Phase Equilibria in Materials (Nature and Properties of Materials-II)
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Lecture - 29
Fe-C Phase Diagram (contd.)

So, welcome again. We begin with this lecture number 29 of this phase equilibria course again.

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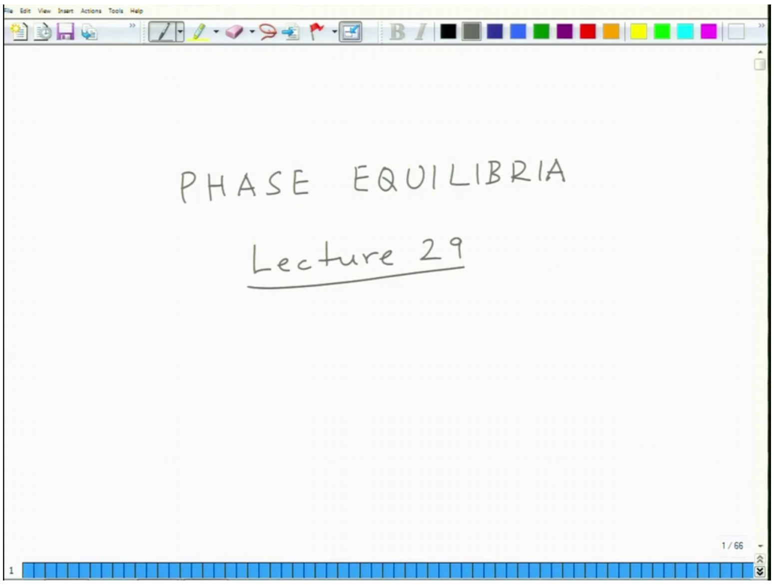

So, we will just do a brief so, the recap of past lecture is, we looked at the microstructure evolution in hypo and hyper eutectoid steels; which consists of basically you can have alpha Fe plus pearlite.

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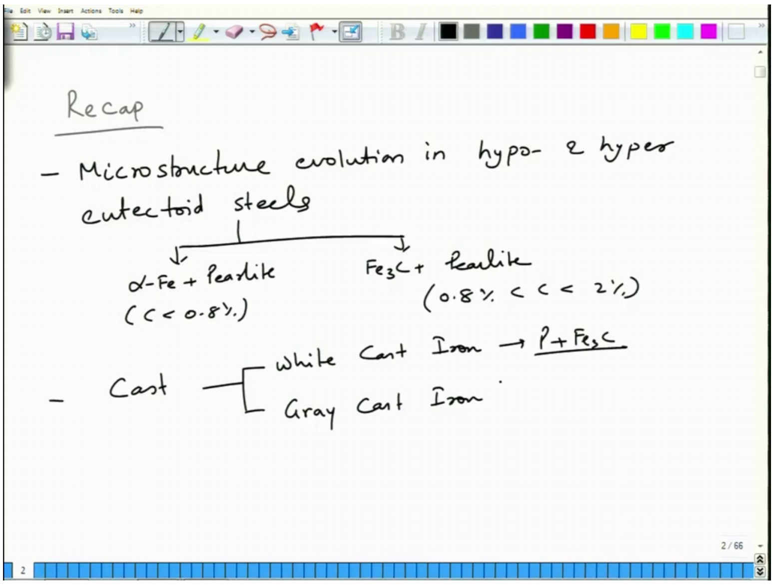

Or you can have so, this is for carbon less than 0.8 percent, and this alpha is pro eutectoid ferrite, and then you can have Fe 3 C plus pearlite, and this is for but less than so, let me just modify this 2 percent ok.

And we also started with cast irons. We looked at white cast iron, which is basically a fast cooled cast iron from liquid temperature, and which is cooled fast going through austenitic region, the eutectic region and then to eutectoid region. aAnd consists of basically pearlite plus Fe 3 C. So, it is a very hard compound, it is useful for certain applications, and it is it has a slightly whitish texture that is why it is called a white cast iron. Then we were looking at the gray cast iron, which is called a gray, because of it is grayish tinge. But it is it is it is an alloy which which is quite widely used because of (Refer Time: 02:15).

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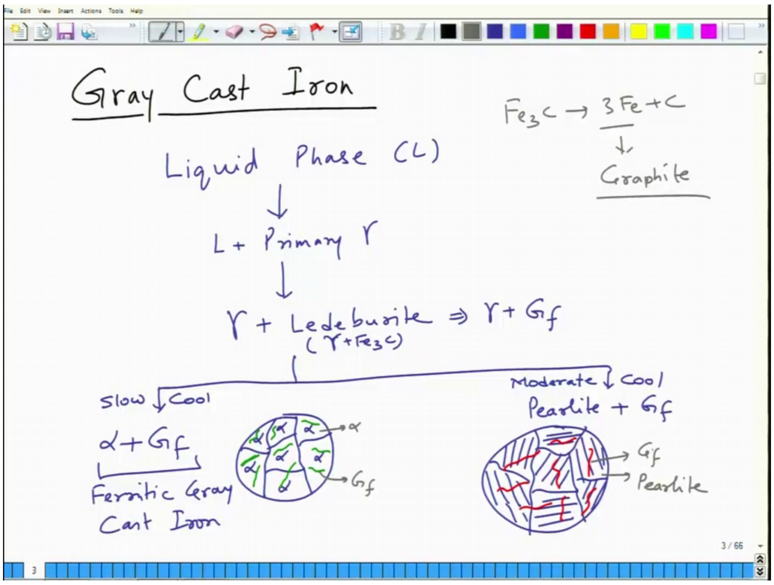

Gray cast iron, as we said was you have you start from liquid phase. You start from liquid phase, then you enter zone one, then you enter liquid plus primary sorry not alpha, but gamma. And then you enter into eutectic region which is gamma plus ledeburite which is Fe 3 C. And this basically ledeburite converts into gamma plus. So, ledeburite is nothing but gamma plus Fe 3 C. Now Fe 3 C being stable if you slowly cool it this is going to turn into gamma plus graphite flakes.

Now, depending upon when ~~when~~ you or you can ~~you can~~ have gamma plus Fe 3 C. So, at this point you can have either gamma plus Fe 3 C or you can have graphite flakes also, present because the decomposition has already started. So, depending upon now whether you slow cool or fast cool, you are going to have.

So, in the in the first case you are going to have on this gamma is going to convert into alpha Fe plus Fe 3 C; which is going to convert to graphite. So, you are going to have ferritic gray cast iron. And it is going to look like this. So, you are going to have this grains of alpha, alpha and within these you are going to have these flakes of graphite, these are flakes of graphites.

So, this is what is called as this is alpha, and this is called as graphite flakes. It is not exactly fast cool; it is basically what we will say it is a moderate cooling. So, let me just draw. So, if you moderate cool it, then what you form is basically the ~~the~~ decomposition of cementite is decomposition, cementite into graphite and ferrite is not complete, as a result what you have is, you have some pearlites, and then you have graphite flakes. So, moderate cooling will give you a microstructure; which is going to be and within these you are going to have flakes which are like this.

So, these are graphite flakes, and this is pearlite. And this is basically due to decomposition of Fe 3 C into 3 Fe plus C, and this is what is graphite phase. And essentially you are going to control the amount of graphite by controlling the cooling rate. So, if you slow cool it, you give enough time for conversion of graphite conversion of cementite into graphite.

But if you give less time then some of the cementite remains with ferrite and the pearlite form, and this has higher strength as compared to a white cast iron.

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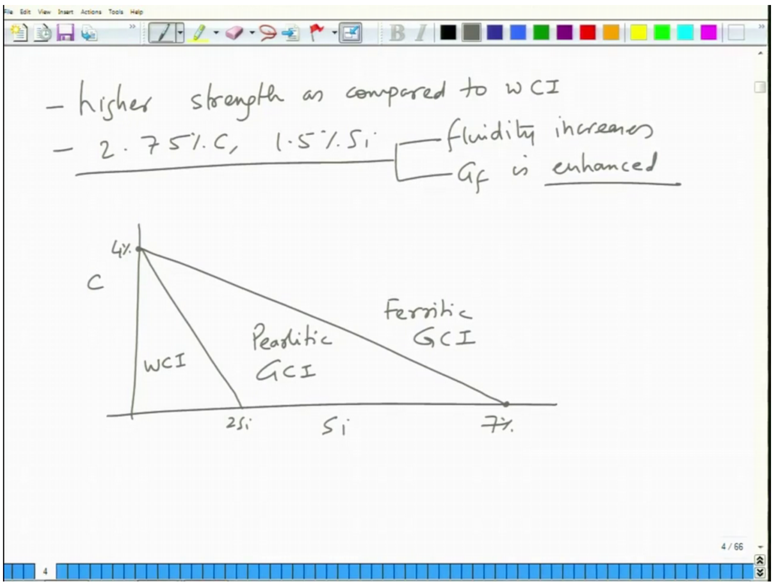

So, it has higher strength as compared to white cast iron, because it is not that brittle. And it contains typically 2.75 percent carbon and about 1.5 percent silicon.

Silicon is added because it promotes the formation of graphite, ~~it is~~ it is a and it increases the fluidity. So, it increases fluidity, and then graphite formation is enhanced. So, that is why some silicon is always added. So, when you look at for example, effect of silicon addition on the cast iron. So, let us say this is carbon this is silicon; you start from around 4 percent let us say. So, 4 percent up to 2 percent silicon you will have a nearly white cast iron, and then you go to about 7 percent. So, between this you will have pearlitic grey cast iron, and after this you will have ferritic gray cast iron.

So, depending upon the carbon content and higher the carbon, you will have more formation of graphite, and more the silicon you will have more formation of graphites. So, both of them promote formation of flakes in gray cast iron. So, this is how the micro structures are going to look, like let me show you the picture of a the gray cast iron.

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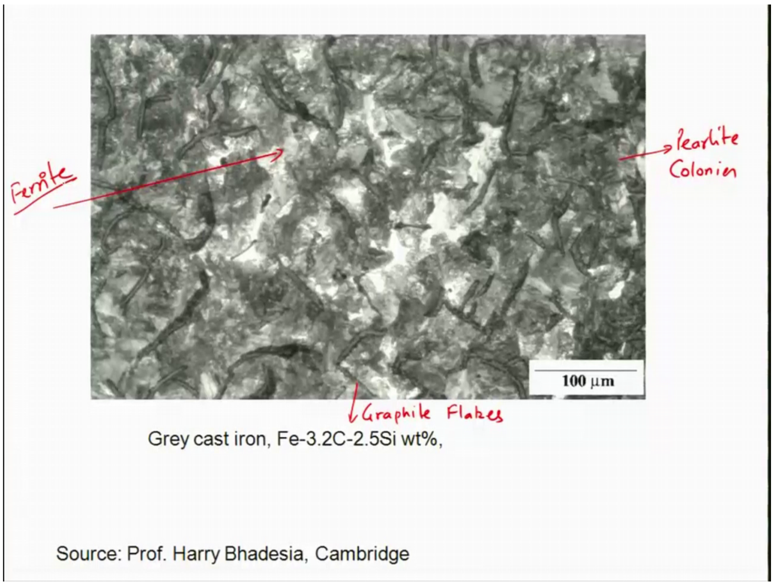

So, this is what a commercial gray cast iron cast iron looks like. It contains about 3.2 percent carbon 2.5 percent silicon weight percent. So, you can see these black ones as these are graphite flakes. And what you have inside is pearlite colonies, and then in between what you have is ferrite ok.

So, you can have some ferrites some pearlite and basically graphite flakes. And this is what is it might as well be pearlite. If possible, you can have also some ferrite. So, so this is basically pearlitic sort of cast iron that is commercially available. And then we move on to another cast iron which is called as malleable cast iron often denoted as MCI.

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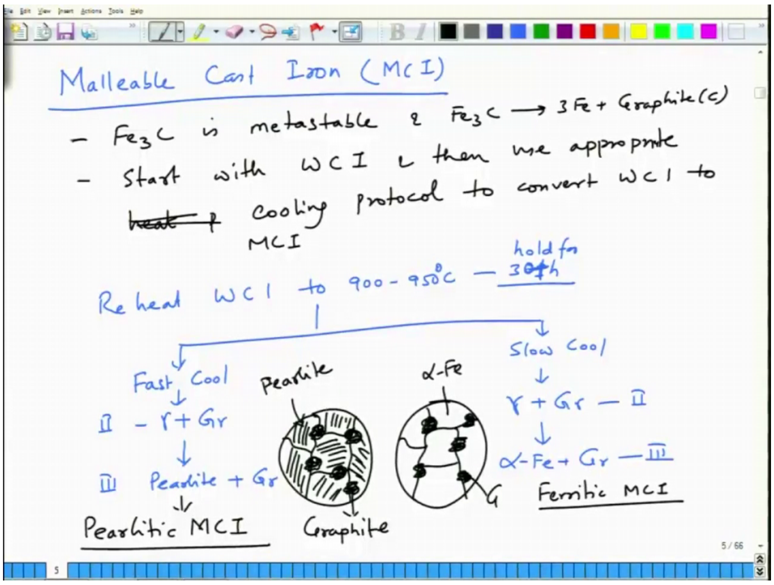

So, basically again as we say cementite is Fe 3 C is metastable, and hence Fe 3 C goes give rise to formation of graphite ok. So, this is what happens. So, essentially what you do is that, in this case you start with white cast iron sort of and then use appropriate heat treatment protocol, appropriate cooling protocol to convert WCI to MCI.

So, essentially what you have is, you first reheat WCI to about 900 to 950 degree centigrade, and hold it at 30 plus hours;. Hold for 30 plus hours. nNow then depending upon the cooling rate from this region. So, we can have cool fast or slow cool.

So, let me just I think better if we write it as fast cool, all right. So, fast cool is going to give rise to so, fast cool we will have in the zone 2 you will have austenite plus graphite. And then when you come to go the zone 3, you will have pearlite plus graphite. And the graphite here that is formed is not in the form of flakes, but rather in the form of. So, in the form of irregular nodules.

So, what you will have is basically; so, these are grains of gamma. So, the graphite will form something like this, and the gamma will convert into pearlite. So, you will have these so, this will be graphite irregular nodules, these are called as rosettes, and then you will have pearlite. So, this will give rise to what we call as pearlite pearlitic malleable cast iron. And if you slow cool it, then of course, you take it to in zone 2 gamma plus G, G graphite, and then when you slow cool it then you form alpha Fe plus graphite.

So, in this case the microstructure is something like this. So, you have these grains of gamma earlier, in which you form these rosettes of irregularly shaped and graphite rosettes. And this gamma will convert to alpha. So, what you will have is basically this is graphite and this is alpha Fe. And this is called as ferritic malleable cast iron ok. And the whole process of converting this white caster into malleable caster is called as malleabilization ok.

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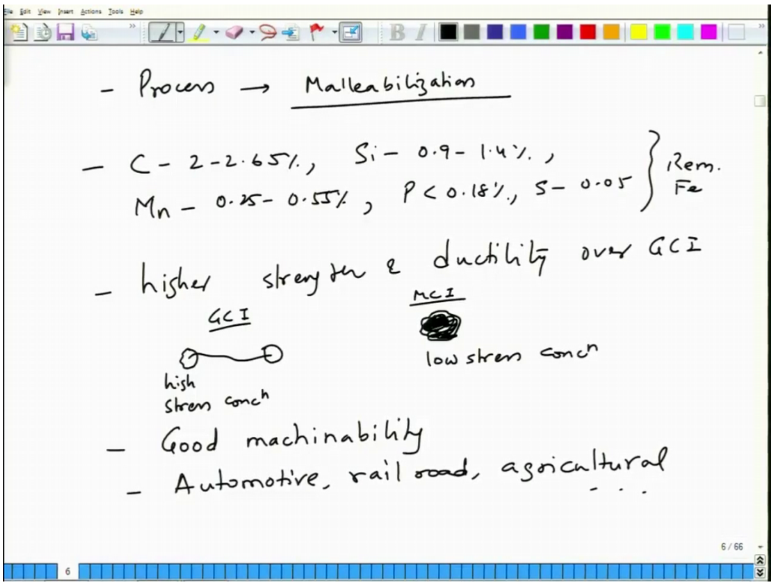

So, basically white cast iron which are suitable for conversion to MCI contain carbon of the order of 2 to 2.65 percent, your silicon is about 0.9 to 1.4 percent, it is not very high as compared to gray cast iron, it is low enough. So, that you do not have graphite flake formation, and then you have manganese, which is 0.25 to 0.55 percent. And then you have pearlite which is point, and then you have phosphorus which is less than 0.18 percent, and then you have sulfur which is 0.05 percent and remaining is F e.

It has higher strength and ductility over gray cast iron, because in grey cast iron you have these flakes. So, these are the points of high stress concentration, and they make them brittle in tension. So, they have poor tensile strength, but in good MCI. So, this is GCI in MCI you have these irregular rosettes.

So, as a result you have lower stress concentration, and you have a less susceptibility to cracking under tension. So, these also have good machinability, and they are useful for lot of automotive components, railroad components, they are also useful for ~~for~~ example, agricultural components etcetera.

So, we now show you certain pictures of this cast iron.

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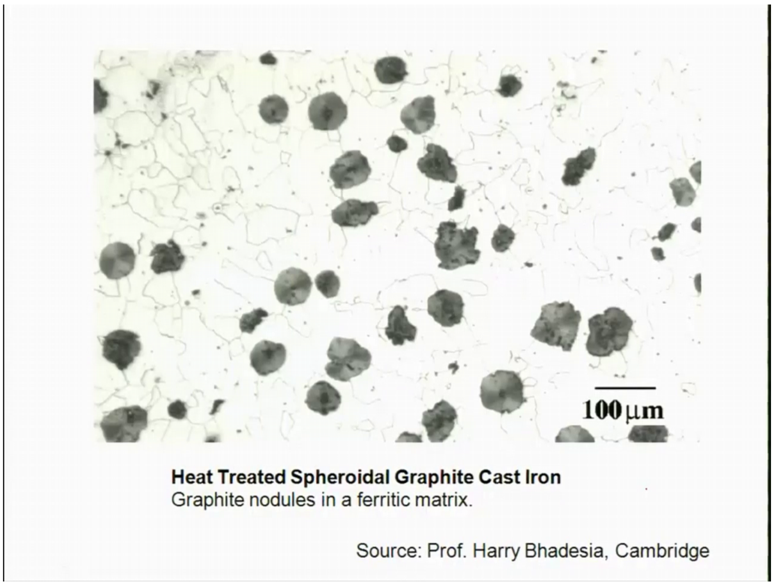

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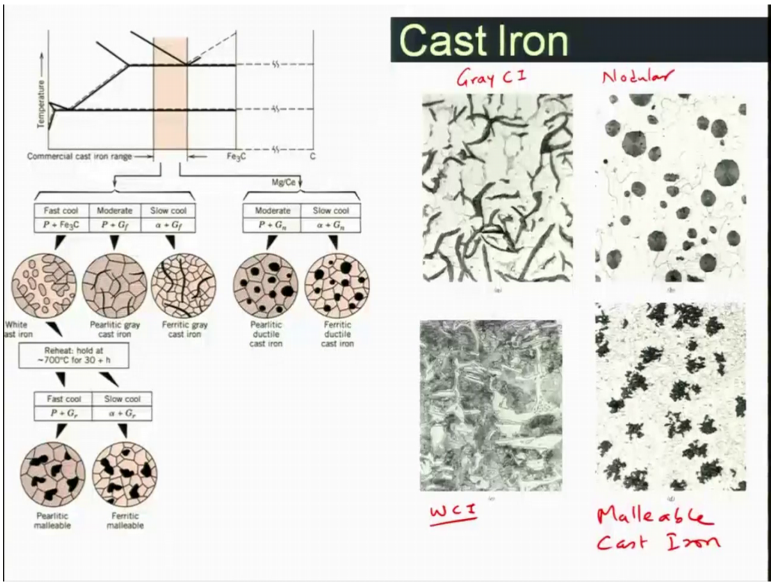

So, the one on the right here, this image is the malleable cast iron. This is malleable cast iron. So, you can see that you have a ferrite matrix, and you have these irregularly formed rosettes of graphite. This is white cast ~~iron,~~iron; you can see that you have cementite~~.~~ a~~A~~nd in between you have pearlite. This is gray cast iron which has these flakes of graphite in the matrix of ferrite and pearlite, of ferrite and pearlite mixture. And then finally, we will come to another cast iron which is called as nodular cast iron.

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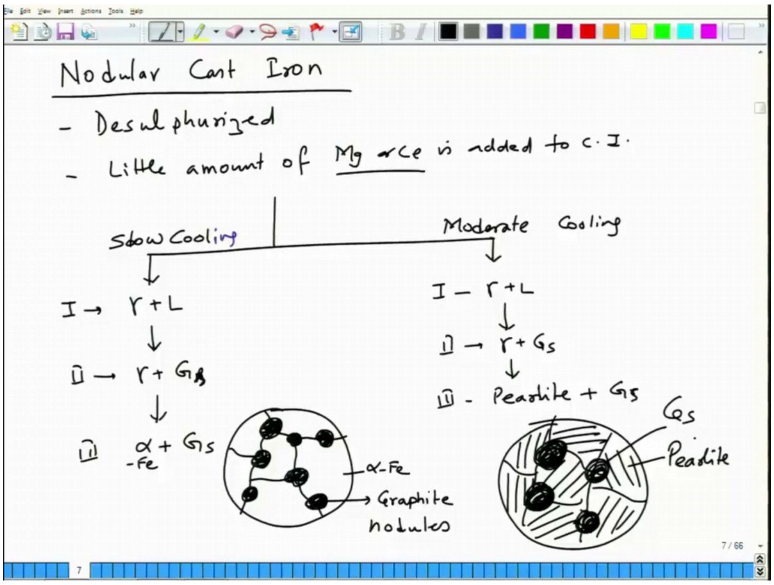

So, nodular cast iron as the name itself suggests, that ~~it is~~ it is basically desulphurized form of cast iron. And it contains very little sulphur. The idea here is to convert the graphite into more round shape and precipitates, as a result that stress concentration is lower the mechanical properties are better, the tensile strength is higher higher and it has higher ductility. And as a result, it is more useful for ~~for~~ engineering applications. And basically it is not require a heat treatment rather a little amount of magnesium or cerium is added to cast irons.

So, what happens here is, you start from the same, you have 2 steps. First is the slow cooling steps. So, I can say slow cooling, and then you have moderate cooling. So, in the slow cooling what will happen is that, you are in the zone 1, you will have gamma plus liquid, this gamma plus.

So, the job of this magnesium and cerium is to change the surface energy, and it changes the surface energy in such a manner so that graphite nodules or graphite rosettes or flakes they try to minimize the surface area, and when you try to minimize the surface area, they become they tend to become more round.

So, as a result this is called as a refiner. And this in this zone 2 this will convert into graphite. And this will convert to graphite spheres G s. And these spherical graphites, then will convert into if you go to zone 3, this will convert into alpha plus G s, this is alpha F e.

So, all the cementite gets converted gradually to graphite spheres, and this is what is called as nodular cast iron the microstructure that you will have is something like this. So, you have these graphite round precipitates. So, roundish graphite precipitates, and you will have alpha Fe and you will have graphite spheres; what we call the nodules ok.

So, this is as a result of slow cooling, which provides enough time for cementite to convert into iron plus graphite. And then we come to moderate cooling aspects when the cast iron is cool slowly then in the zone one again you are going to have gamma plus liquid. This will convert to gamma plus graphite in zone 3, and you are going to have in because of incomplete conversion of cementite to graphite, you will have pearlite plus graphite. And this is going to look like just microstructure.

So, you are going to have, you have paralytic colonies, you might have little bit of a right as well. So, it is not ruled out wise just for the sake of, and then you are going to have these, this is pearlite. And this is graphite nodules. It has better mechanical properties as compared to your malleable cast iron or gray cast iron, and that is why ~~it is~~ it is a good alloy. As far as engineering applications are concerned and microscopically it looks like this.

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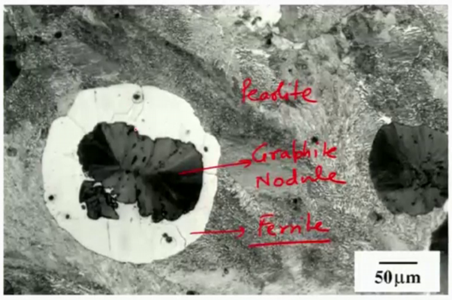

Spheroidal graphite cast iron, Fe-3.2C-2.5Si-0.05Mg wt%,

Source: Prof. Harry Bhadesia, Cambridge

So, you have this is federal graphite cost array it has 3.2 percent carbon, it has 2.5 percent silicon, and it has 0.05 m magnesium. Very little amount of magnesium not much. aAnd you can see that this is pearlitic matrix, and this is graphite nodule, and the vicinity you have complete graphitization of cementite.

So, this is called as this is basically ferrite. So, nodule surrounded by a graphite region carbon free region, and then you have pearlite you can see that in this for example, in this case you do not have any ferritic region. But so, occasionally you have you may have these regions which are free in carbon almost. So, this is what I showed you earlier. So, this is nodular ferritic nodular cast iron. So, you have these nodules of graphite, dispersed in. So, this is a graphite and this is ferrite ok. So, this is how how we are going to have various cast irons produced in case of iron carbon phase diagram.

So, this brings us to the end of iron carbon phase diagram. So, let me now go through briefly again this phase diagram.

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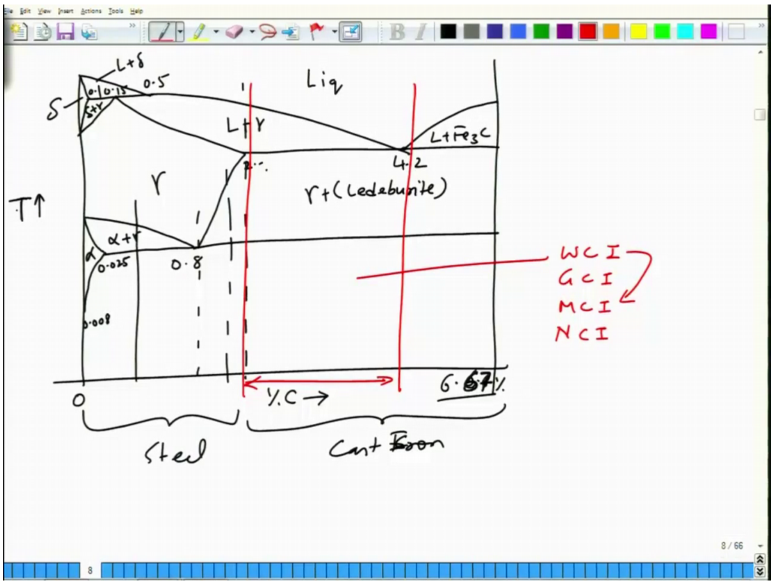

So, this is what we have liquid 6.67 to be precise. And ~~and~~ this is your delta phase, this is your gamma phase, this is your alpha phase. This is alpha plus gamma, this is gamma plus ledeburite. Gamma liquid plus gamma, this is liquid plus Fe 3 C, and this is liquid plus delta, this is delta plus gamma.

So, to summarize you have 3 regions here, your first region is called as paralytic region on the left and at high temperatures where liquid plus delta phase convert into a gamma phase. Delta is high temperature phase of iron; which converts to gamma phase at lower temperatures, and the solids at ~~at at~~ a lower temperature. For pure iron and that is gamma converts to alpha at about 910 degree centigrade. So, gamma delta is BCC gamma is FCC and then again alpha is BCC.

So, it has 3 regions; first is the paralytic region, and then second is the eutectic region, and third is the eutectoid region. As far as utility of this phase diagram is concerned it is divided in 2 parts for carbon less than 2 percent the alloys are called as a steel, and carbon more than 2 ~~2~~ percent are called as alloys are called as cast iron.

Now, we are going to so, depending upon which composition you are at you will have different microstructures. So, for hypoeutectoid steel, you will have microstructures which will have pro eutectic ferrite and pearlite. For eutectoid steel you will have 100 percent paralytic microstructures; which are harder which have higher strength as compared to hypo eutectoid steel. And then you have compositions with point more than

0.8 percent carbon, which are high power hyper eutectoid steel microstructure consisting of cementite and paralytic micro structures.

Then we enter in to cast irons after 2 percent, and most of the commercial cast irons are between this range 2 percent to about this range, this is the commercial range. And within this range depending upon how you cool the cast iron, you will have either white cast iron, or you can have gray cast iron, or you can have malleable cast iron, or you can have nodular cast iron.

~~Ah~~ So, white cast iron is essentially cast iron which is fast cooled which consists of microstructure consisting of cementite as a white phase and pearlite as a dark phase. If you cool it slowly then cementite being unstable phase starts to it is especially unstable at higher carbon contents. So, it does not decompose into graphite in steels, it is also composition dependent and though, and cast iron also contain a little bit of more silicon.

So, both high carbon and silicon promote the formation of graphite ~~ah~~; which is accelerated at under slow cooling conditions. So, if it is low or moderate cool white cast iron you convert into a malleable cast iron, of pearlitic of ferrite, ferritic nature. Or if you have high amount of silicon, you can also convert a cast iron will have a graphite flakes and instead of (Refer Time: 27:04) will be called as graphitic gray cast iron, which can again be pearlitic and ferritic gray cast iron consisting on graphite flakes, in either matrix of pearlite or matrix of ferrite predominantly.

You can refine the grade and the cast iron microstructure by adding some magnesium of cerium. I tends to form graphite to nodule or spherical shape as a result, graphite is more round which provides better mechanical properties, and these are called as nodular cast iron; which can again be ferritic or pearlitic depending upon the cooling condition. So, this is basically a brief overview of iron carbon phase diagram, and it is correlation to various micro structures in different alloys that you get.

Next what we will consider is, we will look at will look at the phase diagrams of some of the non ferrous alloys; which are useful for various engineering applications, such as brass, bronze, titanium alloys, aluminum alloys and so on and so forth. And then we will finally, move on to determination of phase diagrams, and some ~~some~~ work on ternary phase diagrams.

Thank you very much.