Welding Metallurgy
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Lecture - 04
Phase Diagram of Iron Carbon System

Welcome to the lecture on phase diagram of iron carbon system. So, we know that iron is one of the very important element and its alloys are mostly used, so they are one of the most widely used materials for engineering applications.

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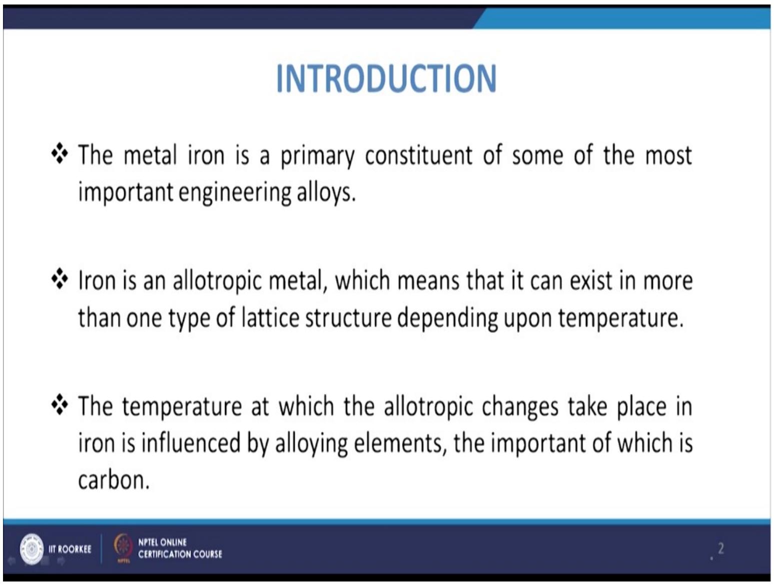

So, the metal iron is a primary constituent of some of the most important engineering alloys and when we take iron as the element, so on that basis we call it as a ferrous material. So, in that category it comes ferrous materials. Now, if you talk about the pure iron, so it is an allotropic material, so that I mean that means that it can exist in more than one type of lattice structure depending upon the temperature.

So, if you draw the cooling curve of iron, you will see that at different temperatures, you will have different you know type of lattice structure of iron and the different temperatures if you try to find the cooling curve for the iron, so that will be you know something at different temperature.

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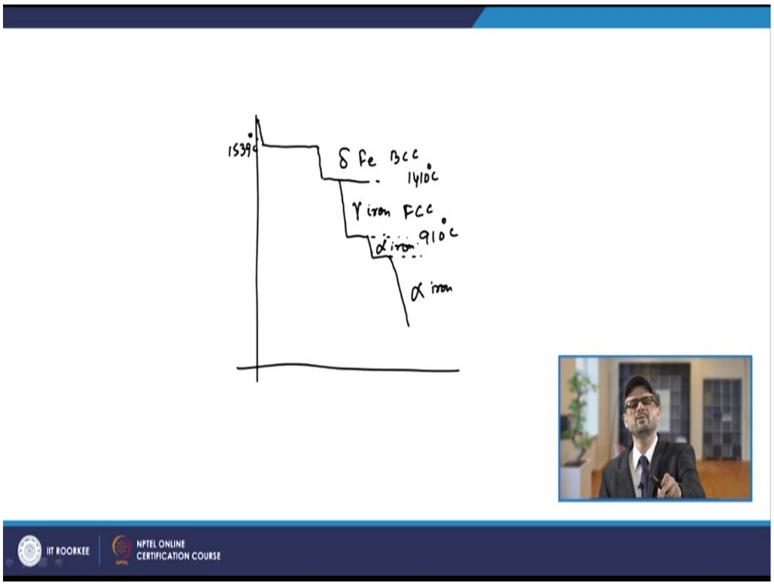

So, if you draw it initially you know we know that its melting temperature is pure; iron has melting temperature close to 1539 or 1540 °C. So, you know if you come to that you know so if you are coming from anywhere from higher temperature, then at this 1538 °C or 1539 °C, you will have you know the so the liquid will start crystallizing.

And then, you know it will up to so you know you have about 1410 °C, so what you get is in that you get, so in this case you are getting the delta type of iron, so that is known as delta Fe. Further when you are decreasing the temperature, so temperature will decrease and then further you are getting you know in between you are getting the γ iron, so now here so here you are getting you know γ iron.

So, we know that this γ iron has the FCC structure. This has the BCC structure, this has the FCC structure and then so this is of the order of, so this temperature is about 910 °C. Then, below that up to 768 °C you know so that in that case you are getting here that is your α iron so and then further also you are getting you know the α iron. So, both these are BCC, the only thing is that you know this α iron is magnetic and here it is non-magnetic.

Γ iron also becomes non-magnetic, so that way this is the cooling curve for the pure iron. Now, when we talk about the engineering alloys based on iron, in that case the carbon is considered to be the most important material because it is influencing the properties of the iron based you know alloy system you know most considerably. So, based on that you have you see the iron-carbon phase diagram.

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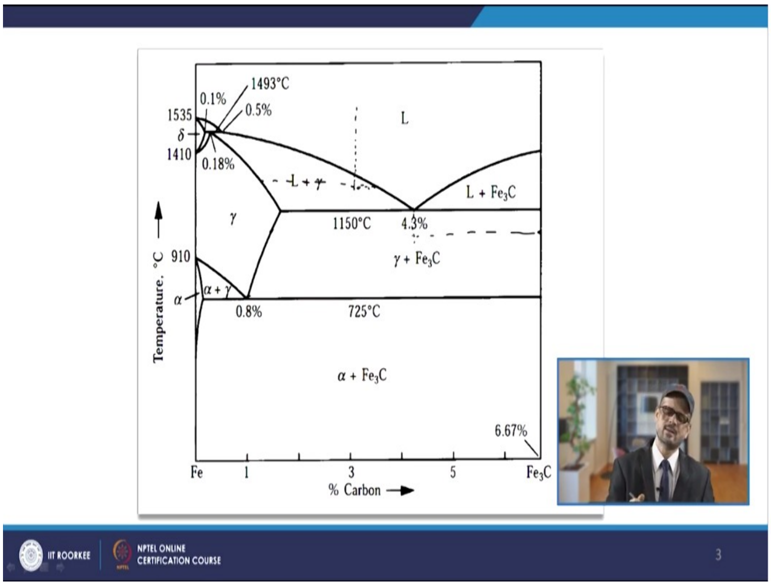

So that is why we need to understand the iron-carbon phase diagram and what happens that normally it is iron carbon or because with the percentage of carbon you know variation you are getting the different phases; however, you have one intermediate phase in between intermetallic phases there at 6.67% of carbon that is Fe_3C iron carbide or that is known as cementite. So, normally many a times, we also call it as iron cementite phase diagram.

Now, if you look at this you know diagram what you see that towards the left-hand side, so this is your carbon percentage which is increasing in this direction and now what you see that this is your 1535 or 1538 °C. So, here in between you have delta iron, then you have γ iron, then you have now the α iron. So, ultimately when you start alloying this iron with carbon, in that case you can see that the solubility of carbon is somewhat limited.

If you take the solubility of carbon at the room temperature, it is very small 0.002%; however, as we increase the temperature and so with that the solubility of carbon will be changing and that will also be you know different for the different types of you know allotropic form of carbon. So, suppose this is the γ iron, so here you can have the maximum solubility and here close to the order of 2% at this temperature.

Now, if you look at this iron-carbon diagram, you see many kind of invariant reactions here. You have first invariant reaction if you look in the lower temperature range, now you see that this is one line. Now, in this case, what you see that this is your α phase and this is your Fe_3C. So, again what we have studied in the phase diagram, using the phase diagram when there will be phase transformation taking place.

So, you can find out when there will be crystallization going on and there will be solid phase coming out of the liquid one. So, by the help of tie-line rule or with the help of lever rule either you can find the composition of the phases or you can also know the amount of phase that is formed. So, this is your eutectoid point, in the eutectoid point what you see that this γ which is of about 0.8% carbon.

Now, this is while cooling, it will convert to one side is this α and another side is the Fe_3C that is cementite. So, this eutectoid reaction will give you and in fact at this composition, the transformation which occurs. Now, in this case, the α and Fe_3C which you get they are in the alternate lamina. So, there will be layers and that alternate layers of α and Fe_3C together we call it as the pearlite.

So, basically the austenite will convert to pearlite and this is known as the eutectoid reaction. Now, if you come to the point left to this point then it will be the pro-eutectoid you know so the point this side and this will be hyper-eutectoid on this side. So, any you know so first of all when we combine the iron with carbon and that two up to suppose say 2%, so below 2% we call it as the steel or carbon steel.

So, in that basically you have no carbon steel or medium carbon steel or high carbon steel. So, it will go maximum to 1.5% to 2%, so that maybe for you know steel. Once the carbon percentage moves from here onwards, then we call it as you know cast iron. So, you know cast iron is the one where basically either you can have the graphite as you know, so graphite will be there in the form.

So, carbon will be there in the form of graphite or you may have also Fe_3C that we will discuss later. Now, so you will have hypoeutectoid steels. If you have steel of carbon less than 0.8%, then it will be hypoeutectoid steel and if it is more than 0.8%, then it will be hypereutectoid steels. Now, what you see that this zone is α and this adjacent zone will be α+γ and this is your lower critical temperature, upper critical temperature.

So, these are the critical temperatures they are known as and you have this is the α+γ, this is known as inter critical you know temperature zone and this will be your γ that is austenite that is FCC you know iron. Then, this is one of the environment reaction and that reaction is nothing but the eutectoid reaction. So, γ will be changing to α+Fe_3C on cooling.

Now, when there will be any composition of any percentage, so if it is of you know eutectoid composition, then γ will come up to this point and after that you know there will be ferrite as well as the cementite coming out. So, after you know transformation, you will get the ferrite and cementite. If you come to any composition lesser than or towards the left-hand side of this point that is your eutectoid point.

So, when it will the temperature will reach you know below this, so you will have formation of α and that will be you know of this composition and then formation of γ, so that will be according to this. So, that will go and from here again you will have α and γ so this γ which is remaining that will be again transforming to pearlite. So, you will have ferrite+pearlite.

Similarly, when you go to this side, you will have pearlite+cementite. So, for hypoeutectoid steels, you will have some pro-eutectoid ferrite also formed because the ferrite which is formed before this, so that is known as proeutectoid ferrite and you can also find the amount of pearlite, amount of ferrite which will be there in this composition that is in pearlite.

So, based on the lever rules, you can find you know amount of ferrite which is there in the pearlite. So, basically if you go to for any you know such composition, you will have proeutectoid ferrite as well as the ferrite corresponding to the eutectoid reaction. So, altogether you can find the total amount of ferrite. So, that is how these you know phase diagram is made use of to find the different type of phases which are formed.

And what will be, you know mass fraction or what will be the amount of proeutectoid ferrite or ferrite formed or pearlite formed or so. Another reaction which we see in this case is after this temperature you see one temperature that is 1150 °C. Now, in this case what you see is that there is this point where the liquid basically above this point immediately you will have this is a liquid zone.

And once the temperature comes below this, you will have the mixture of two solid phases that is one is γ, another is Fe_3C. So, this reaction in which one liquid you know liquid is converted to two solid phases, that is basically known as the eutectic type of reaction and this is the eutectic point. So, this 1140 or 1147 °C or sometimes you will also get 1137 also at many places you will find it.

So, this point is the eutectic point and on this you are getting the mixture of $\gamma+Fe_3C$. As discussed that even temperature comes below this, then as the temperature comes below this, you will have on this side this line is touching to this point that is γ and on this side you are touching this line to this is Fe_3C. So, you will have γ of this composition and Fe_3C of this composition and that is a straight line, so anyway there is no problem.

However, the amount of γ and Fe_3C will certainly be according to the lever rule and the amount of γ which is formed will be this upon this there is a fraction and amount of Fe_3C formed will be based on this distance divided by the whole distance. So, that way you are getting you know $\gamma+Fe_3C$ coming out. Now, when you come to this point slowly, so once you reach to this point you know that you will have γ of this composition.

Now, again after that this γ will convert to pearlite, so you will have ferrite+cementite whereas this is basically the cementite itself inter metallic phase it is, so you will have the austenite further being transformed. So, this reaction is known as the eutectic reaction. If you take any point you know left to this, it will be the proeutectic point and if you take any point right to this it will be I mean hypereutectic point.

So, hypereutectic and this is hypereutectic. Now, as you see that if you are coming to any composition at this point, so as you know when you come to any temperature below this, so you will have γ, γ will be of this composition and you will have liquid of this composition because this is touching that liquidus line here and as we see as per the lever rule, the liquid percentage will be as per the fraction of this by whole.

And the γ percentage will be by this by whole, so this way you will have liquid you know and ultimately this liquid will have, at this point liquid will have the composition of 4.3% and then this liquid will convert to you know the $\gamma+Fe_3C$ that is also known as ledeburite, so you will get that and before that you will have the proeutectic, you will have you know austenite which is formed and that will be coming up.

Now, this what you see is this is normally the result of the equilibrium type of cooling when the cooling is very slow, otherwise what you see and you can see that normally in the case of actual cooling practice when the cooling rate is high, you will have basically the concept of coating developed that we will discuss later because there will be change of the concentration of the constituent.

Because as it is being solidified with time, so there will be changing the concentration as we see. Now, what we see is that we have understood that in this case when we take the carbon more than 2% normally we call it as a variety of cast iron. Now, this cast iron is in the case of cast iron basically the carbon which we see normally is in the form of graphite. So, what happens that when you are cooling in a slow manner, graphite is stable structure basically.

So, you are getting graphite and Fe_3C is metastable, so basically when your cooling rate is high, you will get Fe_3C and when your cooling rate is small you will get graphite and when your cooling rate is small, in that case you are likely to get you know the graphite and in normal case when you have a good amount of silicon and also the cooling rate is very small in that case the graphitization is promoted, so you will have graphite.

And you will get the you know graphite, the type of gray your cast iron that is known as gray cast iron because if the solid surface appears gray, so that will be gray cast iron.

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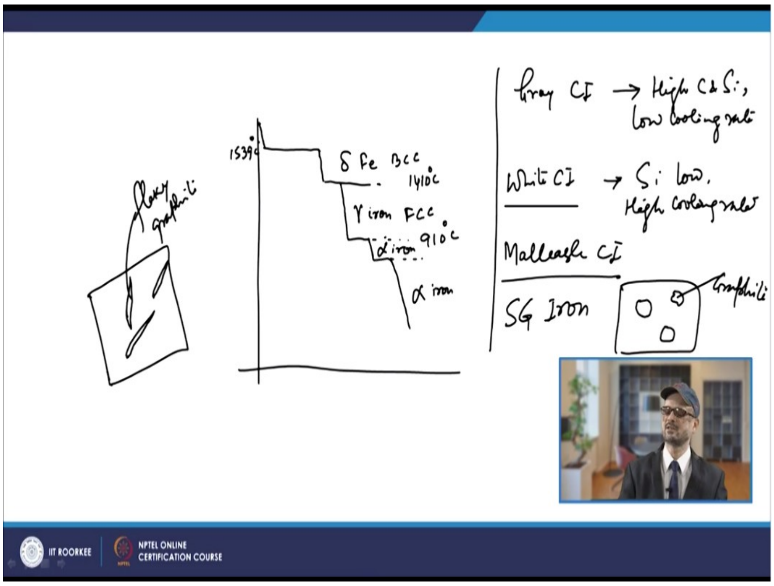

So, when if you talk about the varieties of cast iron, you will have gray cast iron, when you have you know high amount of carbon and silicon and also low cooling rate, so in that case you get the gray cast iron and gray cast iron is characterized by the presence of graphite flakes. So, you will have you know the flaky graphite you know a structure in the case of gray cast iron.

And you have you know iron matrix and the carbon is in the form of graphite. Now, if you increase the cooling rate, so if your you know silicon percentage is less and high cooling rate is there, so in that case you are likely to get basically white cast iron. So, if the cooling rate is higher in those cases you are likely to get the Fe_3C as you know that is known as combined form. So, you will be getting you know carbon in the form of carbide.

So, that is your white cast iron, it is extremely hard and normally not very much used for engineering applications except for some cases where you need extremely high hardness like in the case of rollers or so. Then, you know there are other varieties also, we take into account other factors like we use you know you can further use this white cast iron by further undergoing the heat treatment of this white cast iron.

And that gives you malleable iron because that Fe_3C will decompose into free carbon. So, then in that case you will have small you know globules of carbon as graphite, so that carbide will decompose that is known as malleable cast iron. Then, also you know we also use spheroidal graphite cast iron that is known as spheroidal graphite iron SG iron. So, in this case normally what we do is for the same composition if you use the magnesium you know or C as you know as it is added into the melt.

So, that basically will convert this flaky graphite into the round ones. So, you get the globules of you know graphite and spherical globules that is you know that is known as spheroidal graphite cast iron. So, basically if you look at the so you can make it out that how, at which composition, how much of γ will be there, how much of Fe_3C will be there. Then, further if you come down, so the γ will again further change to α+Fe_3C.

And this side you will have Fe_3C, so you can have the idea of the different phases formed. Coming further to the higher temperature zone, you can see one constant temperature line, this is there is another invariant reaction taking place here, what you see is that you will have this zone, this zone is the liquid+delta zone and at this point, the liquid+delta is giving you the formation of the γ phase.

Now, this is another invariant reaction that is peritectic reaction which is you know happening here at this point and in this case the liquid+delta is giving you the γ. So, one liquid+one solid phase is giving you another solid phase and that is your peritectic reaction. So, what you see that in this iron-carbon diagram, you will have different type of invariant reactions taking place.

So, these are the 3 types of invariant reactions which we are seeing in this iron-carbon phase diagram and as discussed that depending upon the carbon percentage, you will have uses in a different manner to the steel.

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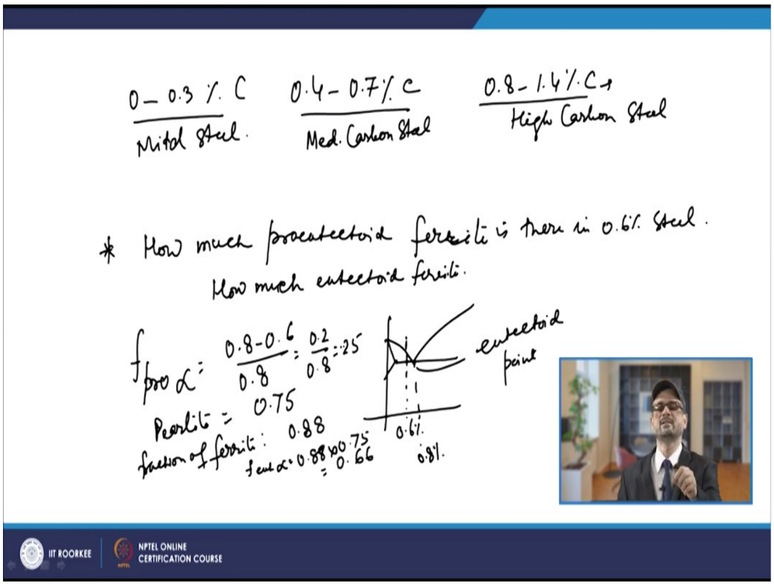

So when you come to the carbon percentage of suppose say 0 to 0.3%, so it is normally the mild steel it is known as and in this case depending upon 0 to 0.1, 0.1 to 0.2 or 0.2 to 0.3, so they are normally known as the mild carbon steel and you can use for you know for chain links or you know nails, rivets because here the ductility must be very high. Carbon percentage is less, so you will have quite good ductility, so for them it is used.

Then, if it is going from 0.4 to 0.7% of carbon, so that is known as the medium carbon steel and it will have better hardness than the you know low carbon steel or mild steel also and its use will be normally in the axles or you can have wheel rails, so there it is normally used and when you go from 0.8 to 1.4%, so this is known as you know high carbon steels and their uses where you require higher hardness.

So, you can use for the cutters, hammers, you know blades and scissors, knives all these are the components where you use them. Similarly, as we have already discussed that for the variety of cast iron, you know we use this gray cast iron where we require the damping properties. So, most of the machine beds you know there we use the gray cast iron because in that case you have the cushioning effect which is given by the graphite which is the soft phase.

And if you have to have the ductility because when you go to the white cast iron, it cannot be otherwise used but when you malleablize it, when you give the annealing treatment to it, then you can use it for automobile components because it develops good ductility malleability, so that is used and in case of SG iron which is found only in the cast form, it has good combination of strength as well as ductility in those cases.

Now, if you take the example of the you know rules like you have a tie-line rule or lever rule, now if you try to see that if you are asked that how much you know proeutectoid ferrite, so suppose you are asked how much proeutectoid ferrite you know in 0.6% you know carbon steel, so is there in 0.6% you know steel, that is slowly cooled. So, you know and also how much will be eutectoid ferrite.

And similarly, how much will be eutectoid ferrite, so as you know that you will have so you will draw the iron-carbon phase diagram and you know that this is how the reaction is for the eutectoid reaction, this is your eutectoid point and here we know that you know this point on this side, so if you go to this point, so this point is basically you can take it as negligible, you have 0.8 here.

Now, what you see is if you want to find the proeutectoid ferrite, so proeutectoid ferrite now if you look at here this is 0.8 and you are talking about this composition that is your 0.6% carbon, now what you see is that you will have ferrite of composition according to this, this line but ferrite you know volume which is formed or amount which is formed will be based on this line above up on that line.

So, this is your 0.8 and this is you know 0.6, so the amount of proeutectoid ferrite, it will be $0.8-0.6$, so it will be $\frac{0.8-0.6}{0.8}$, so you are taking this is very small value, so you are taking that 0.8. So, it will be 0.2/0.8 and it is 0.25 so 25% will be the proeutectoid ferrite that is formed. So, apart from that after this, so the ferrite which is formed before this point, it will be proeutectoid ferrite.

Now, at this point, you will have the formation of pearlite. So, you will have rest as perlite. So, pearlite will be 75% that is 0.75. Now, you are also getting the eutectoid ferrite, now you can get this amount of you know eutectoid ferrite from this point itself because you have ferrite here and you have cementite here. So, based on that you can get the amount of eutectoid ferrite.

So, if you try to find the amount of ferrite which is formed according to this you know reaction, it will be basically $\frac{6.67-0.8}{6.67}$, so that will be basically the percentage of ferrite which is formed. So, if you talk about that fraction of ferrite you know at the eutectoid you know point it is normally $6.67-0.8$ that is $\frac{5.87}{6.67}$. So, if you take its ratio, it is normally 0.88. So, you know if you look at the again ferrite which is formed that is eutectoid ferrite, it will be 88% of 0.75.

So, it will be you know eutectoid ferrite; eutectoid ferrite will be 0.88×0.75 so it will be 0.66. So, according to this you know in this way you are trying to find, so this will be eutectoid ferrite and one will be proeutectoid ferrite. So, accordingly you can have you can see that this will be plus, so you will have the total ferrite which is formed.

So, similar you know type of methods can be used for finding the different amount of you know different phases formed if you come to this point or at any point you can use these rules to find the different phases formed and also you know that will also help you that when it comes to so basically these are the you know lines which talk about the reactions which are to occur after these points or after these points or after this point.

So, you know a proper understanding of these things is required so that when we talk about you know the other aspects you know in our course, then it will be useful and we can have more and more better understanding of all these concepts. Thank you very much.