Introduction to Materials Science and Engineering
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Lecture – 72
Microstructure evolution during solidification in isomorphous systems

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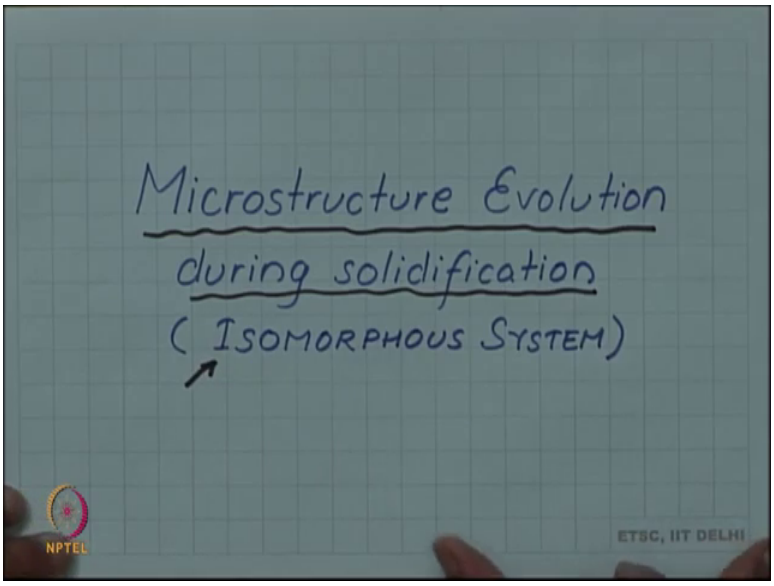

Let us look at how phase diagram helps in the study of microstructure evolution during solidification. And I am using a new page isomorphous system which I will soon explain.

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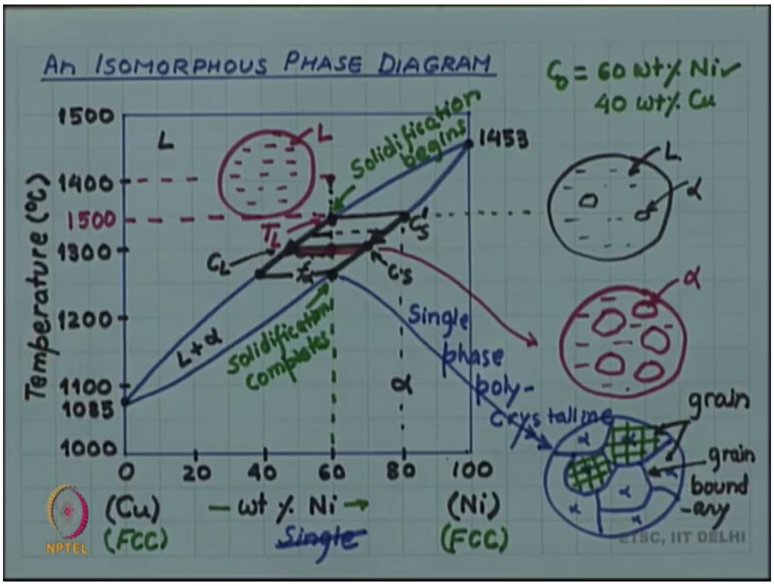

So, isomorphous system or isomorphous phase diagram is nothing, but what we have been seeing. The copper nickel diagram is an example of an isomorphous phase diagram. All it means that there is a single crystalline phase at lower temperature from all the way from starting from one end copper to another end nickel. Similarly there is a single liquid phase all the way from the copper end to the nickel end at the higher temperature.

So, such diagrams which have a single solid phase at lower temperature and single liquid phase at higher temperature and only two boundaries are there in the phase diagram a liquidus boundary, which is the upper line and the solidus boundary which is the lower line such diagrams are called isomorphous phase diagram and such systems, that is such a laws which make such diagram for example, the copper and nickel in this case is an example of an isomorphous system.

So, with this isomorphous system, which we have been studying as our example of phase diagram let us look at a particular T us consider a particular alloy, and look at the microstructure evolution in that alloy. So, in this phase diagram the alloy which I am selecting is let us say a 60 weight percent nickel alloy. So, the C naught or the alloy composition is 60 weight percent nickel. Remember that we are having binary alloy. So, only one component need to be specified 60 weight percent nickel automatically tells us, that the remaining 40 weight percent is copper because we are talking of copper nickel system. So, either 40 weight percent copper or 60 weight percent nickel can be used as composition, we have labeled the composition axis as weight percent nickel. So, we will use 60 weight percent nickel.

So, that is the composition of the alloy. If this alloy is at a high temperature and by high temperature we mean about the liquidus temperature. So, suppose it is at this temperature, then the phase diagram tells us that the phase present is the liquid phase. So, the entire phase here will be a liquid phase. So, if I draw the diagrams in terms of what you will see in a sample what you will see in a sample let me draw it. So, all you will see is a liquid. So, the entire law alloy is a liquid phase at this temperature of 1400 degrees Celsius; as you cool alloy will. So, whatever changes which is there due to cooling for example, there will be thermal contraction. So, the volume of the liquid will reduce, liquids generally will increase in viscosity as the temperature lowers.

So, the viscosity will increase. So, such physical properties will change, but there will be no phase change till you reach the liquidus boundary. So, the liquidus boundary is reached at this temperature and we can call that temperature as the liquidus temperature. So, in this diagram is approximately 1500. 1500 is the liquidus temperature let me label it as T L. So, when the alloy reaches the liquidus temperature you will start having start beginning to see a first solid, and by tie line rule the first solid will have a composition given by this point. Let me label I have drawn a horizontal which is the horizontal tie line you have learnt in the previous class.

So, let me call that C S let me label it as one that is the first composition solid which will form in this diagram you can read, I am not intending to tell you that this is exactly the because I have drawn this phase diagram by hand. So, these compositions I am using as example and these temperatures I am using as example, its not that in the actual phase diagram for 60 weight percent alloy 1500 degrees celsius is the exact liquidus temperature.

So, you have to see the real published phase diagram, which is available in text books and manuals and nowadays on internet also. So, you can look that up here I am taking it as an example that if this vertical line the alloy composition vertical intersects the liquidus boundary at whatever temperature, that is the liquidus temperature and for example, sake I have taken this to be 1500. Similarly wherever this horizontal cuts the solidus line that is the first solid to form and again for example sake I am taking it to be the 80 percent. Then as you now lower the temperature, you now lower the temperature you have seen that the fraction of the solid is given by the opposite lever arm. So, since solid is on my right side alpha is on right side the left side lever arm will be proportional to the fraction of the solid phase and by lever rule this arm divided by total arm will be the actual fraction of the solid phase.

So, you can see here if I really apply the tie line rule. So, my f alpha arm was really 0. So, the first solid is just going to begin only if you lower the temperature a little bit then you have a small arm. If I draw at an intermediate temperature you can see that the f alpha arm which is in this case is this much they divided by the total arm is a smaller fraction. And as you lower the temperature you get higher fraction of solid. So, this is how the solidification is progressing that as you lower the temperature, you will get more and more solid and finally, when you reach a temperature corresponding to where the composition vertical hits the solidus boundary, at that temperature the solidification will complete.

So, we can write this is where it intersects the liquidus boundary that is where solidification begins and where it hits the solidus boundary the solidification completes or replication completes. So, this is the progress of solidification that. So, if I try to draw a few more diagrams like I drew for the liquid 1. So, just at this T L temperature the diagram will look something in fact, just slightly below T L. So, T L we are taking as a limiting case of beginning of solification, but since the lever arm f alpha is 0 there actually there is no solid at this point. So, it just begins if I lower the temperature.

So, there will be a small amount a very small amount of solid just going to begin. Solid is alpha then as we have lowered you can see the tie line also gives the end point of the tie line gives you the liquid composition and the solid composition. So, the liquidus end of the boundary gives you the liquid composition and the solidus end of the boundary gives you the solid composition.

So, you can see that both the liquid and solid compositions evolved along these lines. So, initially the liquid composition was same as the starting liquid, but gradually liquid depletes in nickel and the final liquid which is solidifying is of much lower concentration than the original alloy same thing happens with the solid also. So, the solid composition evolves along the solidus line. So, the first solid to form was the C S 1 which I have written, but the final solid which is forming is of composition same as the alloy composition. So, the composition changes as the solidification is happening. And at this temperature at this intermediate temperature which we are now considering you can draw the tie line and find out what is the fraction of alpha and the fraction of liquid in my drawing its more or less you can see that the two lever arms are the same.

So, I can imagine that at this temperature I have 50 percent solid and I am showing several chunks and not I am not making 50 percent solid as one single half of the diagram has solid and another half has liquid. I am showing several chunks because this is how the physical process develops, that there are several nucleation sites at which solid begins to form. So, it is not that own solid will begin at only one point and that particular point will gradually grow into a single continuous solid mass. So, salt begins to form at different locations, this is called nucleation and we will discuss that in detail later and then those regions gradually develop. So, you have several solid regions developing in the liquid phase and finally, when you come to this come to this last point solidification has completed.

So, you have single solid phase, but then you can see that since the nucleation began at several locations each of them will have their own region in the final microstructure. So, this is what we had earlier called when discussing the surfaces and grain boundary as a poly crystalline, poly crystalline system or a poly crystalline sample. So, what you finally, get is a single phase is same because each of them is alpha all of them is alpha, but the difference is in their crystallographic orientation.

So, if I try to mark some sort of unit cell in them because each is a crystalline phase copper and nickel if you remember both are FCC, and recall that we had talked about Hume Rothery rule. So, somehow copper and nickel things satisfy the Hume Rothery rule and that is why they are able to form a continuous solid solution. Whenever you have an isomorphs system you have a continuous solid solution from one end to the other end and they are quite likely to be satisfying the Hume Rothery rule. And in particular the structure factor rule that the two end components should have the same crystal structure has to be true.

So, the single alpha phase has this FCC or a cubic closed pack structure, but the closed packed structure has different orientations as you cross these grain boundaries. So, you have grains and grain boundaries. We have talked about these before, but now we are showing you how this forms and how it is related to the phase diagram. So, these are different grains and the line separating them is the grain boundary. So, in an isomorphous system if you proceed with the solidification finally, starting from the liquid phase the alloy goes into a two phase liquid plus alpha region, where you have both liquid and alpha and finally, in the end it will end up as a single phase poly crystalline alloy. For a single phase poly crystalline system I was beginning to write it here, but now I have run out of the ace space.

So well, you can remember this; this is a single phase poly crystalline or let me write it here along this blue line. So, this is giving you a single phase poly crystalline structure single phase poly crystalline microstructure is what you will end up with.