Phase Diagrams in Material Science Engineering.
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Lecture – 40
Alloyed Cast Iron

So, students today we are going to complete our discussion on the cast iron, and that will bring to the end of this open discussion on the iron carbon phase diagrams. We will come back to it, or while we will discuss about high speed steels and stainless steels.

So, in the last lecture of cast iron, I am going to talk about alloyed cast iron, so to give you a perspective of this. You know cast iron is in ternary alloy by the way, it consisting of iron carbon and silicon. So, iron is the parent element, carbon and silicons are the alloying elements. Well when you need talk about alloyed cast iron, we do not discuss about the addition of carbon and silicon. We discuss about addition of other alloying elements, and effects of those alloying elements are the microstructure and properties; that you must remember. Anyway, so let me just give a recapitulation what I have done, and try to verify some points on the cast iron point of view.

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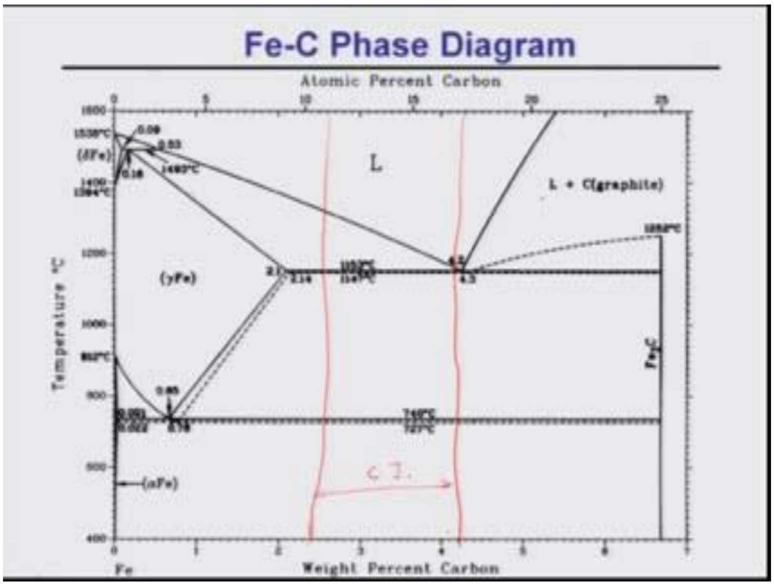

First of all cast irons are alloys of iron carbon and silicon, with a carbon concentration varying from 2.5 percent weight percent to about 4.2 percentage or 4.3 percentage. So, there are mostly hypereutectic alloys of iron and carbon. And you know there are very, mostly four varieties of cast iron we discussed; first one is the white iron, in which the carbon is present as a carbide or f e three c, I will rise star like gray iron s g iron or nodular iron, and malleable iron, where basically consisting of iron phases with graphite.

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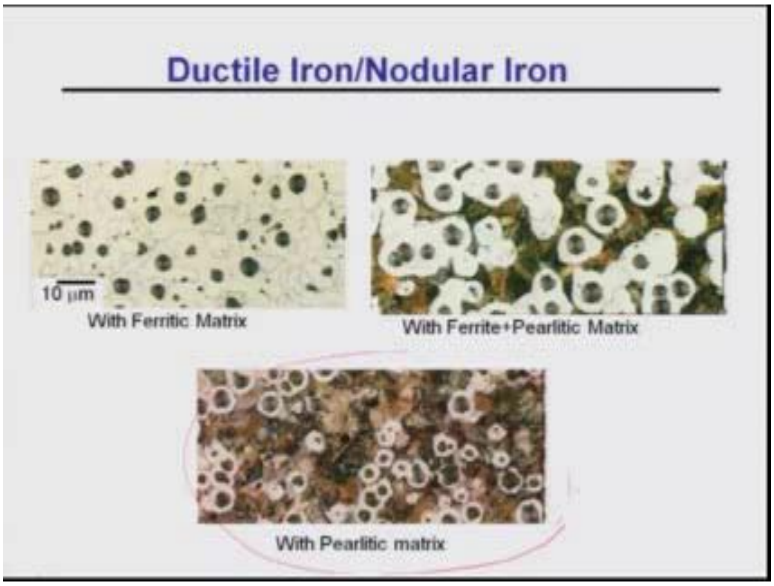

So, to give an idea, this is what I showed in the last class also. You see here this is the nodular iron, where the graphite is comes as a say nodule, or a kind of a structure view which looks like a thrashed roof; not a strayer, that I made you very clearly understood in the last class, and you kind of different matrices; this is the ferritic matrix, this is the ferrite plus pearlitic matrix, and this is the pearlitic matrix. What the meaning of ferrite pearlitic matrix.

Well as you know every graphite will be surrounded by ferrite; that is because of the carbon taken by the graphite therefore, nearby region. So, for that there will be ferrite and this is what is known as bulls eye structure in the ductile iron or nodular iron, but if that fraction of ferrite is substantially large, then we have to call ferrite plus pearlitic matrix, but if that fraction of ferrite is small as you seen in this picture here, then it is called pearlitic matrix. You can now also have martensitic matrix as I told you, it depends on their uses.

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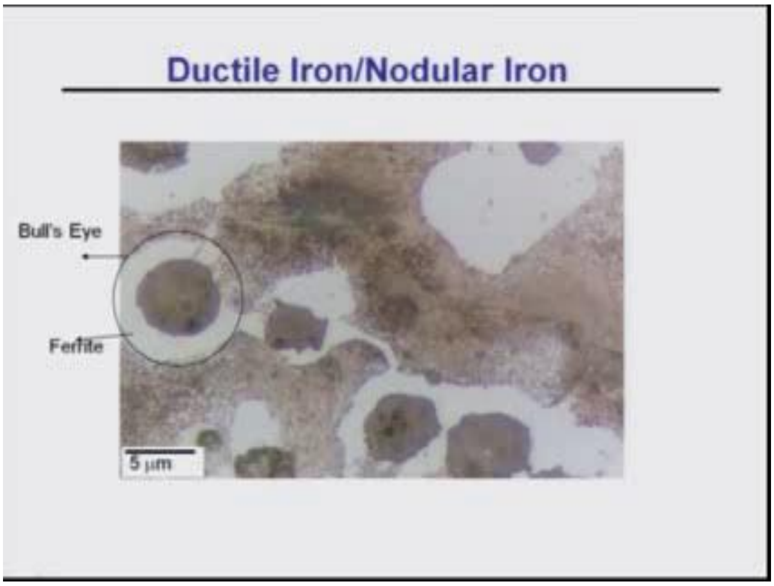

Well if you look at for the pearlitic matrix; this is what I told you very interesting things you have at graphite, and then you have ferrite surrounded by the graphite, and eye from the graphite will have pearlites. So, this structure is known as bulls' eye, because it looks like a eye of bull that is why. There are many discussions why does it happen, but the physically this is mainly, because of the carbon concentration, getting depleted in the region near the graphite that is why it is.

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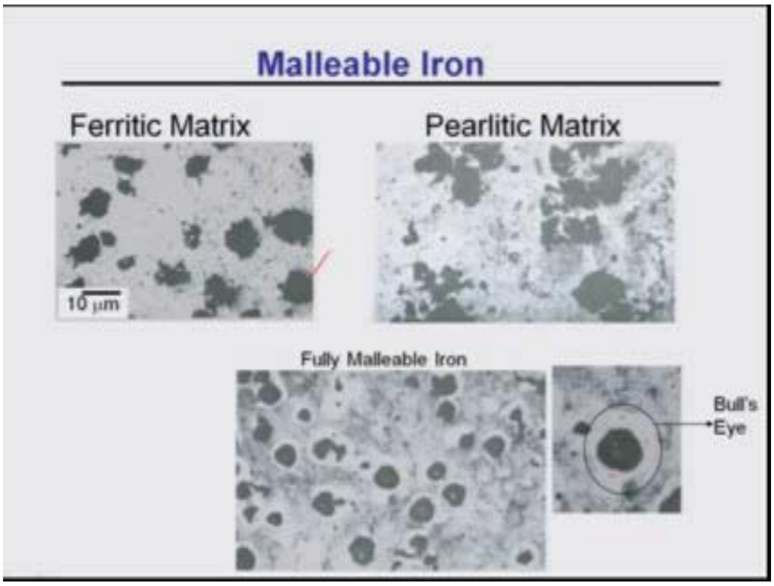

Now, you also have a malleable iron I discussed with you. Malleable iron can have ferritic matrix; that is what I showed. I could not show you pearlitic matrix in the last class. So, this time I got an image with a pearlitic you can see. And you know as you as you look at it these differences in the ferritic and pearlitic matrix probably well seeing same; well no. there are some residual contrast here you see and if you zoom in with optical microscope or scanning electromicroscope you can see that.

You can also create martensitic matrix depending on the requirement, as told you in the last class also by quenching this steel from high temperature. Now, in fully malleable iron also you can have bull's eye structure; that is seen. So; that means, bull's eye structure is not peculiar to the nodular iron. It can be also formed in malleable iron; that is you see here this is the bulls eye, around these surrounding these graphite, but this graphite here as not a nodule, but they are deformed or not deformed they are actually basically called tempered graphite, or they form in solid state unlike in the nodular iron.

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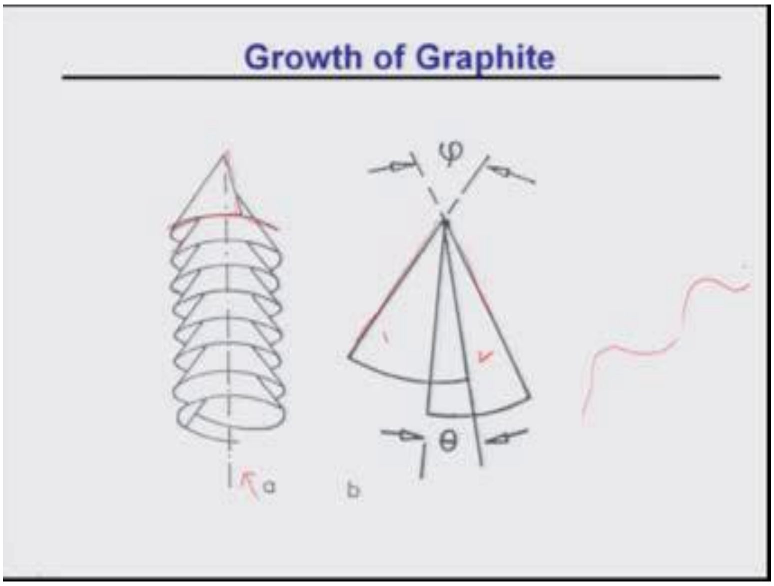

Well this slide which I could not show in the last class also very important. This is how I actually graphite grows. See you known in this nodular iron the structure of graphite is exactly like this of a left side what is shown as a. this is taken from the book of professor S P Gupta. Now, what actually happens is that, this is the needle, this is the fleck which is rotated and form such a cone like structure by this way, and each cone is attached over each other is just like that. It is like a umbrella stack of umbrella above each other, but they are little displaced that is what is show here.

You see here the displacement, is the way two cones are arranged in such that there is a excess of the two cones varies by angle of theta, and also the this top angle, is which extended by these two sides are also you know it makes, between the two ends of this cone one end is bottom end one end of the first cone is this is the first and second cone. So, one end of the first cone to the other end of this second cone they makes an angle of sine, these are the two characteristic features, and this can be varied actually, depending on the growth mechanism it can be varied.

So, this is actually the graphite nodules forms in the thing. By the way in the in the grey iron this thing is opened. So, what you get is this kind of structure, or cabbage like structure and, but in a nodular iron what you get is basically here; stack of cones attached to each other that is what is the growth the more of graphite in a nodular iron, and this is possible only when we add magnesium serum (Refer Time: 06:31) metal, and thereby removing this sulphur from the melt, because sulphur actually possions the growth of graphite. So, by the process of removing sulphur, you can allow the graphite to, you know follow is normal growth mechanism, and then you can get this kind of structures. Well that is how would we recapitulation of the cast iron, what I told you. Now I am going to discuss for the next you know twenty minutes or so about the alloy cast irons.

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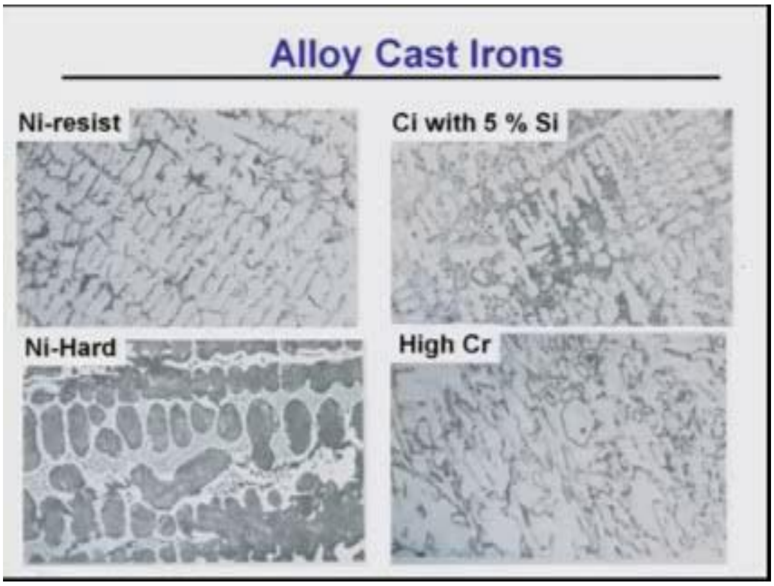

And as I told you alloy cast iron means alloying elements, other than these iron carbon and silicon present, any way silicon can also be added as alloying element when its concentration is more than two percentage. So, basically these alloying elements are added for special purpose. Mostly, to modify the micro structure, and to arrive at very distinct properties, which the normal cast iron cannot provide, what are the alloying elements we add? There are actually five alloying elements normally added; most important ones are chromium, nickel, silicon.

Silicon is; obviously, present, but more concentration of silicon like five percent 10 percent of silicon and then you has moli and aluminum, they can be added. first of all what is the purpose of adding as I told you, to modify the microstructural properties

.what are the properties we will modify.

First thing we need to we need to add this alloying elements to get good high temperature of strength; nickel and chromium does that by forming carbides, and you can also give nickel actually can improves the (Refer Time: 08:11) cast and resistance, can be improved by cast iron resistance again acidic media can be done by adding silicon, more quantity. And chromium can be added to form all kinds of carbides, you know the chromium actually reacts with carbon and form different kinds of carbides; like iron, iron also form a p three c a p 2.0 c a p 2.6 c. Similarly chromium can form different carbides, and these carbides are very hard. So, by forming these carbides, we can actually improve the wire resistance of the cast iron, because cast irons are used for variety of applications.

So, we will see now there are two types of a microstructure we can get, basically; one is graphite fe just like a white iron, you do not have graphite at all you have carbide mostly, other one is graphite. Third one is more demanding in the industry is the mixture of these two. In fact, that is the main reason we add alloying elements in to cast iron; that is the main purpose, because you see in white iron get all only iron 3 c fe 3 c as a carbide and very hard and (Refer Time : 09:25) here. On the other in grey and in nodular iron and malleable iron you get mostly graphite.

So, if you want to have a mixture all the pearlite as the matrix can have a carbide present, but I am not talking about it that if you want to have a mixture of both graphite in the carbide in the micro structure primarily formed, then you would like to add this alloying elements, and carbides being very hard phase it provide you the wire resistance, high temperature strength even many other properties. Well, so, we will discuss about three elements; first one is chromium. Chromium is as I told you added, it can be added from two percentage to about ten percentage weight percentage in the cast iron, and what is the chromium do. you know if it is a chromium is added about 2 to 2.5 percent chromium, then actually it leads to formation of two important things; chromium addition will lead to formation of your a carbide. There are two types of carbide forms, if chromium is above 2 to 2.5 weight percent in cast iron.

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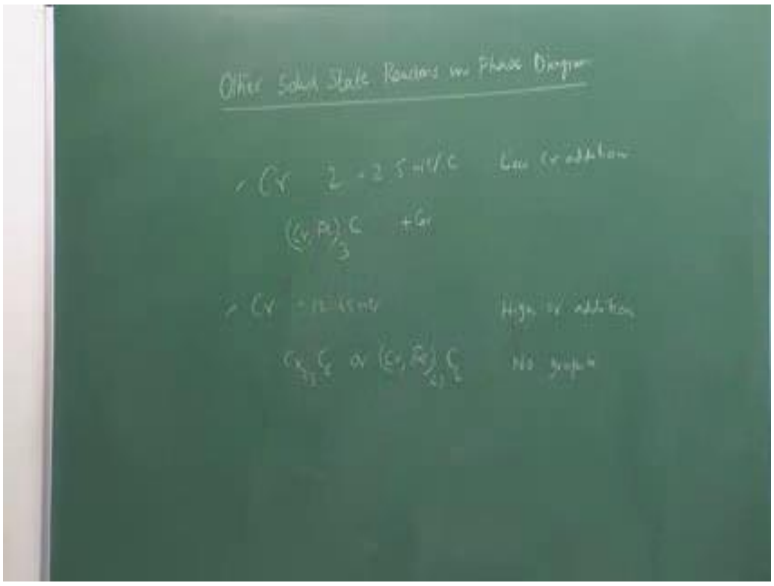

This carbide is most providently formed. This is again iron carbide f e three c, but some amount of iron atoms as to modify as replace by the chromium atoms. This is what happens in a low chromium addition, but if the chromium addition is more, whether if you have a high chromium addition, high chromium addition, then what will happen. Then chromium will form other carbides, like when chromium is from 12 to 35 weight percent, huge amount of chromium is added. Then instead of this carbide some time you know these carbides also forms, or c 6.

This is the carbide which is normally found in the stainless sensitized stainless steel which we will discuss with stainless steel, but this is what people find in any books like professor Raghavan's books also you will find this. So, if I have a large amount of chromium addition, then this is what is going to happen. So, depending on and this carbide is very hard. In fact, very hard as compared to this, therefore, if you add more chromium, you will mostly find carbides; that is another problem. suppose in this case if we add a very low amount of chromium, you will probably get some amount of f e three c or c r f e three c plus graphite, but here when the chromium is very large there will be no graphite, why, because carbon as a. So, large affinity towards chromium then you will bind to chromium only, when chromium is plenty of chromium is available.

So, because of that large concentration of chromium carbide will bind very easily, carbon will bind basically with chromium and form carbides, and that is why actually if you want have a high chromium cast iron then you will never get into graphite, you will only get carbide. So, this is like a white iron. So, but you know these carbide is not as then that as this carbide, this can be used in the really like industrial practice. Well that is what you see in this micro structure when you have high chromium I have written, high chromium as you see here. you have lots of lots of these a c r 3 6 c r 23 c 6 or c r iron 23 c 6 carbide is present. This is the most important difference when you have a large amount of chromium present.

So, the matrix will be; obviously, gamma, because eutectic reaction, if you have a high chromium will be between gamma and carbide, it will not be between liquid going to gamma plus graphite, this will not happen. Only thing will form is gamma plus f e 3 c and some amount of other carbides like c r 23 c c c 6 will form. So, that is the actually the effect of chromium if you, add large amount of chromium this is going to happen. Small amount of chromium you will form carbides which is f e three c type plus some graphite may be present. . So, now, we will let us move on to the effect of nickel. So, what the nickel does. Nickel as you know its fcc structure.

So, this will stabilize the gamma, more compare to the chromium as we just bcc crystal structure. So, nickel addition stabilizes arsenide and. In fact, nickel addition promotes the graphite formation. So, that is one effect of the nickel addition, first and for most effect. What is the second effect of nickel addition? The temperature gap, as you see in the phase diagram between iron and graphite, iron and graphite if you put them together, the temperature gap or let me show you again otherwise you will forget, temperature gap between these two eutectic eleven fifty three eleven forty seven increases as you add nickel.

So; that means, what nickel addition will make the graphitzation easier, because the temperature gap. The high temperature one is eutectic of between liquid going to gamma plus graphite. low temperature one is basically gamma liquid going to the gamma plus cementite, but the difference between these two if it is increased, then predominately the graphite and gamma as eutectic phase will perform the liquid; that is why the nickel actually is normally thought to promote, the graphite formations, graphitization. Not only does that have important issue aspect of nickel. So, first thing I told you the nickel addition leads to stabilization of austenite and graphite.

Second I told you that, this is mainly because of the gap of temperature of eutectic reactions will increase. Third important aspect of nickel addition is that, its shifts the nose of the t t curve. Please go back to t t discussion nose of the t t of the right side so; that means, nickel addition will help formation of austenite a formation of martensite very easily why. So, martensite actually can be formed in the air cooling, because of the shifted nose of nose of t t curves it to right side. So, these are thing things now depended on nickel addition, you can have either nickel resist or nickel hard; two types cast iron as you see here nickel resist and nickel hard.

What is nickel hard iron let us first discuss, or let us first nickel resist that is better. Nickel resist will have a large amount of nickel present about fifteen to thirty percent nickel, and very low concentration of chromium, may be one to two percentage. So, difficulties of these what will happen. The micro structure will have nickel resist, will have basically graphite plus graphite flux and gamma iron.

So, these are the graphite flux you see, these are the graphite flux present, graphite flux plus gamma iron, along with because there are small amount chromium is present some carbide will form; that is what I was telling in the beginning. Basically modifying this you know purpose of alloy cast iron is to modify the micro structure you want both, this flake graphite plus carbide present in the same micro structure, along with austenite. And here you see the nickel is added so much the austenite is stable at room temperature. Austenite even did not any undergo pearlitic transformation reaction correct; that is the basic kind idea of nickel addition.

So, if you have a high nickel content, and this is what is true in stainless steel also you may have high nickel content, the gamma will be stabilized to room temperature even it will, there will be no pearlitic reaction; that is what you see this white regions are gamma and this flux of graphite and these small particles, these particles, these particles are actually what they are carbides, they are mostly carbides of f e three c type. So, this is the micro structure which you can get,, and this is not a nickel resist why it is known as nickel resist thus because resist oxidation. Why resist oxidation there are two reasons; one it is carbide and gamma iron present, second one is that you know this flux of graphite is (Refer Time: 18:05) distributed that is why the oxidation resistance is high. The second category of micro structure is known as nickel hard.

What is nickel hard? Nickel hard will have very low concentration of nickel, not say very low concentration, it is about four percentage four weight percent of nickel, but chromium percentage will be little higher, it can go up to eight percentage chromium and then you have large amount of chromium what will happen. It will lead to formation of cementite that is what you see here. You have gamma and cementite; these are the cementite f e three c. All these are cementites, and these is these eutectic between gamma and cementite eutectic. So, you form white iron like microstructure. You do not have any graphite present, and this is very hard, that is why you can nickel hard.

So, what is the purpose adding the nickel or chromium. Purpose is that you form alloy carbides, not only form these f e three c, but also you form this small particles you see here these are actually c r twenty three c six carbides that is the basically idea. So, by changing this nickel and iron concentration, one can actually form fantastic micro structures. So, I will just go back go to the phase diagrams of those two binaries.

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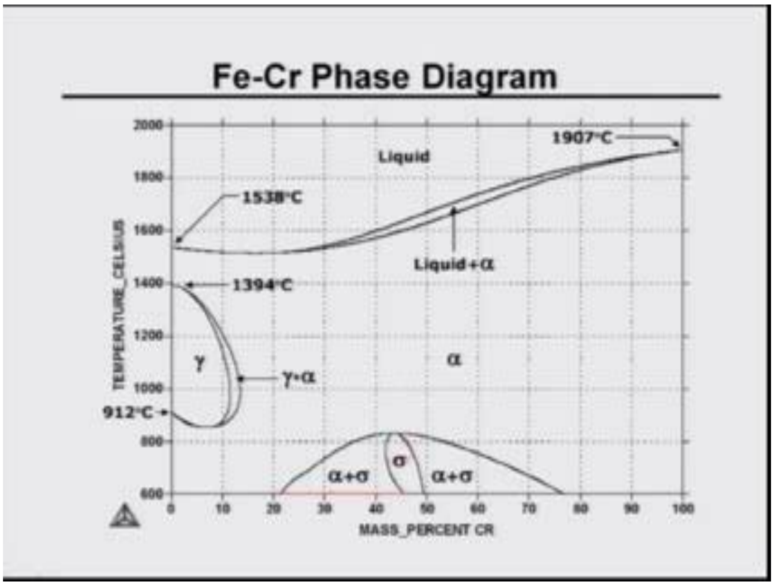

Let us look at iron chromium phase diagram, what will happen to chromium. As you see here if I add chromium, gamma forms a loop small loop command is stabilized only up to ten percentage of chromium. When you have more than ten or fifteen percentage of chromium the alpha r phase is stabilized. So, the chromium is basically alpha stabilizer or alpha un-stabilizer, and not only that in some cases. In fact, this alpha is not stable at room temperature.

You can undergo, you can form even a high chromium concentration, you can form a sigma phase sigma as a tetragonal structure, and it is also very hard. So, if you can precipitate sigma in the micro structure you can again increase the hardness. So, that is why we use this kind of phase diagram data to modify the micro structure. Normally to form sigma unit about 30 percentage 20 25 to 30 percentage of chromium, that only happens when you have a large amount of chromium present in the micro structure. Now what is happened if you add nickel, yes?

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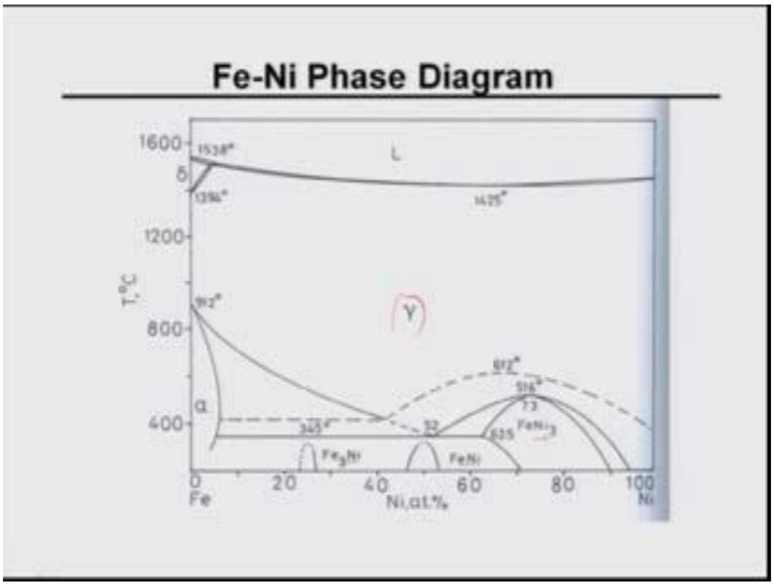

You see these thing changes. Here alpha forms a loop, and most where region is occupied by gamma; that is why a nickel additions basically stabilizes gamma iron, and that is understandable when nickel has a fcc structure lattice parameter is also not very different from fcc iron,, or gamma iron and therefore, that is why it actually forms, but in addition to that there are other phases which can form f e n I f e 3 n I fe n I 3, but anyway those phases can be bypassed by past cooling, and stabilizing this gamma iron is also possible. So, this is what is very important. Now I am not bringing the ternary phase diagram of iron nickel chromium which is the obvious thing for discussions are like this, because I am not here to give you give you, any idea about ternary phase diagram. So, when you discuss about ternary phase diagrams these concepts will borrow this and discuss further. So, that is the idea about addition of chromium and nickel.

Now we can also add silicon. In the last few minutes I am going to tell you what will happen if I add silicon. Silicon is normally present in cast iron, about 1.5 to 2 percent silicon weight percent silicon is present, but I am not talking about that whenever five percentage of silicon is added, cast iron with that c I which five percent of silicon what will happen. You know silicon actually promotes you know that promotes graphitization, it form graphites more graphites it does not allow formation of carbide. So, it will have more tendencies to form gamma plus graphite as eutectic phase that is what you see here.

These are the graphites graphite nodules, and this is these are the gamma. Not only that you know silicon and this this gamma can be stabilized, because here in this particular things nickel is also added quite a lot that is why gamma is stabilized.

So, you have gamma plus graphite flux present in this micro structure, but silicon addition helps you one thing. Silicon actually forms of the sample or the component forms a iron silicon f e s I o three, or f e s I o four type of structure. and these iron silicon actually protects these sample from high temperature oxidation; that is one of the reason most important reason probably to add silicon into the alloy cast irons, and the basically it improves the oxidation resistance of high temperature.

So, therefore, and I am not discussing well, we can also discuss moli I can tell you that, it is acyually moli. Actually moli basically what does it do moli from process will also carbides molecular carbides are presents, and not only that another idea of addition moling is to make solid solution strengthening of the gamma or alpha phases, that can also add strength to it, but they are addition of moli is, aluminum is normally not much its about 0.5 to 1 percentage of this alloy condition is done.

So, with this as you have understood that we can modify the micro structure using the phase diagram informations available, by adding this different alloying elements like nickel, chromium, silicon, moli, aluminum and idea is to improve their mechanical physical properties, by changing the micro structure, and I told you how we can modified the micro structure. What are the properties we can be improved, and how we can basically get those properties, what are the phases which are involved? So, now you should go back to the book and study those things carefully, and try to understand they are you know implications, if you want to really know, because in this course I cannot discuss about the different phase formation and microstructure formation in detail, but most of the information about these is available in the books.

So, that is all about the cast iron. In the next class I am going to discuss about the other solid state reaction, where two important solid state reactions we need to discuss; one is the peritectoid reaction, other one is monotectoid reaction. And this third lecture will be little shorter, because those reactions are not so widely seen in the phase diagrams, but they do appear in some of the phase diagrams. So, if you are working on those alloy systems, you should have some idea how this things happens; obviously, peritectoid reaction is an (Refer Time: 25:06) of peritectic reactions, similarly for monotectoid reactions. So, we will bring those discussions into this.

Thank you