Phase Transformation in Materials
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Lecture - 41
Eutectoid Transformation in Steel (cont.)

So, we have been discussing about the pearlitic transformation in steels. And I showed you that if we cool down austenite from high temperature to below 727 degree Celsius at a very slow rate, austenite transforms to pearlite which is a mixture of ferrite and cementite. And this is very evident from the phase diagram itself.

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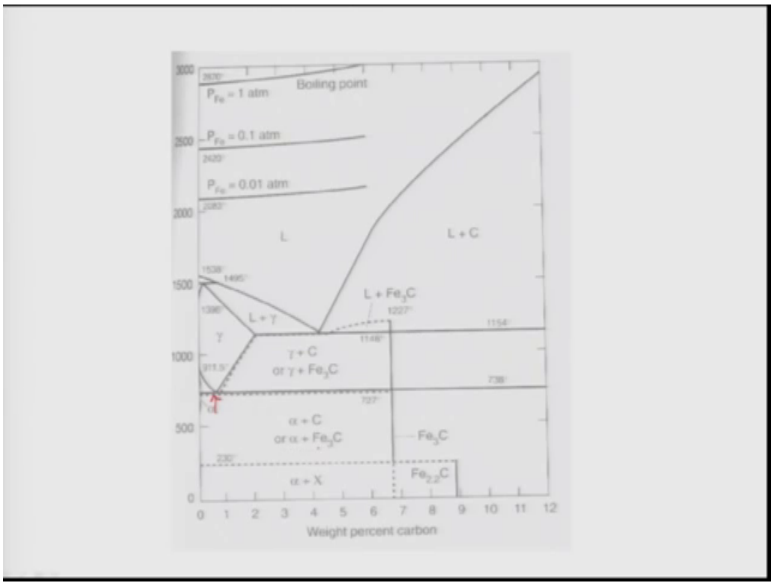

As you see here there is a eutectic eutectoid reaction at about 727 degree Celsius temperature for a carbon concentration of 0.8 percent carbon and this transformation actually leads to formation of alpha plus Fe 3 C.

So, that means carbon get partition between alpha phase and carbide which is known as cementite. And this happens when you cool the sample slowly that is because this is a diffusion on transformation and important pieces which partitions between the phases is the carbon. And carbon diffusion requires time therefore, if we cool it differently the phase transformation will be bypassed and something else will happen and that is the basic purpose of discussion today, what are the things which can happen. And I have pointed out that if we quench the steel from 950 degree Celsius temperature then it will lead to formation of a new phase called Martensite or otherwise if we quench the steel to an intermediate temperature at about 400 degree Celsius temperature then it leads to in in skip long time, then it will lead to formation of a new phase called Binate.

Therefore, depending on the type of heat treatment it calorie different structure by the way pure iron has a polygonal structure as you see here.

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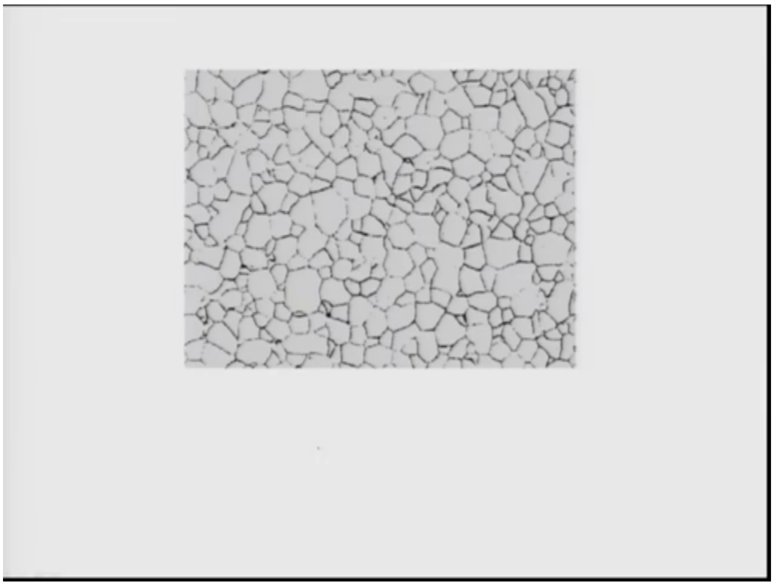

And this is normally body centered cubic magnetic iron. When we add carbon, we start seeing lot of the interesting stuff.

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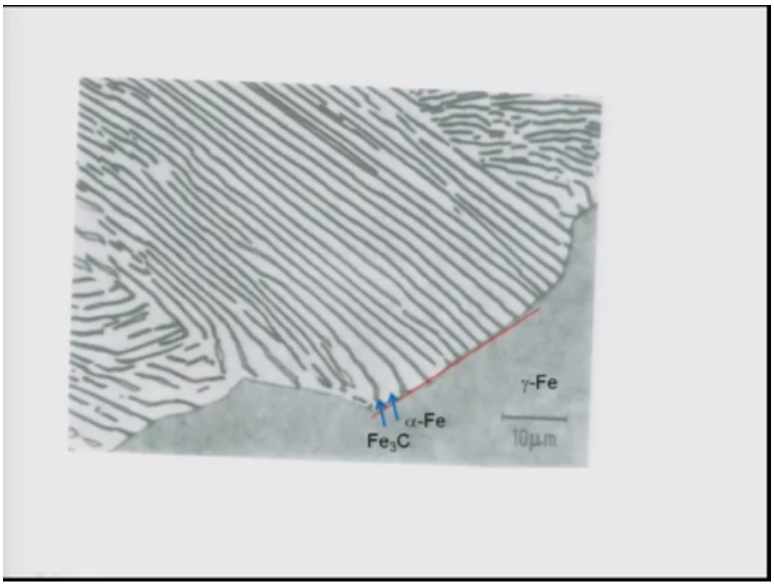

This is the first thing I showed you that if austenite is cooled below 717 d Celsius temperature it will lead to formation of Fe 3 C which is shown as a black color or gray color phase and alpha which is known as Alpha Fe. Basically, it has almost no carbon therefore, it is almost like a pure iron and the interface looks like a very curbed one between the gamma and the product phase. And we discussed lot about these; so let us known to that.

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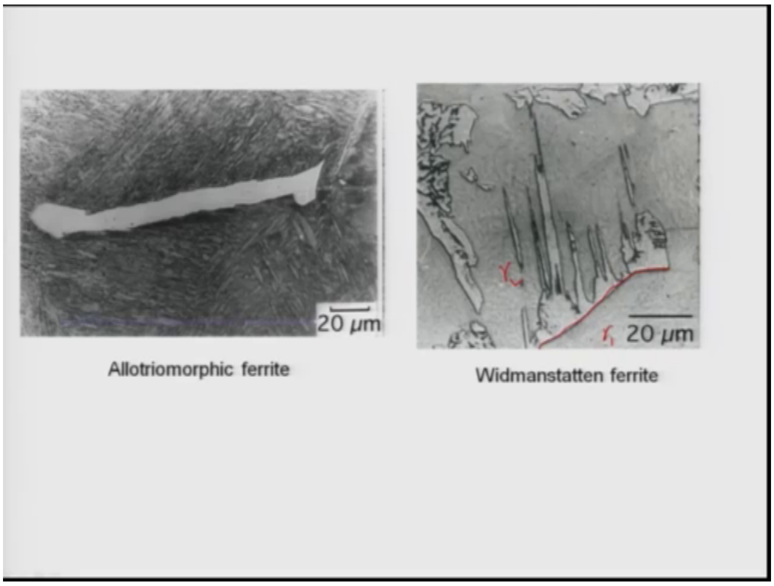

But you know we always have hyper hypo eutectoid steels which will also transform into pearlite, but it will transform into something else plus pearlite. So, if it is a hypo eutectoid steel you can have ferrite as a primary phase that is obvious from the phase diagram. Let us now discuss again the same stuff. But if it is higher than 0.8 to 8 percent carbon it will lead to hyper hyper eutectoid steel, therefore if the primary phase will be Cementite.

So, first let us look at how the ferrite forms, because this ferrite which is forming above the 727 degree Celsius temperature is known as a primary or pro eutectoid ferrite. So, these ferrites can have different kinds of morphologies and that is actually dictate the mechanical property of steel. Because as you know most of the steels are actually mild steels; that means, the carbon cost is varies from 0.4 to 0.6 to 8 percentage. So, they are basically hypo eutectoid steels.

So, if hypo eutectoid steels are produced in large quantity we must know what is their microstructure. As you know the phase diagram tells you that the carbon concentration 0.77 or 0.8 whichever is you take does not matter, it depends on the type of books you read, but it is basically 0.778 percentage as per as the phase diagram is concerned. So, it is less than 0.778 percent carbon then it will lead to such a kind of ferrite known as Allotriomorphic ferrite. As you see on the both side you have certain kind of a pearlitic morphology or on the grain structure or you can also have what is known as Widmanstatten ferrite. Widmanstatten ferrite is named again by the scientist known as a Alloid Widmanstatten. This actually played like structure, as you see here there are 2 grains as I mark this is gamma 1 and gamma 2 initially and then on the this is is the boundary.

So, the ferrite which has nucleated on the boundary had a orientation relationship with the gamma 1, that is why the interface remains flat. And it grows into the gamma two grain which is it does not have a fixed orientation relationships and these plates are actually growing very rapidly into the gamma 2 grain, that is what is observed from this picture. Such a kind of morphology is known as Widmanstatten ferrite. There is another type of ferrite which is very very rarely observe is known as Idiomorphic ferrite. So, it can form inside a gamma grain which is very rare. Basically nucleation of the ferrite will always happen on the grain boundaries as you know because grain boundary grain corners and grain edges are the best nucleation sites for their decision nucleation ferrite.

So, this Idiomatic ferrite which it forms inside a ferrite a gamma grain will be very rarely observed because that requires nucleation or event also. So, therefore, these 2 ferrites are commonly observed. Now let us look at what happens to a.

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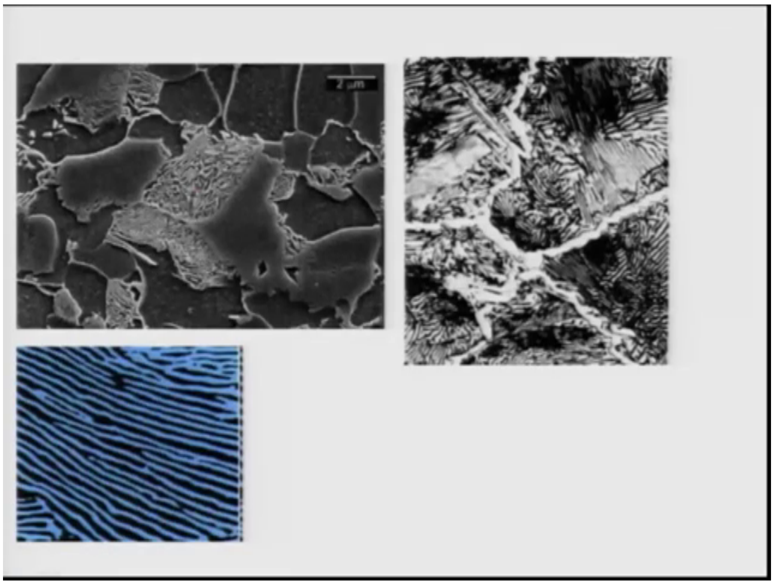

So, let us see that how does it look like even. So, as you see here this is basically typical you know structure of a hypo eutectoid steel and you see this is the pearlite and in in between that you have a alpha ferrite grains are presence on these sides as you see here. Basically, this is about 0.2 percent carbon steel that is why the paralytic pollen fraction is low. And pearlite if you zoom it up it will look like a lamellar structures we discussed long back.

On the other hand if I have a hyper eutectoid steel with a carbon concentration more than 0.778 percentage you will have pearlite in the grains of the gamma, at the grain boundaries will have discontinuous cementite. As you see here they actually cementite crystals up they are joined separately like this and they are present along each grain boundaries. But remember the balled fractions for pro eutectoid cementite is very low, that is also understandable from the phase diagram. If you do the proper calculation using the phase diagram we will find that pro eutectoid cementite balled fraction would be of the order of 5 to 10 percentage as compared to the pro eutectoid ferrite.

So, that is why this balled fraction of cementite is normally low. But nonetheless because cementite is a hard and brittle phase and its nucleates and grows on the grain boundaries of these prior gamma grains, this will the make the steel duct very brittle. That is why the steels of carbon concentration more than 77 percentage are used only for very specific purposes like knives blades or some other things which does not are actually not a structural applications. Because, there you need a very hard and strong material, but you do not need a good ductility that is why they are used. So, normally plates which you use real purposes they actually have a carbon concentration more than above, it is about 1 percent, 1 to 1.1 percentage carbon is used in the steels. There you have a hard cementatic phase at the grain boundaries present along with pearlite in the grains.

So, because of these cementite present in both in the pearlite as well as and the grain boundaries its becomes very hard material, but the same time it is also become very brittle, because the brittle phase is lining along the grain boundaries. So, that is about the pro eutectoid phases in the hypo and hyper eutectoid steels.

Now, let us look at what are the things it can undergo transformation as I am going back to the original lecture. So, as you know Austenite.

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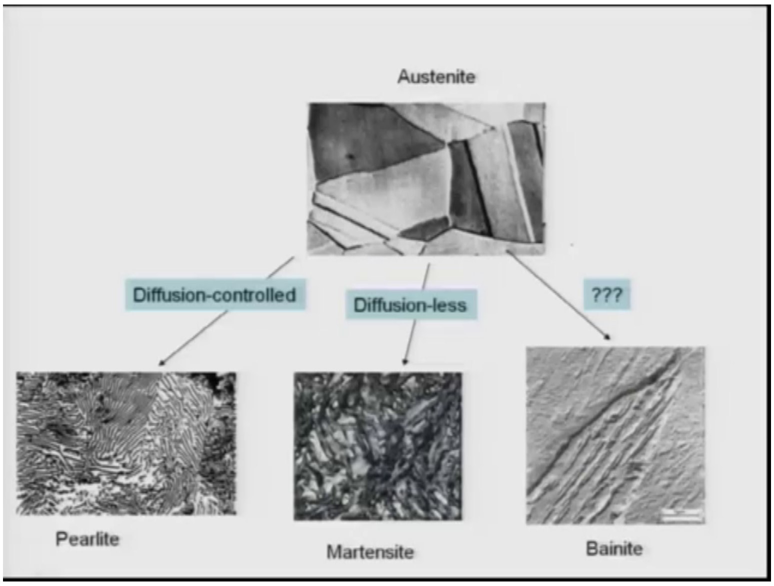

If I start the austenite which is a FCC solid solution of carbon and iron, slowly cooled it will transform to pearlite. That is as per the phase diagram which is seen and it is not basically diffusion control phase transformation, why because this requires diffusion of carbon as the most important thing controlling the phase transformation. If you quench in water you will have Martensites.

So, that is a completely opposite side. That is it is does not require any diffusion of any either carbon or anything. And in between if you quench to intermediate temperature and keep it there for a long time, you will have a new phase known as Bainite, again by the name a famous scientist is Ibrahim and as you see here this is a typical bainitic structure. It is very difficult to say where the transformation is diffusion control or diffusion less its basically can be cannot both the characteristics. So, still a debatable question in the literature.

So, first we will discuss about the bainitic transformations, as you know bainites actually specifically consisting of frame phases as a pearlite.

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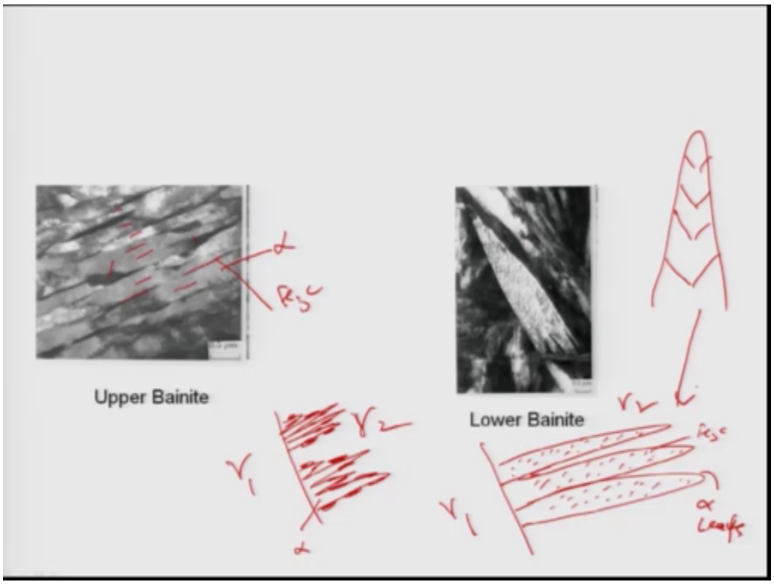

So; that means, it consisting of both ferrite and cementite, but morphologically and crystallographically distinctly different from pearlite. Let me just give a brief introduction suppose if I take a steel say let us about 0.6 percent carbon and directly quench from 950 degree Celsius temperature to about 400 degree Celsius temperature, these remain supersaturated. Or if you want let me just go back to the phase diagram, I explain you again here it is.

So, suppose if I take about 0.6 percent carbon steel and if I directly quench from 950 this is someone 950 to here to 400 degree Celsius temperature here. It should transform into Alpha ferrite as a pro eutectoid ferrite and pearlite right as you have seen the microstructure, but if we cool it slowly then only it can happen that way. Suppose we are quenching the steel from 950 to 400 degree Celsius temperature in one go and keeping there in a spa bath in its, basically fixed temperature bath for long time sometimes maybe 2 days as long as that then it will lead to formation of Bainites.

Depending on the temperature to which the steel is quenched it can lead to 2 types of Bainites, one is known as upper Bainite which can happen at a higher temperature like about 350 to 450 degree Celsius temperature or it can be lower Bainite which is basically nothing, but a Bainite which forms at between 350 to 280 degree Celsius temperature. So, whatever is the situation Bainite is nothing but a mixture up again ferrite plus cementite, but distinctly different from pearlite. It does not look like pearlite morphologically, it does not form with the way pearlite forms and not only that crystallographically distinctly different from that.

As I said the first thing we will discuss is the upper Bainite which forms at high temperature. Upper Bainite this 2 picture shows 2 different morphology, upper Bainite actually basically phase is consisting of alpha plates and in between the alpha plates you have what is known as Fe 3 C precipitated. that is why you see these are the alpha plates red color things which I am marking these are the alpha plates. And in between the alpha plate these are actually these things which is precipitated you see here the black color stuff here and there they are actually Cementite. So that means, what; that means, if I have to draw the microstructure suppose if I have gamma 1 and gamma into 2 grains and this is a grain boundary.

So, what will happen we have quench the steel to a temperature about suppose 3 200 Celsius temperature. So, at the grain boundaries of gamma, alpha plates, alpha basically needles actually well suit out. Like I have shown you just now for a pro eutectoid alpha they will suit out and they will grow very fast why? Because driving force is very high you have given submission in the large under cooling to the steel to the basically Alpha to gamma iron, gamma iron has been quenched. So, from 727 to it has gone on to 400; that means, 327 degree the kelvin is the under cooling. So, large under cooling means the growth rate of Alpha plates or the needles which have forming from the suiting, from the grains boundary of gamma will be very very high.

As you see here the way I have drawn with the this alpha ferrite grains or the plates have fixed quenched relationship with the gamma 1 grain and no orientation relationship with the gamma 2 grain that is why they are growing inside a gamma to grain. Now once they grow what happen? Alpha has almost no carbon and it is growing into a supersaturated gamma phase, because they are going to supersaturated gamma phase at a very high speed so they are rejecting the carbon into the nearby gamma.

As they reject the carbon the carbon question nearby as in regions will be increasing very very high. Initially it was supersaturated gamma grains, but then alpha forms and these alpha grains has no carbon inside it because alpha as for the phase diagram it is has almost 0 percent carbon. But although this is a metastable phase transformation in may not follow (Refer Time: 14:12) phase diagram, whatever the case alpha will be containing very less amount of carbon than the gamma phase.

So, because of that the excess carbon which is there will be precipitating as a carbide on the alpha grains, basically on the grain boundaries of the alpha this. Needless that is why it will look like this. That is what I am drawing here, you see this is how these cementite where nicul tate, nucleate and grow on the sides of the alpha plates. This is a typical structure of upper bainite. You this is what you know to understand, how the transformation happens? Transformation basically happens in the way that at when under cool is very large nucleation of alpha is very easy because under cooling large means driving force for the nucleation and growth is high. And as soon as the steel is quenched to found easterlies temperature these alpha needles will suit out from the grain boundaries of the prior gamma grains.

And this this is how they will grow because their growth will very fast into gamma grains under cooling is high and leaving behind the supersaturated gamma from which then even a Fe 3C can precipitated out. This is not same as pearlite, please keep it mind, pearlite has parallel lammily or Alpha Fe 3 C, Alpha Fe 3 C to be to be making you sure the pearlite looks like that, you see the picture here pearlite looks like that you see the picture has a parallel looks like these it has a parallel lammily of cementite and F alpha, but on the other hand here cementite is precipitated on the boundaries of the alpha needles therefore, these are not same.

So, that is what actually happens for the alpha and this alpha actually are same thing like Widmanstatten alpha. They are not like the electro morphic alpha they are actually looking like Widmanstatten alpha plates all puddles, whatever way you can talk many people say needle or plates difference between is that this morphologically they looks similar plate has a three dimension, dimension quite thicken up.

Now, as you quench still to lower temperature if I quench the steel to about 350 to 280 degree Celsius temperature then I will have a new morphology known as when lower Bainite, what is lower Bainite? Again lower Bainite is similar like consisting of a Alpha sheath or just like Alpha leaf this is Alpha leaf you see here just like a tree leaf it looks like alpha leaf.

Obviously under cooling is larger even here because it is under cooled to a larger extent these Alpha leafs will be shooting out from the gamma grains boundaries, gamma grain boundaries and grow inside the supersaturated gamma very very rapidly. So, therefore, Alpha leaps leaps will be growing they become actually model much like a you know these things become like a more like a the tree leafs structure. And they grow they actually grow like very fast like this. So, but what actually happens is that the alpha leafs which are growing inside the gamma will be have been similar constant carbon concentration as just like a gamma.

So, it has a characteristic like a massive transformation, but it is not truly a massive transformation. Because composition is not changing, all the FCC gamma is tending to BCC alpha. But Alpha cannot hold such am high amount of carbon right, because Alpha has solubility limits of alpha carbon in Alpha is very low compared to gamma. So, what will happen to those excess carbons the excess carbon? It will then precipitate inside Alpha, Alpha sheaths just like that. So, therefore, you have a discontinuous precipitation of Fe 3 C inside this alpha leafs leafs actually. So, these are Fe 3 C and this is Alpha leafs, okay.

So, that is exactly how this lower Bainitic transformation happens, very evident, very clear that because the Fe 3C participate it inside the supersaturated Alpha leaps therefore, this is distinctly different microstructures compared to the, compared to the pearlite or compared to even upper Bainite. Remember crystallographically this also different when in pearlite both Fe 3 C in Alpha grows they will have a distinct orientation relationship among them, but they may not have any orientation relationship with the prior gamma grains. But here they will have orientation relationship with the prior gamma grains.

Similarly look at this one upper Bainite the way I have drawn. The Alpha plates or needles they are shooting out from these grain boundaries. Therefore, these things will have a distinct orientation relationship with the gamma 1 grain on the other hand they will not have much orientation relationship which we will see the gamma 2 grain. But when again cementite precipitates on the grain boundaries or the boundaries of the Alpha needles there will be again orientation relationship between cementite and Alpha.

Here obviously, same thing gamma 1 and gamma 2 you see here the alpha will have precipitated relationship with gamma 1 and then cementite precipitate inside these leafs. that is what I say they looks like leaf. If you look at a leaf structure they look like this, tree leaf structure will be like that. So, same thing happens here these are similarly to with these. The way the discontinuous precipitation Fe3 C happens on the Alpha leafs will be like that. Many people call this excess basically plates of Alpha and the upper Bainite is known as needles of Alpha or leafs of Alpha.

There are different-different kinds of misnomer snail literature. So, let us call it Alpha leafs in case of lower Bainites and Alpha needles or plates in case of upper Bainite, that is better definitions as far as the morphologies concerned. So, that is the way transformation happens. Now let me take you to few of these you know micro graphs which can show you the things, left one is basically upper Bainite.

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You see here these you can clearly see that Alpha needles or you can see that and within which cementite has they, sorry they Alpha needles and the boundaries of that cementite has precipitates you can see here that is okay.

And here these are actually lower Bainites that is very clear. This is a sheath, this is a leap and inside which these are actually cementites precipitate out.

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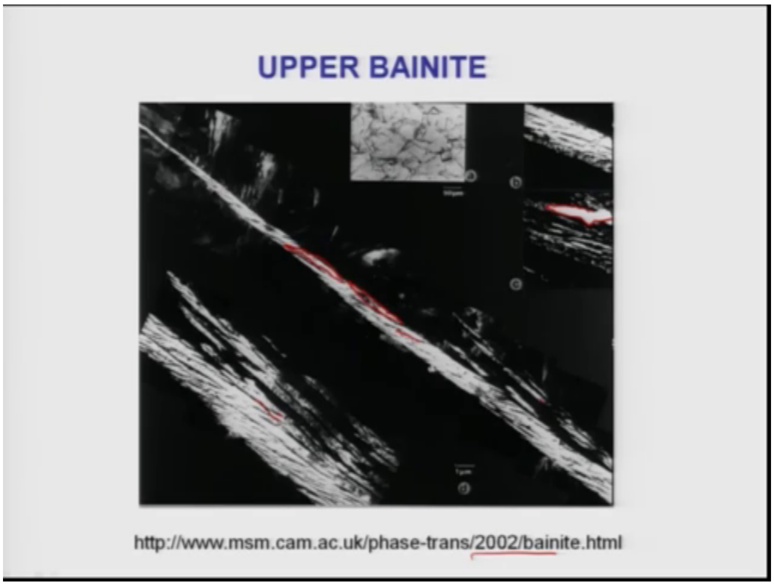

I think, I will have some more picture for you, this is upper Bainites. that is what is seen here that these are the Alpha ones and between these are the actually cementites, you see between the Alpha plates this has been this is taken from the home page of Professor Pardesia that is it is given here. You can see that this is a long Alpha plates or needle and there are many actually and in between that we have this one this is say this about this one I draw this is a thing and in between that this precipitate happen this is the other one I draw okay.

Similarly, or rather it is very easy to see here this is safe actually needle and on the sides of the needles you have precipitate such of the carbide phase a.

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But the one which is lower is shown here this is just like a leaf. You see this is just like a leaf, big Bainitic plates and in between the leafs you have cementite precipitates formed. That means, the way they have form is a still different Alpha grown like a supersaturated Alpha without no injection by carbon to the nearby gamma. So, all these Alpha leafs have grown like that, then because it is a lot of supersaturate of carbon and cementite has precipitated later on from this microstructure.

So, that is the important aspects of Bainites. So, Bainites due form and the intermediate temperatures and they have a very distinct morphology and micro structures as compared to pearlite, they are not same, you have to remember that. So, that is to what something people forget. And it is impact at upper Bainite when its forms at high temperature it is very difficult to distinguish upper Bainite and the pearlite which forms a lower temperatures from the optical wise a micro structures, very is this difficult distinguish. In fact, it is almost impossible to distinguish because they look like same. They look like these alpha plates, Alpha needles and the cementites. Cementite would look like a discontinuous here, but you can also see that cementite in pearlite can be broken also, broken lamellar cementite is also present.

So, we are normally get me you know con confused with the morphology of the upper Bainites and that is why you need to look at is crystallographically in under times electron microscope look at what the kind of crystallography could not, relationship it has with the prior gamma grains are with the cementite then only you can clearly say this is in Bainite under pearlite. So, but lower Bainites, it is distinct, distinctly clearly visible under microstructure because it has precipitation of the Fe 3 C inside these supersaturate Alpha grains which have suited out from the suit out from the gamma grain boundaries.

Therefore, I will just stop here for the Bainitic discussions. In the next class I am going to discuss about Martinsites, they were Martensites are very important, because they are the hardest phase in the steel microstructure. And we use when these Martensites many applications.