Introduction to Materials Science and Engineering

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Lecture – 77
Fe-C phase diagram

Let us look at in conclusion of our phase diagram topic, one of the most important phase diagram in engineering and that is the iron carbon phase diagram. This is probably the last example we will take and we have to take this because, this is a very very important engineering phase diagram, I say very important because you know iron carbon system is what gives you steel steels are basically alloys of iron and carbon.

And you know that modern technology and modern civilization modern engineering cannot survive without steels. So, this is a very very important diagram from that point of view, it is also among the examples which we have seen we have seen two examples till now, one is the isomorphous phase diagram of copper nickel, that had no invariant reaction then we saw the eutectic phase diagram of lead tin which had a single invariant reaction. Now this iron carbon phase diagram is more complicated than any of these because as you are going to see it has 3 invariant reactions. So, let us look at the iron carbon phase diagram.

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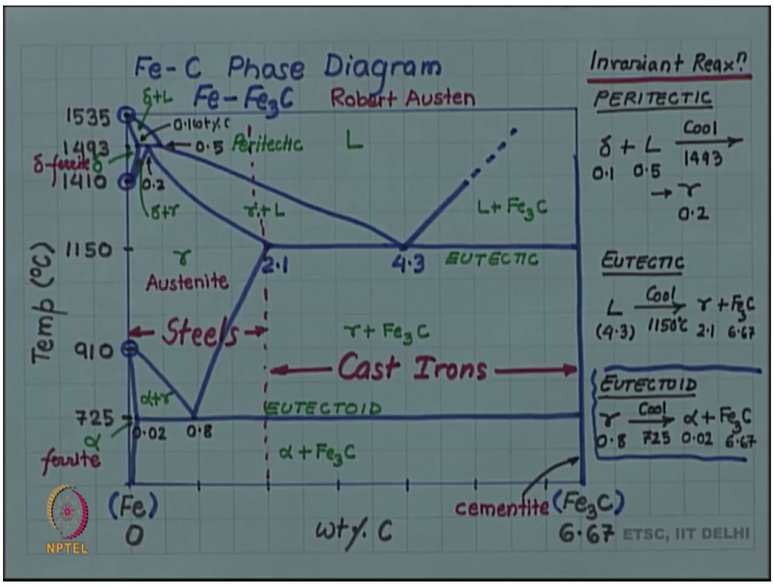

By now, you have become familiar that the phase diagram is a box with x y y axis being the temperature and x axis being composition. And since we are looking at iron carbon phase diagram one of the ends is iron which is 0 weight percent carbon, but this diagram is different from other diagrams which we have discussed, that the composition axis does not go all the way up 200 percent carbon. We stop at all traditional and carbon phase diagram stop at Fe 3 C which is an inter metallic compound and, it is weight percentage 6.67.

If you if you think of it is atom person, you can see there is 1 carbon atom out of 4 atoms. So, it has 25 atomic percent carbon in it, but since carbon is lighter 25 atomic percent carbon contributes only 6.67 weight person. Beyond Fe 3 C the diagram is not interesting to engineers because, structure the alloy will be too brittle and has not much engineering applications. So, we look at this so sometimes because of this the iron carbon phase diagram also is called Fe 3 C diagram.

Iron carbide phase diagram is also sometimes used to indicate that we are ending at Fe 3 C. Now I told you that there are 3 invariant reactions and, we have seen in the last video that every invariant reaction in a binary phase diagram is always represented by a horizontal line. So, we will have 3 horizontal line. So, let me begin with that I am gradually trying to build up the phase diagram because, the phase diagram is complicated and seeing it all at once can be little unsettling to a beginning student. So, we let us gradually begin with each of this invariant reaction the invariant reaction at highest temperature happens at 1493. So, I have 3 points there 1535 is the melting point of iron. So, that is an important point above that is liquid iron for pure iron, for pure iron 1535 is the melting point, then 1410 is a solid state transformation and 9010 is another solid state transformation we will talk about that.

So, let me first complete this invariant reaction. So, there is a phase boundary like this, then it connects 1410; another invariant reaction runs here and the phase boundaries connecting these 2 invariant reactions.

This is 2.1 weight percent carbon, this is 4.3 weight percent carbon and here of course, the compositions are little difficult to indicate, but let me try to indicate that is 0.1 weight percent carbon. This is 0.2 and this is 0.5 and the horizontal temperature is 1493. So, that is one of the invariant reaction, then we have the next invariant reaction at 1150 degree

Celsius, which is shown there and finally, we have an invariant reaction at 725, which has another horizontal line running here, it is end compositions the left hand composition is very close to pure iron 0.02, then this is 0.8 and it goes all the way up to 6.67.

So, let me now connect these you have boundaries here like this, the boundary running from there and a final boundary coming here. So, this now completes the phase diagram. Let us write down the phases, this large region at the high temperature region is the liquid region this small triangle here is what is called delta.

Each phase has a symbol as well as a name. So, it has it is delta we will give you the name the name is delta ferrite, name is delta ferrite symbol is delta. Then this is a single phase region this large single phase region very important region this gamma, this is called austenite this is named after the famous metallurgist, who first made this phase diagram that was Robert Austen, he was a first person to study iron carbon phase diagram. So, in his honor this large single phase region is called austenite and, then again you have a small triangular region here, this is called alpha and, it is name is simply ferrite.

And the vertical line here this vertical line here, itself is a phase is a single phase region, only since it is a compound it exists at a fixed composition. So, it does not have any width in the composition space. And this is so this is also single phase, this is a single phase region and this Fe 3 C the symbol is Fe 3 C; the name given to it is cementite. So, now you know all the single phase regions the 2 phase regions which I have not labeled can be easily labeled recall the 1 to 1 rule. So, if you remember the 1 to 1 rule, you can easily label all the 2 phase regions. So, this region will for example, will be gamma plus liquid; liquid plus Fe 3 C gamma plus Fe 3 C alpha plus gamma and alpha plus Fe 3 C the 2 phase regions here also can be labeled space is not there.

So, this is between delta and liquid, this is delta plus liquid and, this one there is delta plus gamma, each invariant reaction is given a special name. So, the invariant reaction happening at this temperature at 1493, this is called a peritectic reaction; peritectic the one happening at 1150 you might recognize because, you have met it this is the eutectic and the one happening at 725 is the eutectoid.

So, this completes the diagram we know all the compositions and temperatures we know different phase regions, we know what phases are present in that and, we know the names of the 3 important invariant reactions happening in this let us write down in full these invariant reactions. So, invariant reactions the first one at the highest temperature is the peritectic, in this; you can see that above the horizontal you have delta plus liquid region.

So, you have delta plus liquid which transforms into on cooling at a temperature of 1493, it will transform into a single phase gamma delta plus liquid on cooling is changing to gamma the composition of delta is 0.1 of liquid is 0.5 and gamma produced is 0.2. So, that is the peritectic reaction the eutectic reaction is happening at 1150, we can write this as liquid the higher temperature phase is the liquid of 4.3 percent on cooling through 1150 degree Celsius will transform into 2 phase mixture of gamma and Fe 3 C, gamma is gamma composition is 2.1 Fe 3 C, we have already given 6.67 and finally, the last one here is the eutectoid.

In this a single phase gamma of composition 0.8, decomposes on cooling at a temperature 725 into alpha plus Fe 3 C the alpha composition is 0.03. So, alpha is very pure iron and Fe 3 C is again 6.67. So, now you know the details of all the 3 reactions the invariant reactions which are happening in this phase diagram.

Let us look at little bit more about these phases that; what do these phases mean? So, the phases in iron carbon system and one more thing I want to say 2 more things actually, that in this diagram, if you look at compositions less than generally rough demarcation line, because we have 2 kinds of alloys of iron and carbon, one is called the cast iron and another is called steel. And a rough demarcation line is drawn at this point about 2 weight percent. So, alloys less than 2 weight percent carbon, these alloys are called the steels.

And alloys with higher carbon these are called cast iron, you can see that 4.3 percent carbon is a lowest melting point in the whole alloy system. So, this if you have 4.3 percent carbon that iron carbon alloy will melt at a very low temperature of 1150 degrees Celsius. And low melting is beneficial for casting. So, the casting alloys are having higher carbon and so that they melt at a lower temperature whereas steels during manufacturing, it will melt one in the steel melting furnaces, but after that in fabrication processes usually we do not melt it we do not cast it to give different shape.

So, these alloys generally have higher melting point and it is not favorable for casting. And another important point, which I wanted to talk is that this eutectoid reaction happens to be the most important reaction out of the 3. So, this has an important place we will see why because, this is the control of the eutectoid reaction is what gives you the control on the microstructure of a steel through various heat treatments. So, we will discuss that as we go along in this course. So, because of that it is not the full diagram which is of great interest to us, but the diagram close to this eutectoid reaction is what becomes important and that is why it is this part of the diagram which we will usually focus which is what I am showing you here, only the lower part near the eutectoid composition.

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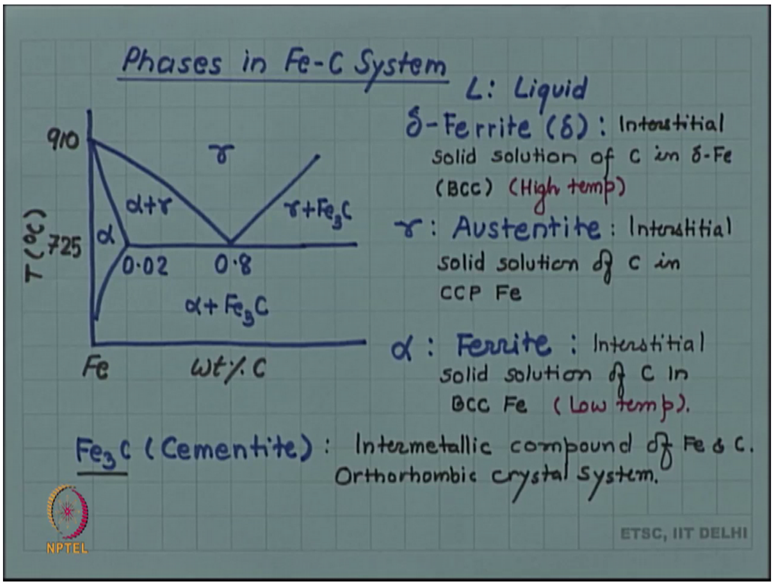

So, let us look at all these symbols and names again of various phases. So, you have at the highest temperature not shown here you have you have delta ferrite of course, before also you have liquid; liquid, then you have delta ferrite symbol is delta this is nothing, but interstitial solid solution of carbon in delta n and delta n is nothing, but BCC form of iron at high temperature.

You remember the look at the phase diagram. So, delta was in this region. So, it was a high temperature form and it was BCC. So, that is delta ferrite and it can have some carbon. So, that carbon goes into the interstitial solid solution, then you have gamma which is also known as austenite, this is also interstitial solid solution carbon in CCP iron cubic close packed iron.

So, the structure will be CCP this is called austenite, which you see in this part of the diagram, then you have you have alpha which is simply known as ferrite, this is in the lower part of the diagram here that is the region of alpha this is again interstitial called solution of carbon in BCC iron. So, both delta and alpha that is why both have the name ferrite, only the delta is known as delta ferrite the difference is that this is a high temperature region, this occurs in the low temperature region. So, let us point that out this is a high temperature version of ferrite, this is a low temperature version of ferrite, and then of course, you have Fe 3 C which we call cementite, you have to be familiar with all these both the symbols and the name. So, Fe 3 C called cementite.

This is this is an intermetallic compound, it is not a solid solution because it have occurs at fixed composition Fe 3 C. So, this is inter metallic compound of iron and carbon, it has an orthorhombic the crystal structure is complicated the crystal system is orthorhombic orthorhombic crystal system.

So, we have looked at the phases the invariant reactions and the various phase boundaries and phase regions in the iron carbon phase diagram. So, look that as a whole the diagram may look complicated, but just remember that there are 3 invariant reactions, the peritectic reaction, the eutectic reaction and, the eutectoid reaction and the names of different phases of course, you have to gradually commit them to memory. And then this region of the phase diagram the low temperature eutectoid region of the phase diagram is what is important and what we will focus in the forthcoming videos.