Advanced Metallurgical Thermodynamics

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Lecture No. # 23

Eutectoid reaction

Last class, we started talking about eutectoid transformation. (No audio from 00:14 to 00:24)

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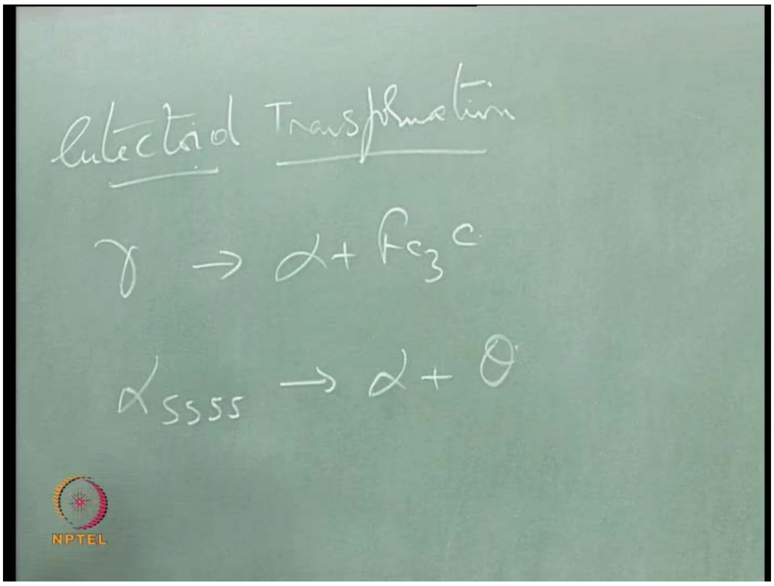

Eutectoid Transformation

$\gamma \rightarrow \alpha + Fe_3C$

$\alpha_{ssss} \rightarrow \alpha + \theta$

This is different from precipitation in the sense; here you get two phases out of parent phase, when compared to precipitation where you get one phase out of the parent phase. So, here we take a typical example of iron carbon system, where you have the gamma which gives you alpha plus cementite, where gamma is the austenite, alpha is the ferrite and cementite is the Fe 3 C phase. And this is what which started looking at, and as you clearly see, when you compare with the previous case of precipitation, where you have an alpha which is the super saturated solid solution is giving you alpha plus some phase, you can call it as a theta.

So, here you have the parent phase remaining with a different composition of course, and a product phase comes out, which precipitate out of the excess solute that is available in the parent phase. So, the parent phase is the super saturated and because it is super saturated, the excess solute comes out as this. So, here the parent phase does not vanish after the transformation. Excepting that, the volume fraction of the parent phase which is initially 100 percent would decrease to certain extent where the product phase takes over somehow some part of the parent phase. So, that is why so you would see that the parent phase remains; whereas, in a eutectoid transformation you would see in principle, there is no parent phase left out.

Excepting in cases, where you are talking about a hypo eutectoid or a hyper eutectoid, where is where there is a proeutectoid phase. In this particular case, it could be a proeutectoid alpha or a proeutectoid cementite depending on whether we are talking of hypo eutectoid or a hyper eutectoid. So, as a result you may have the parent parent I mean pro eutectoid phase; but not really the parent phase. If you take the parent phase of the gamma, gamma does not remain after the transformation. Excepting again if the transformation is not complete, that is where you need to understand that, if you go to the TTT diagrams.

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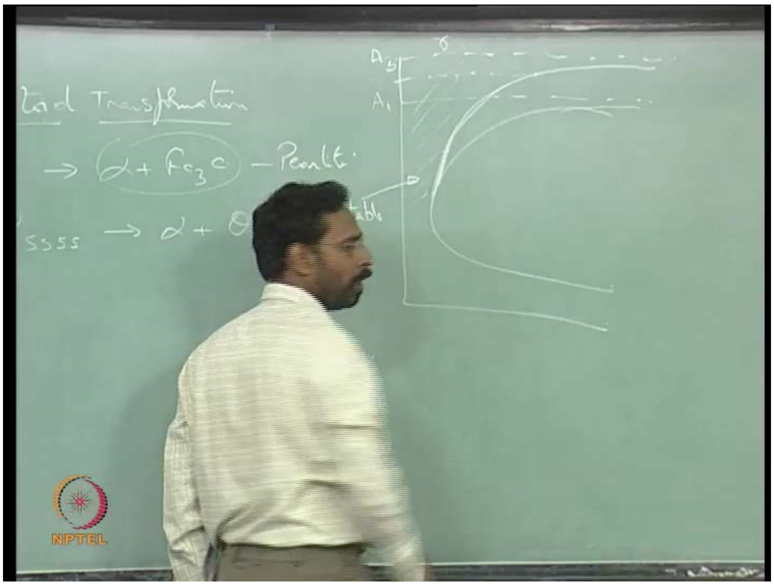

For example, look at a diagram like this, where this temperature is what we call it as the A 1 temperature. What is A 1 temperature? 720. What happens at A 1 temperature? Yeah, tell me; transformation of what to what? Pearlite to austenite; this is while heating or while cooling? While heating. So, we are now talking about the cooling. What happens while cooling? Austenite transforms to pearlite; this is what, we call it as the pearlite. So, that is what you call it as A 1 temperature and in principle, if you have a hypo eutectoid or a hyper eutectoid. In principle, you have another temperature, which we call it as either A 3 temperature in case of a hypo eutectoid and what A c m temperature in cases of hyper eutectoid. So and that is obviously above the A 1.

So, you have another temperature, which you can call it as A 3 for example, in a hypo eutectoid. And then, if you can observe, you would see another additional curve that comes in and that is related to the formation of the… What does it? What does form? Proeutectoid alpha from gamma. So, gamma gives you alpha in this domain. So, everything is gamma above that temperature A 3. Between A 3 and A 1, you will have gamma plus alpha provided. The time that you are providing for the transformation is longer than what is decided by the TTT diagram. For example, if it is if I am holding the alloy at this temperature, I have to cool the alloy I mean hold the alloy for time longer than what is decided at that temperature; so that, I can nucleate alpha.

If I am holding for a shorter time, then alpha does not get nucleated. And that is why, you say that anything to the left of this TTT diagram is basically what? What do you have to the left of the TTT diagram? It is metastable gamma. Do not call it is as unstable gamma. There is lot of difference between metastability and unstability instability whatever it is. So, this is metastable. So, this whole domain is metastable gamma. The reason I have to tell you the difference is, unstable it immediately transforms to something else. The moment I say metastable for it to transform to something else, you need to provide an activation barrier. That is the difference between a metastable and unstable. For example, if you take a situation like this, I told you also an example possibly sometime back.

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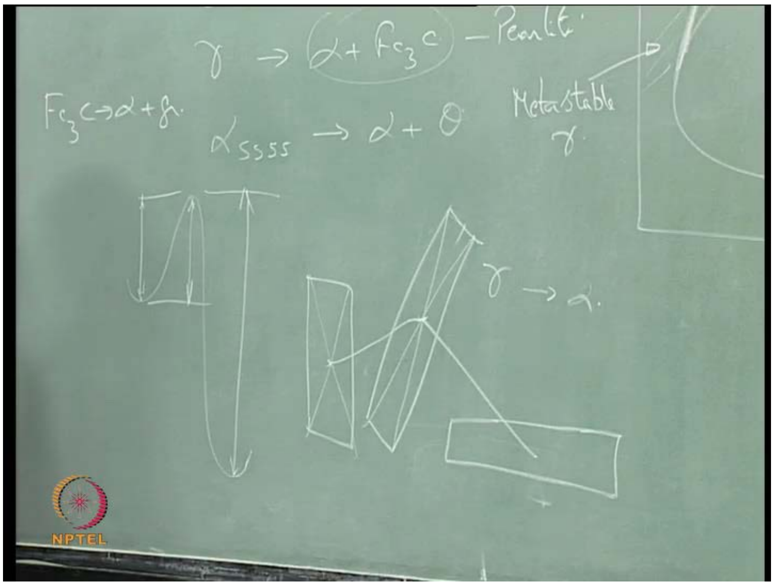

If you take a duster like this, this is in a metastable state. If I keep it like this, this is in a stable state. But from this metastable to come to the stable state, I need to push it. If I do not push it, it remains like that forever. So, as long as activation is provided, it does not come back to the stable state and that activation is this. So it has a higher energy definitely, when compare to the stable state. And infact one can also show in case of the duster also, if it is something like this. If you draw the diagonals and represent the center as the c g and that is at a higher state, when compare to a state like this; where if you draw again this one, this is higher than that. If you represent this as the energy of this and this as the energy of that, this is higher than this energy.

But when it is pushed, it goes through an intermediate stage which is something like this or possibly if I put it on the same base and then finally goes to this. So, here if you join these two, you come to a slightly higher level. So, this c g's which is obtained by joining the two diagonals is at a higher. So, it goes like that and then comes like this. So, it is at a higher energy state here, when compared to this and this is what, we call it as unstable; because at that stage, it does not need a push for it to fall. The question is which direction it falls? Whether it falls this direction or that direction? It has a driving force to fall in both the directions. Only thing is in the direction of the stable state, it has a higher driving force.

Because this whole thing is the driving force for this and whereas, this is the driving force for this. Now, the depending on the direction of your push that is given, it will fall in a particular direction. So, there is definitely a driving force for an unstable state, either to become a metastable state or to become a stable state and that driving force to a large extent. And the direction of the force, that is available decides whether the metastable unstable state becomes a metastable state or a stable state. And if you are starting from the metastable state and you have provided activation energy, then it would go to a stable state. This is the example of Fe 3 C, we talk about it. When you take Fe 3 C becoming alpha plus graphite, this is what we talk about.

So, you need to provide sufficient activation barrier for this Fe 3 C to split into the alpha plus graphite or gamma plus graphite. What does it depend on? Whether you get alpha plus graphite or gamma plus graphite temperature? Whether you are above A 1 temperature or below A 1 temperature is what decides whether you get alpha plus graphite or gamma plus graphite. And ofcourse, for the alpha plus graphite and gamma plus graphite, the time required is going to be different. The activation barrier is going to be different. Why? Because this alpha plus graphite occurs at a lower temperature and gamma plus graphite occurs at a higher temperature. So, the reaction rates are going to be higher for at a higher temperature when compared to a lower temperature.

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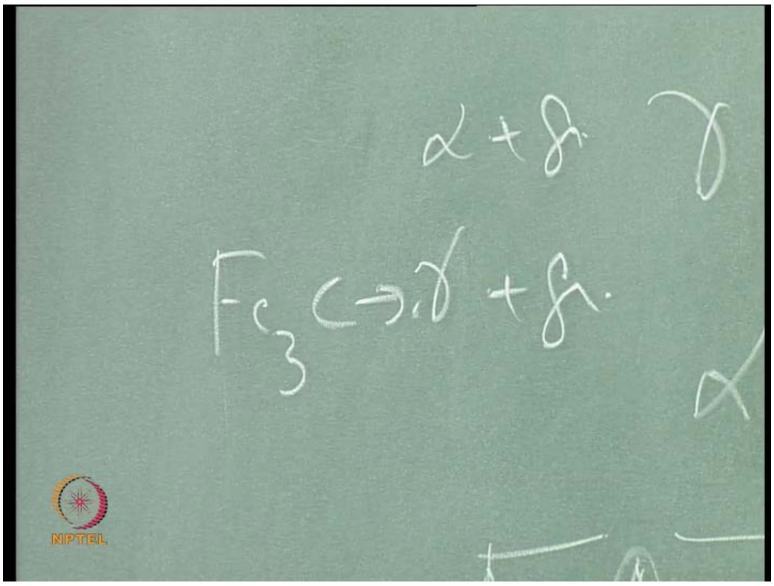

So, the time required for such a transformation either alpha plus graphite or gamma plus graphite can be worked out; looking at what is the diffusivity that is available at a particular temperature? Because it is the diffusion, which controls the whole thing. So, anyway, so this is all slightly beyond the thermodynamics. But for me to have always knowledge of this kinetics, otherwise you are always having half knowledge. So, thermodynamics without kinetics knowledge will not give you any information about the whole phase transformations; because phase transformation is always a combination of the two.

Many times, thermodynamic may say, yes this phase will form; but the phase may not form. But at the same time, one important thing that the thermodynamics tells us that if it tells that, thermo dynamics phase cannot form; kinetics cannot make it form. So, this is important. For example, if you are at a temperature, let us say below the melting point a solid will not become a liquid. Thermodynamically, it is not feasible. So, however fast reactions you do it; however you put a catalyst is there. It will not be able to make a solid into a liquid, until you raise the temperature. The raise using the temperature can be by thermal means by any other means. You can do irradiation. For example, any energy can be converted to any other energy.

So, irradiation also can lead to such kind of transformation of solid into an amorphous structure, which you can call it as a liquid. It is almost equivalent to raising the temperature, where the solid has become a liquid. So, you need to provide energy for it to transform into the stable state. So, thermodynamics definitely gives you clues, what is possible; what is not possible. But at the same time, just because it says it is possible; it does not happen. That is why, you take a liquid bring it below the melting point. It does not mean that solid has to form. The liquid can remain as liquid. If that solid needs a large activation barrier for it to form, and the liquid does not form a solid at all.

And that is the reason why, in a number of cases we get glasses. Because the liquid is not able to transform into a crystalline solid and that is a standard example is our own silicate glasses, where you have brought the liquid below the melting point. But silicate crystals are not able to nucleate; so, as a result, liquid remains as liquid until you reach the temperature of t g and where, this liquid becomes a glass. So, there are number of numerous examples were just because there is a driving force. It it does not mean that, the transformation will take place. At the same time, you also should remember that driving force also helps us to understand kinetics to some extent.

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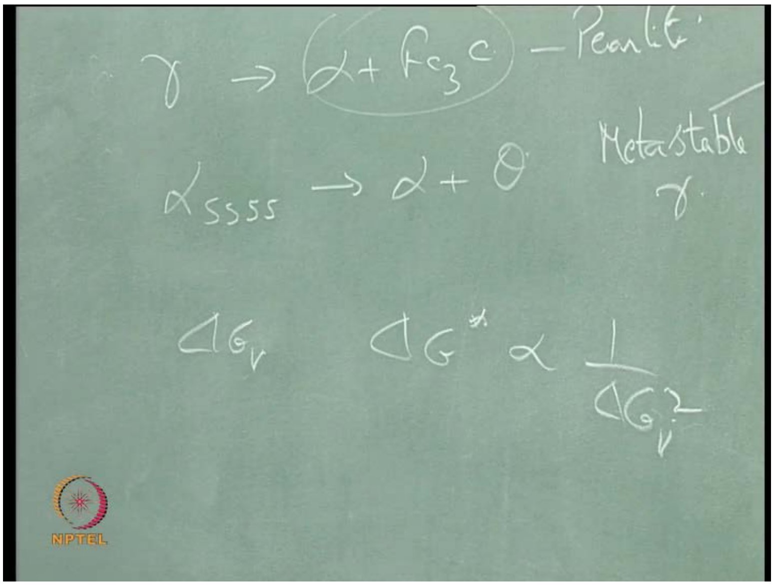

$\gamma \rightarrow \alpha + Fe_3C$ – Pearlite

$\alpha_{ssss} \rightarrow \alpha + \theta$

Metastable γ.

$\Delta G_v \quad \Delta G^* \propto \frac{1}{\Delta G_v^2}$

For example, we have been talking all these days that the delta G v controls to some extent delta G star. How does it control? Preyarna you know the relation? Square, perfect; this is inversely proportional to delta G v square. But but again that is only looking at the nucleation without considering any diffusion without considering any diffusion. So, if you start considering the diffusion aspect that is to a large extent controls to the kinetics. There you would see that this. This activation barrier that we are talking, you need to add some other activation barrier to really know the nucleation kinetics or growth kinetics.

That second activation barrier that we are talking about is an activation barrier for diffusion. If you add that, then you get a full picture. Otherwise, this is not giving the full picture. That is the reason why, you will see that in a TTT diagram, the curve is a c shape. The c shape basically means what? It tells you that as I decrease the temperature what is happening? What does this time tell you at any given temperature? Time needed for nucleation; this is what, we call it as incubation period.

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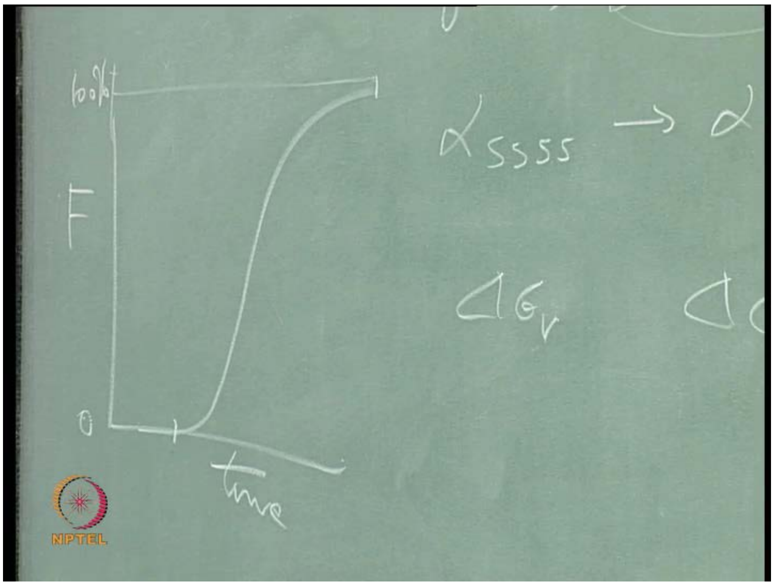

All of you know that, when any phase transformation has a typical S shape; if I plot fraction transform as a function of time, this is something like 100 percent let us say and this is 0 percent. So, if I am talking of gamma to pearlite transformation, it would have a typical curve like this. And this particular time, where the transformation is starting is what we call it as nucleation and this is what is completion; this is start; this is end. And this is what, you will see in a typical S curve and this period is what is called as incubation period. What happens during incubation? What happens during incubation

Nucleate that means what? An r star is something evolves during that period. The atoms come together and form the size of the r star, critical nucleus for decided by that particular temperature. Every temperature has certain r star. Because every temperature has certain delta G and that delta G decides, what is r star? Is not it? You know that, r star is again minus 2 gamma by delta G v, assuming a spherical nucleus. We have done this possibly. All of you must have done at the second year B.tech level, when you are talking about a nucleation.

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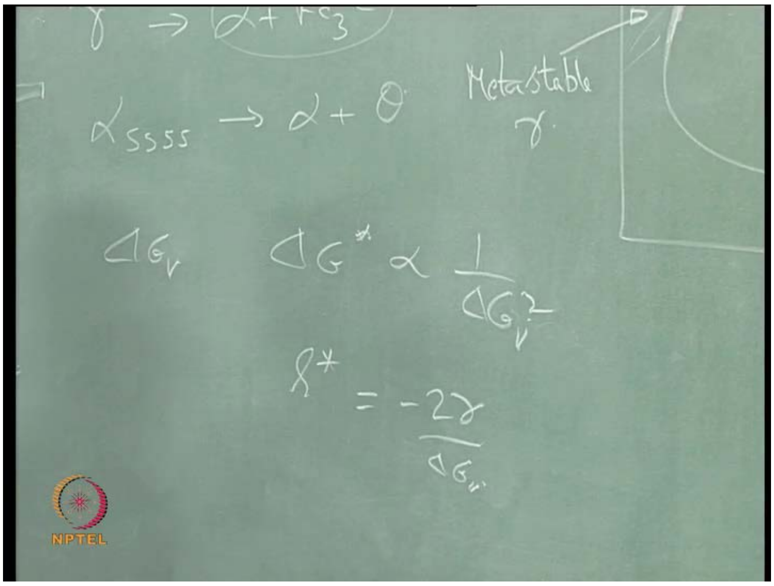

So, this is something which we know. So, for a given temperature, this is fixed. Driving force is fixed for a given temperature, given under cooling. If that is fixed, this is fixed for a given nucleation. Because once you decide, what is the product coming out of which parent phase, then gamma gets fixed; gamma depends on that. So, once gamma gets fixed, then r star gets fixed and that r star once for it to come out, you need certain time. Atoms have to come together, form that r star and this time, if you look at it if you carefully see here, the time is decreasing. Why is it decreasing? Yes, because r star is coming down.

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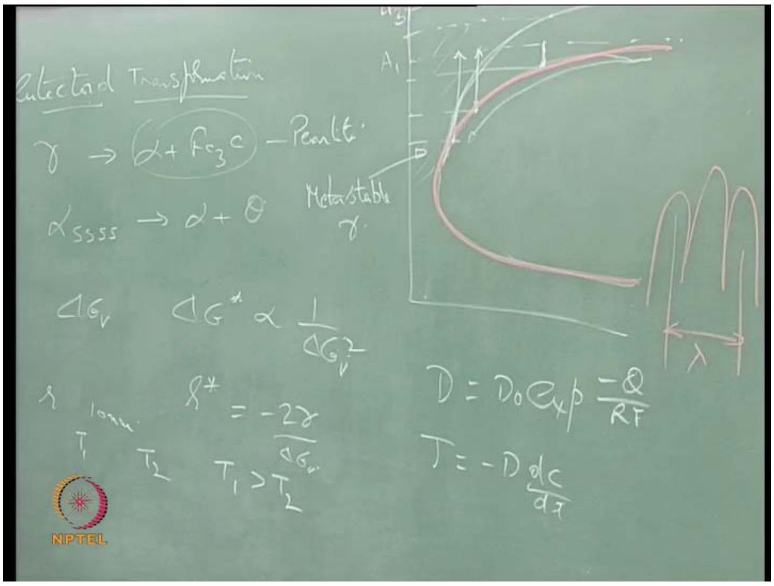

As I decrease the temperature, my under cooling is increasing. See if I look at a temperature here, here this is under cooling. If I look at temperature here, this is under cooling. If I look at temperature here, this is under cooling. Under cooling is always measured with respect to the equilibrium transmission temperature. For us, the equilibrium transformation temperature for this particular transformation is A 1; gamma to pearlite. So, with respect to the A 1 if you measure, you will see the under cooling is increasing and if the under cooling is increasing, you will see the delta G v is increasing and then r star decreases.

But this does not continue forever, that is where you would see the the second part of the C curve. The lower half of the C curve comes into picture because of that. Though the r star is continuously decreasing, in principle if I use that, you will see the r star continuously decreases like this. But though the r star is continuously decreasing, because of the diffusivities are decreasing as a function of temperature D. You all know D is D naught into exponential minus Q by RT, which is known to us. So, as a result you can see as the T decreases, this quantity increases. This quantity is negative.

So, the negative quantity inside the exponential increases and once that increases, D will decrease. So, the D is decreasing. If the D is decreasing, the time taken for any particular size to form; any particular size of r star to form should keep on increasing. Is not it? If you consider a particular r star, let us call it as 10 nanometer size whatever it is. Because the diffusivity at some temperature T 1 and another temperature T 2, where T 1 is greater than T 2. Because the diffusivity at T 1 is higher than T 2, that 10 nanometers can form in a shorter time. At T 2 because the diffusivity is lower, the flux is slower; because ultimately, the flux J equals minus D dc by dx.

The flux will be slower and if the flux is slower, then the time taken is larger. So, if I put that, you will see another curve coming. That is the time taken for a given r star, at any given temperature. And that you would see, because of these two combinations; you would get a C curve. So, at temperatures which are lower, the time taken for the r star to form is so large, because of the diffusion. And that is the reason why, you would see finally, a curve which is which is something like this. (No audio from 19:54 to 20:02) So, the combination gives you a curve, which is for this nature.

And this is only starting, start of transformation and you need to consider the end of transformation also; that means, this part. So, for each temperature… Yes, r star keeps decreasing. But though the r star is decreasing, even for that r star to however small it is for it to form, you need atoms to come together. Is not it? For example, this is a case is this the more difficult case; because two different phases are nucleating. When I say r star, r star of what? I need to actually talk about a lambda star, in case of this kind of a thing. Because a critical inter lamellar distance forms because it is a (No audio from 21:05 to 21:44)

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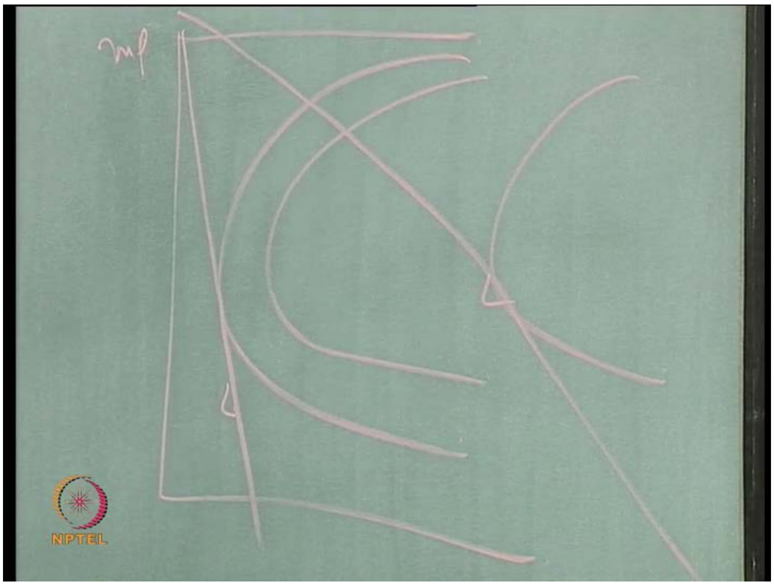

Infact, if you compare for example in the liquid to solid transformation, if this is the melting point let us say. This is let us say he is the seeker for the liquid to solid transformation. Even for liquid to solid also, you will have a seeker. This critical cooling rate, that we are talking about for an alloy, it would be may be slower; because an alloy would be something like this. For a pure metal, it would be something like this. For a bulk metallic glass, it would be something like this, the seeker. Something like a silicate glass, the seeker we shifted so much to the right that you need a very slow cooling rate for it to become a glass. So, it is that diffusion and the structure formation.

Basically, it is the r star and the D combination will decide what is the critical cooling rate that you need to adopt. So that is why, though the r star is decreasing for that r star to form you need time. And if if the temperature is very low, the atoms move so slow; that even that r star to form is very difficult; that r star could be even few nanometers. But even then for it to form; because atomic movement is so sluggish. But in this particular case of this, gamma to Fe 3 C here when you talk of diffusion, diffusion of what? Here, there are two elements that we are talking about, the iron and the carbon. Diffusion of iron and diffusion of carbon, both are important. And most of the cases, in these particular transformation actually, what matters is diffusion of carbon? Because carbon can move much more easily than iron.

As a result, infact all the transformations if you carefully observed pearlite formation and the bainite formation, it is all controlled by carbon diffusion. For example, upper bainite and lower bainite, when you talk about it; it is all carbon diffusion. For example, if you look at the upper bainite… Correct, this will shift obviously. It will shift to the left. Up to the lower temperature, until you have you come to another structure which can form in this particular case, let us say martensite. So, you can keep on under cooling the austenite, until you come to a stage where you can have a martensite transformation, which is a shear transformation that is what you see that. If I keep on under cooling the austenite, let us say carbon initially can diffuse faster at higher temperature. But iron cannot diffuse faster.

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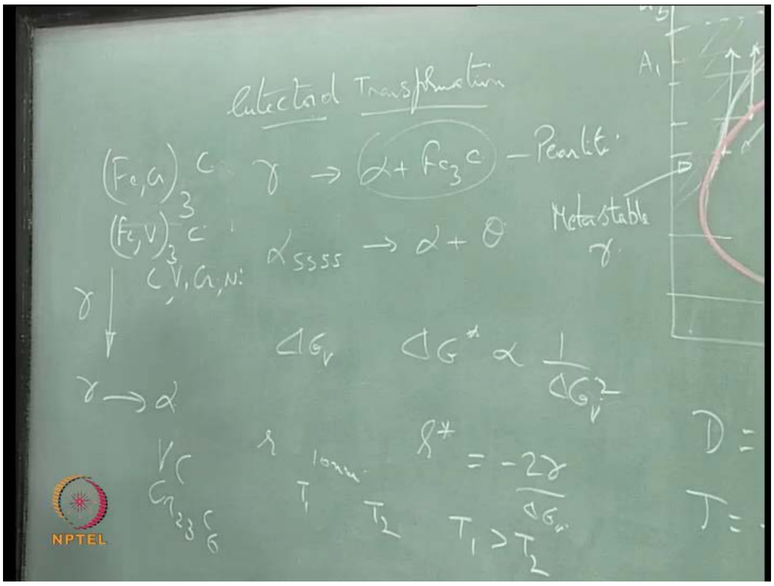

So, what happens is at this particular case when you are cooling gamma at certain temperature, you suddenly see this gamma; because the temperature you have comedown is such an extent that the atomic diffusion is becoming difficult for alpha to Fe 3 C. Alpha plus Fe 3 C to nucleate is becoming very difficult; because alpha has entirely different structure and gamma Fe 3 C has different structure, compositions are different. So, that means you need to have partitioning taking place. Carbon atoms have to go both into the Fe 3 C and get depleted in the alpha. So, that means you need a long range diffusion to occur. So, instead what happens is, there will be a short range diffusion and transformation takes place.

What is that transformation? You will see gamma transforms to alpha. Yeah, there could be. So, they can also shift the TTT diagram. We will come to it as after once we understand iron carbon. Whenever you deal with it, you start with a simple diagram with a binary effect. Yes yes it is it is the diffusion whenever you are talking of a transformation of gamma to alpha plus Fe 3 C, let us say you have alloying elements something like let us say vanadium or chromium or nickel. Now the question is where do these elements go during this transformation? Before the transformation, they are all inside the gamma including the carbon. They are all inside the gamma. It is this gamma, which is now splitting into these two.

If it is splitting into these two depending are their affinity towards a particular structure, they will dissolve into it. For example, chromium, vanadium have a tendency to form carbides let us say. They either dissolve into Fe 3 C and form a carbides such as Fe Cr 3 C or Fe vanadium 3 C or it can form its own carbides. Go means? Obviously at the grain boundaries of your austenite, then nucleate at the grain boundaries of austenite, the new carbides; till the whole transformation is over. And once carbon comes out of the gamma by the formation of special carbides like, vanadium carbide or let us says Cr 23 C 6 kind of carbides, the carbon content of gamma has come down. Once the carbon content of gamma comes down, again this whole thing gets affected, the TTT diagram.

How does it get affected? Tell me. What happens? Let us say I have vanadium or chromium or any other carbide forming element and am cooling this now. So, the moment I am cooling it, because there is a greater affinity; yeah, it will shift to the right. Sure. Why? Why? So what? Question is the moment the the question is which forms first? That is important. If you think that there is a greater affinity for carbon to form a vanadium carbide or a chromium carbide rather than forming a iron carbide, these carbides are the fi[rst] the things that will come out first from the gamma. The moment they come out first, they can act as a nucleating side for the pearlite.

As a result, you would actually see that it shifts to the left and that is a reason why, we always talk about. Whenever you take an alloy steel with has carbide formers, if you want to have a higher hard enability, you need to go to a temperature where they are all completely dissolved. If they are not completely dissolved, you will see that they act as nucleating sides and as a result, the TTT curve shift to the left. The time required for the nucleation is shorter, because there is already nucleating side that is available. So, these are the effects that you get, when you have elements such as this available. If you have no carbide former now no carbide farmer that means, something like a nickel present.

Nickel does not form any carbide. Then, what should happen? That is where you see the diffusion plays a role because of the presence of nickel which is sitting in the substitution inside the gamma. This prevents the diffusion of both carbon atoms and iron atoms. Because wherever nickel is sitting, there is a strain. Because nickel atom size is not same as iron atom size, it is sitting as a substitutional atom and because of which, the movement of both iron atoms and carbon atoms get restricted. And you will see the curve is shifted to the right. That is why, we always say all dissolved elements in iron shift the TTT to the right. Whenever you have undissolved elements in the form of either elemental for example, cobalt is one such example.

Cobalt does not form any carbide. But at the same time, cobalt also does not want to go into iron; it comes out. And that is what people have seen that it forms, because cobalt interestingly has HCP structures which have some similarity with cubic structures. Is not it? Atleast at least one plane is there, which has a similar thing and more or less the packing factor also is similar. So, there are certain similarities with HCP to cubic. So, cubic structure, which is a alpha structure can nucleate on that and as a result, the pearlite formation becomes easier. Any one of the two either alpha or cementite, if it can nucleate easily on something which is already available, then the whole pearlite formation becomes easier; because pearlite is combination of the two.

The moment one comes, the second automatically comes out. True. So, that is the important. So, in such a case what you see is that for example, vanadium carbide or titanium carbide is available. So, when vanadium carbide or titanium carbide is available, obviously around the carbide all the carbon content has come down. So, it could even not only nucleate Fe 3 C, could even nucleate ferrite; because all the carbon inside the gamma in a small region has been occupied by vanadium. So, it has taken all the carbon. So, the gamma around the Fe 3 C gets depleted in carbon. That could lead to alpha precipitation just around the vanadium carbide or titanium carbide.

And once that comes, then because of the thermodynamics that at that temperature, gamma alpha plus Fe 3 C is stable. So, once alpha come out, Fe 3 C comes out. It is not that the carbides are nucleating a cementite, need not. But if the carbide has a structure which is similar to that of cementite, cementite may nucleate. But more interestingly most of the non cementite type of carbide in iron carbon diagram, they are all cubic. Vanadium carbide, tungsten carbide, you take niobium carbide; all of them are all mostly cubic in nature. So, they would have an effect the other way. But ultimately, one thing is true that the precipitate the formation of pearlite becomes faster. That is what, we are talking about.

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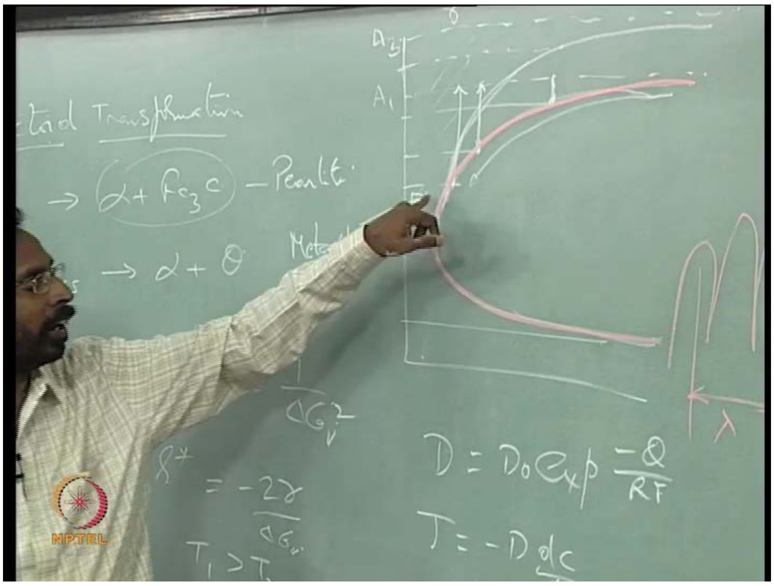

And this is what is going to lead to a second part of the diagram and which is where you will see that you see the curve like this. Now let us look at this particular transmission, which we started talking about. Let us say, I am cooling it fast and brought it to a temperature which is below this somewhere here. At that temperature, the diffusion of iron and carbon both are becoming slower. So, this kind of a splitting and again I will answer (( )) that we are talking about alloy which does not contain any other alloying elements. Let us say in such a case, even if it contains alloying elements, if they are in the dissolved form, there is no problem. So, in such an alloy when I come to…

Dissolve means in the solid solution, it could be either substitutional; it could be interstitial, depending on which element you are talking about. If it is nitrogen present, it is present in the place where carbon is also present; that means either octahedral voids or tetrahedral voids. If it is nickel let us say, it is sitting in the iron positions… Then if the as you keep on adding elements with the higher and higher, what happens is only the solubility decreases; the maximum solubility could there the strain is more. The strain is more and that is the reason why, solute solubility is less. That is what, we talked about when we talked about miscibility gap formation in a phase diagram.

It is not replacing, you people have to understand that there is always vacancies inside a structure. If it cannot sit, it will precipitate with something else; as that is what I am saying. If the dissolution takes place as long as, it can dissolve. If it cannot dissolve, it will precipitate. As long as there is let us say carbon available; let us say iron and tungsten, tungsten cannot dissolve into iron. What happen is iron and tungsten will come out, is like iron and lead. Lead does not want to dissolve into iron. Lead precipitates out and again that is another problem, such a precipitation is going to be again as far as pearlite formation is concerned is going to aid in the pearlite formation; because you have a second phase sitting there.

If the element cannot dissolve, it will precipitate out. There are so many immiscible systems; iron copper is one such immiscible system. Infact people are using copper as a strengthener, nowadays. I do not know how many of you know about it. There are what are called IF steels now. What are these IF steels? Interstitial free steels, where the carbon content is 30 ppm, 30 to 40 ppm. the moment Why do we want such a low carbon? Tell me. Formability, stretchability you want the whole car to be made of one single sheet without welding a number of sheets. So, you want to basically stretch it to the whole body of the car, let us say and which you have a high stretchability, then the only way is to reduce carbon. But when you reduce carbon, strength goes down.

So, how do I get the strength? That is where, people are adding a small amount of copper. Copper precipitates as nano copper with a lot of pins inside. And such a nano copper gives a high strengthening. The reason again is because it is not soluble. So, not being soluble is also a blessing in these guys. We all know, I know for example, very good example of a lead. Lead is deliberately added to steels for many many years, for what? For machinability, free cutting steels we call them. Is not it? We know pretty well that, it does not dissolve. So, the concept of immiscibility is used to our own advantage. So, infact people also use this, for even in powder metallurgy components many times has what are called? Self lubrication.

You add lead in leaded bronges why lead is added? They are all bearing steel, bearing bearing material, bearing alloys. So, in bearing alloys you deliberately add lead, because lead is soft. So, it acts as a lubricant, when the bearing is there inside the component. So, the lead which is available on the surface acts as the lubricant. So, you know pretty well, lead does not dissolve; still you add it, because it is it does some purpose. In case of steels, it is for machinability. In case of bearings, we add it deliberate. Copper and lead do not dissolve into each other. So, you deliberately add lead to copper. Understand. So, it is a question of whether it can dissolve or not dissolve. If does not dissolve, we do not talk of dissolution at all.

Whenever I say dissolves all these elements that we are talking, they all can dissolve including tungsten. The only reason is tungsten can dissolve at a higher temperature. That is a reason why, when you whenever we talk about high speed steels, the austenisation temperature is almost 1200 degrees, 1100 degrees. Because tungsten carbide for it to dissolve into gamma, it you need very high temperature. The stronger the carbide, the higher the temperature you need for it to dissolve. It has to first break and then and then only dissolve both carbon and tungsten. So, the higher the stronger the carbide, that is why chromium carbide can dissolve at a much lower temperature.

So, if you have chromium inside the alloy is no problem 900 degrees is good enough. But if you had vanadium, niobium, titanium, tungsten, the more you add molybdenum all these elements the moment you add, you need to go to a higher temperature. And now once you have them, now I am quenching it. Let us say, I am not providing sufficient time; I have brought it to a lower temperature here. At that temperature, now I have to see what happens to this steel? Correct. I do not need to go to high temperature. I am quenching it to a lower temperature. But at the temperature, now if I want to see whether niobium carbide would form or not?

Definitely, niobium carbide has a higher affinity; higher affinity means larger driving force; larger driving force means smaller r star. So, in principle it would like to form. So, the r star for the niobium carbide would be smaller than the r star for iron carbide Fe 3 C, let us say. Now, the question is whether the diffusion rates at that particular temperature allow for the r star to come out or not? If it not, if it does not. Then, what happens is gamma gives you alpha of the same composition as that of gamma; whatever is the alloy composition. Let us say, I am talking of a iron carbon, the alloy with about 0.8 percent carbon, let us say and plus whatever elements that you are talking about.

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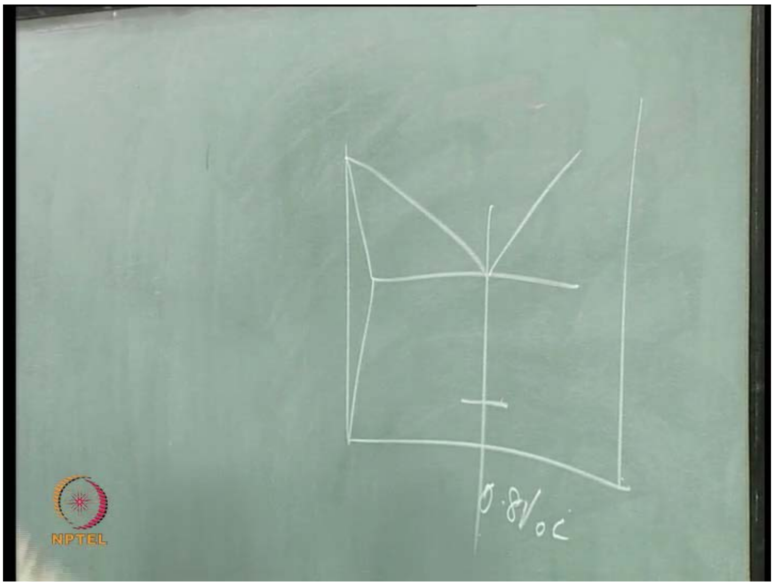

So, if I take the alloy we are talking about; this alloy 0.8 carbon plus some alloying elements, all of them are in dissolved state and the whole alloy is quenched to a low temperature, something below the below the the second half into the second half of the seeker. Once I come there, there because the diffusion of carbon is also takes time. Because the temperature is low enough, iron itself is difficult. So, carbon also takes time.

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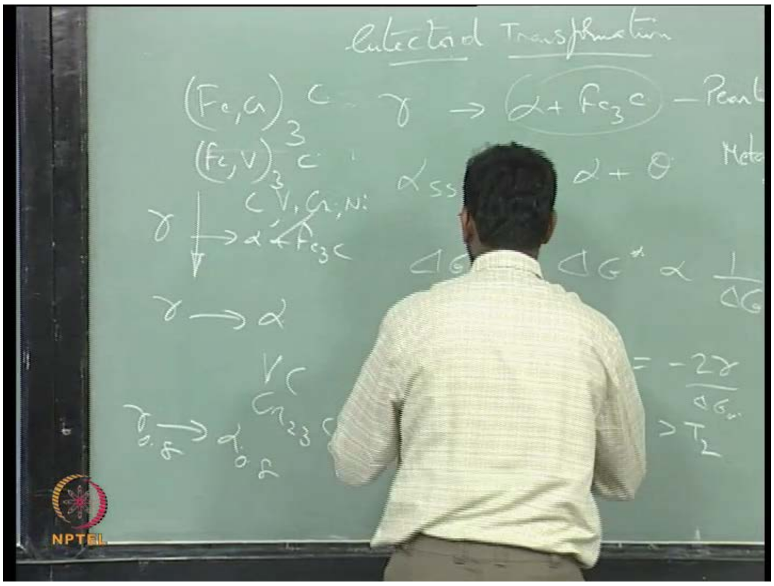

So, what happens is this gamma instead of giving you alpha plus Fe 3 C or alpha plus some other carbide, it would give you gamma gives you alpha. This is what kind of a transformation is this? It is a partition less transformation which is a polymorphous transformation; not an allotropic transition. I mean in one way, it is allotropic transition; but there is no we are not talking of a pure metal. So, once is happens now this alpha is containing a lot of carbon, what is the solubility of carbon in alpha? 0.0 to 5 at room temperature; at at actually 0.0 to 5 at 723; 0.006 at room temperature. But I am having 0.8 percent of carbon that means it is such a highly metastable state.

This alpha which has formed where where only a FCC structure changes to a BCC structure which means it only needs a short range diffusion. So, that short range diffusion has taken place; because short range diffusion does not need a very high activation barrier. It needs only a short activation barrier. So, atoms can move by a shorter distance and once this happens, gamma of 0.5 gives you alpha of 0.5 0.8. So, once gamma of 0.8 gives you alpha of 0.8, now you need to see that this alpha of 0.8 is not stable. It wants to somehow reject the carbon which is inside. Now the question of where does this carbon gets rejected?

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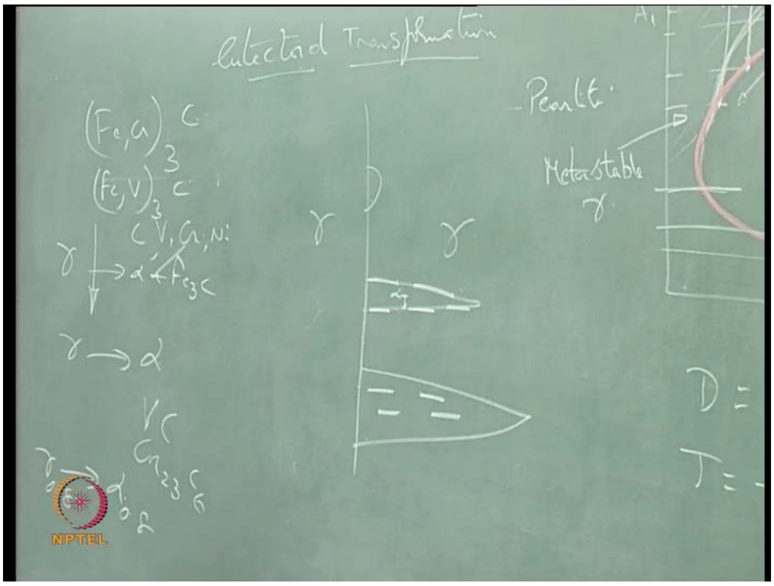

That is where, you see that this alpha and because of only a structural change is taking place. If I have a gamma gamma inter phase, the alpha that comes out will come out as a vesicular form. Because you are the nucleation is taking place at a lower temperature. So, as a result, the alpha that is coming out will form on certain planes of gamma in order to get a coherency. So that, you will see there is there is a habit plane between the gamma and the alpha. So, you see that precipitation forms like a platelets rather than at forming at a at a grain boundary as what is called grain boundaries allotriom (( )). This is what people call it as Widmanstatten structures.

Widmanstatten structures come at low temperature; because at low temperature, in order to have the stain compatibility or the interfacial energy compatibility, you would see that it would form on specific planes. So that, you can have a coherency and once this form, now the question is this particular alpha has a high carbon, it wants to precipitate out. Now, that is where depending on whether you are at this temperature or at this temperature. Now, the carbon the diffusion has to occur not within the whole of gamma; but within this alpha only and that region is smaller. So, as a result now if the temperature is high enough, the carbon can diffuse from the center of alpha to the edge of alpha.

And then, form as precipitates along this inter phase of gamma alpha inter phase. And this is what, we call it as upper bainite where the carbon can diffuse up to the interface between alpha and the gamma in the vesicular structure of alpha and forms at the boundaries of vesicular structure of alpha. And if the temperature is low, it precipitates inside alpha and that is what, we call it as a lower bainite; because it does not have time for moving to this much distance. So, it is almost like our Al to Cu coming out; theta phase coming out of alpha. So, it cannot go and precipitate at the grain boundaries. It precipitates inside the grain.

Similarly, here you will see it precipitates inside and if you go to further lower temperature where the carbon is not able to move at all. And as a result, gamma does not transform to alpha of by by short range diffusion. It transforms to alpha by diffusion less process that is where you get martensite. So, you see a clear cut difference between a pearlite formation which involves wrong range diffusion on an upper bainite and lower bainite. Both of them needs a short range diffusion excepting that carbon diffusion becomes difficult for a longer distances. So, it either forms here or forms here and if you go to below the MS, you see suddenly you will have diffusion less transformation. This is similar to like a glass transition.

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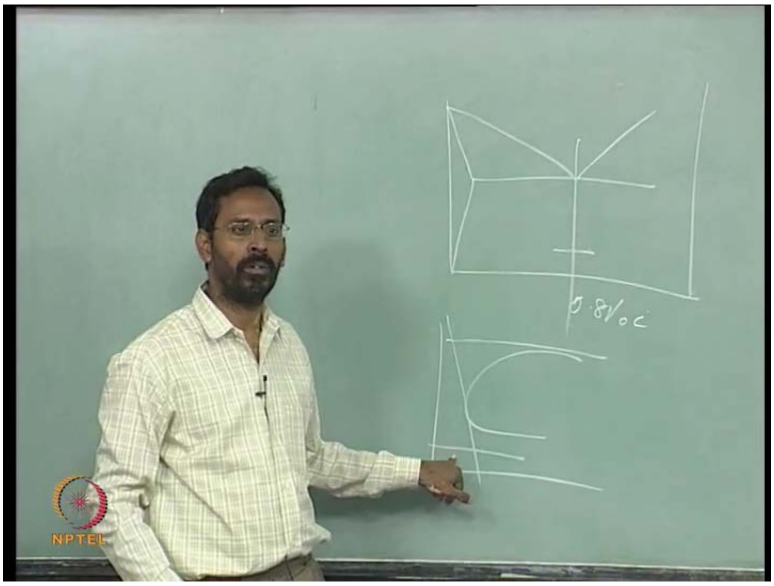

I mean, if you want to compare with the liquid to solid; so, you quench it in such a way come to below t g, you get a glass. This liquid transforms to a glass. Similarly, this austenite if I quench it below the MS, the only difference is it is a solid to solid transformation; whereas, this is a liquid to solid transformation. Liquid to glass is a liquid to solid transformation; whereas, gamma to austenite is a solid to solid transformation and where there is a structural change involved. Remember, gamma has a different structure and the martensite has a different structure and this different structure is coming out because of what is called a shear.

We will talk about it, when we talk about martensite. We will talk about martensite; whereas, here there is no structural change involved. You have come to a certain low temperatures, where the liquid none of the atoms inside the liquid are able to move and as a result, the liquid gets frozen. That is why, we call it as configurationally frozen liquid; configurationally frozen super cooled liquid. So, this is the basic difference between this and this. So, there is a shear involved in that kind of a transmission. So, any solid to solid transformation has to occur either by diffusion or by shear.

The moment you say that product phase has a different structure than that of the parent phase. Otherwise the transformation is not possible; whereas, here you see that there is no atomic movement. The atom simply gets frozen, the way liquidized; excepting the difference is that the viscosity is so high; that you cannot call this as a liquid any more. That is why, we have to. So, this is mechanically a solid, structurally a liquid; a glass. So, that is the difference; whereas, here the structurally itself this is different; martensite is different. Accepting in cases, where you do not get let us say BCT kind of structures and infact, even if you do not get BCT structure.

For example, there are so many iron carbon iron based alloys, where the martensite is BCC in nature. We will talk about it, when we talk about martensite. Most of the cases what you see BCT, BCT comes only because of the carbon. If carbon is not there, martensite in iron based martensite iron based martensite is always BCC. It does not mean that, all martensite. There are so many martensites, nickel, titanium you have a martensite; copper based alloys you have martensite. Infact shape memory effect, the whole shape memory effect is based on martensite formation. So, you have other martensite, but if you talk about iron based martensite, it can be either BCC martensite or BCT martensite. We will talk about it later.