Heat Treatment and Surface Hardening - II

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Lecture – 23
Importance of phase diagrams

Let us start lecture 23.

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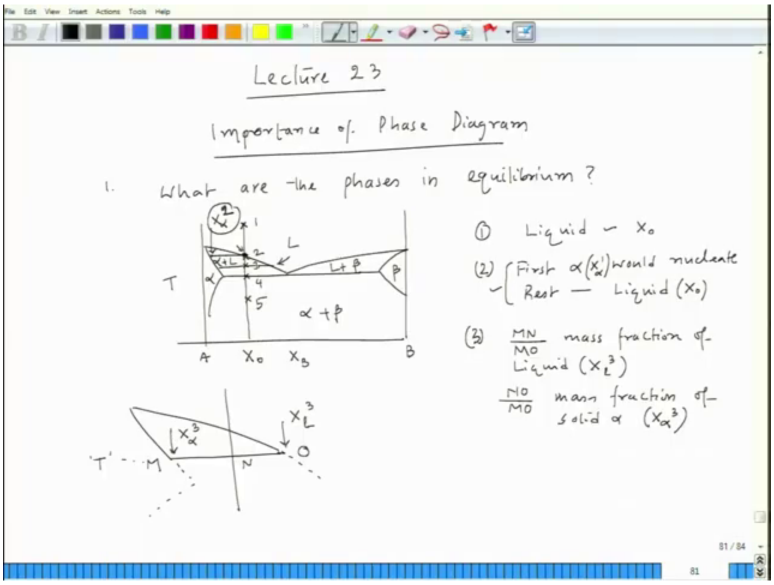

Lecture 23

Importance of Phase Diagram

1. What are the phases in equilibrium ?

① Liquid ~ X_0

(2) First α (X_α^1) would nucleate
Rest — Liquid (X_0)

(3) $\frac{MN}{MO}$ mass fraction of Liquid (X_L^3)

$\frac{NO}{MO}$ mass fraction of solid α (X_α^3)

We have been talking about phase diagrams evolution of phase diagrams. One way was via cooling curve and the second route is more fundamental which is a free energy composition diagram. And then we started talking about the importance of phase diagram. And we saw that phase diagram does tell us that if I try to reach at any point in the phase diagram, I would be able to know that what are the phases that would come up in equilibrium. Now let us iterate little more on the importance of phase diagrams what it tells and at the same time what it will not be able to inform if we try to understand the overall heat treatment practice. And accordingly if we come to know that what it cannot tell us then we have to know what are the routes through which will be able to know the entire part of the phase revolution and it is their distribution and finally, the microstructure of the final product.

Now, first is importance of phase diagram. Now we have already come to know that phase diagram tells us what are the phases in equilibrium. It means if we try to draw a simple eutectic phase diagram, this eutectic phase diagram where this is l this is temperature access this is XB pure A pure B. Now if I am starting with the composition X 0, I know that at this point it would be completely liquid. So, if I draw different points this one point, this is 2 this is 3 and this is 4 this is 5. So, 1 2 3 4 5. Now I need to look at what are the phases that would be in equilibrium.

Now, at one it is all liquid. 2, since is just touching liquid and this is alpha phase this is beta this is alpha beta phase and this is alpha plus liquid this is liquid plus beta. At 2 it is just touching the phase boundary between liquid and alpha and liquid. So, the first alpha would nucleate. And rest all would be liquid. Now if we come down to that means, here if we consider a very small amount of alpha would be there in equilibrium with liquid. And at 0.3, if I try to draw horizontal line with respect to composition axis I could this particular thing I can draw it in the bigger I can zoom this particular section.

So, I can put it as. So, I can put it as M N O. At 3, I would be able to 2 things. One is what are the phases, what are the amounts and also the compositions. Even here also I can be able to know the composition of the phases, here also I would be able to know the compositions. So, here the composition would be nothing, but X 0 and here the first alpha what is forming that composition would be if I draw the line here the composition is this one. So, that composition is X alpha 1. So, X alpha 1, and the liquid would have composition same as X 0, because that composition liquid composition is lying here.

Now, I have if we if I come to 0.3 and if I draw a horizontal line with reference to A B; that means, the composition axis then at that temperature, this is indicating a temperature at that temperature I would get MN divided by MO mass fraction of liquid of composition. And if I try to see the composition this would be my liquid composition X liquid and these liquid composition since I am considering 0.3. This liquid compression I can put it as X, liquid of 3 and this composition is also in equilibrium with the alpha phase that is evolving. And that time alpha phase fraction would be NO divided by MO mass fraction of solid alpha of composition and that time composition is nothing, but this one which is X alpha 3.

So, this is X alpha 3 I just would like to make a small change because this composition since I am considering 0.2. So, you should put it as 0.22 here so; that means, that is corresponding to the temperature at 0.2. So, we know the fractions of alpha as well as fraction of liquid. And those fractions those liquid and solid alpha would have a particular composition and those 2 composition are in equilibrium and we have already come to know the free energy composition diagram and that tells us that these 2 compositions are in equilibrium. Now if I further go down if I reach to 4, and if I see this particular trained as we are going down the temperature gradually the liquid fraction is decreasing because if I can you can see that gradually the liquid fraction initially was almost 100 percent once is start is 0.2. And then the liquid fraction becomes MN divided by MO and gradually this fraction is decreasing.

And also the alpha fraction is increasing. And this is the temperature which is T eutectic. So, whatever alpha that is coming out that is forming before we achieve eutectic temperature that is, what these alpha these alpha we call it as pro eutectic alpha. If we consider eutectoid reaction where a solid transform into 2 new solids at a particular temperature in a particular composition that time before we achieve eutectoid temperature the phases which will appear which will be called as eutectoid phases. And in case of steel we have eutectoid alpha or eutectoid cementite sorry pro eutectoid alpha or pro eutectoid cementite depending on which side, why we are considering if we consider compositions left to eutectoid composition 10 pro eutectoid ferrite would come up. And if we considered composition which is on the right side of eutectoid composition, we will come get we will get pro eutectoid cementite.

Now, since we have seen that the liquid fraction is decreasing the last liquid just before achieving eutectoid temp eutectic, temperature would eventually go and touch eutectic temperature. So, that liquid would have composition this one which is eutectoid, eutectic composition X u and then that liquid with X u composition eutectic composition with convert to alpha plus beta with a composition X alpha beta X beta alpha. So, here composition would be X alpha beta means composition of eutectic alpha which is in equilibrium with beta and this X beta; that means the composition of eutectic beta in equilibrium with alpha. So, this will be 2 competitions. So, then once we get down to this is the situation (Refer Time: 11:14) 0.4 and at 0.5, we get to get only alpha plus beta of compositions. For example, if I consider 5. So, then I am getting this is my composition X beta and this is my composition X alpha.

So, the liquid, if I take the liquid directly to this place; that means, from this point, to this point if I take the liquid directly to that point and then leave it there it will convert into alpha and beta and then composition of that those alpha beta would be this one and this one. So, we are getting to know we are we are actually able to know from the phase diagram that what are the phases or what are the compositions what are the fractions. So, these are the information's, we are getting and in addition to way because when your drawing phase diagram.

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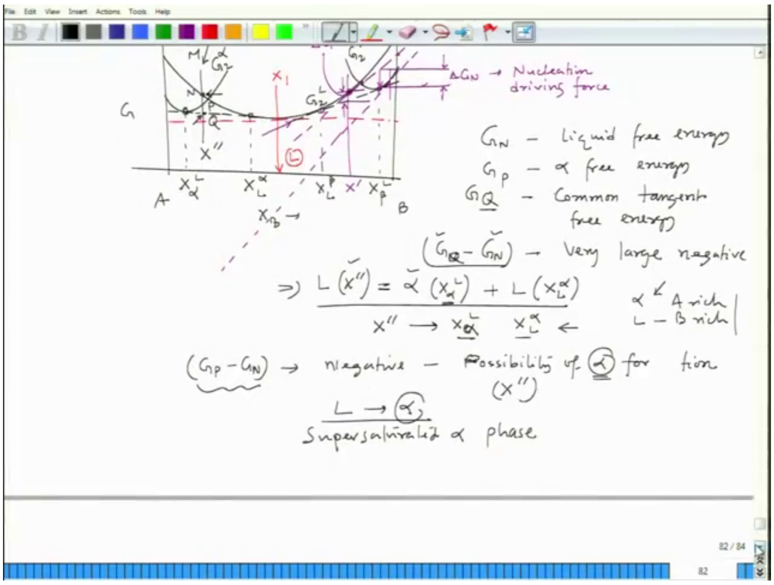

G_N – Liquid free energy

G_P – α free energy

G_Q – Common tangent free energy

$(G_Q - G_N)$ → Very large negative

$\Rightarrow \underline{L(X'') = \alpha(X_\alpha^L) + L(X_L^\alpha)}$

$X'' \longrightarrow X_\alpha^L \quad X_L^\alpha \leftarrow$

α ↙ A rich

L – B rich

$(G_P - G_N)$ → negative – Possibility of α formation (X'')

$\underline{L \rightarrow \alpha}$

Supersaturated α phase

We are also getting a knowledge of composition free energy composition diagram. So, then these also tells us few information that information is what composition would give us the product phase or the phase transformation. So, that is also important because that tells us that gives us an idea of the nucleation driving force as well as overall driving force for the transformation.

Now, as we have understood that for example, let us say if I considered a situation like this. So, if this is my liquid composition G 2 liquid and this is my alpha this is my beta G 2 beta this is G 2 alpha, then we have a common tangent which indicate equilibrium between liquid. And alpha as well as there is a one more common tangent which gives us equilibrium between beta liquid. So, this composition is X liquid in equilibrium with alpha and this composition is X alpha in equilibrium with liquid this composition is X liquid in equilibrium with beta and this composition is X beta in equilibrium with liquid and this is G this is XB and this is pure A this is pure B.

So, this particular situation tells us for example, if I take a composition, let us say I take composition this one X 1 what is the way to go around go forward I will draw a tangent over this liquid line like this. And once I draw this tangent, I could see that all the solid phases either alpha or beta that G 2 line is actually above that particular tangent line the rate tangent line. So, in order to form alpha and beta we are not getting any negative change in free energy. So, nothing would appear and rather I would only get liquid of the same composition, but if I try to take any composition let us say right side of this let us say I take a composition here. If I take that composition then if I draw again I have to draw a tangent at that point if I draw that tangent, if I extend that tangent. Then also I am saying that these tangent is the lowest free energy line compared to any other free energy lines what we have on this particular diagram.

So, only beta phase would be there no other phase would appear. Now if I take any composition between this line this point, and this point let us I take a composition like this. This is let us say a composition X prime. Then I see that again I have to draw a tangent at this point, if I draw that this is the tangent the new tangent what I am trying at this point. Then I could see that from this point to this point everywhere I could have a possibility of beta formation because the beta line is below the line the tangent line this tangent line. So, I could get a situation of delta GN for this particular composition and this is nothing, but nucleation driving force and this point if I see this point is also above this common tangent between equilibrium liquid and equilibrium beta the common tangent; that means, this common tangent this common tangent is below this point. So, there is again the possibility of free energy lowering.

So, overall free energy change for the transformation is this much. So, this is delta G, I can say overall. Now the same situation would happen if I take composition between this point and this point. And I would get nucleation of alpha and accordingly I would get the composition of liquid as well as composition of alpha. And overall transformation is also possible because there is always a negative change in free energy if I go from liquid to liquid to solid phase. So, there is more one more interesting part which also appear if we do non equilibrium processing. For example, if I take any compositions like this. So, now, MNP and this connection is Q. I could see that when I am taking a liquid to a temperature below the melting point of A, then I am having a situation what is depicted by the straight line.

GN is the I can put it as like this GN is the liquid free energy GP is the alpha free energy and then Q, G Q is the common tangent free energy. Since Q point is lying over the common tangent line. Now I could see that if I try to get liquid to a temperature were the possibility of alpha formation this alpha and liquid formation would be there. So, if I go from this to this this point to this point I could say that there is a huge free energy difference so; that means, GN minus G Q, it is very large. And that time I am going to get phases alpha of composition X alpha liquid plus liquid of composition X liquid alpha which is coming from liquid of composition. If I consider this is to be X prime X double X double prime. So, this X double prime is breaking into alpha and liquid because there is a huge this difference is very large and also it is negative, because the final point I would point it I will I will can change it as d Q to GN because this is final this is initial.

So, this becomes very large negative there is a possibility of formation because driving force is there which is negative. Now this could be my transformation and this is actually equilibrium transformation, but while we do that we could see that X prime is differentiating into 2 composition. These 2 compositions which are widely different, but interestingly if I try to see GP minus GN this is also negative; that means, there is a possibility of alpha formation. And if alpha forms that time alpha composition be nothing, but X prime double prime. Now this is becoming interesting because if I go to Q position then I have huge composition difference, when I have that particular product phase formation alpha phase and this distribution of BB element has to be there as well as distribution of A element has to be there, because these liquid is enriched in B and these alpha is also and wish to it A.

So, alpha it will be predominately A rich and liquid would be predominately B rich. So, long range diffusion needs to take place, but if we form this alpha because there is a possibility since this is negative. So, then it would it can form alpha with a same composition of the liquid which is X double prime. So, a diffusion is not needed for this the only other short range transformation can be able to form alpha. So, this particular phase formation the same phase formation actually if I form this particular reaction I would get alpha of a lesser B content, but if I form alpha through this reaction; that means, the liquid is going to alpha I would get alpha with a higher B content. This is taking place at a particular temperature T at that temperature the equilibrium concentration of alpha is this one.

But if we from alpha through this reaction, I am getting much higher concentration of B in the alpha. So, this particular situation we call it as supersaturated alpha phase. And this super saturation is extremely important from the point of second phase formation just like precipitation hardening. Or many a times these phase can remain stable at a room temperature for a long time. And if we have higher salute content than the equilibrium content what it should have been then it is strength would be much higher because it contains it gives more solid solution hardening. So, this is also a processing which we call it non equilibrium processing, non-equilibrium processing. Where we get to see non equilibrium phase because these particular phase which appear at the same composition what is there in the liquid.

So, this is not the equilibrium phase, it is a non equilibrium phase. And equilibrium phase is this particular phase will basically the equilibrium phase of the composition X alpha in equilibrium with liquid. So, this non equilibrium forces can give us a solid solution extension we call it solid solution extension. This is also an important aspect, but we will not get detail into this solid solution extent extension because and just, but it is very important to mention this because this way many processing happens. Now if we see this entire thing the first advantages, this one if I put it as information. What you are gathering second advantage of the phase diagram and associated G X diagram is this one where I could get to know what phase would appear. And also the possibility of supersaturated solution as well as it also tells us we have to take a specific composition which would give us phase transformation.

Otherwise you would end up getting the same phase at another interesting part it is important from the point of evolution of entirely different phase which is call amot first phase. Now if I consider X 1 composition these X 1 composition is not converting into all final liquid alpha and beta. So, this X 1 composition remains liquid. Now when we cool a liquid then liquid viscosity goes up and the liquid viscosity follows a VFT equation.

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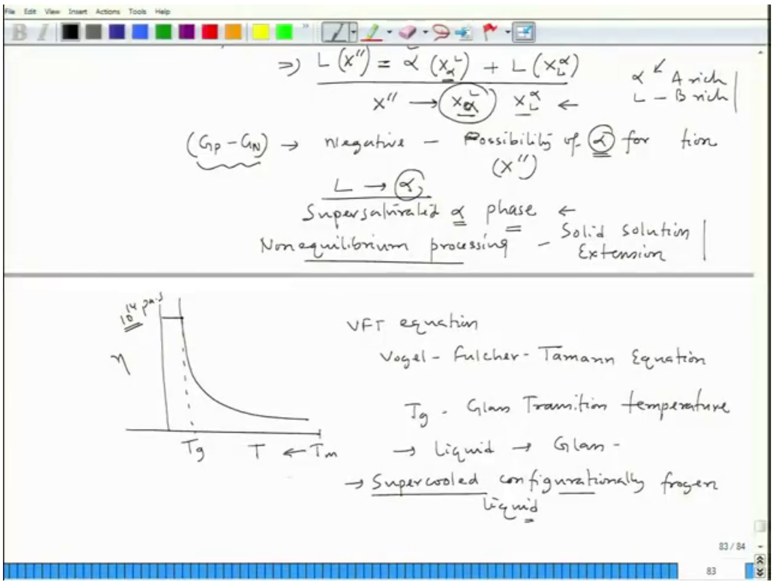

$\Rightarrow \underline{L(x'') = \alpha(x_{\alpha}^{L}) + L(x_{L}^{\alpha})}$

$x'' \rightarrow \boxed{x_{\alpha}^{L}} \; x_{L}^{\alpha} \leftarrow$

α ↙ A rich

L – B rich

$(G_P - G_N) \rightarrow$ negative – Possibility of α for tion (x'')

$\underline{L \rightarrow \alpha}$

Supersaturated α phase ←

Nonequilibrium processing – Solid solution Extension

VFT equation

Vogel - Fulcher - Tamann Equation

T_g - Glass Transition temperature

→ Liquid → Glass -

→ Supercooled configurationally frozen liquid

So, this liquid viscosity with temperature if this is my TM, it follows like this it follows like this and it follow VFT equation which is called Vogel Taman Fulcher equation. So, this viscosity immediately start shooting up, if we it decrease the temperature and then at some point of time the viscosity reaches around 14 Pascal second and that time the shear movement of atom stops of the liquid.

So, the liquid atom liquid remains liquid, because if I cool this particular for composition liquid all the time remaining is remaining liquid because I am not able to get other solids as per the free energy diagrams. So, these liquid since we are also dropping the temperature viscosity is going up. And then finally, we are reaching to the viscosity around 10 to the power 14 Pascal second and then shear moment of the atom stops and that time, we get to know one particular temperature which is called T G or glass transition temperature and the material the liquid, we will convert to glass and that time we call it as so; that means, the liquid structure is maintaining glass and we define it as super cooled configurationally frozen liquid.

Since it is super cooled why because it is dropping the temperature from melting point configurationally frozen means all the atoms of the liquid certainly once the viscosity reaches to around 10 to the power 14 shear moment stops and those atoms literally it is stopping and actually occupying that particular position and remaining there and actually this is a frozen liquid that is what the glass is nothing, but super cooled configurationally frozen liquid. So, people also fob glass and then from that we get to have many other properties and the glass also has got different heat treatments and then accordingly we can form glass crystal in mixture so that we can tailor our properties.

So, from the discussions, what we have today it tells us the importance of phase diagram what are the information, it give the phase diagram. What it gives us, and now next in the next lecture we would try to see what other information phase diagram cannot give and. So, we have to use some other things to know the other aspects of phase transformation which will be required for heat treatment.

Thank you.