Heat Treatment and Surface Hardening - II
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Lecture – 22
Effect of ΔH mix on determination of phase diagrams contd..

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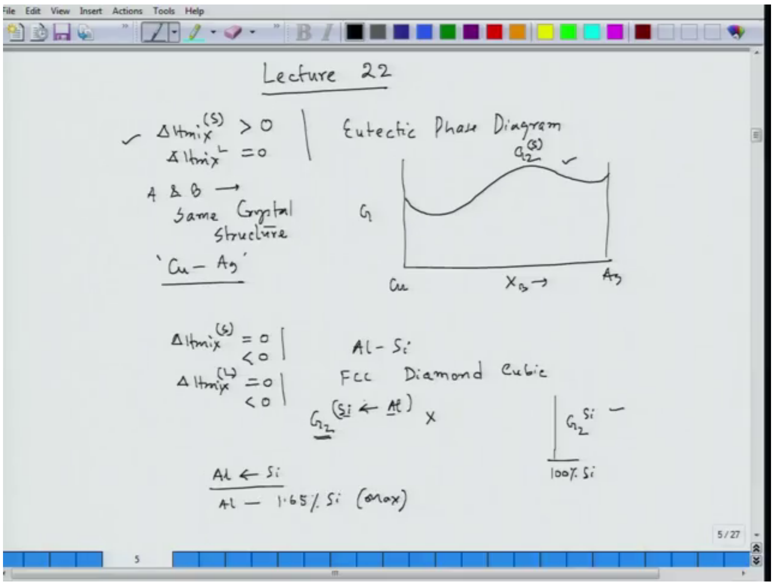

Lecture 22

✓ $\Delta H_{mix}^{(S)} > 0$
$\Delta H_{mix}^{L} = 0$

A & B → Same Crystal Structure

'Cu – Ag'

Eutectic Phase Diagram

$\Delta H_{mix}^{(S)} = 0$, < 0

$\Delta H_{mix}^{(L)} = 0$, < 0

Al – Si

FCC Diamond Cubic

$G_2^{(Si \leftarrow Al)}$ X

G_2^{Si} –

100% Si

Al ← Si

Al – 1.65% Si (max)

Let us come to lecture 22. So, we have seen situations where solid solution and liquid solution. They have a different enthalpy of mixing. And that is what you are getting eutectic phase, or in some cases congruent phrases. And if enthalpy of mixing of liquid solution is highly negative. You could see that the liquid stability increases step is a liquid is stable at much lower temperature. And in case of a situation where enthalpy of mixing of solid solution is highly negative, then I could see that the solid phase is stable at a very high temperature, and we get to see congruent melting phase, but whatever discussions we had we could see that the solid solution they are forming from 0 to 100 percent b. They have same crystal structure that was basically the basic assumption. But situation could be different. That the even if the enthalpy of mixing of solid solution is positive, then also I could have a different crystal structure of the solid solutions. And that time situation would also lead to eutectic phase diagram.

But we cannot touch continuously draw the phase free energy line for solid solution. So, that time 2 different phases would have a different free energy line; that means, the G 2 lines. Now in one case del H mix of solid I considered 0 greater than 0, and del H mix of liquid equal to 0 that time we could get eutectic phase diagram. Now another situation where del x and that time in this situation I could see that the this is G this is X B the G 2 of solid solution was like this, because that time we consider A and B both have same crystal structure. And one example for this particular phase is copper silver. Where I could get to I could get an eutectic phase diagram, but there solid solution line would be like this continuous from 0 percent copper to 100 percent copper and let us say this is copper this is silver.

So, I could get a continuous line. The situation is different. Even if del H mix of solid is 0 or less than 0. And of course, that time del H mix liquid I can either considered equal to 0 or less than 0. So, in these situations and if we see that the composition range and different composition levels I could get a different phases of different crystal structures, then we have to consider the G 2 line of those phases separately. And those phases would have limited solubility; that means, it can take some second element in the solution to certain extent, but it cannot take it up over the entire composition range. And that would lead to a change in the shape of the G 2 line of those phases.

For example in case of aluminium silicon, there aluminium is FCC, but silicon is diamond cubic crystal structure. And if I try to see silicon, and if I try to incorporate aluminium into it. Silicon would never contain in aluminium in it So, that I could not get any free energy line; that means, G 2 of silicon and where aluminium is mixed that mess aluminium becomes solute, it is not possible; that means, these 2 cannot form in alloy. So, that case there is no need to consider the solution thermo dynamics solution formation in case of silicon because it cannot contain any aluminium. So, that time the free energy line would be simply a single line it cannot have any curvy nature like this would be my G 2 of silicon. Because it has only one composition which is 100 percent silicon.

Now, on the other side aluminium can incorporate silicon little bit, and that percentage is very limited maximum around close to 2 percent, it can content in the solid condition. So, in the solid state in the solid state here also I am talking about the solid silica. In the solid state aluminium can content 1.65 percent silicon maximum, this is the maximum limit of the solubility of silicon in aluminium. So, here I could see that maximum 1.65 percent silicon it can go into aluminium in the solid state. So, solid solution is the limited solid solution. So, that case I cannot extend this aluminium G 2 line; that means, G 2 of solid aluminium alloy where silicon would be the solute would be again G 1 plus del G mix the extent of G 2 line would be very short.

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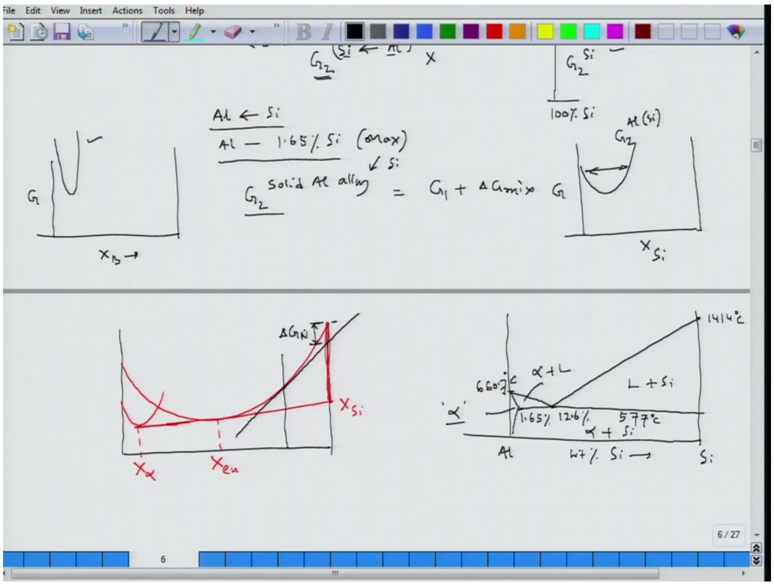

So, I mean to say G 2 extent of G 2 line means if I try to plot this is X B or in this case it would be x silicon and this is G. So, this should be my G 2 aluminium silicon. So, this should be shorter not extending to the entire range of compositions from 0 percent aluminium to 100 percent silicon, because it cannot contain that much amount. And if it is inter metallic compound this cap would again further shrink, and it would become let us say if we try to see free energy G 2 line for X B some inter metallic forms. That time that free energy line would be very much like this. So, it cannot have very wide alloy formation or the composition acceptance.

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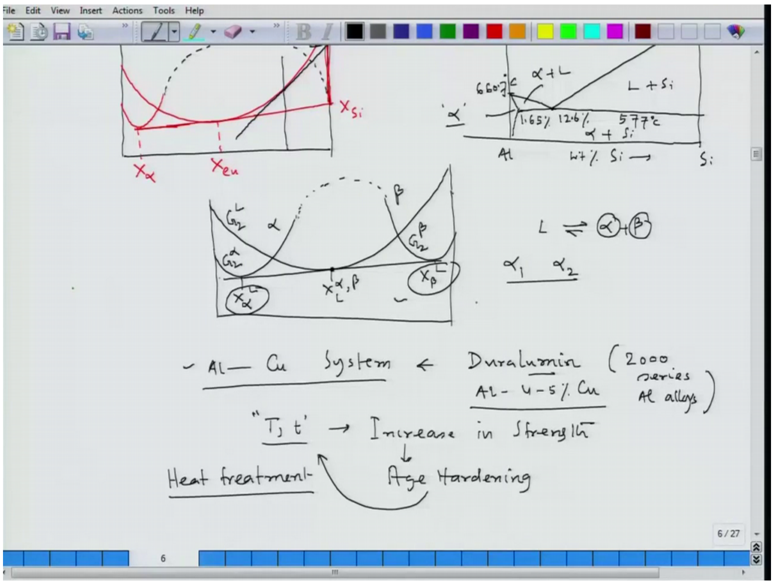

So, if I try to plot phase diagram for aluminium silicon system. So, the phase diagram looks like. So, silicon melting 0.1414 degree celsius this is silicon this is aluminium and this melting point is 6 60 point 7 degree celsius. So, I could get maximum of 1.65 of silicon percent this is in terms of weight percent of silicon. This becomes my eutectic temperature which is 577 degree celsius. And the eutectic composition is 12.6 percent silicon these are all in terms of silicon. So, I get phase diagram like this. So, I have this is liquid plus silicon, and this is since it contains little bit of silicon. So, I could may say that this is alpha now solid solution of silicon, self solution of aluminium and which contains silicon is a second phase as second silicon is a solid.

So, this is alpha plus liquid phase and this is alpha plus silicon. Now if I try to draw the free energy composition diagram at this eutectic temperature, the free energy composition diagram would look like this. So, that time silicon would have spleen line, because it cannot contain any aluminium one straight line. And this is my liquid line and this is my aluminium line. So, in this case this is composition of alpha, this is the composition x eutectic and this is the composition x silica. So, I have a phase diagram like this. Now if I try to choose a composition like this, that time again as per our understanding we have to draw a tangent over this. And then the formation of silicon if it has to form then my free energy barrier would be this to this.

So, this becomes my delta G n as per our previous understanding. Now what I mean to say that if the crystal structures are different for the phases which will be in equilibrium, they will not touch that free energy line will not be continuous. Because this line is not going to match with the silicon line. Now situation could be one arbitrary situation could be like this. This is my liquid line, and this would be my solid 1 alpha phase and that is a this is my solid 2 beta phase and I could have a common tangent. Then they should be x alpha in equilibrium with liquid this is x liquid in equilibrium with alpha as well as beta and this is X beta in equilibrium with liquid.

Now, interestingly in one of the situations in case of copper silver, I could see that they were continuous line this solid this is solid G 2 of alpha this is G 2 of beta and this is G 2 of liquid. So, there are continuous, but since this alpha and beta they have different crystal structures that is what we are not able to connect this entire solid solution line. This is the difference when I have different crystal structures and here also I am getting eutectic because this liquid is in equilibrium with 2 different phases. And that time these composition would disintegrate between 2 salutes 2 alloys one would be having composition x alpha in equilibrium with liquid and this should be X beta in equilibrium with liquid. And when we had similar crystal structures we used to indicate as alpha 1 alpha 2, but since here they have a different crystal structures.

So, that is what we are giving 2 different notations alpha and beta; that means, they have a different they have different crystal structures. Now on that basis we can explain aluminium copper system. This aluminium copper system is highly important from technological rather engineering sense because this system gives us an important alloy which is called duralumin. Generally this is an alloy of aluminium 4 to 5 percent copper. And this basically in weight percent. And duralumin also it is basically we call it 2,000 series aluminium alloys. This duralumin has got a tendency to get age hardened, and that is what we get to do know the concept of age hardening; that means, with time a material can get harder and harder. So, the mechanical property becomes much better and better from the point of view of strength.

The strength increases to a great extent. Because aluminium if we see pure aluminium it could have a strength of about 100 to 120 mpa, but once we have a aluminium copper system and that too around 4 to 5 percent copper. And if and aluminium and copper there in solution the strength improve definitely strength improves because of the solution, solid solution hardening. But that strength improvement would be very minor maybe around close to one if it is 100 then it can if the pure aluminium is has a strength of about 100, it can improve by almost about one 20 something like that. But interestingly if that solutionized; that means, everything is in solid solution that alloy is taken to a low temperature, and if it is kept for a long time then gradually the strength increases to a great extent it can even go up to around 300 to 350 mpa.

So that means, almost about 3 times increment in the strength which is remarkable and this remarkable strength increment comes from the concept called age hardening. And this age hardening since we are we are the way we have started that aluminium copper 4 percent let us say, it is to be in solution and then it is to be taken to room temperature. And then it is to be held at the temperature for long time. So that means, we are talking about temperature and time. So, because of that we get increase in strength. So, this strength increase that means, is fundamentally it is related to age hardening and that is dictated or the control by temperature and time; that means, the time temperature where you are holding it and time how long you are holding it.

So, actually this relates to processing which is decided by the heat treatment condition, because nothing but the heat treatment. Now we are talking about room temperature. Since the room temperature diffusion is sluggish. So, if we put it a little higher temperature let us say around 170 degree celsius this hardening process becomes quicker. Though the overall hardness would be lower, but it would become if the process becomes quicker, which is of great advantage because the industry does not allow much now long time because the long time of operation means the cost would increase. But depending on the requirement again I am coming to that part the requirement part of we require this much of strength and then you have to see how quickly we could attend that particular strength.

So, depending on that we choose the temperature as well as time; that means, if we go a very long time, then it might happen that instead of increment in strength there could be decrease in strength. So, that is what we have 3 stages of age hardening. We call it under age peak age and over age. So that means, this aluminium copper system is an important system to look into. So, that we could understand the concept of age hardening. Now since, but we have been looking at the phase diagrams for the entire last 10, 12 classes we talked about phase diagram. Now what could be the importance of that phase diagram? So, there should be some importance of the phase diagram with in regard to with regard to heat treatment.

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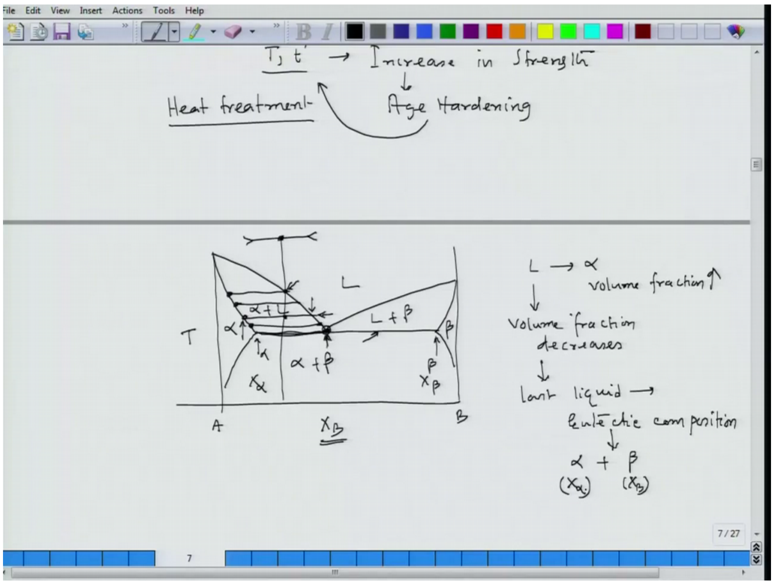

Now, if I try to see something phase diagram let us say I try to see a phase diagram eutectic phase diagram. So, this is my eutectic phase diagram. This is liquid this is alpha plus liquid this is alpha liquid plus beta, and this is beta is alpha plus beta. Temperature X B this is A this is B and this X B is basically the mole fraction this particular temperature is nothing but the eutectic temperature this is eutectic compositions. Now entire diagram has been drawn on the basis of equilibrium between different phases. And when we talk about equilibrium we are drawing free energy composition diagrams. Now once we get this diagram; that means, if I let us say I take this compositions, when it is very high temperature if the temperature is this one. Then everything will be liquid.

But as it comes down if the temperature drops at certain point of time it will appear it will come and touch this particular solid liquid phase line. And the solid liquid phase line is nothing but the equilibrium between solid solution and liquid solution. And that time I could get first alpha phase. Sprinkler of little small nucleus of alpha phase, know as we go down as we go down the temperature I could see that the alpha phase is forming with a different compositions, but if we give a very long time. Then these composition and these composition and the liquid composition is also enriching; that means, if I am here let see at this temperature the composition of the liquid solution would be this one, and composition of alpha solid solution would be this one.

So that means, that liquid phase is disintegrating into 2 different compositions. So, that is what you need diffusion. Now as we go down then I would come to this particular region this particular eutectic temperature. Once we reach to that eutectic temperature then the remaining liquid. So, we are we are getting solid phases as we are going down. So, the liquid content is decreasing the volume of liquid content is decreasing. So, the last liquid which is to be solidified, that will have the composition of eutectic and that eutectic composition, once we achieve this composition it to disintegrate between beta and alpha. So, the alpha phase and beta phase would appear at this composition.

But initially it will contain So that means, liquid it will start getting alpha, alpha volume fraction increases. Liquid volume fraction decreases. And then the last liquid we will achieve eutectic composition. And then once it achieve achieves eutectic composition it would it would have eutectic reaction which is nothing but alpha and beta with a composition this x alpha beta and this is x. This is x alpha this is X beta. So, x alpha and X beta. So, this 2 compositions it will form. So now, from this phase diagram, I will be able to tell what will be the possible phases, that could formed during cooling or during heat treatment or during holding all those things can be obtained from this phase diagram. That is the importance of the phase diagram. Because we must have the knowledge of phase diagram that would tell us that what phase would appear otherwise, we will not be able to do any justice to the heat treatment process.

Thank you very much.