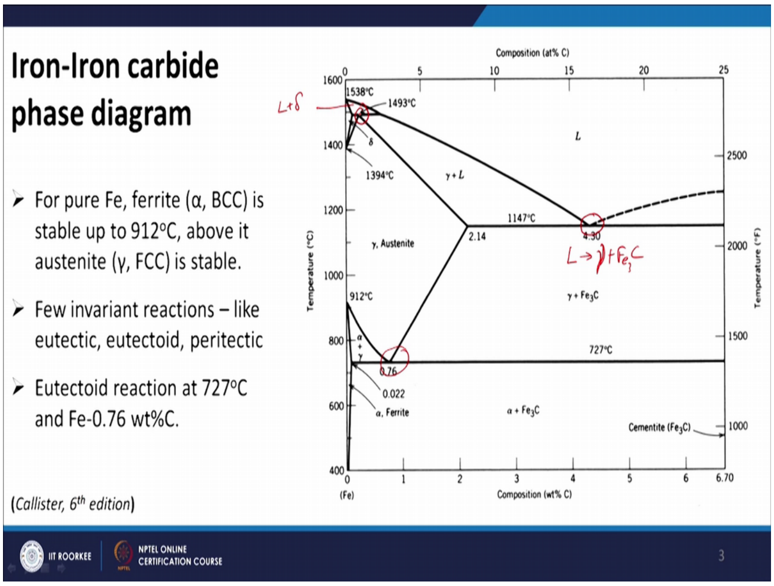

Now there are so many things happening here, in fact, I would suggest you to when you are going through the lecture to stop your lecture and look at this phase diagram very carefully, 1 of the things which I would ask you to find out is can you find out that what are the different invariant reactions which are there, till now we have discussed only the 1 invariant reaction which is called there eutectic reaction ok, where the liquid transform into 2 solids so.

You can stop your lecture here by pressing the pause button and look at what are the different eutectic reaction you can find out. Of course, you can find out a eutectic here oh sorry different invariant reaction you can find 1 you can find is eutectic, there are 2 more invariant directions they are taking place.

Of course, we have not discussed that, but it will be a good exercise if you can try to identify and how you can identify them 1 of the ways is to find out that at a certain and do you see the degrees of freedom is 0; that means, my you know that there are only 2 components here again it is a binary phase diagram, you have to find out that at any point if there are 3 phases are in equilibrium then you should have degree of freedom s 0 at that point ok.

So, in overall this phase diagram you should try to see that at which point you are saying there are 3 phases are in equilibrium ok, do you give it a time pause at it and look at it and I think you should be able to see some, the names are written here as you can see ok. I will come to that for example, for pure a pear which iron-iron they write alpha BCC is a stable up to 912 degree celsius ok, above it Austenite comma phase is stable. So, as you can see up to 912 degree celsius you have alpha phase which is alpha phase is carbon in iron ok, alpha phase means carbon in iron ok.

So, a very low carbon alpha phase will be stable up to 912 degrees celsius ok, about that it will be austenite phase then there will be another phase transformation here. The alpha phase is FCC and sorry gamma phase is FCC and alpha phase is BCC and then there is another phase transformation here where the gamma transformed into a delta pherite right which is again BCC.

So, you have room temperature b BCC structure then it becomes FCC then again it becomes BCC and then there is melting at 1438 degree celsius ok. So, this is how the transformations are there in very pure iron; that means, carbon is uh very low.

So, alpha to gamma to delta and at 1438 degree celsius you have melting into liquid phase, now few invariant reactions are there 1 is eutectic another is eutectoid and the third 1 is periodically. So, these are the 2 names which are coming here, first come to a eutectic you can see that this whole is the liquid phase here and you see that at this point my liquid is transforming into austenite and cementite ok. So, liquid here is transforming into gamma plus or gamma plus Fe3C, which is we call this cementite ok.

So, this is my eutectic point where liquid is transforming into 2 solids ok. So, this is 1 of the invariant point, another is eutectoid that is here at 0.76 percent carbon and here what is happening austenite which is a solid phase is transforming into alpha and Fe3C2 solid too good sold phases. So, let me write this equation for you for eutectoid, this is my eutectoid reaction these are all invariant reactions as we discuss earlier also.

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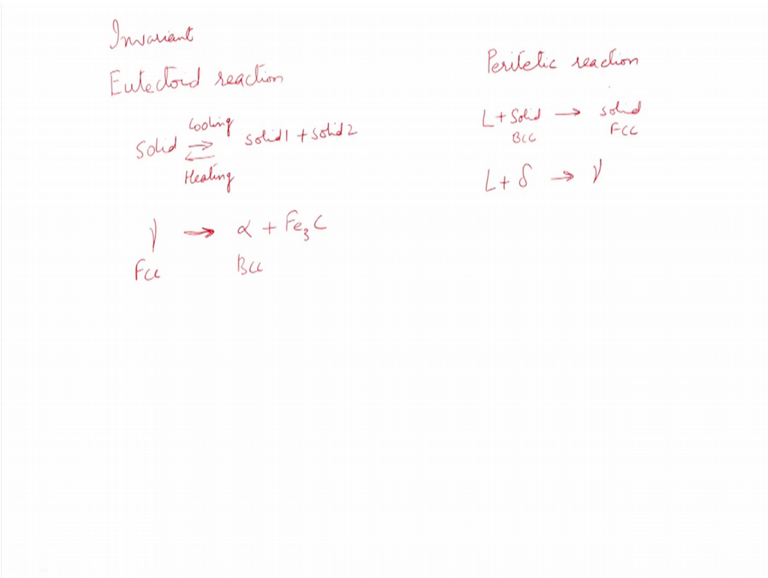

So, in this case solid transforms into ok. So, in this direction it is cooling, transforming into solid 1 plus solid 2 1 solid is transforming to solid 1 and solid 2, in this direction it is heating. In our case iron carbon phase diagram this solid is the this gamma phase and that is transforming into alpha which is alpha ferrite plus cementite.

So, it is transforming into these 2 solid. So, this is 1 of the invariant reaction another 1 which you will find here is called peritectic reaction ok. Let me show you where it is then I will come to this.

So, this is the point where you have a peritectic reaction taking place, now let us find out what are the phases here this is a liquid phase throughout everywhere, now liquid and this is my delta phase as I showed you. So, in between these is will be a 2 phase region which will have liquid plus delta and below that it is only the austenite single phase austenite solid phase.

So, at this point the circle point what you are seeing 2 phase liquid plus delta is in equilibrium with the single phase gamma ok. So, this is 3 phase equilibrium, so as I told you in a binary system where you have 2 components, if there are 3 phases in equilibrium at any point you should have invariant reaction taking place at that point.

So, this 2 phase liquid plus delta is in equilibrium with the gamma phase here; that means, it is a equilibrium invariant point and there has to be a invariant reaction there and that is known as the peritectic reaction. So, let me tell you what do you mean by peritectic, so in this case a liquid plus solid transform into another solid.

Why we calling this solid as a difference solid because, this solid it has a BCC structure and this solid has FCC structure in our case ok. So, in our case now come to our case you have liquid plus delta ferrite ok, which has a BCC structure transforming into another ferrite the gamma which is what we call it austenite and later the FCC structure.

So, liquid plus delta ferrite is transforming into austenite, liquid plus solid reacting together to form another solid of a different crystal structure, this reaction is called peritectic. Solid transforming into to solid is called again you can see that this is an FCC structure, this is a BCC structure they are transforming into 2 solid 1 solid is transforming into 2 solid, liquid plus 1 solid is transforming in another solid peritectic reaction. Eutectic reaction is a liquid transforming into 2 solids is a eutectic reaction. So, these are invariant reaction where different type of phases react to give you another type of phase.

So, this is what is happening 3 invariant reaction eutectic eutectoid, solid transforming to 2 solid and peritectic where liquid plus solid transforming into another solid. Now a lot of things you can see here you have a liquid plus delta giving you another solid then there is another 2 phase region, where gamma plus liquid are in equilibrium.

Coming below you have alpha phase here you have cementite here and in between you have alpha plus Fe3C in equilibrium, at 0.76 percent you have eutectoid reaction transforming austenite into alpha and Fe3C. Then there are temperatures given different temperatures eutectoid reaction will takes place takes place at 727 degree celsius, then eutectic reaction takes place at 1147 degree celsius; then peritectic reaction takes place at 1493 degree celsius and so on.

So, I think this is how the whole phase diagram will be for a iron carbon system. Now we will try to see that again as we did in the eutectic system, that at different composition what type of microstructure you will get. So, we are interested only in the phases which are at low temperature.

So, we will not go at higher temperature where liquid or delta phases are there, but only where the austenite is transforming into the austenite is again a solid phase ok, of carbon in iron but has a FCC structure. The iron atoms have FCC lattice that is transforming into 2 solids ok. So, as I told you the eutectoid reaction takes place at 0.768 percent carbon. So, if I take an overall composition of 0.76 percent and I have taken all this information from book by a callister material science and engineering ok, so that is why I have written in it here.

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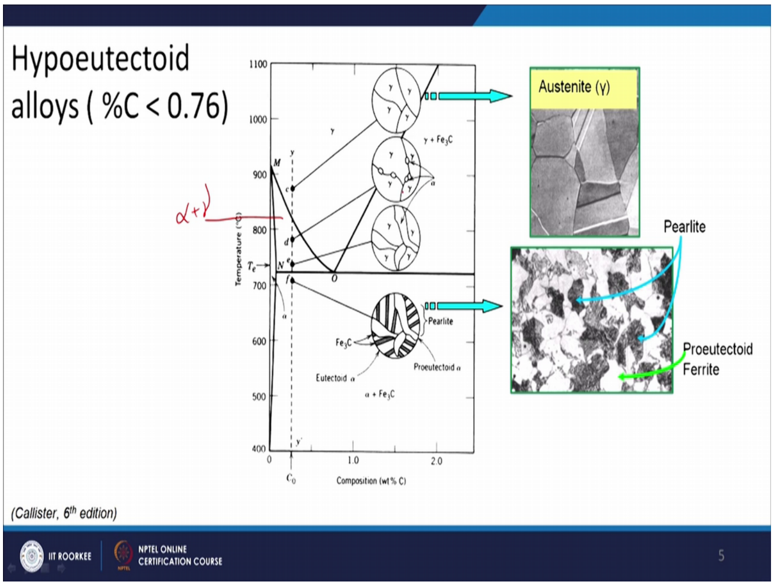

So, when you are a in austenite phase you will have a austenite microstructure which will look something like this ok, the austenite phase maybe that microstructure, that is transforming into at the eutectic point eutectoid point it is this asteroid is transforming into alpha plus Fe3C that is what we said and as he we discussed in eutectic system that when you have 2 phases coming from a single phase ok, the most appropriate is usually is that they form the 2 phases in close vicinity.

So, they are forming lamella 1 lamella another lamella so, alpha F3C alpha Fe3C and so on. So, there will be close to each other, so when the redistribution takes place of carbon between the 2 or iron atom between the 2; the atoms have to travel very small distance between the 2 when they are close to each other ok.

So, that is what you will see here also, that all this alpha phase are very close to the cementite phase ok. So, that distribution of carbon from carbon protected from alpha phase will go to Fe3C iron rejected from Fe3C will go to alpha phase and so on and that is how these will go.

So, all the gray ones are shown by Fe3C and the white ones are shown as alpha here and that is what you see here also now although these bright ones are the ferrite phase and this dark ones are the Fe3C and that is how their form as lamella close to each other ok. So, this is the microstructure you will see when you have a overall composition equal to eutectoid composition.

Now let us see what happens if I have a composition which is lower than eutectoid composition ok, in case of steel it is called hypo eutectoid alloys or hypo eutectoid steel. So, carbon percentage is less than 0.76 percent less than eutectoid composition hypo less than the eutectoid composition ok.

So, again as you can see at point c here for an overall composition c naught, you will have gamma austenite phase grains of that as soon as you cut this o M line here ok; some of this austenite phase will have a nucleation of alpha phase ok, you can see that in in this region there is a there is an equilibrium between alpha and gamma austenite.

So, some of that some places you will have nucleation of the ferrite phase ok, the alpha ferrite alpha phase and as we also discussed that the nucleation should occur at the grain boundaries which are high energy sites. So, the this will form at the grain boundary of the austenite phase.

As you come to the point all this will grow maybe they will joined together. So, you can see that there are now continuous alpha ferrite phase is there continuous in continuous form and at this E point is just above the eutectoid temperature, as soon as you go to the point F which is below the eutectoid temperature all the remaining austenite you can see here. All this remaining austenite has transformed into this lamellar structure of alpha and Fe3C.

So, it is a constant temperature reaction all the remaining oxide, in case of eutectoid reaction all the, it remaining oxide will transform into alpha and Fe3C when you had eutectic reaction all the liquid will transform into 2 phase solid in this case all the solid will form into 2 phase solid.

So, this is alpha eutectoid and Fe3C forming together as lamella. So, all this austenite which was remaining just above the eutectoid temperature transform into this lamella structure. So, if you remember at that time we said that to distinguish the alpha which is formed before this eutectoid reaction and the alpha which is formed after the eutectoid reaction we want to kind of say segregate these two.

So, you can see that the alpha ferrite which formed before the eutectoid temperature, that we are calling as pro eutectoid alpha before the eutectoid reaction and alpha which is forming in the eutectoid reaction is called eutectoid alpha.

So, just to differentiated between the two, the microstructure will look something like this, but light will have because it has lamellas of 2 1 dark 1 bright phase. If your microscope does not have a good resolution now you also connect this thing with the resolution which we discussed when we were discussing about microscope. So, if your resolution is not very good it will look almost like 1 single dark phase, but if it the resolution is good you may be able to see that there are lamellas in the in the microstructure and this is 1 way of knowing a good microscope that it is able to resolve pearlite structure.

Now another thing is that what in case of a steel you have names for all type of microstructure, people used to love steel at 1 time and they used to give name to each structure. So, this lamellar structure in steel is called pearlite please remember that, this is the mother of pearls analogy is there to that is why they call it as pearlite and these have this lamellar structure. So, if you want to identify a good microscope just take 1 steel normalized steel maybe low carbon the steel a normalized sample and see it under the microscope if it is able to resolve pearlite then the microscope is good.

For example, here you are not able to resolve that, in some cases some location we are able to resolve the lamellas. So, this will be a pearlite type of structure and the ferrite which has formed before the transformation it will be called pro eutectoid alpha or pro eutectoid ferrite. Then the next case will be hyper eutectoid steel, again you can see that we are starting from an austenite phase as soon as we are crossing this op line.

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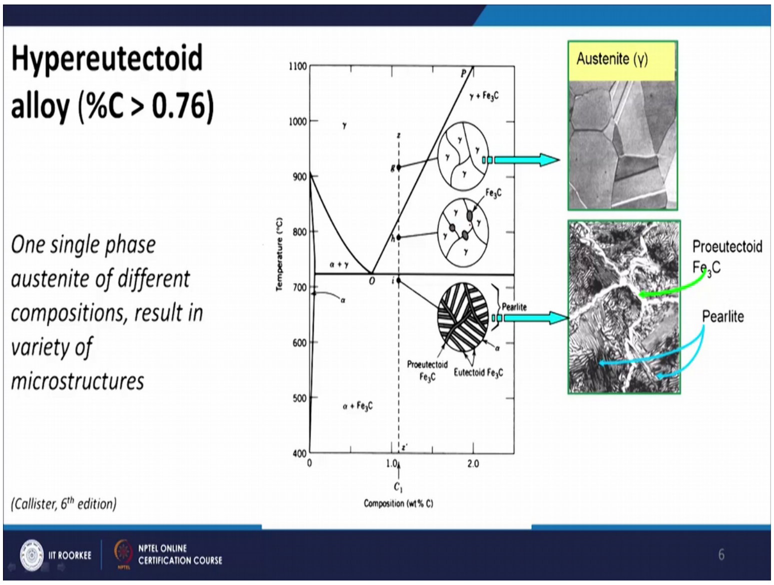

You see that some cementite which has started nucleating on the grain boundaries of austenite, the earlier it was ferrite which was nucleating here now it is cementite which is nucleating yet, because this region contains the equilibrium between austenite and cementite.

Whatever the austenite is remaining just above the eutectoid temperature that; will be transforming to again this lamellar structure after it crosses the eutectoid temperature. So, you have this type of lamellar structure again and this will again contains the Fe3C and alpha lamellas.

So, now in this case earlier we when alpha was transforming before the eutectoid reaction we were calling it as pro eutectoid alpha or pro eutectoid ferrite, now we are calling it as pro eutectoid Fe3C or pro eutectoid cementite which as formed before the eutectoid reaction and the cementite which is forming after the eutectoid reaction is called eutectoid Fe3C or eutectoid cementite and then there is a pearlitic microstructure, as I told you then this is all pearlite lamellar alpha and Fe3C phases.

In terms of microstructure actual microstructure of course, this is again austenite phase having grain boundaries and grain this is transforming into. So, you can see this white structure here or at the grain boundary of the austenite, this is all cementite pro eutectoid cementite and some cementite which is in the lamellar that will be called as eutectoid cementite and the microstructure of this lamellar will be called as pearlitic. Please understand that the pearlitic is not a phase here sometime that that is 1 confusion students have, pearlite is not a phase ok.

Phase as if you remember our first condition of phases that it should be a homogeneous mixture of and a physically and chemically it is it should be homogeneous. But here pearlitic it contains alpha ferrite which is a pc structure and then you have Fe3C, carbon is very low in alpha ferrite and carbon is very high in cementite. So, you have 2 different chemical compositions species. So, this is a phase mixture, it is a microstructure basically. So, you have two phases which are together that is what is pearlitic, so pearlitic is not a phase it is a phase mixture.

So, this is the microstructure you will see when you have a hypo hyper eutectoid steel. So, in both the hyper eutectoid and hyper eutectoid in both the cases you will have some phase which is pro eutectoid ok. So, either it can be alpha or it can be cementite depending upon what is your composition and some which is pearlitic ok. So, pearlitic will be whatever is oxide remaining just below before the eutectoid temperature, that will be transforming to pearlitic.

So, with that thank you this is a 1 of the very important system to understand and we will do lot of question during the assignments to clarify our understanding of these phase diagrams.

Thank you.