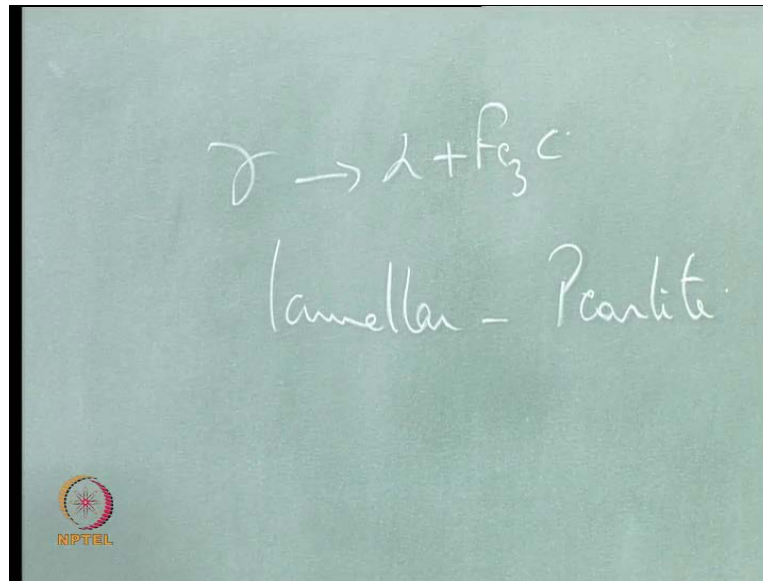


**Advanced Metallurgical Thermodynamics**  
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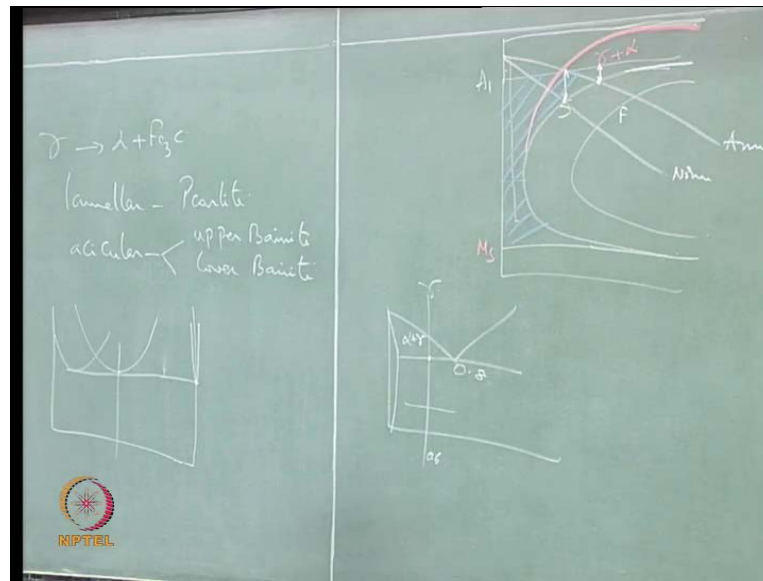
**Module #01**  
**Lecture #24**  
**Bainitic Information**

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We will continue with our discussion on the eutectoid transformations. we took up the case of the steel which is a easy and more commercial example for us, where the gamma gives you alpha plus F e 3 C. and in this we see that depending on the temperature at which this transformation is taking place, where the gamma giving alpha plus f e 3 c, there are different types of products that are possible; different morphologies that are possible and each morphology has certain name given to it. The lamellar morphology is what we call it as the pearlite. And you actually get this usually at higher temperature. At temperatures closer to the one temperature; closer to the transformation temperature when the under cooling is smaller.

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When the under cooling is larger, you end up into the domain which is, if this is the A1 and this is the start; this is the finish of the pearlite transformation, if you are somewhere, if your under cooling is somewhere here, below the nose, then you end up into another type of morphology which is what is called the acicular morphology. Where, you call them as either upper Bainite or lower Bainite. In fact, if you take some hypo eutectoid steels, it is possible that if your under cooling is high, then you may not even get let us say the pro eutectoid phase.

We all know that if I take a steel with, let us say, a composition like this. This is 0.8 or eutectoid composition if I take something like point 0.6 percent: in principle this alloy as you cool from gamma, it gives you alpha plus gamma first. And then this alpha plus gamma, as you cool down, the amount of alpha will increase and once you reach this temperature you will have some alpha plus gamma and the gamma will undergo this transformation. This is what is known to us.

But if you have cooled this gamma very fast to some temperatures low like this, then you may see the situation that you actually may not even get alpha directly the gamma, may undergo a transformation. for example, if you look at this, mind you if you carefully observe this particular start of transformation and the end of transformation, both of them as you come closer to the transformation temperature they almost become parallel to the transformation temperature. What does that indicate? it indicates that the incubation

period increases significantly. In fact, the incubation period, as you reach the one temperature it actually becomes infinite.

That means the start of transformation itself takes an infinite time. Why does this happen? Under cooling is less. When the under cooling is less what is less? The driving force is less. And if the driving force is less then, the activation barrier is high. So, at transformation temperature the under cooling is actually 0. That means, the driving force is 0.

For the gamma to transform to the pearlite, in fact, at A1 if I draw the free energy composition diagram, how does it look like? You have a gamma; you have alpha. And somewhere here let us say you have a cementite, I mean let us say, this is pure carbon going that side. Or if you want to take this as a cementite, you put cementite here it is up to you. This is the free energy of the cementite let us say. So, at the A1 which is a eutectoid temperature, in principle this is the type of the situation. And once that is the situation if I am considering an alloy of eutectoid composition, if I am choosing the alloy of eutectoid composition there is no driving force for the alpha plus cementite to come. Because all of them are on the same tangent. So, once there is no driving force obviously, the activation barrier is infinite.

So, in principle there is no transformation possible. And that is indicated by the TTT diagram going parallel to that, the transformation temperature. This is true for this or this. This particular line which we have drawn, this indicates the formation of alpha from the gamma as you cool the pro eutectoid phase in this particular case. So, this is gamma plus alpha. That is the reason why in fact, if you carefully observe. Have you ever checked what the difference between a steel which is annealed and a steel which is normalized is? In terms of the micro structure can you tell me? A point six percent carbon steel I am not take, let us say take a point eight percent carbon steel and tell me what should be the difference?

Yes? No, I am asking you micro structure difference. What will be the difference in the micro structure of point eight percent carbon steel, which is annealed and which is normalized? Prarna, do you know? Normalized. Anything more the interlamellar spacing in the pearlite within the pearlite is coarser in the annealed sample and it is finer in the normalized sample. Why? Because the nucleation rate is higher. Why nucleation rate is

higher in a normalized steel? Whenever I normalize a steel basically I am cooling it faster.

Imagine that this is the cooling this is the TTT diagram. Forget about the alpha plus gamma just for the time being you ignore that this is existing and I am taking a steel above the  $A_1$  and I am cooling it. Let us say these are the two different cooling rates. If these are the two cooling rates: one is let us say, corresponds to the annealing; one is corresponds to the normalizing, let us say. What is the difference between these two cases? You will see that the one which is the annealed one intersects the TTT diagram at this point. the normalized one intersects the TTT diagram at this point.

Once this happens then you would see the difference between these two is the extent of under cooling. If you look at this, the extent of under cooling that the normalized steel has gone through is different from the annealed steel. The under cooling is smaller for an annealing and larger for a normalizing.

Even physically also you can understand that when you are cooling is very slow the transformation occurs near the transformation temperature. When you are cooling it very fast the systems gets under cooled, because of the inertia in the system. Why does this inertia come into picture? Because a product phase has to be nucleated; it needs diffusion. Alpha plus Fe<sub>3</sub>C has to nucleate. So that means, a critical radius has to form. That means you need certain time. If you are not providing that time the gamma will tend to keep on remaining as gamma until a certain lower temperature, where its starts transforming. That is the reason why you will see a normalized one will have a higher under cooling than this. The moment you have a higher under cooling, automatically a lot of nucleation kinetics come into picture. We have discussed this a number of times.

So, when you have a higher under cooling obviously, the activation barrier is smaller because the driving force is larger; the higher the under cooling the driving force is larger. In fact, what would happen to this? The higher the under cooling the gamma curve will be much above the alpha plus cementite. As a result for the same alloy composition I can see that the driving force will keep on increasing. This will get shifted. Why? Because as I come to lower and lower temperature below the  $A_1$  gamma is less and less stable. And the alpha plus Fe<sub>3</sub>C mixture is more and more stable. Because we are below the eutectoid transformation temperature.

If at all gamma is remaining below the eutectoid transformation temperature it is only metastable gamma. That is it. So, it cannot in principle remain as a stable gamma it is only metastable gamma. So, that is why all this that you see here, all this gamma that you see, until you reach this ms temperature this whole left of this curve is all metastable gamma. Gamma is there, but it is not a stable gamma.

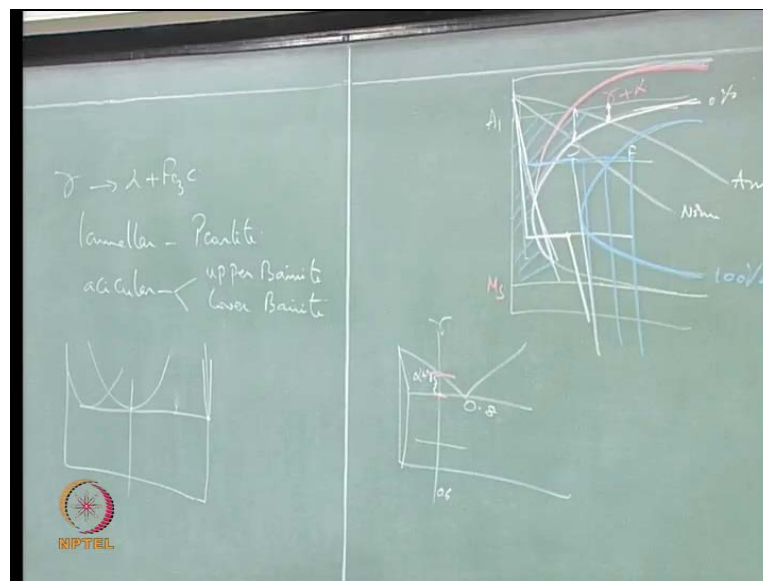
In principle when I when I simply just use two different cooling rates, I am getting two different under coolings. And because of the two different under coolings obviously, the activation barrier is low; the nucleation rate which is related to the activation barrier exponentially is also going to be very high. I, we know a into exponential minus delta g star by R T. So, as a result you will see that if the activation barrier is small then the nucleation rate is higher. If the nucleation rate is higher then, you will see inter lamellar spacing will come down. That is the reason why, in normalized steel you see a smaller inter lamellar spacing, in annealed steel you will see a larger inter lamellar spacing.

In addition you would also see one more difference. What else? Pearlite colonies. Again it is going to be smaller, the number nuclei. Here when I say nucleus it is a pearlite colony getting nucleated. It is not a simple one single phase getting nucleated; one pearlite colony is getting nucleated. So, when I say nucleation rate is higher a number of pearlite colonies are getting nucleated within a particular grain. So, one grain is broken into a number of colonies if the under cooling is higher. If the under cooling is smaller you will see it is going to be less number of nuclei; that means, bigger colony size. So, colony size and the interlamellar spacing, these are the two basic differences that you see in a normalized and annealing. This is as far as it is a point eight carbon steel.

The moment I make it point six what will be the difference now? These two are any way going to be there, whatever two differences that we just now talked about it. in addition something else would be different. Amount of hypo eutectoid phase, is going to be smaller, in a normalized case when compared to annealed case. That means, basically if I am cooling it faster this particular temperature difference which is what we call it as what is, what do we call that? This? There is a name given for that range. This, what is it called? From here to here, for a given steel. It is called intercritical range. Inter. because these are the two critical temperatures, what is this temperature? A<sub>3</sub>, A<sub>1</sub>. A<sub>3</sub> and A<sub>1</sub>.

Whether it is c or r depends on whether you cool or heat, let us is not bother. So, this is the A 3 temperature this is the A 1. So, between A 3 and A 1 is what we call is a intercritical range. And that range there is certain amount of what is called some temperature difference between a 3 and a one. If I am cooling it faster, the time taken for crossing this range is going to be shorter. And once that is the case the probability of gamma coming out, because you are crossing that very fast, that particular inter critical range if you are crossing it very fast the probability of the time available for the alpha to come out of gamma is going to be smaller.

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So, when you are cooling it faster the amount of what is called the pro eutectoid ferrite or if you are on the other side pro eutectoid cementite to come out will be smaller. So in fact, if you keep on cooling it faster and faster you would even see a situation where you may not get the alpha at all. For example, if I use a cooling rate something like this you do not intersect this alpha plus gamma region at all. If you do not intersect the alpha plus gamma region, this alloy which you are cooling like this would not give you any pro eutectoid phase; it will straight away give you some pearlite.

But at the same time, because this cooling curve is not intersecting this, because it is not intersecting this then you will see only some amount of gamma will transform to pearlite the remaining gamma will be left out and once it you reach below the ms that remaining

gamma will undergo a martensitic transformation. So, such an alloy would not give you any pro eutectoid alpha it could simply give you pearlite plus the martensite.

And instead if I cool it to a high temperature like this and hold it there then you the same gamma would undergo a martensite, a bainitic transformation whether it is upper bainite or lower bainite. And if I hold it for a shorter time and then cool it then you will get a what? Bainite plus martensite. Not pearlite plus. If you cool if you hold it here and then quench it then you get a pearlite plus martensite. If you hold it here and then quench it you will get bainite plus martensite, because below the nose we have already discussed yesterday that the morphology of the pearlite is different. You do not get lamellar.

So, it because the of the diffusion problem the gamma first gives you alpha of the same composition as that of the gamma. So, it is a polymorphous transformation, followed by precipitation. Whereas here, it is first actually it is cementite coming out and then alpha coming out. So, that is the difference between this and this. So, that is why you get a lamellar alpha plus cementite mixture here, and if you have not crossed the end of transformation and if you are. In fact, one can draw a number of other isotherms here. Other, if you call this as a for example, call this as start of transformation, it means 0 percent transformed. If you call this as end of transformation, it means it is hundred percent transformed. between the two we can draw a number of other C curves which indicate different percentage of transformation.

All of you possibly know how we get this: TTT diagram. You basically take a steel of a number of samples which are all austenitized there and then brought to a particular temperature. At that temperature at different regular intervals, you take out the steel and then quench it. And then look at the micro structure. Or indirectly you measure the hardness which is an indicator of the micro structure. So, in principle the micro structure is much more accurate. So, you keep on seeing the micro structure for example, if a steel is quenched from here itself, what would you get? You get a hundred percent martensite. If a steel is held up to this time and then quenched, then you would have some of the gamma would have transformed to pearlite and the remaining gamma would give you the martensite.

And like that if I keep on holding for different-different times like that, you would see once I cross this line I would not get any more martensite. Why not? I am crossing the

ms temperature while quenching, because there is no gamma left out. And we know pretty well that pearlite cannot transform to martensite. Why pearlite cannot transform to martensite? It is already pearlite is already stable. No that is; austenite is also stable. Of course, at a different temperature. it is not that the reason.

Why pearlite cannot give you. So, martensite forms by a shear transformation of one structure to the other. That is why the FCC structure of the austenite shears and gives you martensite. Whereas, when you are talking of pearlite it is already a two phase mixture. with two different structures and two different compositions. So, such a two phased mixture cannot shear and give you one single phased structure. So, that is the reason why a pearlite cannot.

So, if I have a pearlite and I want to get a martensite what do I do? I have a pearlite and I want to get a martensite out of it. Again re-austenitize it and quench it. That is the only solution. If I have a pearlite and I want to get a martensite out of it the only way is re-austenitize it. Heat it back to above  $A_1$  and then hold it until all the pearlite gets converted to the austenite, and then from there you quench it and depending on your quenching rate, you either get a partial martensite or a full martensite. Depending on whether it is intersecting the start of transformation or not intersecting the start of transformation. But if intersect the cooling curve, if it intersects the end of transformation, there is no chance for you to get a martensite.

Once the cooling curve, any cooling curve that you adopt if it intersects the end of transformation, the moment it has intersected the end of transformation that means, the transformation is complete: gamma to pearlite. When we say transformation, we are talking about gamma to pearlite transformation. That is complete. And once that is complete then obviously, even though you say sir I am cooling it and then coming it coming in below ms its of no use, already transformation has taken place.

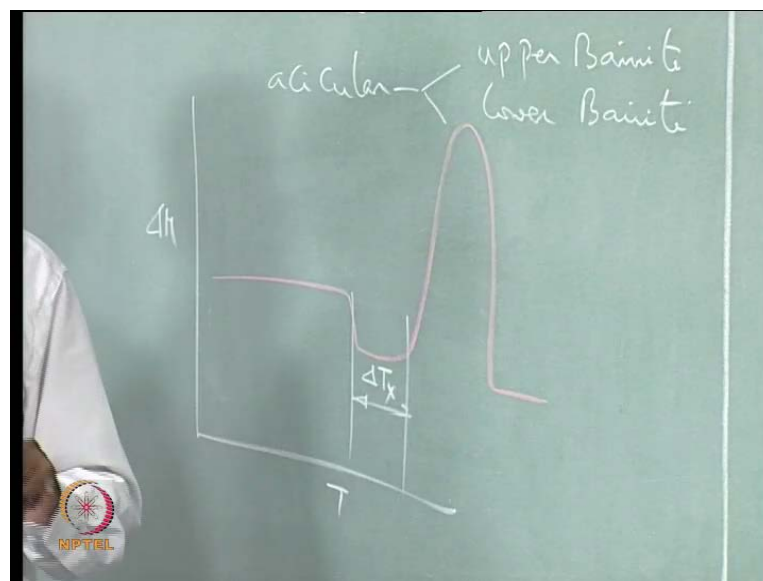
This is similar to saying that, sir I take a liquid, bring it below  $T_g$  why glass is not forming? It depends on whether before you bring it to  $T_g$  whether it has formed crystal or not. If it has already crystallized then that crystal cannot give you a glass. Crystal can still give you not a glass, but amorphous structure under different circumstances. Can you tell me when? A crystal can become amorphous. Have you ever



heard of such situations? Yes, ball milling is one: irradiation is one. Basically you have to break the crystal structure. You have to destabilize the crystal structure.

How do I destabilize? I introduce lot of defects into it. So that, this crystal with lot of defects, becomes unstable. And at some stage it cannot remain as a crystal and under goes a transformation. We call that as an amorphous material, we do not call it as a glass. Glass is a term which is specifically, you know, reserved for a liquid to solid transformation. Because it is, because the reason is when you take such a glass, because it has come out of the liquid when you are heating this glass you start seeing first a glass transition, where is glass that is what possibly you have seen when we talked about it earlier. That for example, if I take a glass and then and do a DSC, this is what you get. I am heating a glass this is  $\Delta H$  verses temperature; enthalpy evolved, verses temperature.

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If you do that the glass first gives you a liquid. At this is what kind of a transformation? We already talked possibly. it is a second order transition. And in a second order transition what do you see  $\Delta H$  is 0.  $\Delta H$  is 0. Because  $\Delta H$  is 0 you do not see any peak there? You just simply see a step. And now once this super cool liquid is crystallizing you get a peak, and the area under a peak tells you how much is the  $\Delta H$  evolved or absorbed during any particular transformation.

And this particular region, from here to here is what we call it as  $\Delta T_x$ , which is called super cool liquid region. So, where you have, the glass is no more a glass it has become a liquid, but the liquid is still remaining as liquid; it has not yet crystallized. So, it is like a liquid state. That is the reason why many people are doing a lot of deformation in this domain. Metallic glasses and then getting super plastic deformation. Glass we all know it is a brittle, but the same glass can be super plastically deformed if you are in this domain, and get any shape that you want. So, many people do that. In fact, all the shapes of normal glasses that we talk about also are more or less done like that, in a liquid state they do it, and then freeze it.

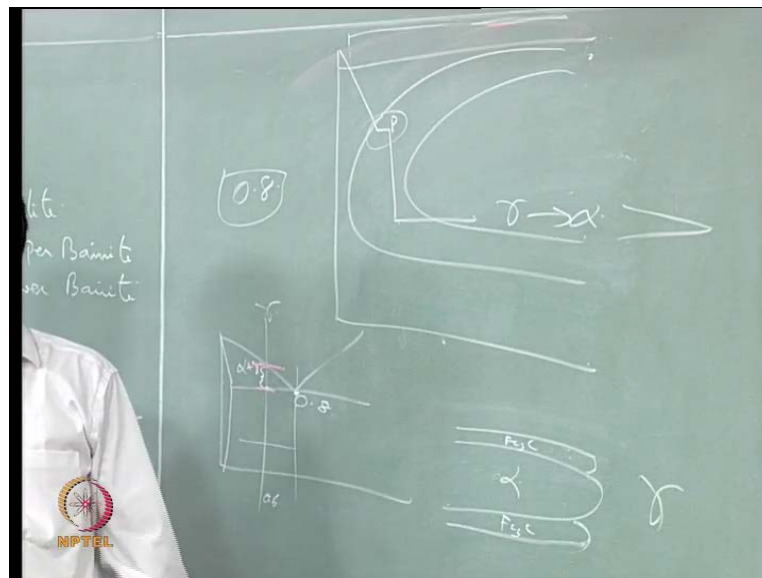
Similarly here you can do that shape it and then further heat it if you want so that you can crystallize. And in fact, you can control that crystallization by controlling the temperature and time of crystallization so that you can induce nano crystals in a glass. Lot of people have shown that, when you induce nano crystals into a glass, you can make the glass very tough. People have shown that a typical wind shield of a motor vehicle like a car will not crash into pieces when there is a crash whereas, it simply bends and goes back.

There are examples like that where, basically you induce small nano crystals so that a small shear bands form and then there is no growth of that. So, it because each particle will act as an obstacle for the shear band to grow. So, as a result you have some kind of an obstacle for any crack propagation and that gives you higher fracture toughness. Fracture toughness is always related to either crack initiation or crack propagation. If you can make the crack either initiation more difficult, how do you make the crack initiation more difficult in a typical metallurgical scenario? We do some things. In steels let us say, you want to make the crack initiation more difficult what do you do? Reduce inclusions. Harden the surface. Yes, sharpening. There are many things where people up you know try to seek compressive stresses on the surface.

Hardening is one way; even inducing compressive stresses on the surface so that there is no; fatigue life for example, everybody knows fatigue life increases when you do sharpening. So, it is simply that. So, you either make the crack initiation more difficult or crack propagation more difficult. One of the two, if you can do that you can make a material tougher any way. So, that is yeah yeah. This is, when we come to martensite we will talk about it.

So, there is also always something called deformation induced martensite. You can, the  $M_s$  temperature can go up. You, all of us know that  $M_s$  temperature whenever you add alloying elements it always goes down. Why does it go down? Again when we come to martensite we will talk more about it. Basically again shear is made more difficult. Because martensitic transformation is a shear transformation. Whenever you have alloying elements present there because of the strains that are there around each of the element that is sitting, you would see this shear becomes more difficult. and when the shear becomes more difficult  $M_s$  goes down. we will talk about it when we came to martensitic transformation.

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Any way coming back here, so there are possibilities where you may not even get a ferrite a pro eutectoid phase and straight away get a pearlite. And depending on the actual cooling rates that we are adopt fine. So, to start supplying carbon atoms to  $Fe_3C$  and  $\alpha$ , the  $Fe_3C$  needs more carbon atoms. So, you need carbon atoms to diffuse from the  $\gamma$  which is here, into this. At this temperature that diffusion can be very difficult, because you need a longer diffusion, because from the whole of the  $\gamma$  grain the atoms have to start moving. And that, because is difficult at lower temperature this pearlite whatever has formed will not grow much.

It may grows, but at a very slow rate. But at the same time, the  $\gamma$  that is there is not stable at that temperature, because you are far away from the  $A_1$  temperature. So, this

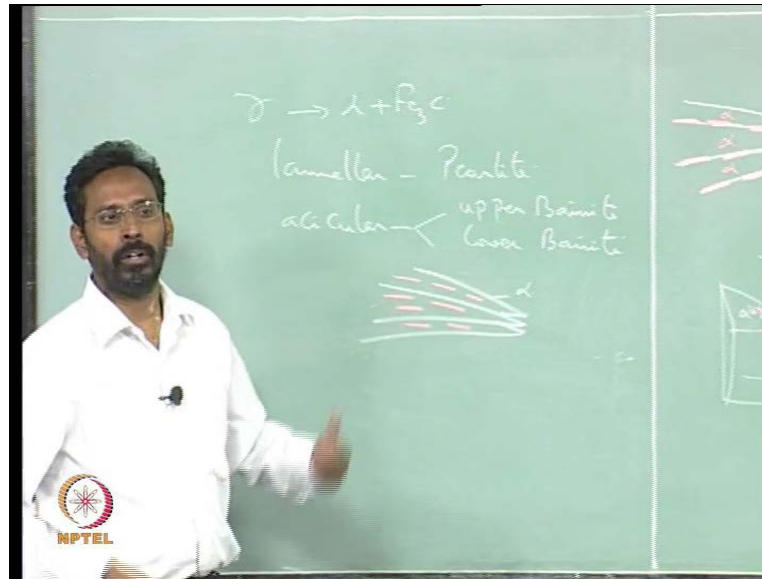
gamma has to somehow transform. As a result new nucleation events will occur. So, this gamma which is now, in fact, this gamma will be already depleted in carbon. You are starting from point eight carbon let us say, but this gamma will not be point eight carbon, because already some pearlite has come out of it. Because some pearlite has come out of it, some carbon has come out of it so, there is a possibility that some depletion might have taken place.

Otherwise if you think of it, you know other way to look at it pearlite though there is cementite and ferrite, the overall composition of pearlite is always point eight. Isn't it? When I say here you have pearlite coming out what is the composition of pearlite if somebody asks though it is a stupid question, because it is not one single phase. If you say what is the composition of pearlite then basically it is point eight only. Only thing is the fraction of alpha multiplied by the composition of alpha plus fraction of cementite multiplied by the composition of cementite should become equal to point eight.

And if you call this as a pearlite where alpha and cementite is there so, the overall composition of the pearlite is point eight. So, it is because gamma of point eight is giving you this. So, we can say that this pearlite would have point eight, but some regions of gamma will be left out; that gamma because it is not stable at that temperature it wants to nucleate something. And that is where you will see this gamma would undergo a polymorphous transformation and gives you alpha. In some other regions of alpha, of gamma; and that particular thing will be basically in an acicular nature and depending on where you have actually held it that may give you either lower bainite or upper bainite.

Though academic exercise a number of people who have tried this out and see a mixture of lamellar and acicular structures. This is possible. We have talked about it yesterday; a upper bainite is one where; if you look at if you think of an acicular structure like this in an upper bainite the cementite will be precipitated here. This is upper bainite: where all the cementite particles will be at the grain boundaries. In an acicular ferrite this is all alpha whereas, in a lower bainite the same acicular ferrite will be there, but in the acicular ferrite some kind of things like that in that, acicular ferrite you will have cementite nucleated on certain habit planes. They are like plate like cementites, formed inside the ferrite and this ferrite is formed by polymorphous transformation.

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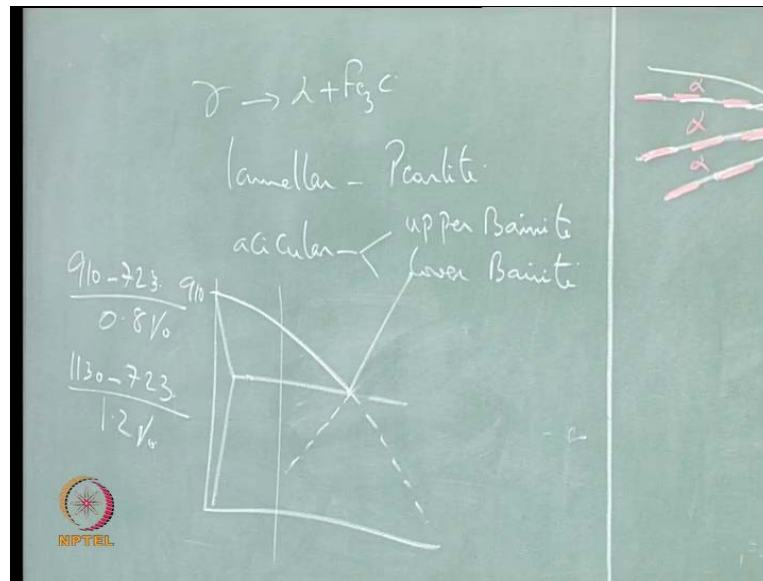


So, at the time of transformation this ferrite will have the same composition as that of the gamma. If it is point eight this will be point eight. And that carbon, excess carbon will be rejected out and then will be given in the form of cementite so that at the end of the transformation is over then the alpha will come back to the original alpha composition decided by the phase diagram.

Whatever is the alpha composition at that particular temperature you will get that. Whereas, the remaining a carbon the excess carbon will be converted into the cementite. But if this process is not complete you will always have possibly some excess carbon left out in the ferrite so that it will remain as what is called a super saturated ferrite. So, you will always have some super saturated ferrite, because if the temperatures are very low let us say and if you have a lot of alloying elements in the steel, the diffusion rates being very slow, you may have always a situation where some super saturated ferrite will be left out. The complete transformation has not taking place.

But provided, if you have a plain carbon steel and if the transformation is done at relatively higher temperature for a long time, then you would see complete excess carbon will come out as cementites, and you would see the ferrite having let us say point eight two five composition and the cementite will be there according to the volume fraction that it is suppose to be there. This is how you would see transformations taking place.

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Second thing is, if we look at this we also talked there is a possibility that if I take an alloy of this composition, we just now said, there is a possibility that it will directly give you pearlite instead of giving you a ferrite; that can happen provided if I extrapolate these two lines. What are these two lines? What is this line? A3 and this Acm. Again there is a mistake here; this has to be steeper. Why that is steeper? Acm line is steeper than A3 line. Can you tell me why? That is also phase transformation. Gamma is giving you a cementite; it is phase transformation. Simple geometry. That is it.

You should know that here A3; what is this temperature? 910 let us say. So, from 910 it is coming to 723 in point eight percent. Am I right? And where does this go? 1130. So, from 1130 to 723 it is happening in how much? 1.2 percent. as simple as that. So, if you divide that you will get the slope of it. And obviously, this slope is higher than this. This divided by this if I put it, you would in principle get the slope of that. Because from it, it is going up to 2 percent; from here point eight it is going to 0. So, this total is point eight. As a result that is the reason why we always say in the hyper eutectoid steels, if you want to go the single gamma region you need to go to very high temperatures. Whereas, in case of a hypo eutectoid steel, you need not have to go to very high temperatures. The highest you have to go is only 910, whereas here as you go closer and closer to 2 percent you need to go beyond 1100 degrees at two percent actually it is 1130.

So, if you are something like a one point four percent carbon steel something like that tool steel is there: one point four percent carbon or one point five percent carbon, such a steel you need to go to very high temperature and that has its own problems. It has certain advantages certain problems. What is the advantage tell me? If I heat a steel to a very high temperature, what is the advantage? Physical metallurgy if you are thorough you will know. Yes? Coring. Why are you talking of coring, why? We are coring will be decreased, you are talking about, let us not bother. We are talking about heat treatment; in terms of heat treatment; in terms of micro structures.

Coarse grains so? Toughness will be better coarse grains? Hardenability is higher. You will get a higher hardenability, if I take it to a higher temperature. Because the grains are coarser; the number of nucleating sites for pearlite to form are lower, obviously, the pearlite formation is like: when we talked about glass formation we said every liquid would form a glass until and unless crystallization is intervened- this is what we said. **Turn bull** has made this statement long back. Liquid wants to become a glass because it has no problem in becoming a glass; because its structure is the same. But unfortunately some crystallization is coming in the middle.

If I can suppress that crystallization I will get the martensites, I will get the glass. Similarly here if I can suppress the pearlite formation I can get the martensite, isn't it? So, in order to get a martensite, you need to suppress pearlite formation. So, whatever mechanism methodologies that you can adopt to somehow suppress the pearlite formation is good for you. So, one such methodology is increasing the grain size. But there are problems. What are the problems? If I grain boundary oxidation, fine. If I am not if I am doing my annealing or austenitizing in a reduced atmosphere you would not have problem of oxidation.

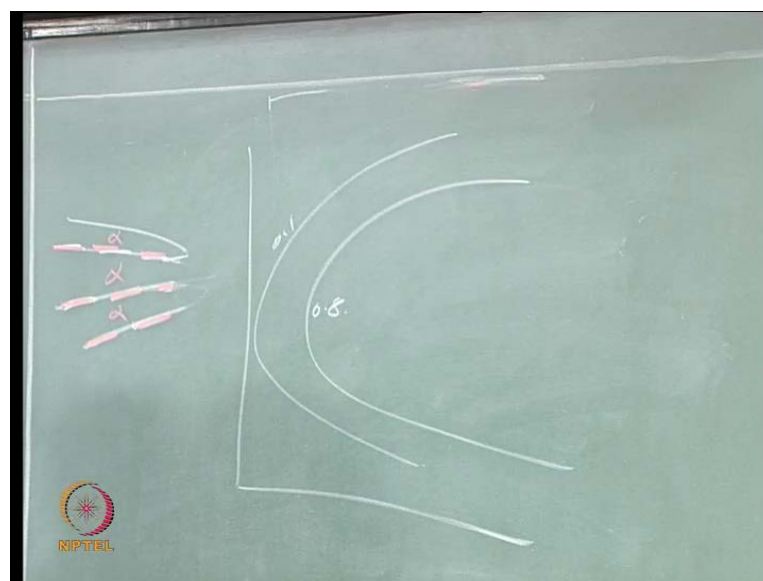
But still there is a problem. Strength decreases coarse grains' strength decreases, fine. Toughness decreases. One more, you can you get more quench cracks, when you are quenching to get martensite. Because you are quenching from a higher temperature; thermal shocks are more. So, that is the reason why. That too, tool steels. So, there is a possibility of quench cracks. That is the reason why tool steels you do not quench them. Luckily, luckily because the carbon is higher, the hardenability is higher already.

Why hardenability is higher if the carbon is higher? Again diffusion problem. Whenever you have a high carbon steel there is more stress inside. if you take an austenite with a one point five percent carbon, austenite with a point four percent carbon if you are comparing these two, you would see that because of a large amount of interstitials are occupied by these carbon atoms, the diffusion is more difficult. Each carbon atom would be an obstacle for another carbon atom to move. It is like having too many dislocations; you have a work hardening taking place.

So similarly here, you have diffusion gets basically, any alloy diffusion or chemical diffusion nor self diffusion, chemical diffusion is going to be more difficult if you have the solute content is higher. That is why chemical diffusivity is always a function of, if you read about diffusion, is always a function of composition. The dilute the alloy is, the higher the diffusivity is. the more concentrated the alloy is the lower the diffusivity is. So, that is one of the reason why diffusion come rate comes down. And once the diffusion rate comes down the hardenability is higher.

Of course, there is always something which is counteracting this. What is that, that is counteracting? Because when you take high carbon steel there is, a pro eutectoid cementite coming out. And the pro eutectoid cementite, the moment it comes out it can nucleate pearlite.

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So, there are always issues like that. **The moment you are.** That is why, you know interestingly, if you ever have seen the TTT diagram, in principle. If this is the TTT diagram for a point eight percent carbon steel I am only drawing the start of transformation.

If I take a let us say point four percent carbon and one point percent carbon. So, I decrease by point four; I increase by point four. Look at the TTT diagram. How will it look like? How will the start of transformation, that curve will look like? You forget about that. I am not going to talk about pro eutectoid. I am simply going to ask you the eutectoid c curve. The c curve, related to the eutectoid, will something happen to it? Will it shift for that matter? If it shifts in which direction will it shift and how will it shift? I want you to think about it and may be draw it and bring it in the next class. Do not consider any alloying elements, nothing. I am not even concerned about the pro eutectoid. Simply point four and one point two - what would happen to the TTT diagram?

Both sides a case, I mean. Till point eight it shifts to the right, yes. They do not observe the shift after point eight. It is very interesting, from almost zero percent carbon if you start looking at, and start increasing the carbon content, I can give you the answer here itself. So, if you look at from zero percent carbon, if you start looking at I mean 0 we do not consider, let us say point one percent carbon or something like that, you would see slowly the TTT curve shifts to the right: until point eight, because you are increasing the carbon content; hardenability is increasing.

And also in another words also, amount of ferrite is also decreasing. So, the number of nucleating sides are also decreasing, isn't it? Amount of pearlite as you go towards the point eight percent carbon, the amount of pro eutectoid ferrite is decreasing. Once the pro eutectoid ferrite decreases, the number of nucleating sides for the pearlite also decreases. So, that is the reason why you will see may be, a point one percent carbon would be like this; and point eight would be like this. Now if I am increasing it further what would happen? It would actually start coming back. But there is, this is where the question is, there you have two counteracting effects.

So, in this particular case you do not have that. In the hypo eutectoid you do not have that problem. If I decrease the carbon content, I am decreasing the carbon content I am

increasing the ferrite amount. Both are detrimental for hardenability. Whereas, if I am increasing the carbon content beyond point eight, I am increasing the carbon content which should actually increase the hardenability, but I am getting cementite, which should be detrimental for the hardenability.

So, you have two counteracting effects. And as a result, actually, you do not see significant shifts. What Sri Ram said is right. You do not see significant shift, because, whatever you lose because of one you gain because of the second one. So, you do not significantly see shifts. Whereas, you see significant shifts on the hypo side. So, that is something which you need to understand. So, as if you do not understand that you would not be able to understand the hardenability effects in different compositions and this is very important.

So, what I am trying to say is, if you take this alloy: if the moment this alloy intersects this; if your under cooling is sufficient such that this alloy is brought below that; then, you would suddenly get a pearlite. Because, now, you are below that cementite ACM line. So, cementite can nucleate out of that. The moment cementite nucleates immediately, you will get a ferrite next to it and that is what is pearlite. So, you can get things like that and if the temperature is too low there, you would get a bainite instead of a pearlite. But you would get one of the two phase mixture: either a pearlite or a bainite, you would get if you are below that, provided nothing has happen before it. We will stop here.