Heat Treatment and Surface Hardening (Part-II)

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Lecture - 05
Determination of Phase Diagram (Experimentally) – II

Hello everyone. Welcome back. Let us continue and today would be lecture number 5. In the last lecture we have tried to calculate isomorphous phase diagram in case of copper nickel binary system from cooling curves. Now let us look into a system where we have eutectic, and let us see whether we can get phase diagram from different cooling curves.

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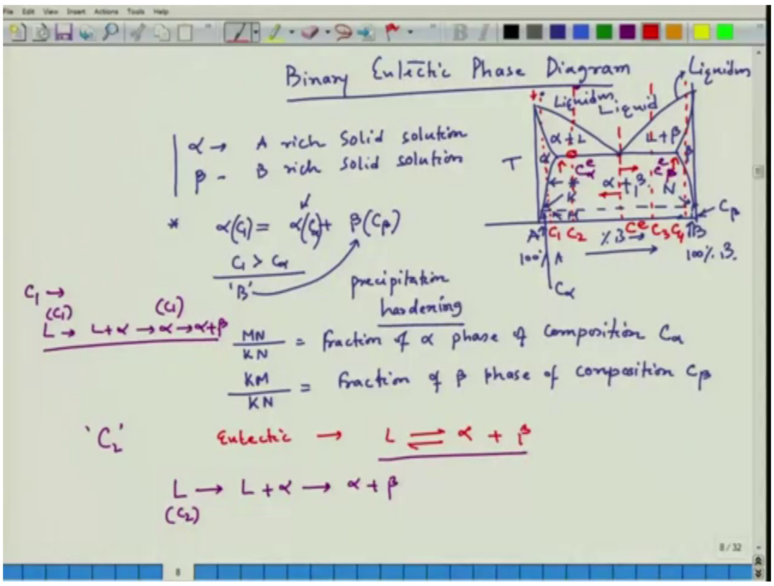

So, binary eutectic phase diagram and if we try to see a particular binary phase diagram, so hypothetical space diagram let us say where this is liquid, this is alpha, this is beta, this alpha plus beta, alpha plus liquid; liquid plus beta, and this is temperature and this is an alloy of A B elements, and the B weight percent or atom percent increases along this line, and this is 100 percent A and this is 100 percent B.

Now, we can choose any competitions between these 2 segments, between this and this segment. So, let us choose some composition; let us say 1 composition I am choosing 1 is 100 percent A that is pure A, then I am choosing a composition, which is let us say c 1, and that composition follows a track where initially I can start with liquid, and then as I go down I will come across a line, where first solid appears so; that means, this line is nothing, but liquidus here, this line is also liquidus, and then it goes into a single phase region, and alpha means a rich solid solution, and beta means B rich solid solution, in the beginning we are just concentrating on solid solution there are systems where beta can be a compound for example, in case of aluminium copper system, where theta phase is a l 2 c u which is a compound.

Now in this case we are considering solid solution, and then as we go down it will end up getting into alpha phase, and then at this point there will be another change, where alpha would convert into alpha plus beta. So, at this point which is let us say star; the star point, I will have alpha converting into alpha plus beta, and interestingly here we how do we separate these 2 alpha.

Now once we reach here, we have a single composition which is alpha c 1 composition, but once we come to this level, I will see that there is a segregation of B and the B rich phase beta would come out, and that time that composition if we try to see the composition here, I can say that this is c beta composition, and here it would be c alpha composition. So, I can write it as c 1 and this 1 would be c alpha, and this 1 would be c beta.

So, the only change is the alpha which has higher content of B is getting into another alpha which has a lower content of B, and the rest B which is given so; that means, c 1 is greater than c alpha so; that means, the B solute will be taken out from alpha c 1 that will form that extra B which is coming out from c 1, that will form beta phase and the rest of the phase will be alpha with a lower composition of c alpha. So, this is a principle of getting precipitation hardening also.

And they are also we can use lever rule so, we can say that if we put a name for example, this case this particular point I can put it as K, and this composition which is M, and if we put it as N, then we can say that M N divided by K N this is the fraction alpha phase of composition c alpha, and K M divided by K N to the fraction of beta phase of composition c beta. And these fractions are weight fractions because it is the main principle behind it is basically the mass conservation.

So, now we could see that how the transformation is taking place, similarly I can take another composition which is this 1 let us say c 2, and in case of c 2 again it will arrive at liquidus, line where first solid would appear, but there is another transformation that is taking place which is at this point, which is basically the temperature. And the way we have seen the composition is changing as we have seen that the composition is changing, so here we have seen that the composition is changing from c to s.

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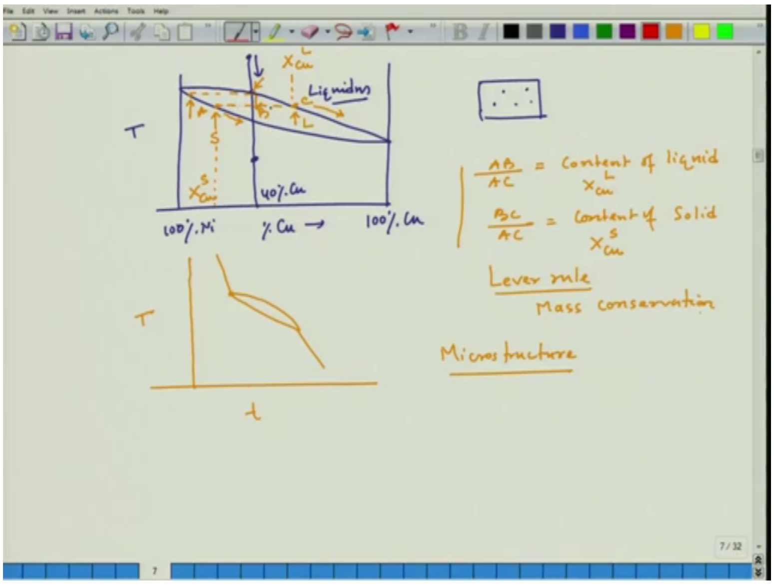

So, similarly here also composition would change as the metal comes to this particular position, the composition of the remaining liquid would be here, and it will have a transformation which is called eutectic, where a liquid converts into 2 new solid, and the composition would be if I consider at this point close to this point composition would be this point, and this point. So, this composition let us say I put it as a composition here c alpha u, and here c beta u, e means eutectic. So, this reaction would start.

So, now if I consider c 2 composition of the base of the initial alloy, I take it to this level I will get all liquid solution and as we go down, I will get initially alpha transformation where it is a mixture of alpha and liquid, and at this point we will have a transformation to eutectic the remaining liquid which calm which will convert into eutectic reaction phases.

Now so that means, in the first case if I try to write in case of c 1 if I try to write sequence of transformation liquid; then liquid plus alpha, then alpha; then alpha plus beta, and interestingly all the time we do not have any fixed composition here, we have fixed composition c 1, but here the composition of liquid and alpha both are same different, but here also we have a fixed composition which is same as c 1 again. But here also we are changing the composition, but if I try to see in case of this particular line, I see that initially it is liquid, then it is converting into liquid plus alpha, then it is converted into alpha plus beta. And here only this 1 would have composition c 2, but all the liquid and alpha, and alpha and beta, they would have different compositions as we keep going down, but the sequence of operations a sequence of phase appearance would be like this.

Now, I can have another composition which is same as eutectic point. So, I can term it as c e, and if I try to see what happens at c, I see that initially we have liquid of composition c e, and there is only 1 temperature where the liquid is converted into 2 solids alpha and beta. So, the transformation is alpha and beta.

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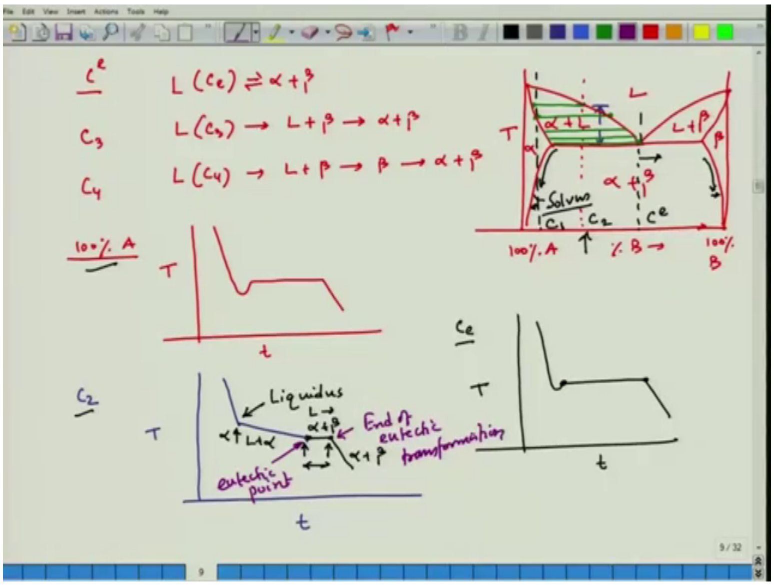

Now, if I take another composition here which is let us say c 3 the sequence of change would be this is c e composition, and the c 3 the change would be liquid c 3 first transformed to liquid plus beta, then going to alpha plus beta, and we can have a composition which is let us say this, which is c 4, so that time c 4 the sequence of changes would be L c 4 L plus beta, then going to beta, then going to alpha plus beta.

So, it is basically the same on this on the right side, on the left side the way transformation pattern has changed, on the right side it will have the same transformation pattern, but the phases would differ in the left side of this eutectic, we have alpha phase in after liquidus, and then after eutectic temperature we have alpha plus beta, but on the right side of this eutectic, we have beta phase appearing in liquid after it crosses liquidus, and then alpha plus beta, but if we go into the single phase zone which is alpha or beta depending on which side we are. And then we can have another reaction, where liquid plus solid going to a single phase solid, and then that solid is again converting into 2 different solids.

So that means, this is the entire story that is going on, now if we try to analyze the cooling curve pattern. We will see that the cooling curve would also change according to the pattern of changes what we have seen in case of transformation, if we take a liquid alloy to lower and lower temperatures. Now, again we just take the reference of that eutectic phase diagram, this is alpha, this is beta, liquid 100 percent A. If we see 100 percent A, that time I will get a cooling curve pattern same as like this, because it is a pure matter.

Now, if we have a composition this one that time, I will have cooling power pattern, which is let us say in this case we have seen this was c 2. First the liquid will cool down then we have solid phase appearing, and from these 2 this, which is the solidification range, we have alpha phase appearing, and then during that first solid which is appear which will have will have composition this, then the second solid and the liquid is also getting richer in B and as it is going down. Finally we are reaching the liquid composition is reaching to eutectic composition.

So that means, this is my liquidus, and here it is alpha appearing. So, in this range liquid plus alpha, and as we see that as the temperature is going down I am saying that the solid the liquid is getting richer in solute B. And gradually it is reaching to the composition of eutectic, and the last liquid what will be remaining for solidification we will have composition eutectic composition.

So, if we solidify that eutectic composition, it will go for eutectic reaction. Since we have seen that the eutectic reaction is a single temperature phenomena, and here we will have a situation until unless that eutectic composition solidifies the temperature does not change. So, then we will have a flat line depending on the amount of solid liquid what you have, and once it completely solidifies temperature would further go down and every time this eutectic composition is acting as a pure metal solidification.

So now here we have alpha plus beta, and then here we have alpha plus beta, and every time as we go down depending on this curve nature of this particular solidus and liquidus as well as this particular slope, and interestingly this is called Solvus, and hey this is also solvus. This is alpha solvus, this is beta solvus, this region is beta solvus; this is alpha solvus.

Now, we see the transformation pattern looks like this the cooling curve looks like this, so we have 3 segments a definite slope change are happening at 3 segments. And in this zone we are getting single temperature transformation, that is during the product formation from liquid to alpha and beta as we have seen that here, we have liquid converting into alpha and beta eutectic transformation is taking place the temperature is not changing until unless the all the liquid solidifies.

So, this is the phenomenon that is going on at c 2, now if we try to see a composition which is eutectic which is c e this is c 2 and c e as if it would have a pure metal solidification, the situation would be like this. So, this is the solidification pattern, and this is the cooling curve at c e, and this is 100 percent A.

The similar pattern would happen on the right side of eutectic, now interesting part is what happens at c 1, so we have to see the cooling curve pattern at c 1.

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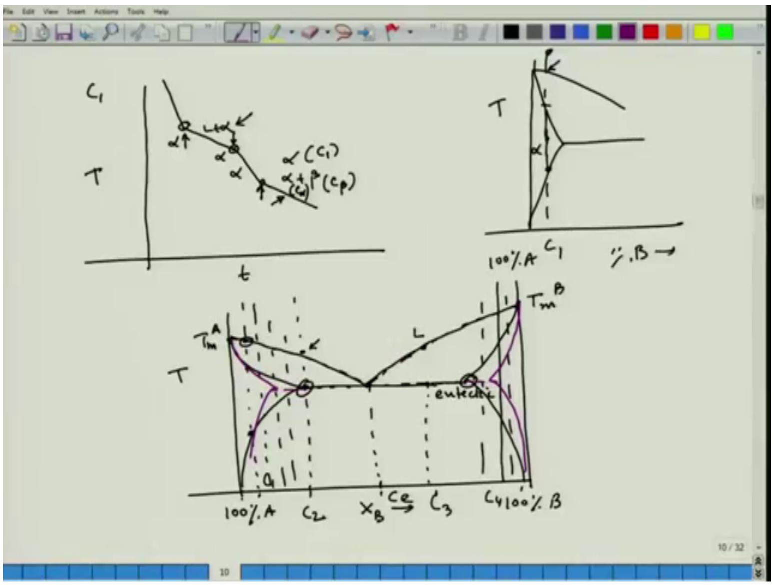

So, I am just drawing this part, so this is my composition c 1 and here it is this is temperature percentage of B, and this 100 percent A, this is the phase alpha.

Now, if I try to see what is the cooling curve pattern at c 1 at this point it will be all liquid until it comes to touch this particular point it will be all liquid, but the liquid temperature would gradually drop down. So, this is temperature, so it will drop down and then once we come across this particular point, then we will get a slope change and it continues till this point ok.

Now so; that means, this is liquidus alpha phase appearing this is liquid plus alpha, and here I get entirely alpha phase. Now this alpha phase temperature would again drop down, because as we are going down alpha phase temperature would up drop down, but that time there will be no compositional variation that composition would remain on this particular line.

But once it touches this, then we have again another transformation, which is alpha plus beta, and that time alpha of c 1 go to this composition would be c alpha, and this composition would be c beta. As we have seen in this particular diagram, so the transformation products should be alpha and liquid this is alpha, that there is no composition change. But here there will be continuous composition change and again when we come to this level. This level, I get another transformation. So, we have 3 big points again.

Now, we can try to connect those plot those points, now if I try to plot those points on temperature composition. So, first let us take 100 percent A, so it is a single melting point, so this is the point T m A, now if I take a composition c 2 this is the composition if we take let us say, this is the composition we take c 2, so this is the composition c 2 one would be this composition and on this composition level there will be another composition. So, it is like this; this, point corresponds to this.

Now if I take a composition close to this as we are going down, we will see that lets say eutectic composition which is c e, I will get a single plot c e, and on the other side our glade this is let us say c 3; c 3 I will get liquidus here, liquidus this is eutectic. These all the points are eutectic, then I can and here there is another point which is 100 percent B. So, I can connect those points, I will get the liquidus line.

Now I see that this is straight, because here we are getting liquidus transformation. Now we have to see how we can construct this on this line first point is this 1 which corresponds to this, the second point is this 1 which corresponds to this, and then another point what we are appearing is this. So, now, I can join them like this, but refinish and then I can join them, and I can continue for some compositions.

And then finally, on the other side I will get the same similar change, the accuracy of this particular phase diagram will be decided by how many number of experiments you are doing how close compositions you are choosing for doing this cooling rate transformations. For example, if you only take 1 2 3 4 5 6, 6 compositions let us say this is another composition so; that means, 1 2 1 pure A c 1 c 2 c e c 3 and c 4 then you are actually not able to get this point properly, this is always better to have very close proximity compositions. Then actually you are you can refine this. So that time you would get much refined data, which is close to the data what matches with the actual phase diagram of that eutectic system.

So, as we see that depending on the composition what we are choosing in the entire eutectic phase diagram from composition 100 percent A to 100 percent B, the main motto would be taking many more compositions and very close proximity compositions, and then we can carry out cooling curve experiments, and try to see where the slope change is taking place, and accordingly we just plot those points those temperature points on T versus x plot, and then we can choose for example in this case; in this case, at least I can see this is the liquidus point, this is the eutectic point, and this is the end of eutectic; eutectic transformation, so those points we can get an idea, and then plot them accordingly.

So, we will join eutectic points only for example, in this case only eutectic points we have drawn and we have joined and then we are getting a straight line, because that is the single temperature point say single temperature line eutectic line. And then we are also connecting liquidus line, a liquidus points to get liquidus on the on the left side of eutectic, we can connect we are connecting liquidus points on the right side of eutectic, and then we are also getting solvus information. So, actually we have got an eutectic phase diagram out of simple experiment, and getting the information of cooling curves.

And the next phase we would get into the thermodynamic ways to find out these phase diagrams, whatever we have discussed in lecture 4 and 5 are pointing towards the experimental way to find out simple phase diagrams like isomorphous as well as eutectic.

Let us stop here. We will continue in our next lecture.

Thank you.