Phase Diagrams in Material Science Engineering
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Lecture – 38
Ductile Iron and Nodular Iron

Today, we are going to discuss on ductile iron. So, the last two lectures I discussed about the iron graphite phase diagram as well as iron carbide iron carbide phase diagram to tell you the difference between the eutectic reactions, when silicon is present in the system. Well finally, we also discussed about the grey iron as who have seen in the last part of my last lecture I told you that the flakes in the grey iron create problems when the stress concentration is an issue in the material that is mean that if I consider this flakes in the graphite that is suppose, let me go back little bit and tell you if you consider the flakes in the graphite.

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Suppose, these are the flakes in a grey iron matrix as you see here every flake has end and end is very, very fine is very thin at the order of few dense of nanometers. So, because of these small diameter at the ends of the flake, once the load is applied to the material it can lead to huge stress concentration at the tip and this stress concentration can be very, very severe in the sense that this can lead to crack at the tip and material can fail and these are the things have been observed on the well. This is the main problem on grey cast iron.

Although it has many disadvantages like it can have good ductility, good lubrication ability also good thermal connectivity which is required and good cast ability; obviously, which are required for the cylinder block of the engine in the automobile components therefore, this particular problem of stress concentration just now I discussed requires the solution and the solution by the way is very simple very, very simple theoretically obviously, why it is it if I make this flakes from flake to let us say that is what I showed you at the beginning of this lecture, last lecture.

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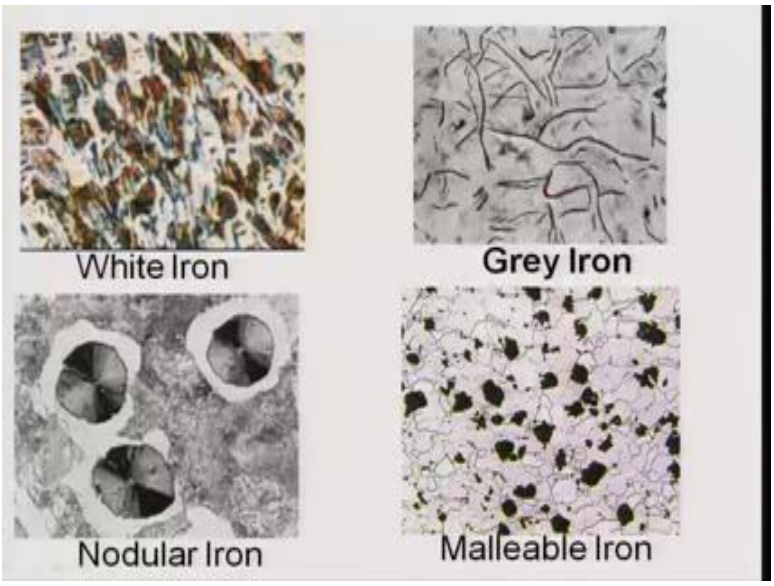

Yes, instead of this flakes here you see if I make them circular around then there will be no issue of stress concentration because it is a circular particle. So, therefore, surface area is known and it is uniform. So, amount of load you are applying you know the stress generated and this is the reason you know the reason why the spheroidal graphite iron or nodular graphite iron or ductile iron has been prepared and. So, it is todays lecture when you discuss in detail how that thing happened. So, pioneer in in the field of grey ductile iron is Georg Fischer two scientists from UK, who actually developed Georg Fischer converter in which a grey iron can be converted to spheroidal graphite iron.

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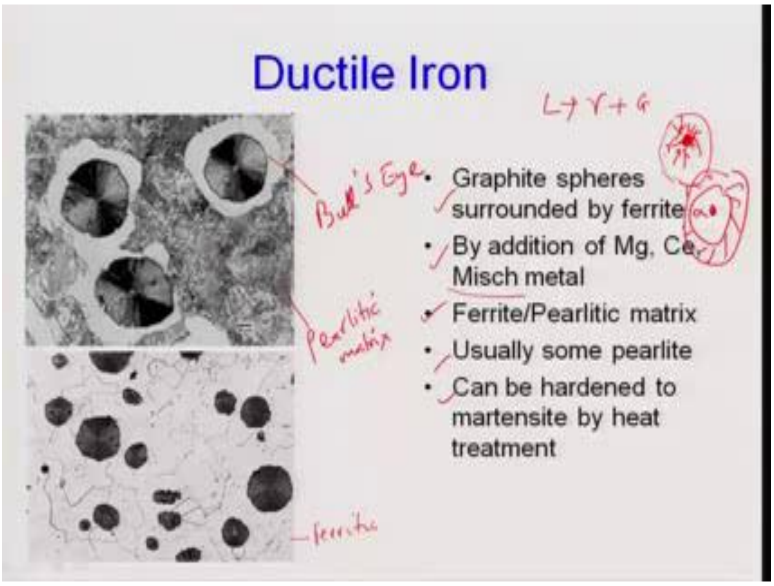

So, let us first discuss. So, I give you an idea that the problem in the grey iron lead to the discovery of ductile iron now you know in ductile iron all the graphite for us are actually sphere spherical and if you look at carefully these phase are basically surrounded by very ductile matrix is called ferrite well if you go away from this phase you have a pearlite only around it is a ferrite we will discuss why it is. So, this is called bulls eye structure this whole called bulls eye, if you see a bulls eye you will see this kind of text well the batteries can fully ferritic also like this at the another bottom this is a completely ferritic matrix this is pearlitic matrix.

So, the another question is that how this long you know flakes in grey iron is converted into round graphite affairs this is mostly done by addition of two elements in the matrix the first one is magnesium or cilium or misch metal, misch metal is mixture of rare earths cerium and any other many other rare earths there is a dysprosium. So, many rare earth materials are there in metal. So, earlier there is magnesium used to be the main material in which this conversion form flaky graphite to circular graphite used to happen, but in the magnesium and this was done in a Georg Fischer converter magnesium is basically a has a low vaporizing temperature which is about 1116 and the grey caste iron melting temperature is also similar to that about 12500 degree.

Therefore, magnesium is basically used to get evaporated and that is the reason why cerium misch metal also came into picture. So, that is the second characteristics is cerium magnesium or misch metal is to be added to commit this conversion from the flaky graphite to a circular graphite matrix can be ferritic or pearlitic usually the pearlitic matrix is better because this is hard and in many cases the matrix can be hardened also and may martensite possible.

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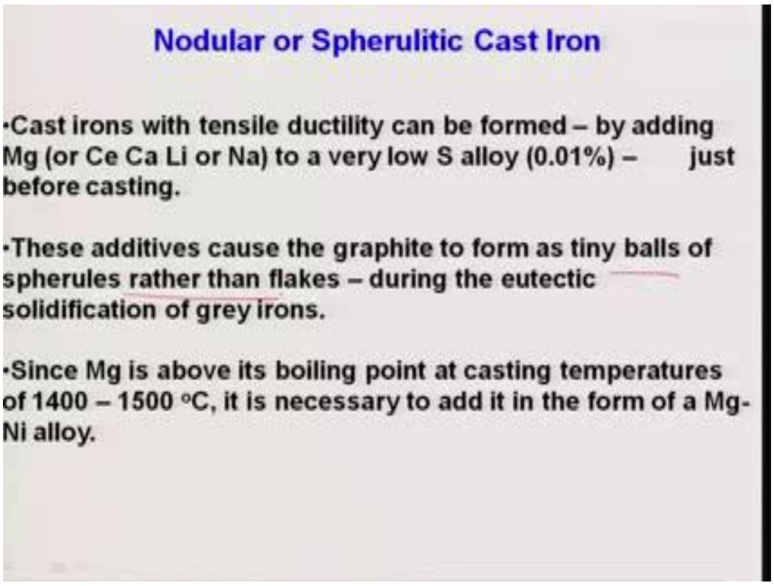

Well you know cast iron with tensile ductility can be formed by adding this magnesium cerium lithium or sodium is not really used magnesium cerium calcium just before casting these additive cause the graphite to form as a tiny balls of spherules rather than flakes during the eutectic solidification of grey iron since magnesium is above it is boiling temperature the casting temperature magnesium is basically boils at 60 degree Celsius temperature, but casting temperature can be assigned as 1300-1400 degree Celsius temperature. So, it is necessary to add magnesium in the alloy form normally magnesium nickel alloys are added or otherwise you can do in which magnesium is kept with the bottom of a huge liquid of grey iron and operation can be stopped.

So, basically the concept which you are getting is that this magnesium cerium calcium they basically do something. So, that the shape of the graphite changes from flakes to spherical now if you are a little bit intelligent and clever it is very easy to understand or very easy to think about it, but that is not the way the reason difference between the flake and a sphere is that the surface area of a sphere is much lower per in volume then a flake. So, it is because of a surface area reduction answer is no answer is that magnesium actually removes this alpha from the melt and this alpha actually poisons the graphite growth morphology in a few lectures here it will be clear to you much more. So, now, if you see here this is what I am showing you.

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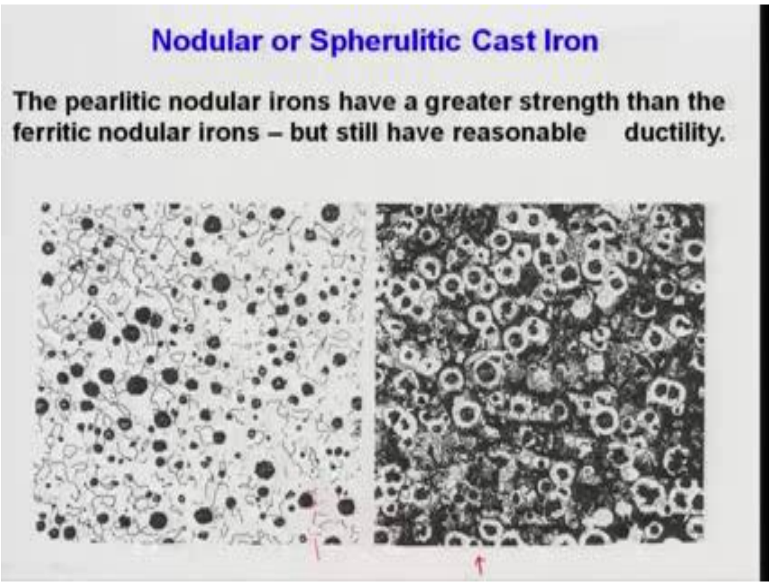

Let me just show you first in micro structure then discuss you can have a spherical graphite nodules in a in a in a ferritic matrix or a graphite nodules in a martensite in in a quality matrix, but in this case also the graphite loses also around by ferrite then the pearlite comes.

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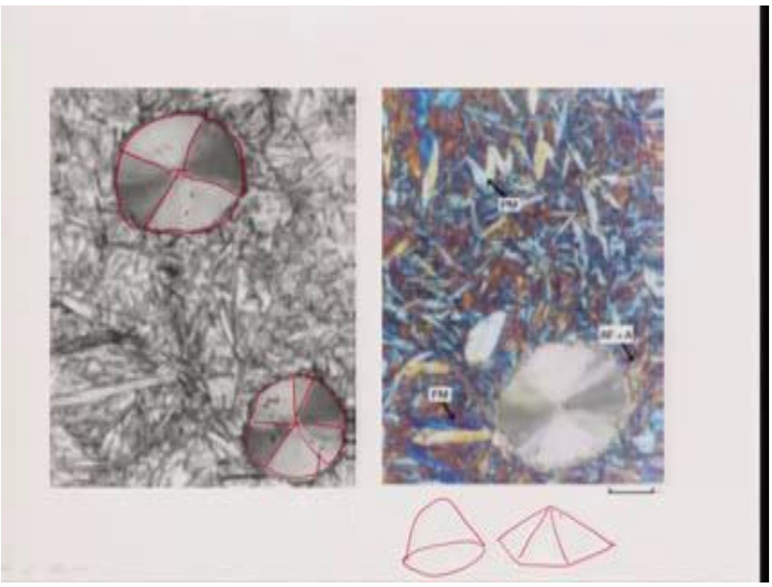

Well let us first discuss about will come back to this issues will lets discuss about the shapes of this of these noodles although I am telling you these noodles actually of you know spheres, but they are not spheres, but they are actually they have a shape of thatched roof as you see here this is the pic of the roof and these are the you know graphite things join like thisyou know like this am I it is much clear here this picture you see this are the graphite there are plots there are actually 1, 2, 3, 4 components and this is one is this. So, it is very clear this is not a sphere on the other hand the structure is like this this is what it is or it is better I can write like this. This is like a thatched roof if you see in phantom movies and. In fact, the matrix is pearlitic as you see here and much clearer picture will come to here.

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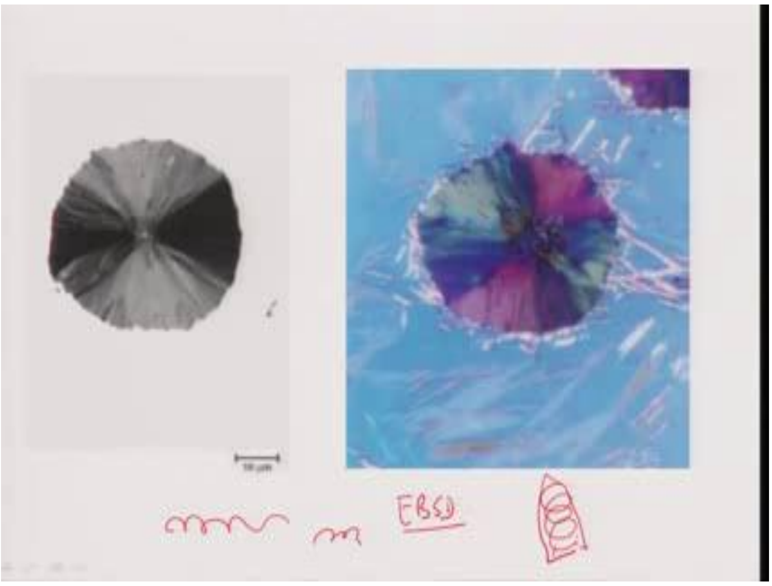

This is a same picture of one such nodule you see here the defined contrast black and grey contrast so; that means, they are of different crystals and one can actually use EBSD electron backscatter diffraction then you can map orientation of these and if you see clearly there are different orientation there is a color there is a blue color there is a you know some other colors. So, there is 3-4 different orientation within the graphite nodule.

So, what actually happens is that you know flakes of graphite are like this they are like a fibers now in this I have such things. So, this flakes actually then form they rotate and form a structure like this like this. So, that is what actually happens in form therefore, the actually the structure structurally the grey iron the graphite flakes in grey iron is similar good morphology wise and this although this sentence is not fully correct, but I am making it because what do we changing is all way the graphite flakes or graphite fibers is basically arranging that is what we are changing in spheroidal graphite iron and this mainly happens because of the removal of sulphur. So, magnesium removes the sulphur magnesium form magnesium sulphite sulphur goes removed and sulphur amount when it becomes very low is about 0.01 percentage normally actually theoretically speaking it should be less than about 0.054 percentage weight percentage of sulphur remain in the melt

So, that sulphite cannot be poison basically sulphur actually poison the growth of this graphite and that is how the flakes forms. So, if you remove the sulphur you cannot poison then this low energy configurations of graphite can come into picture and that is exactly what happens now all the sulphite forming elements cannot be added because they can react like you can add cadmium cadmium form very easily sulphite, but cadmium react with melts and not only that it can oxidize very, very fast. So, that is why magnesium or calcium or cerium is better of calcium forms sulphite very easily those of you know it little bit of it still making they know that calcium carbide calcium slag is used to remove the sulphur or this sulfuration of the steel is basically done by adding sulphur so that means, basically this elements in the sulphur going to melt and make the melt cleaner. So, that the graphite can take low energy configuration and low energy configuration is this nodule.

So, I hope this is very clear to you that graphite is not a sphere is basically a nodule with different orientations and which is shown in this picture much nicely. So, this has a main tremendous effect on the mechanical properties first and foremost thing is that stress concentration is removed has is the case for iron grey iron. So, that part is gone it says it is uniformly distributed across this interface of the nodule. So, that is that is why these graphite iron or nodule iron is widely used in the load application where the toughness is requirement is high like housings in all these automobile the housings housing gear box housing they made up of these spheroidal graphite irons because it can absorb lot of lot of lot of you know impact energies when a car moves on a bumpy road the huge impact happens and these impact can break away these housing. So, that is why these housing are made up of these casting.

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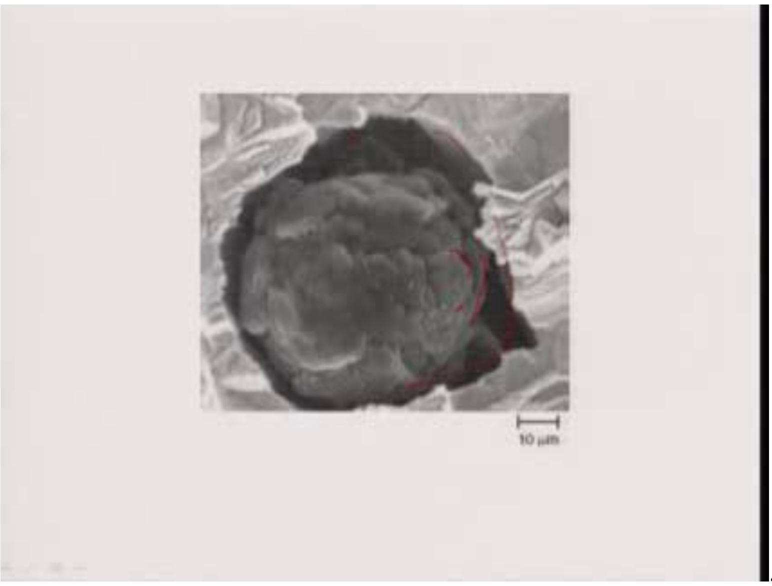

Another picture of these graphite you can see here is ACM picture heavily sample and these are the different things this is one I have shown for the grey iron one is a nodule. So, this part of the thing has out correct.

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Compositions and Properties of Ductile Cast Irons

Type	C (%)	Si (%)	Mn (%)	S (%)	Ni (%)	Mg (%)	Modulus (GPa)	YS (MPa)	UTS (MPa)	Elong (%)
Malleable										
Ferritic	2.25	1.15	0.40	0.10			172	255	386	20
Pearlitic	2.25	1.30	0.75	0.10			193	345	550	6
Nodular										
Ferritic*	3.50	2.40	0.50	0.01	1.00	0.06	158	330	448	12
Pearlitic#	3.40	2.15	0.50	0.01	1.00	0.06	158	448	655	5

* = Annealed at 900 °C and furnace cooled
# = as cast

Now, to give an idea comparative things I know there are different matrices has I said to you have ferritic matrix pearlitic matrix and these are the different steel composition if you look at the ductility you can see here an ferritic matrix has a twenty percent ductile things and then the pearlite well this is of the case for malleable iron malleable iron we will discuss later malleable iron are very ductile, but if you see a nodular you can actually achieve about 12 percent ductility which is practically good and pearlite also it is about 5 percent ductility strength wise you gain you do not lose much it is a 158 GPA this is modulus strength wise you gain lot 448 or 665 you can see has compared to on the malleable iron malleable iron I will discuss and then you come back to the stable again. So, basically I will just get a good combination of strength of ductility by making this spherical graphite iron.

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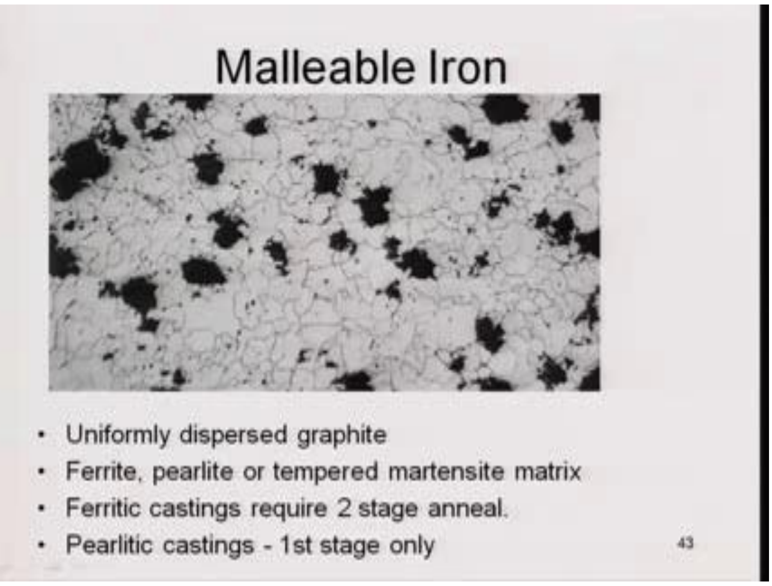

So, that is the part of what is called that is the part of the spheroidal graphite iron, but I think we just wanted to tell one more thing before we wind up this lecture.

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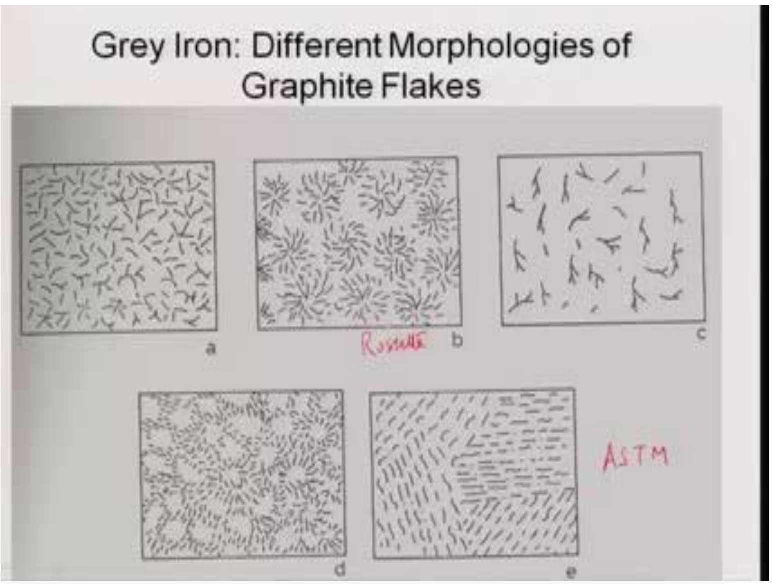

So, as you seen in in case of grey iron the graphites cannot different deflakes size wise shape wise basically you have you know rosettes you have long ones oriented or you can have you know random, but though that is the that means, you have many ways of graphite by getting the different graphite flakes.

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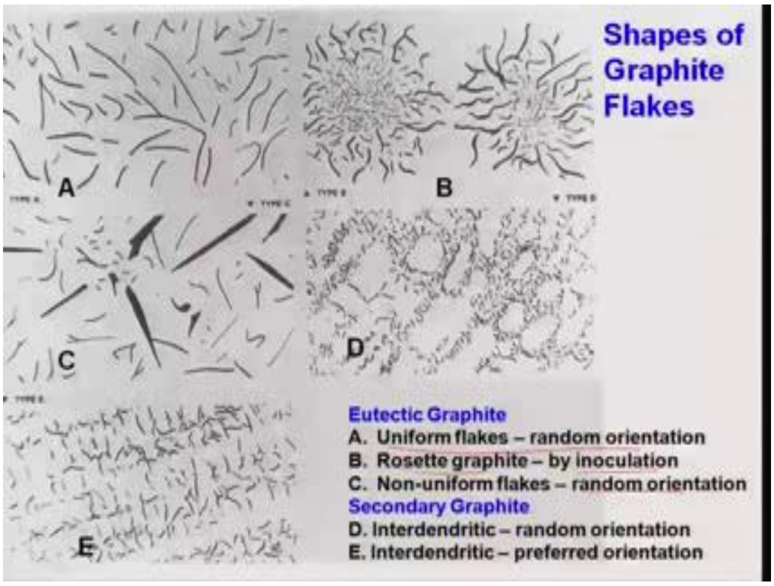

You do you do not have that you have very less you know limitation of these yeah and another important thing I forgot to tell you have very less stimulation on these; obviously, you want a spherical wants a particular shape. So, you do not have much control on the mechanical variation mechanical properties well now the question I need to answer is that how does the bulls eye form.

So, normally ones this graphite nucleate in the liquid that is because graphite in liquid high temperature graphite has a high melting temperature. So, for the growth of the graphite you requires lot of carbon. So, what happen it takes a nearby carbon it absorbs all the nearby carbon because it needs to grow and become bigger. So, nearby thing will be very lean in carbon that is why the nearby region becomes ferritic because it is again same thing the things form is transformation is again liquid transforming to gamma plus graphite. So, either graphite nodules form you have a gamma matrix this is gamma and what will happen it takes away all the carbon for the nearby carbon it takes it all the carbon because it takes away all the carbon from the nearby gamma the nearby region will be deputed of carbon. So, this gamma then will come back to alpha at low temperature, but on the other hand far away regions will transform to pearlites because the carbon content remain quite high there.

And that is the reason this bulls eye form normally, but there are other tricks on that now question is that if I keep the sample at high temperature for long time this graphite nodules will keep on growing as they keep on growing what will happen they will take all the carbon from the matrix from the regions nearby if they take away the carbons that regions the gamma will depleted of carbon whole gamma runs sample depleted of carbon is becomes depleted of carbon it will take away all the carbon from these regions and this matrix will become ferritic that is a way you can create both the way pearlitic and ferritic matrix. So, therefore, I told you that this is these are the basic features of nodular iron now I am in the next lecture I am going to discuss about malleable iron which is also a important material used in the space industry and I will tell you how things are done according to the theory behind it.