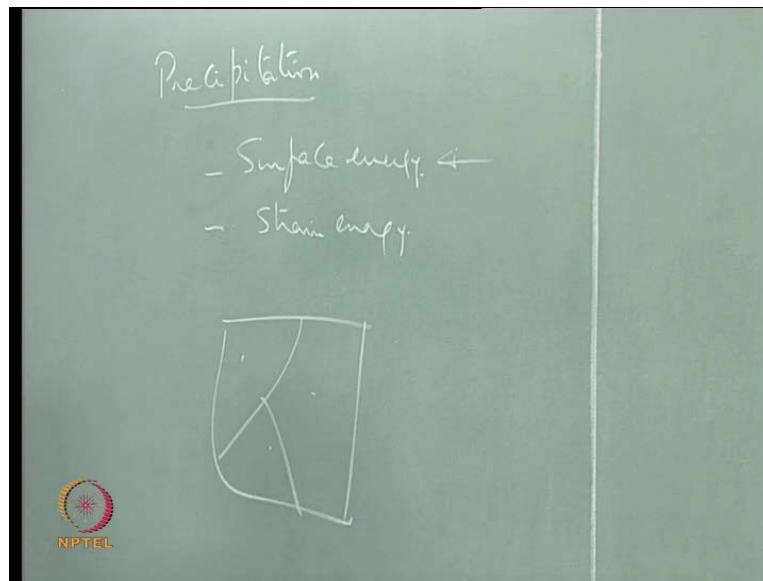


**Advanced Metallurgical Thermodynamics**  
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**Department of Metallurgical and Materials Engineering**  
**Indian Institute of Technology, Madras**

**Lecture No. 18**  
**Precipitation**

We have been talking about solid state transformations, and we started with Precipitation. And we looked at the basics of precipitation, where is the driving force coming from.

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And also we started looking at where is barrier for precipitation, we said there are two barriers, one is the surface energy, and two is the strain energy **right**. These are the two barriers, when we are talking of solid state transformation, any solid state transformation in principle will have both these barriers, and precipitation is just one of them.

And when we are talking of liquid to solid, this part will not be there, this we have already seen it, and only the surface energy is what we talk there, now and we all looking at the both these things, the system wants to somehow minimize at the overall energy,

that it has to spend; this is the energy that it has to spend, a summation of this two energy, is the that it needs to spend for creating a precipitate.

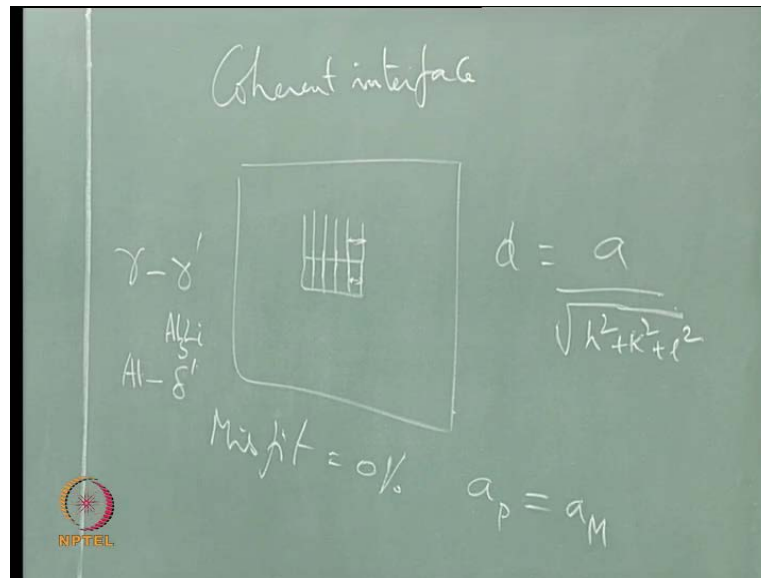
If that is the case, the system would like to choose that particular precipitate, which has a minimum combination of strain and surface energy; this is what **actually** we were looking at in the last class. And that is what leads you to the formation of what are called tangent phases for example, in a number of systems, the final product may have a structure which is entirely different from that of the parent phase, particularly let say an example of aluminum copper itself.

The theta phase, which is the orthorhombic, is entirely different from in its structure there is no real similarity, in terms of the any of the atomic planes. If you look at any of the atomic planes in orthorhombic structure, there is no real comparability with any of the planes in the FCC type of structure, which is aluminum is FCC, so the matrix is FCC. So, in such case, when you have such phase trying to precipitate out inside the grain, **the** all the problem comes only because, the precipitation has to occur inside the grain.

Why it has to occur inside the grain, because the temperature is low, our **our** precipitation is happening at a temperature which is very low for the diffusion to happen, so that the atoms move from the centre of the grain to the grain boundary, and nucleation to occur there. As long as nucleation is occurring at the grain boundary, there is absolutely no problem any kind of precipitate, whether it is compatible with the matrix or not compatible with the matrix, can precipitate at the grain boundaries.

Because, grain boundaries are the regions where you can accommodate, strains can be accommodated and already grain boundary has a higher surface energy, so with respect to that this surface energy can be accommodated. So, because we are now talking about nucleation within a grain somewhere inside the grain that is where we have to worry about this, this is what we start looking at in the last class. And we said basically it looks first of all, what is the misfit between the two, and also the system **also** look for, **what is the** is there is any possibility of a phase, which can have very low inter phase energy with matrix.

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And such phases are what we call them as coherent inter phases, a coherent inter phase is that where, there is a continuity of lattice planes across the inter phase for example, if you think of a matrix and inside that you have a precipitate, and precipitate let us assume, that the precipitate as the same structure as that of the matrix. And it as certain atomic planes, if I draw certain atomic planes here, and then also the matrix also as certain atomic planes; and these all one single grain let us assume, that inside one single grain precipitate as form and this precipitate is a trying to have a comparability with the matrix.

And when is this comparability possible, when the atomic planes that are, there in the matrix have similar inter planar distance with respect to the precipitate, then what you see is there is a continuity of the atomic planes. Whenever there is a continuity of atomic plane, any plane it can be 1, 1, 1 plane, 1, 1, 0 plane **some of** some plane, if it can have a continuity from the precipitate to the matrix, then we call it as coherent inter phase.

And for this to exactly have a matching what you need, you need to see that the misfit should be **actually** 0 percent that means what, the lattice parameter of the precipitate should be equal to the lattice parameter of the matrix. Because, inter planar distances are related to  $a$ , all of **you know** in cubic what is relation between  $d$  and  $a$  in cubic, Prerana do **you know** you remember, what is the relation between  $d$  and  $a$ ,  $d$  which is the inter planar distance,  $a$  which is a lattice parameter in cubic, **a by**  $a$  by 2.

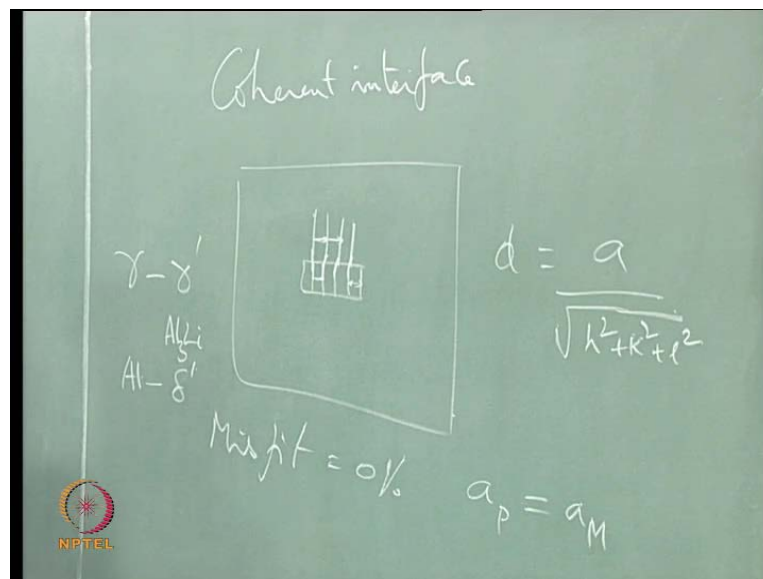
(c)

Correct, so we know that  $d$  is  $a$  by under root  $x$  square plus  $k$  square plus  $l$  square, this is only for cubic. So, if that is case I know that if  $a$  of matrix and precipitate are the same, then the  $d$  for any plane whether, it is  $1, 1, 0$  or  $1, 0, 0$  or  $1, 1, 1$  for them you would also see the  $d$  also will be the same; and if the  $d$  is same the inter planar distance being the same, then you would see there is perfect matching.

And this is the very ideal situation, very difficult to really see and there are very few cases where such a thing happens, one such case is the  $\gamma$   $\gamma'$ , where  $\gamma$  is the matrix which is the nickel base super alloy, and  $\gamma'$  prime, what is  $\gamma'$  prime,  $\text{Ni}_3\text{Al}$ . And there also another situation something like  $\text{Al}_3\text{Li}$ , which is called delta prime, and in an aluminum matrix there are few such examples,  $\text{Al}$  to  $\text{Al}_2\text{Cu}$  is another example, aluminum copper phase diagram.

So, whenever you have such a situation, you will see that there is a matching, in case the lattice parameter of the matrix is different from that of precipitate, what should happen you will see some kind of  $a$  for example, let us assume that, the precipitate is like this (Refer Slide Time: 07:50).

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This is the  $d$  spacing for a particular plane, for the same plane here, you would see that what I would like to say is, that this spacing is slightly larger than this spacing by about

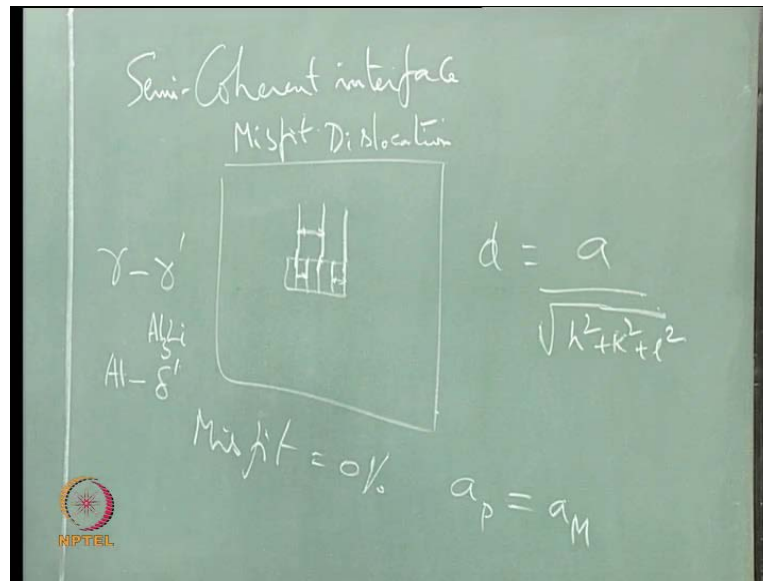
few persons let say. If the  $d$  spacing is slightly larger what happens is, there will be some kind of bending at the inter phase of the planes, in order to maintain the continuity the atomic planes will have a kind of a strain that comes in because, there is a bending of the atomic plane at the inter phase and that causes what is called coherent strains. In order to maintain the coherency, the system tends to have some kind of strain, and this strain can be accommodated up to a certain value.

We talk about sometime back whenever, you put a solute into a solvent also the strain can be accommodated up to certain extents beyond that, the solute is rejected, similarly up to certain extent it maintains. And if let say the distances between the  $d$  spacing here, and the atomic planes here and the distance between the atomic planes come becomes much larger difference, then what happens.

Then you would see for example, let say this is the situation, that the  $d$  spacing here is much larger than the  $d$  spacing there, then what happens is, in a unit distance the number of atomic planes any particular plane that we are talking about, is different for the matrix and the precipitate. So, that means, across the inter phase if I look at it, here below the inter phase you have certain number of planes in a unit distance of  $x$ , and above that you have less number of planes. So, as a result you do not have one to one matching for every plane which is there in the precipitate, you do not have a matching plane **in the** in the matrix.

Then **what happens** what happens is some of the planes you will have a continuity, and some of the planes are left out and this is exactly similar to something like a dislocation. What is the dislocation, you say you have an extra plane of atoms is below, you have a extra plane of atoms above a particular plane. So, exactly you see, that means you are creating dislocation, these are called interfacial dislocation.

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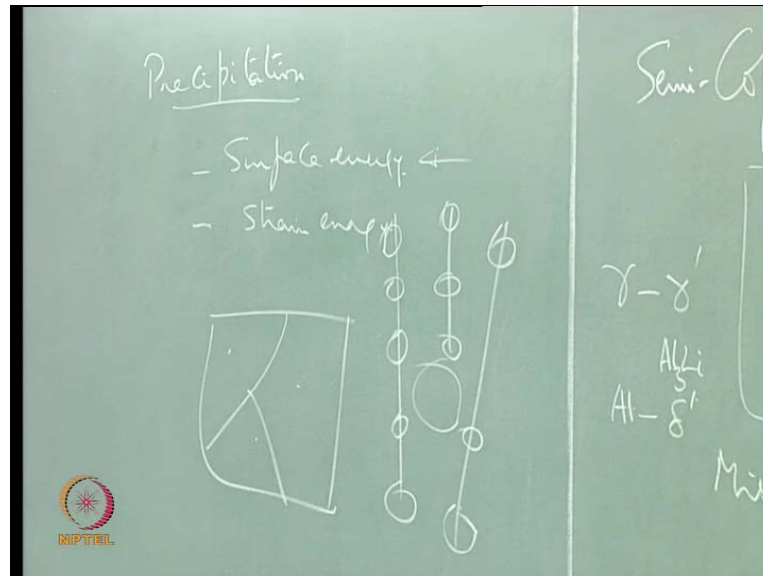
And these are also called misfit dislocation, because the dislocation are coming because of the misfit, and that is why they are called misfit dislocation, and these the moment you generate misfit dislocations, we **colour** called this anymore as a coherent inter phase. We call now this as a semi coherent inter phase they are called semi coherent inter phases, partially coherent and if this keeps on increasing, then what you see is that the number of dislocation will keep on increasing.

If the misfit is keeps on increasing that means, for any given number of a atomic planes in the precipitate, the number of the atomic planes on the matrix it continuously keeps on decreasing let say, because the spacing is increasing, one of them is increasing with respect to the other, we are only looking at the relative change. So, if that is the case, you will see that as this increases more and more with respect to this, you will see more and more planes within the precipitate are left out on the other side, you do not have a matching planes.

So, that means, you have more and more dislocations generated, and every dislocations is associated with certain energy that means, the energy of the inter phase is increasing, every dislocation as an energy. And that is why, reason why we **actually** considered dislocations also as one of the heterogeneous nucleating sites, why because if you can have a dislocation, **I mean** nucleation there the energy can be reduced, because

dislocation has an energy, where is this energy coming from for dislocation, because there is distortion above and below the plane.

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If you remember, **the the** if you have atoms like this let say, you see that there is a strain associate there, and this strain is what causes the energy of the dislocation and so that is what, is going to increase as more and more dislocation come. And at some stage the overall energy is so high, that the system prepares not to have any coherency, and that is what we call it as in coherent precipitates, usually you get in coherent precipitate, when the structure of the precipitate is entirely different from the atomic matrix.

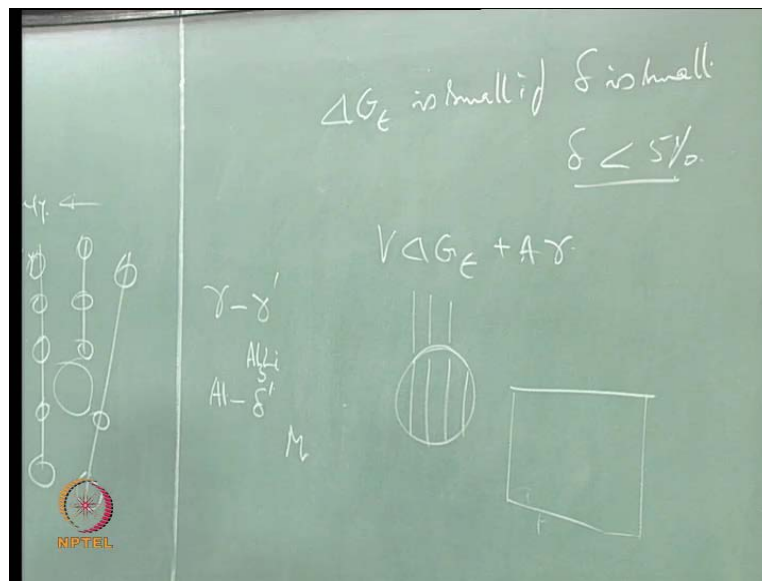
As long as the structure is the same, the system the only difference is the only lattice parameter; the system tries to have either coherent or semi coherent, and let see you the misfit you get in coherent, when the misfit which we call it had delta, delta crosses about 15 to 20 percent assuming that structure is the same. The moment structure is different, then it is not possible to have any coherency, so it automatically irrespective of what is the lattice parameter of the precipitate and the matrix, you **you** get an in coherent precipitate automatically (Refer Slide Time: 13:41).

The moment structure is same, then we look at this and usually if delta is less than about 5 percent, you get completely coherent inter phase, and gamma gamma prime such a cases are all something like that, where you have the delta very **very** small, and such a case you get this. So, this is in general this as nothing to do thermo dynamics, but

coming because of the strain, and because strain energy is also part of one of the thermodynamics parameter we need to discuss this.

So, this is also going to decide, what is the type of precipitation that is going to come out, now what we are talking is we are assuming that the coherent precipitate is coming out, and what is the shape of this coherent precipitate this is what we were talking in the last class. What should be the shape of the coherent precipitate, assuming that it is coherent, if you think that it is coherent that means, strain is not to large.

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If a strain is not to large, then the strain energy is too small that means, delta G epsilon is small, if delta is small once that is the case, then what decides is the surface energy, once for given precipitate and matrix if this is small the system will choose that particular shape, which as the lowest surface energy. And coherent inter phases mind you, coherent inter phases always will have the lowest surface energy, because there is continuity it is as if like, **you know** if I give you analogy you, it is like low angle grain boundaries with respect to high angle grain boundaries.

A low angle grain boundary as a lower energy, because the extent of misorientation between the two grains is very small, and the more the misorientation, the higher the energy of the grain boundary, exactly similarly because, there is a continuity of the planes at the inter phase coherent precipitate always have the lowest energy. And in coherent will have the highest, and the semi coherent will have somewhere in the middle.



So, as long as you say a coherent precipitate is forming, it will always have a lower surface energy, so we are saying the strain energy is already low, because  $\Delta$  is small, then what should be the shape, that is were you will see the shape automatically turns out to be a spear. Because, as you know whenever we are talking of overall energy you have to remember, it is  $V \Delta G_{\epsilon} + A \gamma$  that is what as to be minimize, this is the overall thing that as to be minimize, the system want to minimize this.

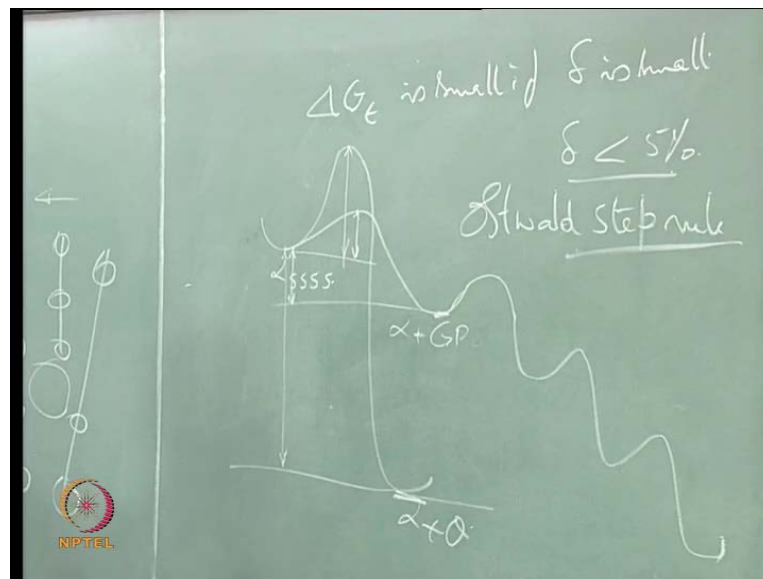
And once this is small, and if this is also small **the** it would try to have a smaller area, and that is what is the spear, spear as the smallest surface area. So, once it chooses a spherical particle you can see this overall can be minimize, and that is how you see spherical precipitate come; only when the  $\Delta$  is very small. When the  $\Delta$  is large and even you will see, that in some of the cases where **where** the spherical precipitate come when they grow to bigger sizes, you would not see this spherical precipitate maintaining their spherical nature, in a liquid to solid there is a possibility that is if you have **spherical precipitate** spherical particles forming a from the liquid to solid.

They can still grow as spears, there is no strain associated there because, liquid everything can be accommodated all the strain can be accommodated inside the liquid, whereas if you have spherical precipitate which is growing inside a solid, then in order to maintain the coherency becomes very difficult for a spherical. If you think of a curved inter phase, a curved inter phase if you have atomic planes, curved inter phase to maintain the coherency on a curved surface is not easy, maintaining a coherency on a flat surface is easy; as a result what happen is, as it grows to bigger and bigger this coherency becomes more difficult.

So, it slowly changes into shapes which are like this, that is why  $\gamma'$  you see cubits, when they grow they become cubits at the nucleation scale they all spears, if you look at them at the initial stages of precipitation, there all spears and then they become cubits. These all in cases where the misfit is small, if the misfit is large that is what yesterday we have seen, if the misfit is large then the system wants to somehow see that, you do not have anyway the strain energy with a spear is always higher, that is what we have seen the highest is the with the spear.

So, spear is avoided and then the other two possibilities are one is a plate like precipitate, and another is could be rod like precipitate, and you see that a plate like precipitate as a better comparability and as a result in a most of the cases, you see plate like precipitate. And that is what you see in most of the cases, that plate like precipitate come because, the delta is larger. So, this is all more of somehow minimizing the overall, but this is all at the starting only we are talking of the starting, and were you have only come to an intermediate stage.

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Why intermediate stage, because if you start with a super saturated solid solution for it to give you alpha super saturated solid solution, to give you alpha plus theta **though there is a large driving force** though there is a large driving force, the activation barrier is also large. So, what the system does is system chooses that particular structure, which as a lower activation barrier that means lower combination of this two what is the activation barrier it is this, which is the activation barrier, combination of this two is the activation barrier.

And that it tries to minimize that, and then gives you another precipitate with a lower activation barrier, but at the same time you see the energy of this, will be higher than the energy of this, because that is after all a metastable phase. So, a metastable phase comes out of this, and there is definitely driving force for this two come, because this as a lower energy than this. So, from a super saturated solid solution a another phase which as a

lower energy than this comes out, and that is what in our case is what we call it as G p zones; alpha plus G p zones, and that goes through next stage and then the next stage and then finally, you reach this level (Refer Slide Time: 21:51). So, it goes to theta double prime to theta prime and finally, it to theta as the precipitate starts growing to bigger and bigger sizes, it slowly changes from the original state of super saturated solid solution to the final equilibrium shape, which is the theta in a number of steps.

Because, at each of the steps if you draw and see G p zones wants to jump to theta, again that activation barrier will be large. So, it tries to see that the same thing happens in steps, this is what people call it as Ostwald step rule; Which basically talks about whenever an activation barrier for a particular transformation is very large, the system tries to achieve that final equilibrium stage in a number of steps, were it each of the step the activation barrier is much smaller than the original activation barrier.

And that is why you see the free energy shifts from here to here to here to here finally, and the number of steps that you need to go through, basically it depends on the **the the** extent of difference in the crystal structure between the parent and the product (Refer Slide Time: 22:57). In some cases it can happen it directly in one step, that is what gamma gamma prime cases directly gamma prime comes out, you do not have any step, in case of cemented case you see you have one step which is epsilon carbide from the marten site you get first the epsilon carbide, and epsilon carbide directly gives you the cement type.

So, like that you can see depending on the type of system depending on the crystal structure **complicate** complication, you can have a various number of **I mean** aluminum copper is one classic example of a large number of steps. Otherwise, there are many systems where it can happen in directly one step.

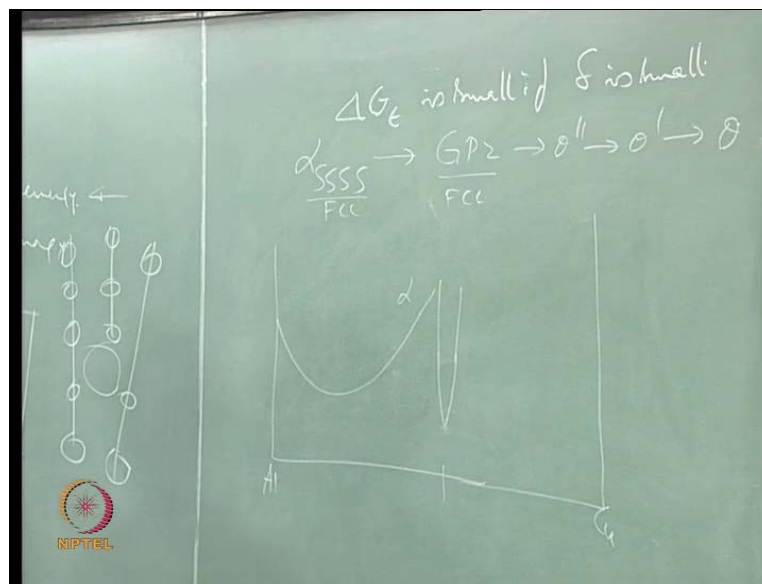
And now, if you try to look at this from the thermo dynamic angle

**(O)**

If you look at see the point is, **ya** interesting question, but the point is once you have come to this stage, it does not bother what is the activation energy here, now you are starting state is this the past is gone. So, now, you have to look at from here, if I have to come to hear what is the activation energy, can I now reduce it by going to some other

stage, where the activation energy can be lower. So, it is not that each of the individual activation energy, if I calculate and add it off will it be lower than this, it can lower, it can higher, but that is not question here so but, each type definitely this particular activation energy will be smaller than this going directly to theta, that is what is important, is not it. So, **so** final stage what you are coming this not really important at each of the step it tries to look at, **what is** how do I minimize the activation energy.

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Now, let us look at the aluminum copper, we said right now that alpha super saturated solid solution goes to G p zones first, and then theta double prime, then theta prime, then finally theta, this is what we said. And G p zones and alpha have the same crystal structure, this is FCC, this is FCC the only difference is, what is the difference?

**(O)**

Anything, where is this lattice parameter difference coming out

**(O)**

The composition is different as simple as that, the G p zones composition is different from alpha, alpha super saturated solid solution as 4 percent copper, and 96 percent of aluminum where as G p zones are possible very **(O)**, we call them as copper crestless. But, unfortunately there is no **ah** easy technique to find out what is the exact composition of it, because the crestless of so small, have you heard of what could be the technique

that you can use to find out, such as the composition of such a crystal let say, you have a crystal of about I know 100 to 1000 atoms.

(O)

Electron

(O)

Electron mass spectro meter

(O)

(O) a large number of people use pre-dimensional atom, where you basically can see each atom, how many of you know about atoms prove, atom prove is a technique which is basically field dynamic microscope, where you take a sample in the form of tip. And then basically (O) away the atoms, when you are factoring over the atom depending on the weight of the atom, there the velocity of the atom is going to be depend on, this is what we call time of flight measurement we called them.

So, you put a detector certain fixed distance, and try to see what is the once you have apply a placid voltage and you fatter atoms, you try to measure what is the time that a particular atom as taken to reach here, once you have done the placing, then you start you time  $t$  equal to 0. And then you see some time  $t$  equal to 0 when an atoms is detect by the detector, and from that particular time difference you can find out that calculate, and find out this could be an element of this particular mass, if this is the mass of this element it would take this much of time.

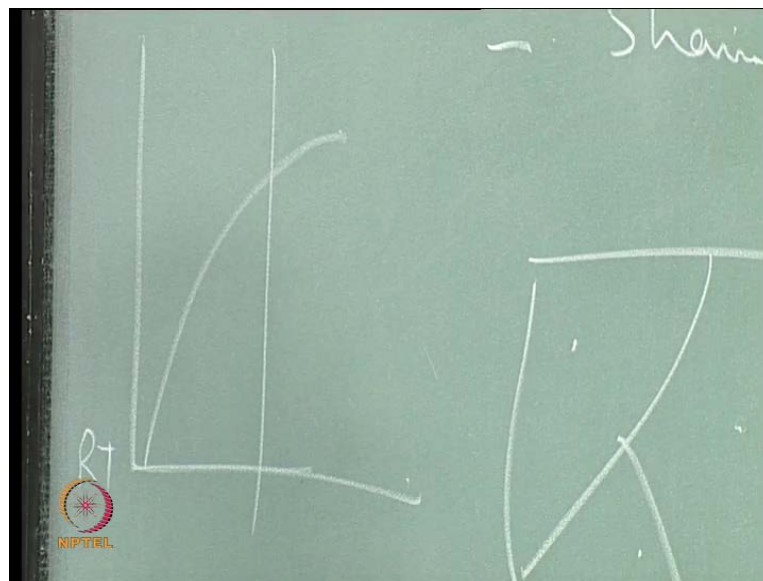
So, all this once you know that you can the moment each atom reaches there, you can start assigning a particular mass number to it; and that is how if you do layer by layer, factoring and keep on detecting atom, and then store them. You can **actually**, when you reconstruct the whole thing, you will able to see how the atoms are distributed inside this, in a nano metric level one can see that and there you can actually see, if there are any small crystals of copper or fire whatever it is.

And people regularly see this for example, carbon atoms going and sitting near the dislocation, we call them as crystal atmosphere this is the only technique, which can

actually prove that. There is no way you can see by **a** let sat t amides or any other technique you will not be able to see, because the reason are so small, so this is the wonderful technique where large number of people, in the whole country is only one place where we have **(O)** as this, incidentally I work for 2 years on that instrument in Japan **anyway**, so that is why good technique where you can see that.

So, the point is if this is the copper rich crustal, and this is a aluminum rich crustal, let us look at how is the free energy diagram is going to be, let us draw the free energy diagram, and on one side you have aluminum on the other side you have copper, you start with an alpha, let say this is our alpha and somewhere here is a the midpoint let say, and so 50, 50. So, theta as approximately around 55 percent this is what we have said, so you have theta phase somewhere here, and let us say put it slightly down, because we are let us draw the phase diagram.

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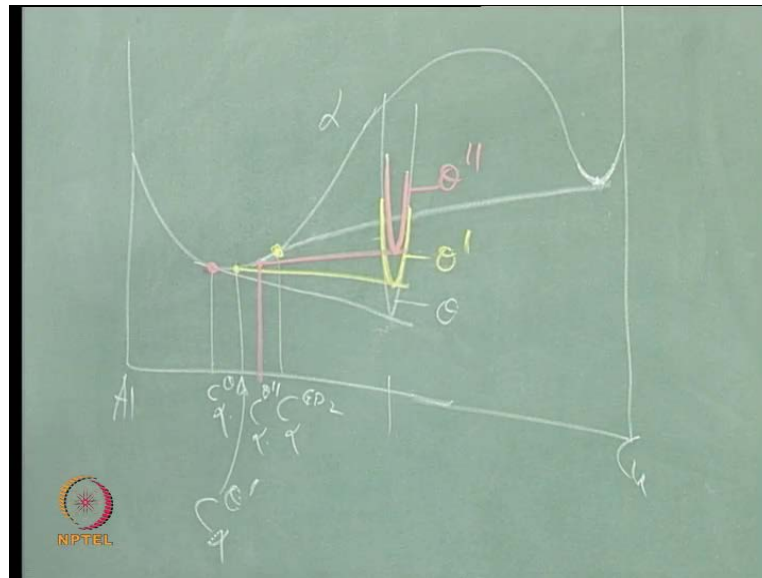


We are talking of at a temperature let say somewhere here, may be we can even consider room temperature why not, at this temperature I am talking of the precipitation, I have taken the alloy to high temperature quenched it why do I quench it, to get this superstasion; if I do not quench it then what happens?

**(O)**

Yes theta will precipitate the grain boundary, if I do not quench it you will have, in fact this is what people observe whenever you are doing age hardening, unless you real quench it fast, you do not see this whole thing. Otherwise, during the cooling itself you can have precipitation taking place, so then super saturated solid solution does not form; so once the super saturated solid solution come, and at this temperature, if you look at the free energy composition diagram, you will see this is the common tangent, where this composition is what, is this composition.

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So, this is this composition right, and now we are talking about that this is all under equilibrium, but we are saying that equilibrium is not happening, theta is not able to come out of the alpha, then what is coming out of alpha, it is what is called the G p zones. Which are nothing but, copper rich and because, there are also FCC, if I want to draw the free energy composition diagram for the G p zones, how I will draw?

(O)

It will be the same curve extended towards the pure copper side, there will be no separate free energy curve for the G p zones, because they have the same structure, whenever there are two phases with the same structure, they will have same free energy curve; this is what somewhere we have talk about it. So, you can see that this **this** will look something like that, pure copper rich phase, so this is the G p zones free energy that is the case, now if I draw a common tangent between the two, then how will the common

tangent look like (No audio from 32:52 to 33:16) (Refer Slide Time: 32:52), so this is a composition now, what do I call that composition now?

(O)

Correct, it is the composition of alpha in equilibrium with G p zones, what is this composition?

(O)

Yes, so now, let us say that this is the composition of alpha in equilibrium with theta, this is the composition of alpha in equilibrium with G p zones and both are different, why they are different because, the free energy of this two phases are different. And this is similar to what we have done earlier, if you remember when we are talking of iron carbon diagram, and iron cement diagram, we need to exactly something similar, and this **this** is the metastable phase, this is the stable phase.

The composition of any phase in equilibrium, with metastable phase is always higher in the solid content, when compare to the composition of the same phase in equilibrium with equilibrium phase; that is what exactly you see here. That means, at this temperature if I now want to show, what is the composition of alpha in equilibrium with the G p zones, where do I show on the phase diagram, it will be to the right of this point. So, that means, somewhere here I do not know exactly where it is, but that can be calculated one side have the free energy curve.

Now, if I say where are then the next phases, what are the next phases theta double prime and theta prime, and theta double prime and theta prime they will definitely have lower free energy than what, than G p zones, but higher free energy than the theta. So, as a result I can say that, and they will also have the same composition as that of the theta, that is the reason why we still call them as theta double prime and theta prime; otherwise, we could have given some other name, thus difference is only structure, structure does not still become same as that of the orthorhombic.

So, the final structure involves, so the structure slowly involve from the FCC two orthorhombic, so you will see that, if I draw I can possibly use **may be** (No audio from 35:49 to 36:00) (Refer Slide Time: 35:49) something like this, one is a this is the let say

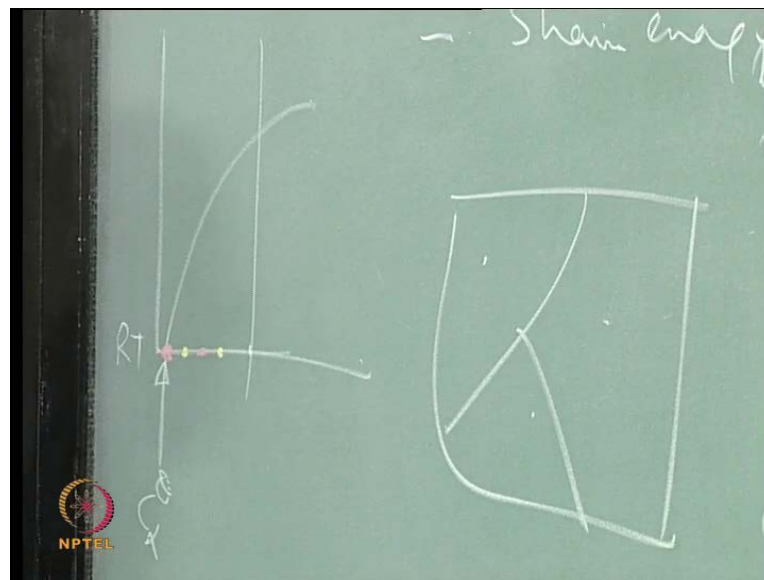


theta double prime, and this is theta prime and this is our theta. And now, if I again if I look at this thing, and again draw common tangent what you will see is that, if I draw common tangent, now let me draw a common tangent with this, and another tangent common with this, again if I look at those points I will see two additional points, this which is composition of alpha in equilibrium with theta double prime (Refer Slide Time: 36:31).

And this is the composition of alpha in equilibrium with theta prime, see this is **sorry** your right, this is no right, this is correct no problem. So, G p zones theta double prime theta prime theta, it will always been that order, the composition of alpha in equilibrium with G p zones will have the highest solid content.

The composition of alpha in equilibrium with theta will have the lowest and it goes because, you can see G p zones to goes to theta double prime, and then theta prime and then theta. So, the free energy levels, this is highest, this is lower, this is lower and this is lower and this is further lower (Refer Slide Time: 37:37).

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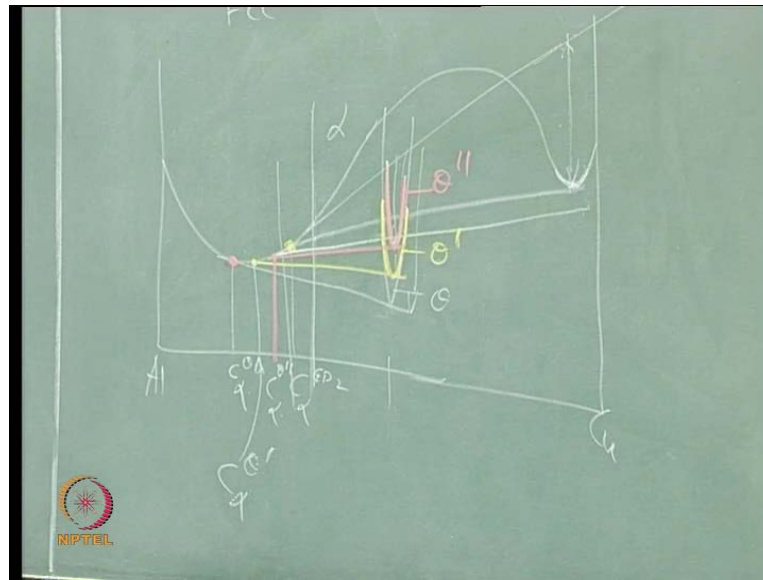


Now, if I put all these points on the free energy, on the phase diagram you will see four different points (No audio from 37:51 to 37:59), one is the equilibrium composition of alpha in equilibrium with theta. And yes

**(O)**

We are not talking of lower than alpha or higher than alpha for example, if that is the case this the way I had drawn is higher than alpha, what is important is not whether the phase as higher; when I am taking alloy of a particular composition, what precipitate is more important.

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In an individual phase what is important is, when this is coming out of as a part of you may be saying that, sir this should be lower than this for that to precipitate, is not like that, you have to see for at that particular composition. For example, if I have this kind of free energy curve, the moment I am choosing alloy of this composition, and what will come out for this alloy, when I **start** keep bring this alloy of that composition, bring it to that particular temperatures room temperature, hold it there.

What comes out, depends on when I draw a tangent for that particular alloy, **what** where does the tangent intersect, that is what is going to decide. So, now, once I draw a tangent for that particular composition, and you will see that this tangent goes like this, and then the driving force is decided by this now, not with respect to alpha. Once I draw a tangent for the alloy composition, the alpha **that I am staring** with I am starting with alpha, that alpha for that particular alloy, I draw a tangent.

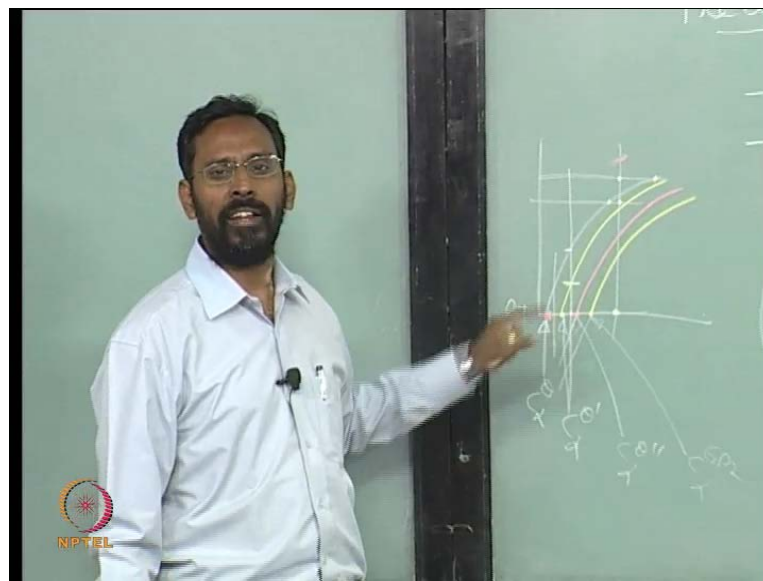
And where does the tangent goes that is going to decide this as this much driving force. where are this as this much driving force where as this as this much, and this as this much, each phase will have some driving force (Refer Slide Time: 39:55); and

depending on now this driving force now which phase will come out, all four of them have driving forces let us say, then what will come out is going to be decide by what is the activation energy for that phase.

But, now if I choose another alloy composition because, we have raise that question let us look at this, if I choose this particular alloy composition and draw a common tangent, I will come to a situation like this, that this particular alloy composition is such that, it can have a driving force for this phase, this phase, this phase, it cannot have a driving force for this phase (Refer Slide Time: 40:42). That means, if I choose that particular alloy, I will not be able to get G p zones, you are going to see it within a minute when you look at this particular thing.

For example, now if I look at these four compositions, this is compositions of alpha in equilibrium with theta prime, this is compositions of alpha in equilibrium with theta double prime; this is compositions of alpha in equilibrium with G p zones (Refer Slide Time: 41:05). Now, if I do this exercise at different-different temperatures, these all being at one temperatures, if I do at different temperatures, what would happen, at each of the temperature I will have this common tangent, at each of the temperature I will be able to generate this four points.

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And then that will lead you two different curves, you will get **three different** four different curves, what are these curves?

(O)

Here, all solve of line, they are different solves line we call this as theta solves, we called these are the theta prime solves, this a theta double prime solves, these are the G p zones solves. And now if you look at this particular solves, and carefully observe what I have been just saying in answer to Anisha, if I take this alloy bring this alloy to this temperature, at this temperature these alloy is below the solves line for all the **three of them** all four of them, the movement on when does the precipitation take place, whenever my alloy compositions comes below the solves, then only precipitations happens.

For example, if I take this alloy, heat it to this temperature, keep it there will a precipitation take place no, why because may at the temperature, if I extrapolate for example, if I choose not that particular temperature or temperature like this, easier to see. At that temperature, if I draw horizontal my alloy compositions is having less solute content then what is the solubility limit, what is solves line, solves line tells you solubility limit at each temperature, **am I right**.

So, if that is the case the my alloy is contenting less salute content, then what the solid solution can content, and in that is the case then there is no chance for the precipitations; the amount of solute it smaller then what it can content, but the movement I bring this alloy to this temperature let say, at that temperature again, if I draw a tie line. Now, my alloy composition is higher than what the solute can content, and my alloy having higher then what solute can content; obviously, it has to precipitate.

So, precipitations can happen only when the solute content of the alloy is greater than the solubility limit, and that when is it happening in terms of temperature if I look at it; so, far we talked about compositions in terms of temperature, when I bring it below the solves line. Now, if how at this particular temperature for this alloy compositions, **I** my alloy at that temperature is below the solves of all the four of them that means, in principle all four of them can precipitate.

Instead if I choose another alloy of this composition, instead of 4 percent copper, 2 percent copper let say, if I choose 2 percent copper, then if I carefully look at it these particular composition at this room temperature is below the solves of this, below the solves this, but it is above the solves of this and above the solves this (Refer Slide Time:

46:50). That means, the G p zones and theta double prime cannot nucleate, from this alloy if it is brought to that temperature, and that is what I was trying to explain. If I choose the alloy of that compositions draw a tangent, I will see that the G p zones and theta double prime will be above the tangent; once there above the tangent, there is no driving force for them precipitate.

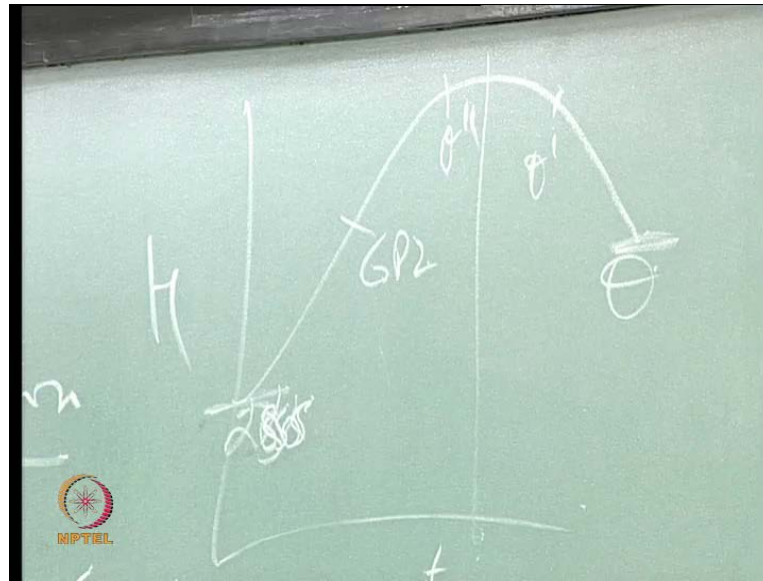
So, if I keep on shifting the compositions towards the left side, you will see one by one each of the phases starts dropping off, and that is why if I choose the alloy of this particular composition, the only phase that can come out is theta; if I bring that alloy to room temperature. And that is why we do not use such alloy compositions for (O), you you never think of (O) of 1 percent copper alloy, because for such an alloy the only precipitate that can come out is only theta, and that theta anyway you know that is start going to give you higher strengthening.

Because, it basically and in coherent and again I should tell you because, we are talking of strengthening strengthening is depends on all of you, know about precipitate strengthening. Whenever you have a coherent precipitates, the strain energy associated with a coherence, coherent precipitate what is called coherent explains can had to the strength, not only the particle and also this. And whenever particle gets shared by dislocations, the new surface that is generated also has to be new energy has to be spent.

And as result the that is why the smaller the energy of the of the precipitate that means, the more coherent it is the more difficult it is for the cutting, because for cutting you are creating and extra surface this system is already in a lowest energy state, so it does not want to create a new surface. So, the the the stronger are those alloys which have coherent precipitate.

But, it again there is a other issues coming into a pictures, coherent precipitate being very very small, the they can also be shared because, size itself very small, so the totally area that you are creating, when your cutting it is not a very large. So, you have to look at a waving both the case cases that is why, usually when you do (O) the peak aging comes when you have a semi coherent inter phase, G p zones do not give you peak aging.

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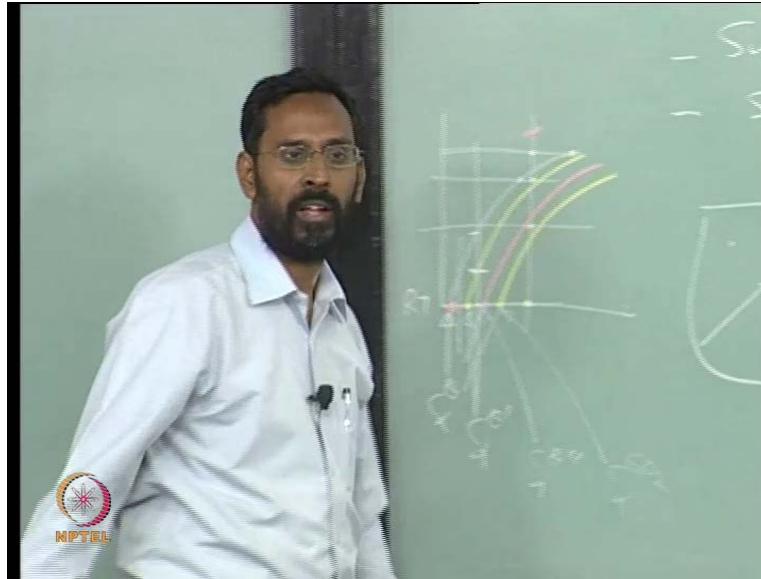
For example, if I draw hardness versus time, you will see this kind of curve, all of you are aware of it, this peak comes. This is the super saturated solid solution, alpha super saturated solid solution at GP zone are somewhere here, and theta double prime is somewhere here, theta prime is here and then finally, theta is here, something like that. So, somewhere between the theta double prime and theta prime is where you get the peak aging, that is where you get semi coherent inter phases, so **so** the strengthening aspects you do not want theta, **theta gives you**.

Now, but at the same time **you know**, you will always remember that this value and this value, if you carefully observe this value will always be higher than this, because strengthening here is coming from what, in this case?

**(O)**

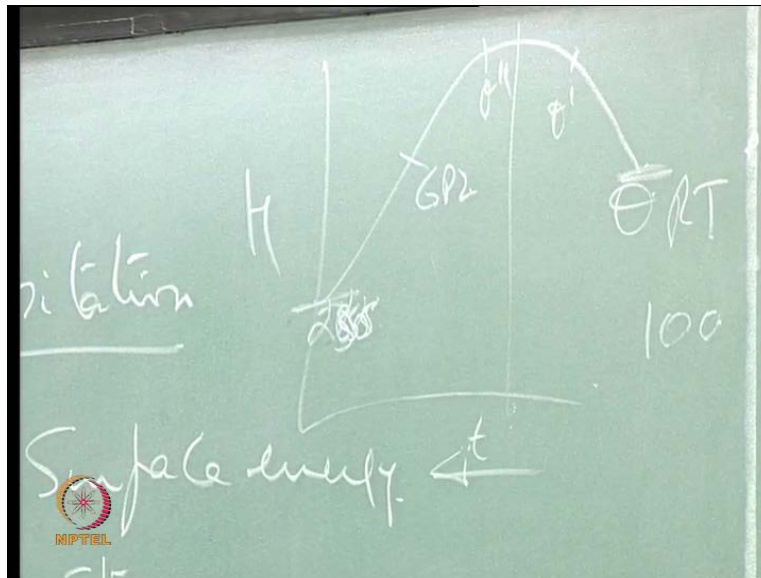
Is only solid solutions strengthening, whereas here you have precipitate, and there the precipitate are larger and only the strengthening that comes is by formations of the loops for a one loops; the by a bending of the dislocations not by the cutting of the dislocations, so that is the another aspects. Let us not go in to the detail of it, what is important for us is to understand that depending on alloy compositions, and depending also on the temperature which is doing handling, now I am talking of this alloy age adding being then at room temperature.

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Now, if I increase the age adding temperature two, somewhere here let say, why you do increase the age adding temperature, diffusion is faster. So, the kinetics will be faster, the precipitation will happen at a shorter time for example, if this is one of the age adding curves.

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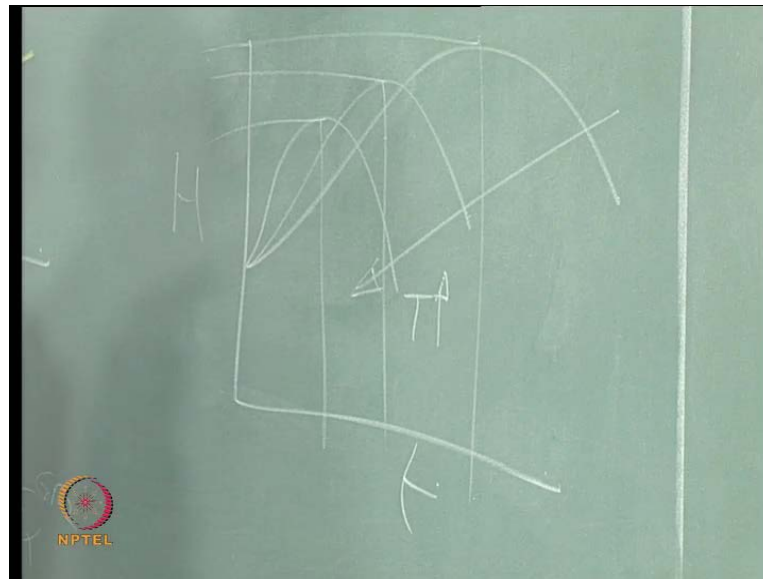


And if this is room temperature, if I am doing at let say 100 degree centigrade, how will age adding curve look like?

(0)

Short time that means, peak is reached that short time.

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Now, can tell me anything more

(O)

Now, I am not talking with respect to this simply am increasing the temperature, let us not bother about what phase is the forming, the **peak time** peak time decreases and what about peak hardness, peak hardness comes down, that is very interesting. So, if you look at this, this is kind of scenario you find, as the temperature increases in this directions, the peak time comes down and the peak hardness comes down, why does the peak hardness comes down, can somebody tell me?

(O)

Coherency is one question sense, something more **more** fundamental which you can see from the phase diagram, if you look at the phase diagram ignore all these solves line, just think of only one theta solve us. And then tell me, what would happen if I keep on increasing the temperature?

(O)

Let see outside more than that



(O)

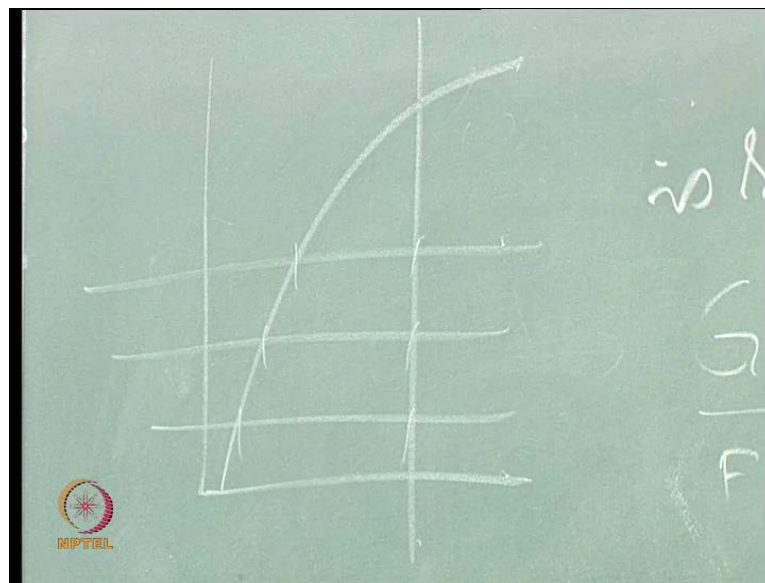
Solubility is more

Solubility is more, so

(O)

The amount of precipitate will be lower, because the if I look at this, I will possibly draw a separate thing.

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As a keep on going to higher and higher temperatures, the extent of super saturation is decreasing, extent of super saturation decreasing and it is this which tells you what is the if you use the liver rule, this is what which tell you what is the amount of precipitate that is forming; go back to your liver rule, how do you calculate the amount of theta phase, the amount of theta phase is going to depend on this. And the movement I reach here, it will be 0, so that is why the higher the temperature you would see the lower the amount of this; and that is one and the size being higher both of them will cause this, will stop now.