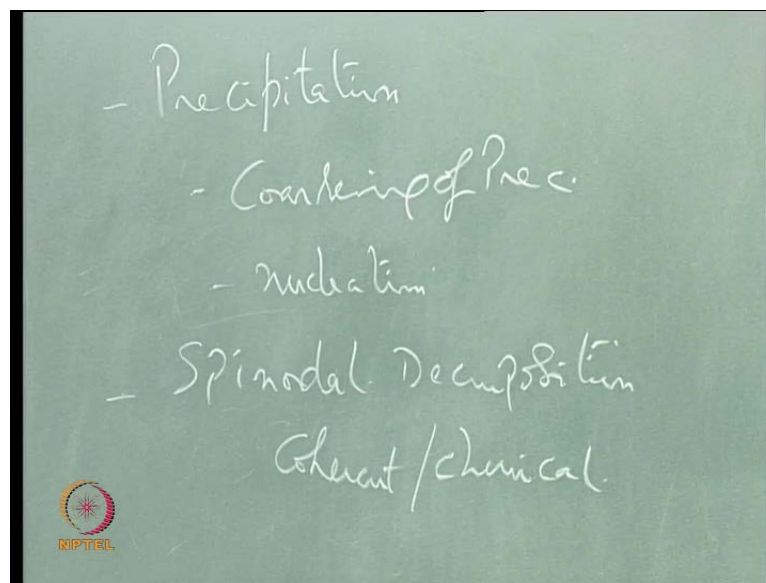


**Advanced Metallurgical Thermodynamics**  
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**Lecture. #22**  
**Eutectoid reaction**

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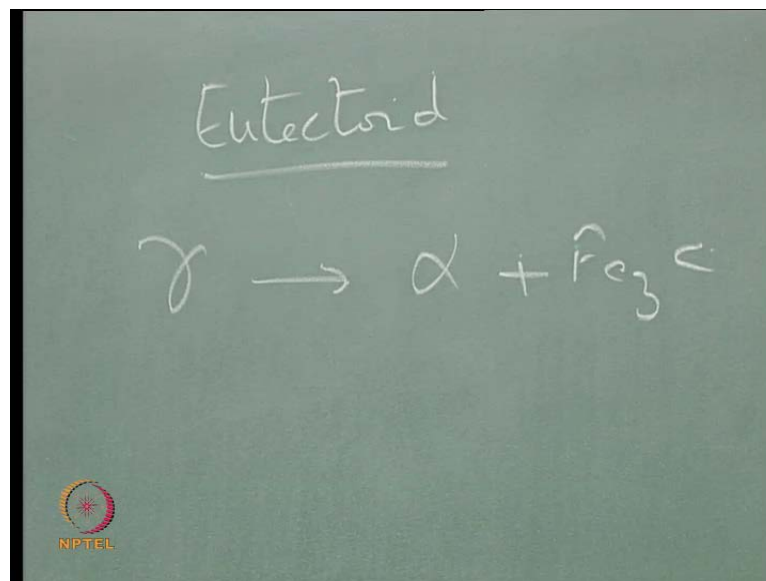


So, we have been talking so far on basically solid state phase transformations we have been seen, we took up the precipitation and dealt with it. So far, both the precipitation per say and also coarsening of precipitates this also, and of course nucleation. We did not go too much into the growth of it, because the growth stages basically it is more of kinetics. So, we did not talk much about that, but if somebody is interested may be as we go along we will talk those issues also, but because we this course is more on thermo dynamics, I thought I would stick to thermo dynamics aspects of it.

Then, we went to the other kind of extension of precipitation which is spinodal. So, we have been talking on spinodal so far, spinodal decomposition, and how it is different from normal precipitation and how does an alloy which is outside the spinodal behave and how does an alloy which is inside the spinodal behave, in terms of their decomposition characteristics.

We also looked at what is called coherent and chemical spinodal, and looked at the differences between the two. And we also talked to some extent on the activation energy for this spinodal decomposition, and looked at how the composition profiles change as a function of time, whether it is the alloy which is inside the spinodal or outside the spinodal, this is what we have talked so far. Any clarifications that you need on that so far, otherwise we will now go to the other type of solid state phase transformation

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For example, eutectoid the most common phase transformation is eutectoid for all of us mostly metallurgies, because we deal within steels all of you know. What is the eutectoid transformation in steel aneesha? What is the eutectoid transformation in steels? What happens during eutectoid transformation? What is it when I say steel that means, what happen changes to what yes cementite good. So, it is austenite which is refer to as gamma transforms to ferrite, which is refer to as alpha to cementite, this is what we see and in general our statement.

That one solid gives you two solids and that what it are a eutectoid transformation and this transformation if you carefully observe in comparison to the precipitation. In precipitation you have a matrix from which a precipitation coming out and this precipitate has either a different structure or the same structure. For example, if you are talking of spinodal decomposition where the alloy is outside this spinodal, then you have basically a precipitate coming out of a matrix of the same composition, same structure

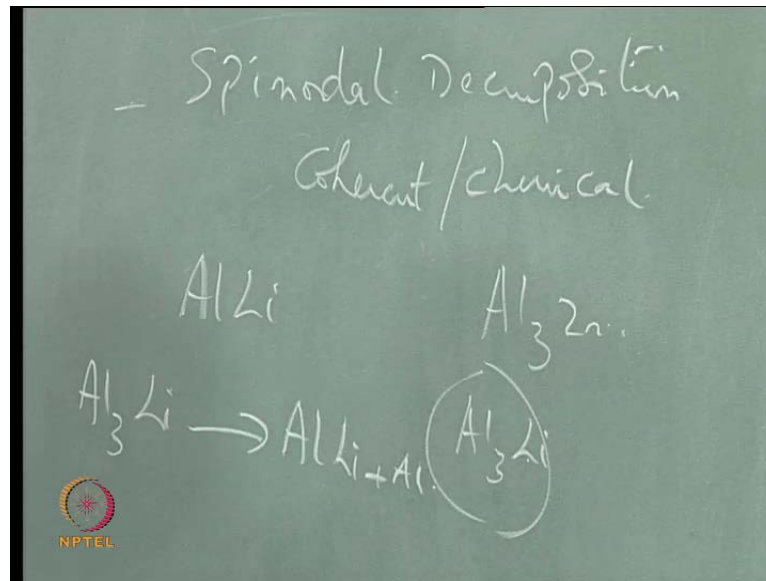
accepting that the structure the composition is different. You can have a situation here the structure is the same or a situation where the structure is different, but definitely the precipitate has a different composition when compare to the matrix in all precipitation.

You will see the only difference could be either the structure is same or structure is not same with respect to the matrix. If the structure is also different, then the question comes is a whether the precipitate is able to nucleate easily in the matrix or not and if it is not able to nucleate easily in the matrix then you have transient precipitates. If the structure of the precipitate is exactly same as the structure of the matrix, you do not need transient precipitates accepting again in some cases you may need transient precipitates when you need it. When the structure of the precipitate is same as that of the matrix when the lattice parameter is significantly different, whenever the lattice parameter is significantly different, there can be a necessity of a transient phases, but you rarely see this happening.

Wherever you have the structure for example, simple example that we can take is an  $\text{Al}_3\text{Ni}$  in a nickel base super alloy or  $\text{Al}_3\text{Li}$ . In fact, if you carefully look at aluminum lithium phase diagram, what is special about aluminum lithium? Tell me high specific strength. What is special about lithium? Who knows high very light, it is the lightest metal its density is 0.53 remember. So, it floats in water in principle, when you add lithium to aluminum itself we use it, because of low density because all aerospace materials you want a lower density material. So, if you add lithium obviously, the density can further come down and incidentally people have also observed when you add lithium to aluminum the youngs modulus increases.

As a result, the strength is going up the density is coming down. So, the ratio of this which what he talked about as specific strength, specific modulus is going to be much higher. The numerator has gone up the denominator has come down. So, obviously the modulus by density or strength by density if you calculate you are going to have higher.

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But there also if you look at aluminum lithium phase diagram, where you see a phase called Al Li, the stable phase in aluminum lithium diagram, in fact, large number of people has worked on aluminum lithium aerospace industries to see, if they can have a replacement for aluminum copper alloys. So, that you can have much lighter, but there are problems. First problem that comes is the lithium. Lithium being a lightest metal and it has a very small atomic size. First and foremost is lithium is reactive. Handling lithium is not easy; you cannot simply keep lithium outside the atmosphere. So, that is one, but once you put it inside the aluminum you make an alloy out of it, but even after the alloy is made the lithium has a tendency to diffuse out being a smaller element.

So, if you take an alloy of a rod like this aluminum lithium rod after a month, if you see the surface concentration of lithium is going to be higher than the concentration inside. It has diffused to the surface and as a result and once it diffuses to the surface there is a possibility that it can react with the environment, but more importantly your composition as changed alloy composition. So obviously, whatever precipitates that you have inside the matrix they are going to be reduced, the precipitate concentration or precipitate volume fraction comes down, because the lithium content as decreased.

But, people try to overcome that by coatings, by cladding, variety of things people have done aluminum cladding and things like that. But more importantly the problem was what is called, how many of you read about aluminum lithium? There is a problem, in

aluminum lithium alloys particularly which is associated with deformation characteristics. Have you ever heard of plan or slip? Whenever you have the precipitates inside a matrix and the moment a precipitate is cut by the dislocations, there is a tendency for the rest of the dislocations to find a easy path. This is what is called people call it as plan or slip.

And this tendency people have seen it in the aluminum lithium alloys to a great extent and as a result once one some of the precipitates are cut you can see easy deformation taking place and the fracture toughness of this alloy, people found out to be very low. So, processing of the alloy was very difficult and to some extent again there that is, where you know the whole alloy does not become. So, interesting how do I now prevent this precipitate to cut to the plan or slip taking place or what people called as slip localization. So, if slip localization which is happening because of the precipitate being cut, how do I avoid it. The best way is to make the precipitate in such way there is no get cut, but how do I change a particular precipitate. So, that it does not get cut.

What people have done is they try to put something inside that precipitate. So, what they have done is they have added certain precipitate, certain you know the heterogeneous nucleating sides. For example,  $\text{Al}_3\text{Zr}$  is used as a nucleation side for the  $\text{Al}_3\text{Li}$  incidentally when I started I said in aluminum lithium phase diagram. This is the stable phase, but this is not the one that you get when you do age hardening of aluminum lithium alloys.

What you get is this phase  $\text{Al}_3\text{Li}$  exactly for the same reason why you get  $\text{g p}$  zones in aluminum copper alloys that  $\text{Al}_3\text{Li}$  is exactly similar to  $\text{Ni}_3\text{Al}$ . It is what we called as  $L_{12}$  structure.  $L_{12}$  structure some of you have heard of basically, it is an ordered structure based on  $\text{Fcc}$  where you will see that three atoms, the three lattice points which are the phase centered lattice points are occupied by one type of atoms and the body corner lattice points are occupied by another type of atom  $\text{Al}_3\text{Li}$ ,  $\text{Ni}_3\text{Al}$ . So, you can easily see. So, here aluminum will occupy the phase centers, lithium will occupy the body corner and that is how you get an ordered structure and what they saw is because this is also cubic it can easily nucleate this and once this nucleated on that. So, inside the  $\text{Al}_3\text{Li}$  you have  $\text{Al}_3\text{Zr}$ . So, every  $\text{Al}_3\text{Li}$  particle will have almost like one  $\text{Al}_3\text{Zr}$  particle inside and once you have that kind of an situation, you would see this plan or slip or this slip localization becomes difficult.

Because, Al<sub>3</sub>Zr the bond between aluminum zirconium stronger there. The ordering energy here is much stronger than the ordering energy here first of all this is a metastable phase, whereas this is not a metastable phase. In fact, how do I know about the ordering energy you will see that, whenever you see an ordered phase usually an ordered phase at higher temperature is disorder. Why does it get disorder? More entropy from the thermodynamic point view, we can easily talk in that we will have one session on ordered structures and how to understand them from the thermodynamic point of view will go it.

So, once you look at an ordered structure usually it transforms to a disordered structure at a higher temperature. There is a particular critical temperature, where this happens which is what we call it as ordering temperature or disordering temperature whatever it is and this temperature is a function of how strongly bonded the two elements are, which is basically related to the interaction parameter the omega. If the omega between aluminum and other element the solute element is very largely negative, then you would see this disordering temperature will be very high that basically means when an ordered structure becomes a disordered structure means the bonds are broken the strong bonds which are the ordered bonds are broken. So that means, you should have when you have a lower bond energies then you will see.

For example, copper zinc is a very easy example have you heard of beta brass. Beta brass for example at lower temperature is ordered and above something like 450 degrees also it becomes disordered. Beta prime and beta that is what we talk about and this again if I compare Ni Al or Ni<sub>3</sub>Al these structures are stable as ordered structures come to very high temperature. In fact, Ni Al he becomes disordered only after it melts. So, up to its melting point is both chemically and structurally ordered.

Once it becomes liquid obviously, in a liquid there cannot be an order, the only order that you can see in a liquid is what a short range order is. It structurally also disordered and obviously, chemically also gets disordered, but within the short range there can be a chemical order is possible, otherwise if you take Ni Al 50 50 liquid and when you make it solid that means, solidify it automatically becomes ordered Ni Al. That means, there is a chemical order inside the short range clusters and those clusters start growing the nucleus forms and then grows all these things.

So that means, there could be in a short range order a chemical ordering also, but any way we do not really call it as a big order, because whenever we refer to ordering we always mean a long range ordering. Short range order is not really considered as a very important thing particularly basically, because it is not contributing to a large extent to the mechanical properties of a material. But it is a it decides what kind of structures will come out of it the short range order inside a liquid is going to decide whether an F c c is going to come out or b c c is going to come out when it solidifies ultimately.

So, what I mean to say is when you look at structures like this the fact that Al<sub>3</sub>Li is a metastable phase indicated that this ordered structure and if you heat it to higher temperature Al<sub>3</sub>Li vanishes and finally, gives you the AlLi; that means, Al<sub>3</sub>Li in principle would split into AlLi plus aluminum. So obviously, you can see for every lithium atom there are three aluminum atoms. So, two extra aluminum atoms are there so, that two extra aluminum atoms will come out this is something like Fe<sub>3</sub>C splitting into iron and carbon at higher temperature.

Similarly, this can happen at high temperature; that means this is not really a stable phase. So, whereas this is a very stable phase and because it is stable phase and that is the reason why whenever I take a disordered structure and an ordered structure and try to deform both of them you see a ordered structure. The strength is much higher; the stress that is necessary to deform an ordered structure is very high. Why?

That is a simple example I take a nickel base solid solution and Ni<sub>3</sub>Al compound and try to deform both of them or take the same Ni<sub>3</sub>Al compound and make it disordered and once it becomes disordered. For example, take copper zinc beta braze and take disordered beta braze and ordered beta braze and try to deform both them. You will see that the ordered beta braze would have a higher strength than the disordered beta braze. Both are exactly the same composition both have the same structure, the base structure is the same then what difference in bonding. So, how does it reflect he in slip what is that which is a very important parameter that decides what is healing strength? Shift systems beyond that critical this is all shear stress and anything else.

What do you call that in during slip there is a there is a particular parameter that we use burgers vector. Whenever the burgers vector is smaller the slip is easier of course, the other parameter are there the when you talk about critical resolved shear stress. Critical

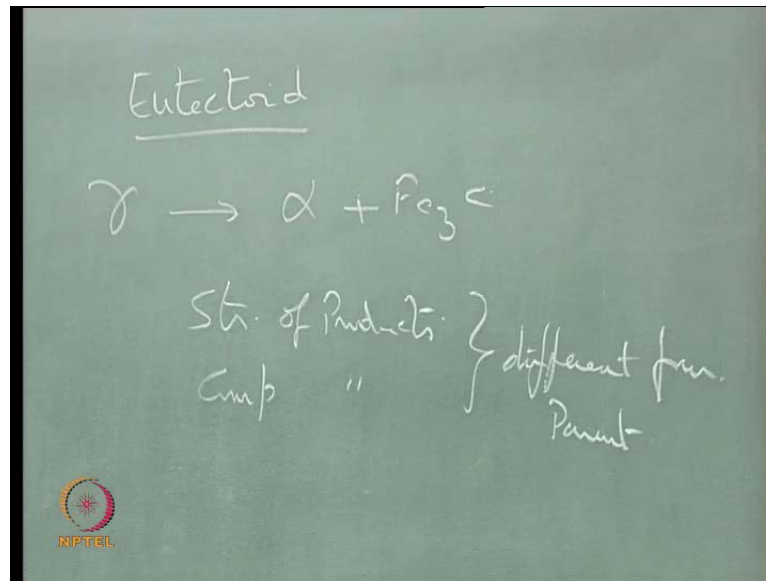
resolved shear stress will be higher obviously; because bonds are stronger where this critical resolved shear stress does come. Because a dislocation motion is decided by bond breaking and bond reconstruction unless the two bonds break the dislocation cannot move. And then this bond gets attached to another atomic plane. So, it is if you look at how a dislocation moves it is all bond breaking and restructure.

So, for that you need to consider the bond energy as aneesha as pointed out, but in addition if you look at the second issue, which is the burgers vector in an ordered structure, the burgers vector is much larger than a disordered structure. I want you to think about it and come back in the next class and tell me why it is so? Why burgers vector in an ordered structure is long larger? For example, if I take FCC structure, what is the burgers vector in an FCC structure a by  $2\ 1\ 1\ 0$ .

So, now you look at a by  $2\ 1\ 1\ 0$  in an ordered FCC structure, in a disordered FCC structure and tell me what would it be. Think about it, I will leave it to you. Any way, more importantly that is one of the reasons, why you see the deformation in ordered structures is more difficult. So, the burgers vector being larger the reconstruction of the bonds becomes difficult. So, dislocation motion becomes more difficult. So, the moment you convert a disordered structure into an ordered structure you make it stronger any way. So, and on top of that if the bonds are stronger, you will get much higher strength. Any way this is all related to the precipitation. So, the reason I had to come to this is this kind of metastable phases can come out of it provided a stable structure is more difficult to nucleate and you have in numeral examples of it, one example is aluminum copper itself.



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So, now if you come out of a normal precipitation and look at this case. In this particular case where the difference between this, and this that we talked about so far is that in this the two phases that are coming out or having different compositions, and in a **in a** number of cases they are difficult crystal structures. In fact, in most of the cases they are different crystal structures. They can be some cases where the structure of this could be structure of one of the phase could be the same as the matrix, but in a number of cases you will see the structure is also different. So, obviously that means structure of product, and composition of products is different from the matrix or the parent phase, we will call it as a parent phase. The moment you have this situation obviously, you will know that the activation energy for such a transformation is going to be higher.

So, when compared to normal precipitation you would see that this is more difficult. So, that mean you need more under cooling and so obviously that means, if you talk in terms of a precipitation; we the system tries to avoid going through a process of higher activation energy by choosing something which has a lower activation energy. That is where transient phases are come into picture g p zones and things like that here you have no choice. Here your phases are fixed; your eutectoid phases are fixed. So, the product phases are fixed.

Once the product phases are fixed, automatically their structures are fixed, their compositions are fixed. So, as a result the system has no choice of choosing something

else. So, it has to go through only that process if it has to go through that process then that means, the activation energy for such a process depends on what. Can we still change the activation energy for such process? How do we change the activation energy? Can I reduce the activation energy for such a transformation? Nucleation. One way is to have certain nuclei already available. When do I have such a nuclei already available, if I am choosing an alloy which is a hypo peritectoid, eutectoid or hyper eutectoid.

Once, I chose compositions which are hypo or hyper that means, some one or two phases is already there inside the structure obviously. So, in a hypo you alpha that already form, ferrite forms from the austenite, in case of hyper cementite form from the austenite. So, before you reach the eutectoid you already have one of these two phases already being present. So, that phase which is already there can nucleate this and as a result the activation energy can be lower, but if I am choosing the eutectoid composition exactly I do not have this choice with me there is nothing, before the only thing that is before is austenite. So, then if I want to reduce the activation barrier, how do I reduce the activation barrier giving some other alloying elements. Interesting very good sometimes yes in fact people have seen that you all heard about harden ability.

Any way, the extension of this is going to harden ability we will talk about it possibly today or in the next class. Harden ability there are different elements which either hide or do not hide in increasing harden ability. Then, certain elements which we say that the decrease harden ability, have you heard of such cases. Cobalt, why does it decrease? Why does it shift? These are issues unless we understand this wise we do not.

There are a number of cases where the T diagram can shift. For example, there are cases where if I take a high alloy steel, let us say vanadium or chromium or any such steels which are carbide forming elements are present in steels. You always see that such an alloy precipitates; I mean such an alloy undergoes eutectoid transformation very easily. For example, in such a case I do not know whether you heard of in tool steels; tool steels which are suppose to be very hard. In tool steels you use a very high austenization temperature. Do you know why? To dissolve carbon carbides. Why do you want to dissolve all the carbides? Carbon need not have to go into the solution, the reason is the moment carbides are there then austenite can undergo eutectoid reaction easily.

Because, these carbides can act as nucleating sites for the cementite. So, whenever you have carbides present that are why, we say any element any element give increases harden ability or shifts the  $T-T$  diagram to the right, only when it dissolves inside the austenite. If it does not dissolve inside the austenite, you will never see the  $T-T$  diagram shifted to the right when it dissolves inside the austenite. Why does the  $T-T$  diagram shift to the right, the same alloy, same you know high speed steel containing tungsten and so on. I heat it to very high temperatures austenite sometimes it can be even 1100.

So, when you heat to such high temperatures everything dissolves into it then so what then, when I am cooling this austenite. How does it prevent nucleation of the eutectoid mixture? Reduces the diffusion position. Whenever you have alloying elements particularly alloying elements with a higher melting point, then iron present inside it the diffusivities the self-diffusion or the chemical diffusivities are going to be slower. Because, every atom that is present in a substitution and interstitial sites is going to make the diffusion of iron more difficult.

Because, the moment the solute is present there is always a strain around the solute, why because the solute does not have the same atomic size as that of the matrix. Obviously, it is impossible to have a solute which as exactly the same atomic size as that of the matrix. Because the moment you have the atomic number being different, then atomic size is different. Once the atomic size is different then there is either a compressive strain or a tensile strain depending on whether it is smaller or bigger than the atom.

So, you are always having strain and this strain affects the diffusion. So, at any given temperature the diffusivity is going to be lower and why diffusivity is important, because nucleation needs diffusion that is the reason why you actually see the  $T-T$  diagram shifted. So, but whenever I add elements which form carbides and remain as carbides they can easily nucleate the pearlite and that is the reason why if you want a high harden ability and if you want to get martensite in such high speed steels, you are bound to go to higher temperature and that has its own problems. What are the problems? Oxidation, grain growth, but grain growth also sometimes is useful for you. What is the use of grain growth? Tell me, what happens if I have a large grain size. We are talking about harden ability.

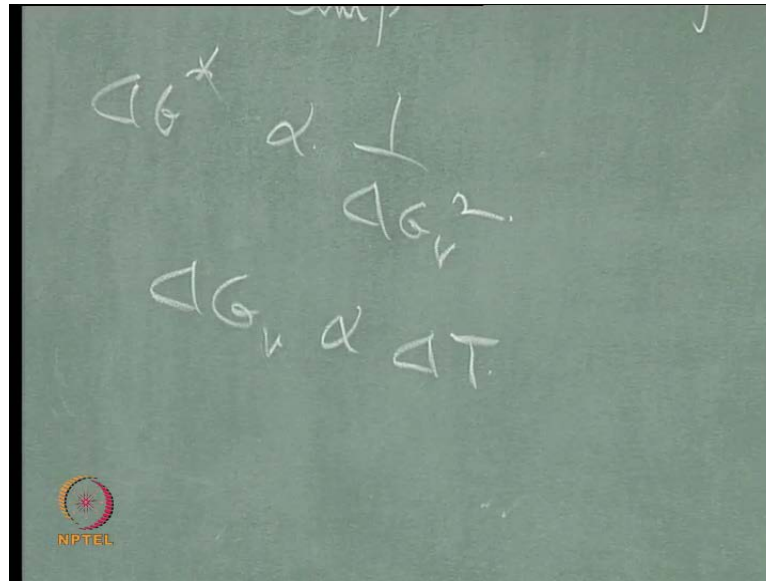
In this context, do you know less number of nucleating sites for the pearlite. So, a coarse grain size is always useful if you want a high harden ability, but that is not the whole life. A coarse grain structure always have problems also in terms of strengthening, room temperature strengthening is going to be lower. Obviously, if you want use the alloy at a lower temperature it is going to be a lower and a coarse grain structure also has other problems related to the toughness is going to be lower for a coarse grain structure.

And in addition even quench cracks are much more in a coarse grain structure. Of course, that is not really related to coarse grain structure, it is because of higher temperature to which you have gone. So, when you are quenching it, obviously and that is the reason why we do not actually quench, such alloys they are all mostly aid hardened. So, because the  $t-t$  diagram shifts to such an extent, that they are all aid hard enable and because they are aid hard enable you do not really see a significant quench cracks.

But, if you want if you do not want to go to higher temperature to dissolve all of them and still get a martensite that means, you need to use a higher quench rates, because the  $t-t$  diagram has already shifted to the left. And if you want to avoid the  $t-t$  curve and get a martensite you need to use a higher cooling rate and that can lead to problems of quench cracks. So, these are all the issues that one has to worry and understand then only we become a good physical metallurgist. So, as you can see that this is one of the major issues that this difficulty in the precipitation can be to some extent overcome, by as they said putting things which can nucleate or giving a higher under cooling.

The higher under cooling can lead you to a higher driving force and once you have a higher driving force at least up to the nose. We will talk about it as we go along that there is a possibility that if you under cool it. If you can come to a lower and lower temperature you can have a higher driving force.

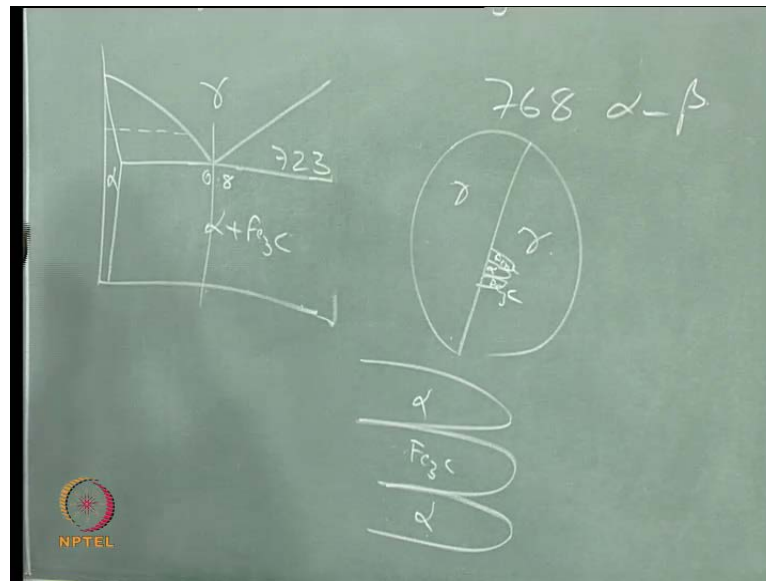
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And if you can have a higher driving force obviously you have lower activation energy, because we know that the activation energy for nucleation is inversely proportional to  $1$  by  $\Delta G_v$  square and we also know that  $\Delta G_v$  is proportional to  $\Delta T$ . All this we have done and the principles remain the same whether it is liquid to solid or solid to solid accepting that in a solid to solid. We need to replace this part with something else what is that with the combination of volume free energy and strain energy.

The surface energy that we talk about it is going to be a combination of various surfaces, because various inter phases can be possible depending on where this particular phase is nucleating. So, as long as we know that one can consider this. So, these are some of the issues which are not directly related to thermodynamics, but one need to understand them, if you want to understand the whole eutectoid transformation.

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Now, let us go into the thermodynamics of it. If I look at a phase diagram having a eutectoid transformation let us take the case of a let us not put this fellow here, because if it is iron carbon there is nothing there. So, this is gamma giving alpha plus cementite is there somewhere. So, you have an alpha plus cementite. What is this temperature? 7 and what is this composition 0.8, by the way have you ever thought about you had an alpha and you have a gamma. You do not have a beta; here it is a non magnetic form of alpha. So obviously, it is there and at what temperature it goes off 768. So, 768 is the temperature where you see an alpha to beta transition which is a ferromagnetic to paramagnetic transition. So, that is why in some phase diagrams you see somewhere here a dotted line. So, that indicates you of that any way.

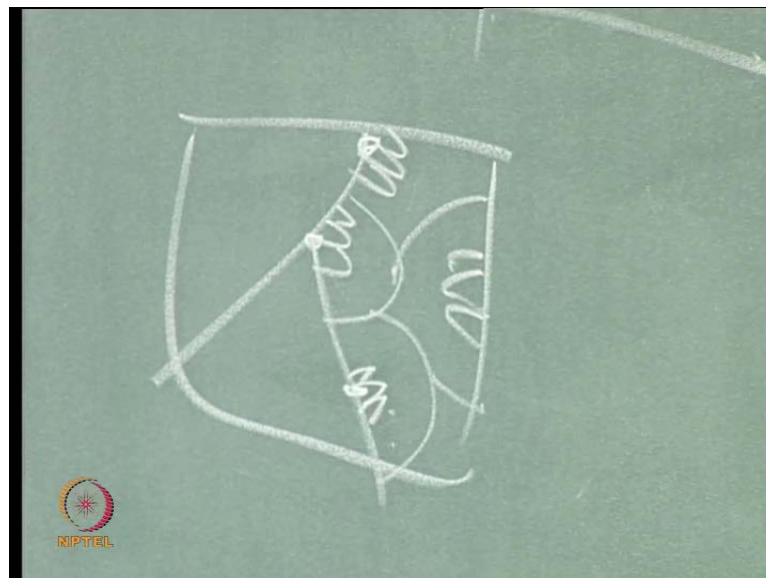
So, now we are talking of this transformation, if you take an alpha gamma a grain of gamma let us say gamma and an alpha plus Fe<sub>3</sub>C is nucleating. So, if I make it this would be Fe<sub>3</sub>C alpha there is always a botheration what nucleates first. So, many people broke their heads in this particular context, because always when you talk of two phases coming out whether it will be alpha first or Fe<sub>3</sub>C first that is true. But is ultimately you may say that as far as the properties are concerned, I am not bothered about what comes out first.

Because properties depend on what in this particular case, in a pearlite structure what do the properties depend on inter lamellar spacing anything else, beyond only the inter

lamellar spacing that is enough, amount of Fe<sub>3</sub>C is fixed in a pearlite, its fixed. In pearlite, once I say pearlite you can do a what is called lever rule and then find out and turns out to be approximately around how much 12 percent 88 12. Something likes that 12 percent of cementite shape of. Once, I say pearlite I am defining the shape, pearlite is always lamellar you can a non iron cementite mixtures, what are they called non lamellar iron cementite mixtures, ferrite cementite mixtures spheroidite. Any other non lamellar ferrite cementite mixtures, bainite, again you have two types of bainite upper and lower, we will talk about them may be as we go along.

So, they are all non lamellar. So, when I say pearlite I define that it has it is lamellar. So, once it is lamellar. So, the other point which decides the strength is the pearlite colony size. How is that decided? How what decides a pearlite colony size? Number of nucleating sides and number of nucleating sides are decided by your under cooling. Your under cooling and of course, the grain size also, the prior austenitic grain size all these things control. So, if your under cooling is higher, under cooling controls both the factors one the pearlite colony size, it controls because the number of nuclei.

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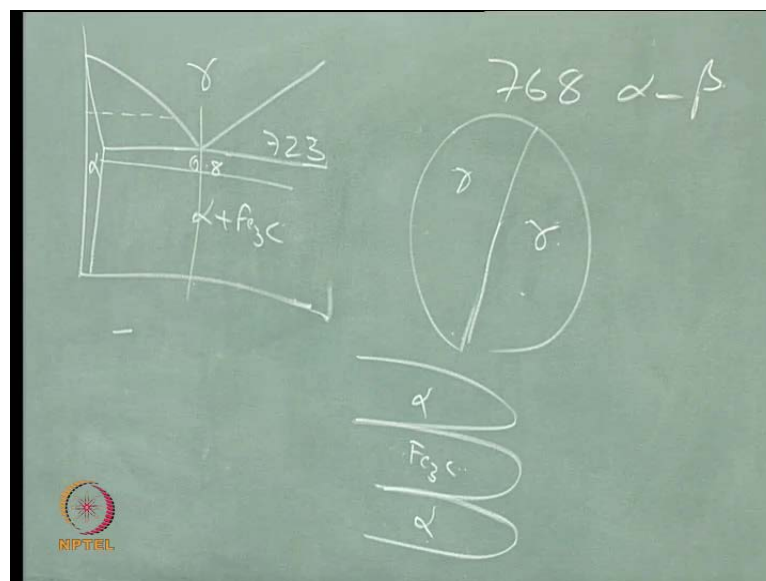
So, if you imagine that in one grain if you have different nucleating sides here. So, each of them will have a combination of a cup we call it as a couple ferrite cementite or cementite ferrite. So, once you have a cementite obviously, you will have ferrite on both

sides or once you have ferrite you will have cementite on both side. We will look at what should come first in a minute.

So, once these things grow ultimately this becomes one colony, this becomes another colony and may be somewhere here you may have another. So, that becomes another colony. So, these are all what we call them as pearlite colonies. This is different from grains. So, within one austenitic grain you would have a number of pearlite colonies possible, depending on the number of nucleating sites that have formed. So, if you have a higher under cooling, you would see a possibility of a number of nucleating sites. Because,  $I$  is going to be higher and in addition within the pearlite colony the inter lamellar spacing is again going to be a function of that we will see.

What is the relation between the inter lamellar spacing and the under cooling? As we go along this is one thing which is going to ultimately define the properties, because always eutectoid has been so interesting for people. Because, you can really control the mechanical properties just by heat treatment and the whole cracks of heat treatment revolves around this eutectoid transformation. So, we can modify the micro structure the way we want simply by controlling the way, the temperature to which you heat it or the rate at which you cool from that temperature. So, this is how we are going to modify it.

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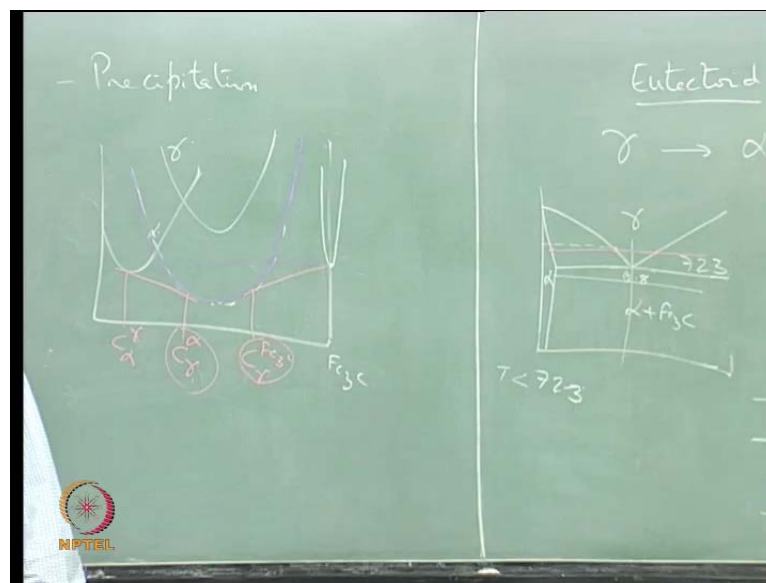
So, now if you look at this aspect of, what should come out first? After a lot of debate what people have thought about is the moment, I have a let us say a situation like this



you have two gamma grains and you are keeping at a temperature just below the eutectoid which is around 723 degree centigrade. What can diffuse more easily at that temperature? Carbon. Among the iron and carbon, it is the carbon can diffuse very easily.

Because, it is a interstitial atom smaller atom. So, it can diffuse more easily and as a result there is a possibility that at the grain boundary, carbon atoms can accumulate. Why do they accumulate? Because, I am at a temperature at which gamma is not stable. How do I again look at it, I can draw the free energy composition diagram for it.

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If I draw the free energy composition diagram, I have the gamma here. I have the alpha here. I have the cementite somewhere here or if I call this as this should be in principle a dot and if you want to show it you can show something like this. And if I call this as cementite and this is the alpha, this is gamma and if I am at a temperature  $T$  less than 723. Then only this phase this free energy composition diagram is valid, if I am at temperature higher than 723 then, what should happen then austenite. So, austenite free energy curve will be below. So, you would have a situation something like this.

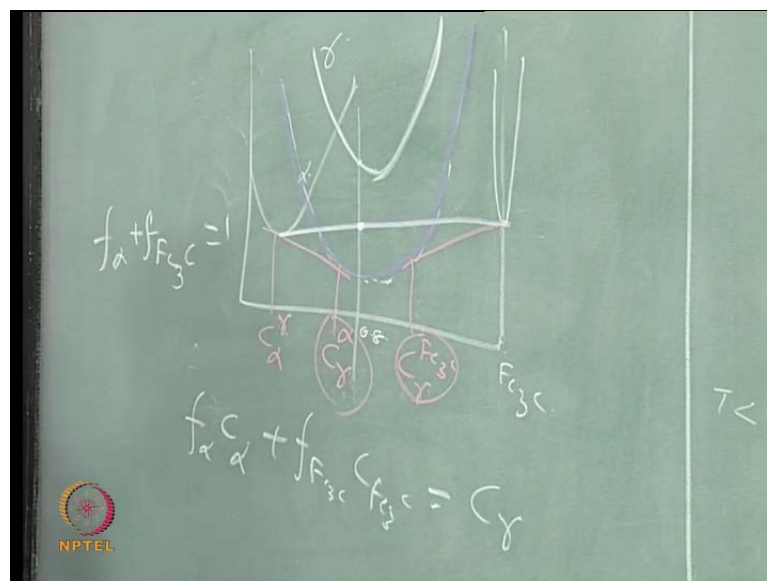
So, something like a curve like this and then if I draw a common tangent between this two, the common tangent between those two is going to be higher than the free energy curve of gamma. As a result, in principle so if the same alloy I heat to a higher temperature or keep it at a temperature higher than that then at that temperature in

principle you would see that a the only way, I can see is I would have a common tangent between alpha and the gamma.

I would have another common tangent between gamma and Fe<sub>3</sub>C and this two compositions, if I say what is this composition then composition of gamma in equilibrium with alpha and this is composition of alpha, in equilibrium with gamma and this is composition of gamma in equilibrium with Fe<sub>3</sub>C and this is Fe<sub>3</sub>C composition. And these compositions if I want to see at that temperature, simply I draw a line at that temperature and this composition is what c gamma alpha, that is this composition and this composition is c alpha gamma. So that means this line is nothing, but a locus of all gamma compositions in equilibrium with alpha and this is nothing but the locus of all gamma compositions in equilibrium with cementite. So, this point is nothing but c gamma cementite.

So, if I am at a temperature above the eutectoid, I can easily see it that this is how it looks like. But the moment I come to a temperature below the eutectoid as I decrease the temperature what happens to free energy, as I decrease the temperature free energy increases all of us know this. So, free energy increases that means, these free energy curves of both of them start increasing of all three of them start increasing. But because at lower temperature the gamma is not stable, the rate at which the gamma free energy goes up is going to be higher. So, when the gamma goes up.

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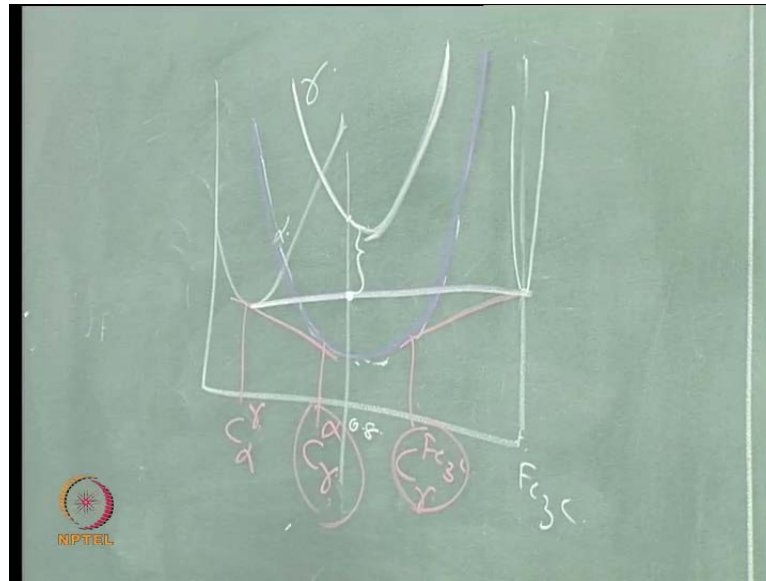
So, you would come to a situation like this. Now, whereas relatively though I am fixing these two things they will also move up, let us understand that relative to these two it is sitting somewhere there and if that is the case then I can draw a common tangent between these two and if I take an alloy of 0.8 percent carbon.

Let us say that 0.8 percent carbon alloy, now will have a higher free energy than a mixture of the alpha plus cementite which is given by this. The free energy of the two phase mixture is always a point on the line joining the two free energies. Whenever, I identify any two phases find out the free energies of it draw a line joining the two free energies and any point on that, would give you a free energy of a mixture having a overall composition of this. The overall composition is this, but the individual phase compositions are different.

So, the only way is we can say that the fraction of alpha multiplied with the composition of alpha plus the fraction of cementite multiplied by the composition of cementite should be equal to the composition of gamma. This is how it is so, the composition of alpha and cementite are definitely different from that of gamma, but their fractions will be adjusted in such a way that this mass balance is maintained and that is what leads you to lever rule. But in lever rule we also use one more thing what else we use, just with that equation you can you get a lever rule.

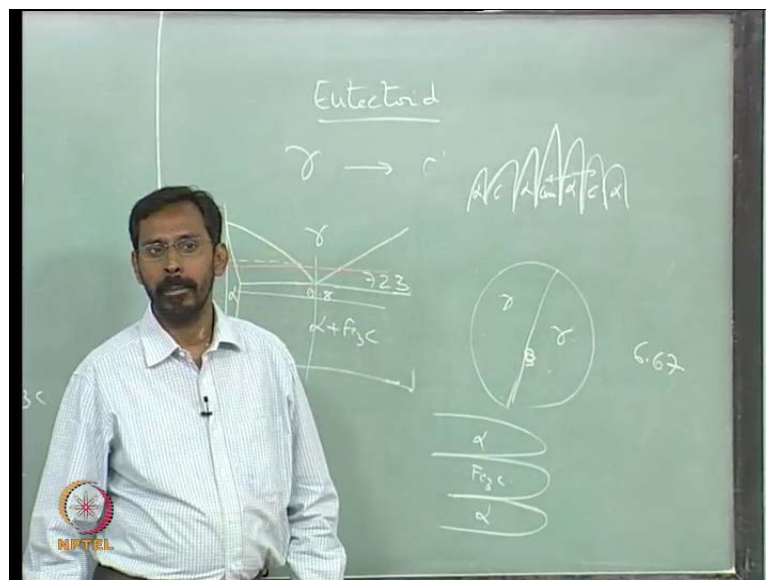
What else you need? The fractions have to be equal to 1. Because at after the transformation is over you know that  $F_{\alpha} + F_{Fe_3C}$  should be equal to 1. That is the second boundary condition; if you do not have that boundary condition you cannot get the lever rule. So, lever rule these two equations are the crucial equations which ever phase that we are talking, here we talk about alpha and cementite. You can call it alpha beta, you can call it alpha gamma anything that you call it. So, the same equation and for liquid to solid also, we use the same thing. So, this is what you see that the moment I come to a temperature which is below that now you have a situation here.

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So, there is a driving force. Because, there is a driving force gamma does not want to remain as gamma. It wants to precipitate alpha plus  $Fe_3C$ , the question now we are talking about is what happens. How this initiate, gamma does wants to transform how this transformation get initiates. That is where we say the moment you have a gamma gamma inter phase at the grain boundary the atoms. At that temperature have a chance to move, because the temperature is high enough for the atoms to move.

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And the moment in a small region, you see the carbon atoms coming to a level of 6.67 percent at weight percent and in terms of atomic percent is how much 20. Why are you so doubtful? 25 Fe 3 c very easy, three atoms of iron, one atom of carbon. So, that means in a small region if 25 percent of that particular region has carbon atoms immediately that region get converted to Fe 3 c.

And it does not have any problem of nucleation. Because, it is nucleating at the grain boundary it is not nucleating within the grain. So, there is no major problem of surface energy problem or strain energy problem for it, because the nucleation is at the grain boundary. So, happily a cementite will nucleate and the moment cementite nucleates obviously, the regions adjacent to that gets depleted in carbon, because carbon has come closer to a particular place from both the regions.

And as a result, this particular region next to it becomes ferrite and for becoming ferrite it also rejects out carbon in both the directions. So, if I draw it in a bigger fashion, the moment a cementite comes out. A ferrite is there, this is alpha, this is alpha, this is Fe 3 c call it as cementite. So, the carbon is rejected out of this region in both the directions. Once it is rejected out then again you will see a cementite coming out here and this happens and it grows laterally in a with alternate layers of cementite cementite.

Then again obviously, alpha alpha and this whole thing start growing perpendicular to the grain boundary, and for that growth again you have to remember, what we talked about eutectic. In case of eutectic, we said how does liquid supply atoms to both the alpha and beta does, in such a way that alpha and beta grow together, and we talked about it we understood that if I look at the composition of alpha composition of alpha in equilibrium with gamma, and composition of cementite in equilibrium with gamma is going to be different. We will talk about it later; I think we will stop now.