Phase Diagrams in Material Science Engineering
Prof. Krishanu Biswas
Dept. of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture - 39
Malleable iron

So, in the last lecture I discussed about ductile iron or nodular iron. Now, I am going to discuss with you, malleable iron or sometimes known as vermicular iron.

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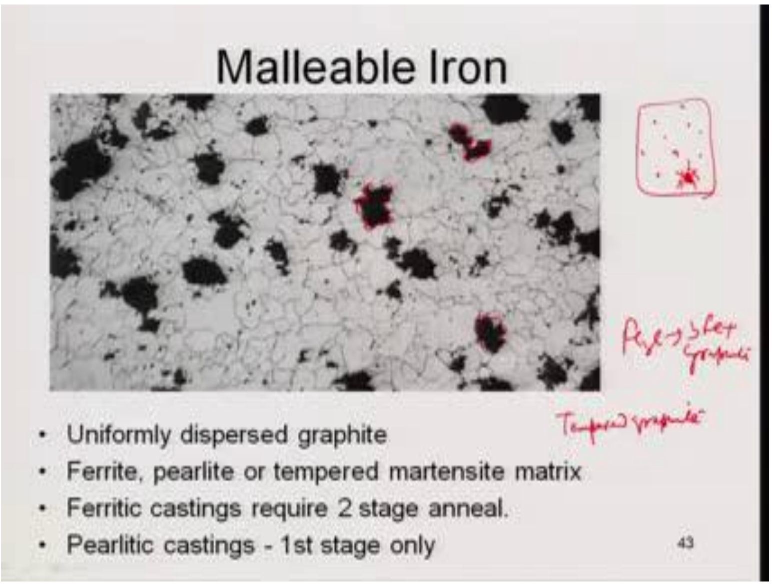

So, what is it? Malleable iron is a solid state product. First of all, let me tell you gray iron, graphite iron all of them are white iron are from reproduced from the liquid, but this is a solid state product in this case the graphite forms like you know, it is like a deformed graphite. It is not deformed graphite, irregular separate graphite you can see here forms and they are called tempered graphite basically tempered is better term tempered graphite.

So, these things are very, very non-uniform is said, either they are spherical nor they are nodule nor they are flaky. They are not, but fact they form graphite and they are uniformly dispersed and you can have a matrix ferrite, pearlite or tempered martensite ferrite castings requires well; obviously, this are done by the annealing and which you will discuss in detail now. So, ferrite requires two stage annealing process pearlitic or first stage and one stage annealing process.

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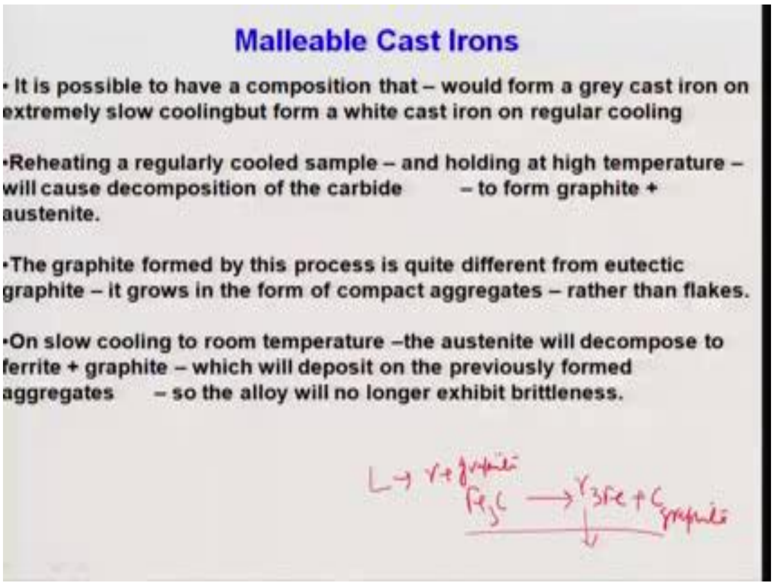

So, let us first discuss what it is possible to have a composition that would form a grey cast iron on extremely slow cooling condition, but form a white cast iron on regular cooling that you seen that means, if I take a steel alloy composition of cast iron and cool it very fast, which is instead of forming graphite it will form cementite that we have seen. Basically, there are two competitive eutectic reactions; one is liquid going to gamma plus graphite taking place at 1154 degree celsius temperature, other one is liquid going to gamma plus cementite and it occurs at 1146 celsius temperature, so hardly about 8 degree difference - 1146, 1154. So, if you cool it very slowly, the fast reaction will happen and you will form graphite instead of forming cementite.

But if you cool it fast, the second reaction the liquid going to gamma plus cementite will happen and in that case will form cast, the white cast iron as I told you white cast iron is a very duct brittle material. It has large chunk of cementite present and because of that is brittle correct and let me again show you this pictures, otherwise it will not be clear to you.

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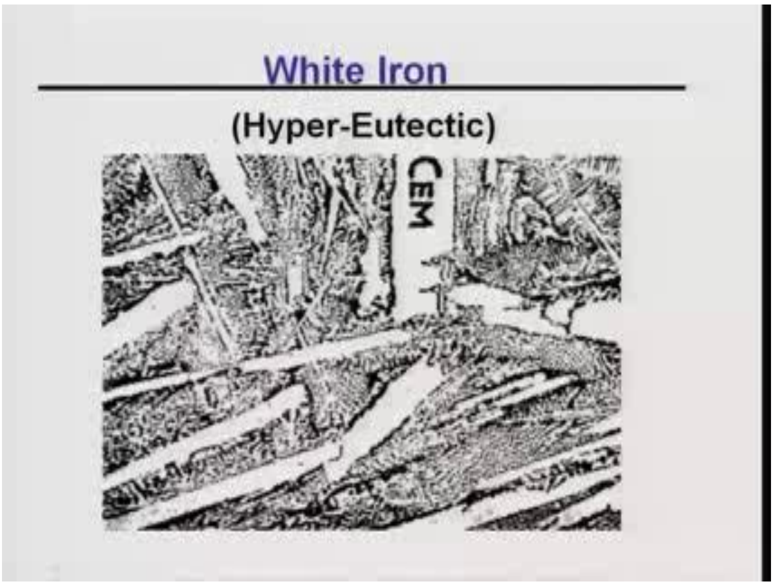

So, white iron has large cementite and a matrix of gamma plus cementite, which is where the gamma again transforms to pearlite in solid state.

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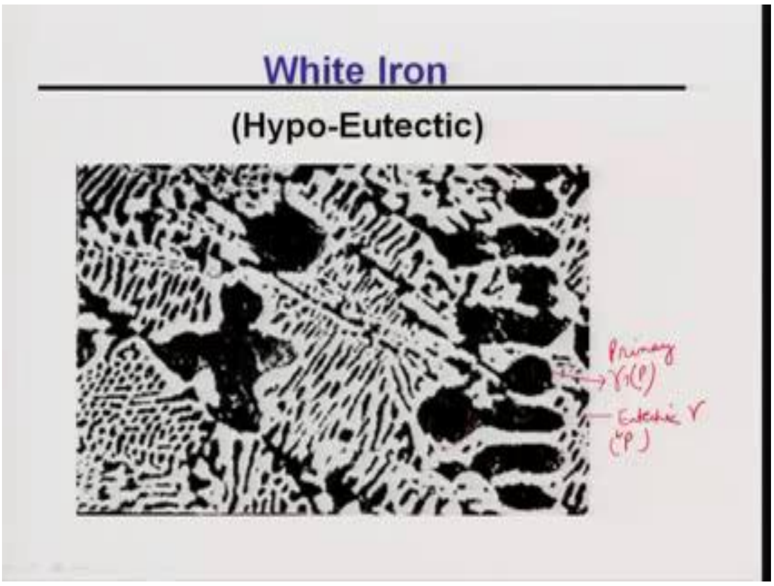

So, this is very brittle. Again in a hyper eutectic also you have large chunks of cementite both the cases.

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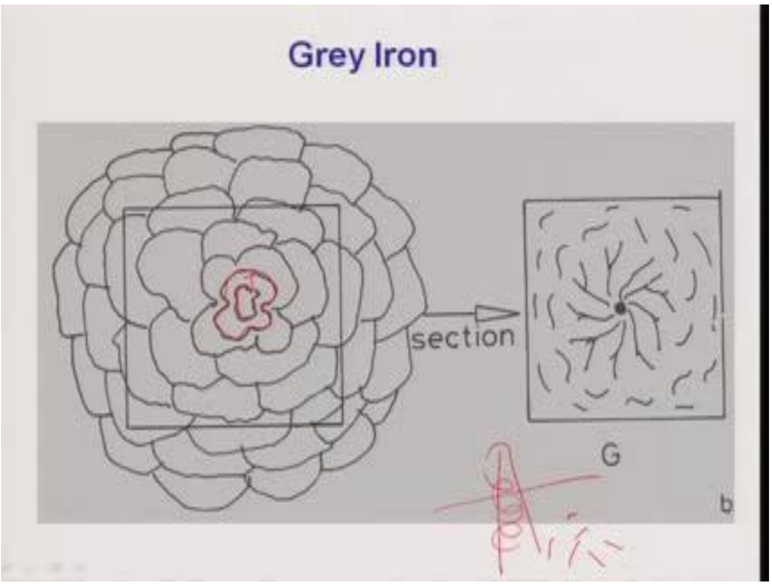

As you know cementite is not a lower metastable phase. This is a not a metastable phase. So, it is not the lowest energy configuration I have raise it has it will if you provide some driving force. It will transform into it, transform into graphite and that is what is this is what is used for the formation of your malleable iron. So, what you do, to do that will it heat this white iron and at a high temperature; high temperature means at about 800-850 degree Celsius temperature and this will lead to decomposition of cementite.

Why because Fe 3 C, if you see here it will heat, it will transform to 3 Fe plus carbonium form to graphite, correct that is what will happen and this is exactly the way malleable iron are made. So, malleable iron you take the white iron heat up to 50 degree Celsius the temperature keep it long 48 hours or 72 hours sometimes 96 hours, so that these transformation happens Fe 3 C, which is present in a metal stable phase, it gets converted into Fe plus graphite.

Now, at 850 degree Celsius temperature, this Fe will be gamma iron and then if you cool it down this Fe will get converted into either pearlite or ferrite correct depending on the carbon concentration. So, graphite form by this process, this is a solid state process right we are not cooling it from liquid we are taking a white iron heating it up to 850 degree Celsius temperature. So, these is a solid state process the graphite form by this process is quite different from the eutectic graphite because eutectic graphite which forms by this eutectic reaction liquid going to gamma plus graphite is forms a liquid state liquid to solid transformation, but these graphite in the malleable iron forms by solid state reaction. Therefore, this is not spherical separate graphite it is irregular steps that is what you have seen in the last picture irregular surface picture.

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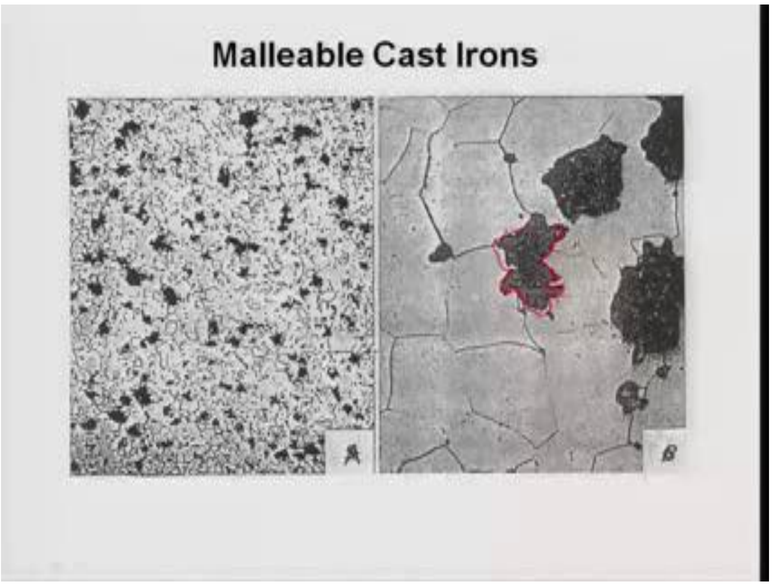

Now, depending on the depending on your cooling conditions, you can either have a ferritic matrix or you can have a pearlitic matrix. One can also create martensitic matrix that I will discuss maybe end of this lecture I have been telling you the formation of martensitic matrix, but I have never discussed with you I will tell you that also. So, you have basically this pascal graphites which has which are actually called tempered graphite or solid static form graphite and then surrounding has a ferritic matrix as you see here my high imagine picture graphite you see a regular separate graphite picture correct here also.

So, because of these tempered graphite malleable iron is very malleable malleable was what very ductile normally malleable iron not use in the automobile industry. It is normally used in the space industry because space requires certain applications where graphite the ductility is a major issue and graphite also leads to be of this kind of steps. Now, you know all though graphite has irregular step, but it has very sharp edges also therefore, the problem of the stress concentration remains. In this case, you can also create pearlitic matrix.

Here, how you can actually see the way we can create matrix are basically depending on the heat treatments as I told you now that how this form I take a white iron of same composition like a grey iron 3.5 to about 4 percent carbon silicon is about 1 percent or 2.5 percentage cool it very fast from the white iron. Now, you anneal it at 850 degree Celsius temperature. If you anneal it for a shorter time, let say about 24 to 48 hours that is a sort of time 24-48 hours is also short time.

If you anneal it that time then what will happen? This graphite the transformation of this cementite will happen cementite will transform to Fe plus graphite transformation will happen and graphite will nucleate and the graphite will grow as I told you that graphite grow because more carbon. So, it will absorb the carbon it will absorb the carbon from the near the matrix.

So, if I nucleate this graphite for the cementite for it grows it will take the carbon for nearby region a solid state and become bigger. Once, it is become bigger nearby regions will be depleted of carbon and this depletion of carbon will; if it is happening uniformly also route it all the nodules becomes big and then whole region become deplete of carbon then it will form ferritic matrix because there will no carbon left are very actually very little carbon are left in the matrix for you to have a pearlitic transformation at 723 degree Celsius temperature.

So, that happens if you when you anneal it a longer time sorry, when you anneal it for 72 to 96 hours, but anneal it for shorter time 24 to 48 hours the diffusion of carbon will not be happening uniformly, only the regions which are nearby this graphite nodules a graphite non nodules graphite tempered graphite things will be deplete of carbon and they will become ferritics. So, then only then you can create pearlitic matrix on the other hand if you keep it long time 70 to 46, 96 hours then that the carbon will diffuse.

To graphite from all the regions and the whole matrix will become deplete of carbon and then it forms ferritic matrix correct. So, that is the way it forms, in ferritic matrix requires two stage annealing that is why what is two stage annealing first you anneal at 850 degree Celsius temperature to form the graphite then you cool it down from the graphite. Graphite will become an critical size and grow then you keep reduce a temperature this happens for about 48 hours.

This treatment then you temperature to about say, then you increase a temperature to about 950 degree Celsius temperature. At the temperature all the carbon will diffuse from different parts of the sample to the graphite and then this will be diffused the matrix will be depleted of carbon it will form pearlite. But if you want a pearlitic matrix the 850 degree handling is sufficient for 48 hours. So, that is how you can create different kinds of cast iron graphiting morphology in cast iron.

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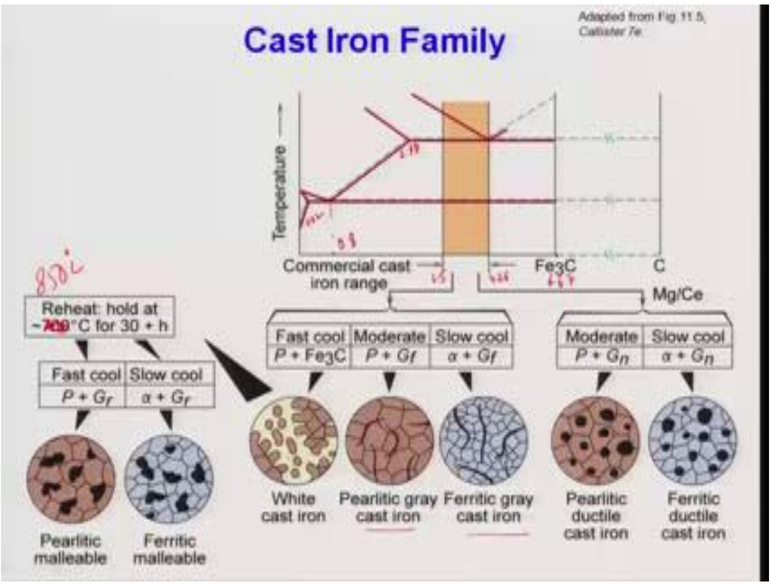

Now, in next 5 to 10 minutes what I am going to do is I am going to discuss with you the in one slide? How things happen as you know, this is the iron carbon phase diagram these are the commercial range and I am just showing you a temperature versus composition. This is the commercial range of the for the cast iron family as you see here.

So, most of the alloyed composition varies from 4.3 percentage or 4.25 percentage of carbon and this is the Fe3 C, 6.67 percent carbon. So, this is 0.8, this is 0.02, this is 2.01 or 2.1 rather and this is 2.5, this is 4.26 carbon. So, this is the commercial range of the cast iron correct, now what are different things if you cool fast, fast cool lead to pearlite plus cementite as you see here this white things are cementite and this are pearlite. So, that is why you form the white iron correct cooled and you have quite lot of silicon. Second thing you have to silicon and moderate cooling then your pearlite plus graphites flux correct you see here, flux of the graphite and if you cool it slowly silicon is present then you can have ferritic cast iron.

So, difference between this pearlitic gray iron and the ferritic gray iron is that you cooling, which is if you moderately cooled, moderate means how much about 10 to 15 degrees per minute as slow cooled means 1 degree per minute. So, if moderately cool you form a pearlitic gray cast iron and if you cool this very slowly form the ferritic gray cast iron that is very simple if you cool slowly the graphite will have more time to absorb carbon from the nearby regions and nearby regions will be depleted of carbon then it will from ferritic matrix.

Now, this is one part of the story second part of the story is what you can modify the shapes of this graphite correct that is done in liquid state whole thing i am talking in liquid state. So, what do you do is that you can add magnesium or cerium of calcium of metal. So, what you can do you can form graphite nodular, the G N is basically terms of the graphite nodular if you slowly moderate liquid if you from graphite nodules and the pearlitic matrix, but if you cool slowly you will form the ferritic matrix same as earlier why graphite will absorb all the carbon, but basically you are adding this magnesium or ceranium then only you can change the shape of the flux to the nodular that is the idea without that you cannot basically do that. So, the addition of magnesium ceranium lanthanum or calcium is basically due to what due to shape change. So, that is this is what is for the solid state a liquid state liquid to solid from the liquid, but a eutectic reaction will happens.

Now, there is a another part of a story if I take this white iron which contains lot of cementite and pearlite and I take re heat about 700 degree celsius temperature, 700 is a wrong I will tell you it is 850 degree celsius temperature. So, 700 is not correct sorry and I keep it 24 to 48 hours that is why 30 plus hours and if I cool it, if I keep it long time and cool it slowly I form ferritic matrix if I cool it fast I form pearlitic matrix that is one part second part is that you form this pearlite or ferrite depends on what is your what is the way you are treating that what temperature you are treating if you treat it high temperatures for a long time that is about say 48 to 96 hours you found the ferritic matrix if you treat it slowly things at a low temperature low temperature sorry not at lower time about 24 to 48 hours then you can form pearlitic matrix.

This is a nutshell adopted from the book of calister and you can see the figure number about eleven point five you can read also this will you will tell you the whole cast iron families together cast the how the different cast iron are basically forms. Now, the things which I supposed to tell you is that are then this pearlitic and ferritic matrix. We can also form what is known as your martensitic matrix thus not difficult, what you do is that for matrix because many application requires gray iron or graphite iron with the martensitic matrix, what you do is that you cool very fast which is not shown here moderate and slow cooling both for the gray iron and the graphite and so on.

But, if you cool it very fast, you quench it in water after this eutectic reaction, these gamma iron will come at into martensites. Normally, we do not need martensites in the cast iron why because the cast iron as basically ductile they are very, very ductile. So, that is why you do not want to create a martensite to make it brittle that is the idea. So, martensite martensitic matrix is normally not used, but there are few situations where we need a martensites you need a high variations at the sometime you need those lubrication properties of the graphite.

So, they are actually you can cool it very, very fast like quenching in water or a well you can form this martensites that is the one part, you can also form bainite in a matrix and that is actually more widely used tempered ductile iron. So, which are very, very widely used now, for making the connecting rods of the automobile engines they had the matrix is bainite. How do you found the bainite again the same way by the isothermal holding at 350 point degree celsius temperature. So, you have the eutectic reactions leading to formation of these flaky or the nodular graphite, iron graphites and then you can actually do this cool it very fast go to 350 degree Celsius temperature keep it there for a long time from the bainite.

So, by forming a bainite you can actually do use more ductility into it and also strength because bainite has both the strength and ductility quite a good. So, you can see that it gives you wide opportunities to create different kind of micro structure from the same alloy. I can change the micro structure differently by different mechanisms and great different kinds of properties I can change this model nodules, the shape of graphite there is one part from the place to nodules to you know tempered graphite in malleable iron. there is one part of the story second part of the story is that I can change the matrix.

So, it gives you empty number of choices of creating different micro structure that is the beautiful part of these cast irons and that is why you wanted to spend lot of time on that. So, the my basic idea is that now, if you want to again change the matrix, you can add alloying elements that is why what is called as alloyed cast iron, you can add chromium you can add tungsten you can add titanium, you can add all the alloying elements nickel to change the matrix because these alloying elements will change the matrix compositions these alloying will also change the graphite morphology that is possible.

So, that is the another set of things you need to be discussed that which we will be doing it in the next class, but for your understanding gray iron the cast iron family this is the basis of the cast iron things which I wanted to give you in a one slide and this is nicely done in Calister book, if you want to look at it is available on the net. So, please do read it and try to understand it very nicely, so that you can have a good sense of what is a cast iron family is and what are the different ways you can modify the micro structure and that is what is the key of from this course.

Usually, I can say I am only giving you the tip of the ice part because there are many, many interesting things available in the book text book that is why you follow the text book you know as the exams will be held just about one and half month time is 24, 10, 30 it is the deadline for the end last exam. So, and these are the parts which are very important, you should concentrate on this parts more or nicely then you know whatever I am going to teach for the next subsequent lecture. So, what I am going to do is the next subsequent lecture is that first I will finish in the next lecture.

I will finish up this alloyed cast iron then I should go into some of these phase diagrams of ceramic systems which I have not discussed, and this will take me about 3-4 lectures and after that I am going to start the area of your ternary phase diagrams that is the basically the whole things which planned of discussion for the ternary phase diagrams will takes me about me about 20 lectures and finally, we will discuss about; again come back stainless steels and some other testing alloy systems where ternary elements are presence. So, let us stop it here, we will discuss in the next class.