Phase Transformation in Materials
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Lecture - 32
Alloy Solidification (contd.)

Let us now discuss the effect of the solid pile up in the liquid in the different growth for formations then solidification of pearlites. As you see I have kept all these pictures all the things plots which I have drawn in the last lecture for your reference. So, that you do not have to follow up again from the earlier lecture, and as well as I have drawn the phase diagrams for you to understand.

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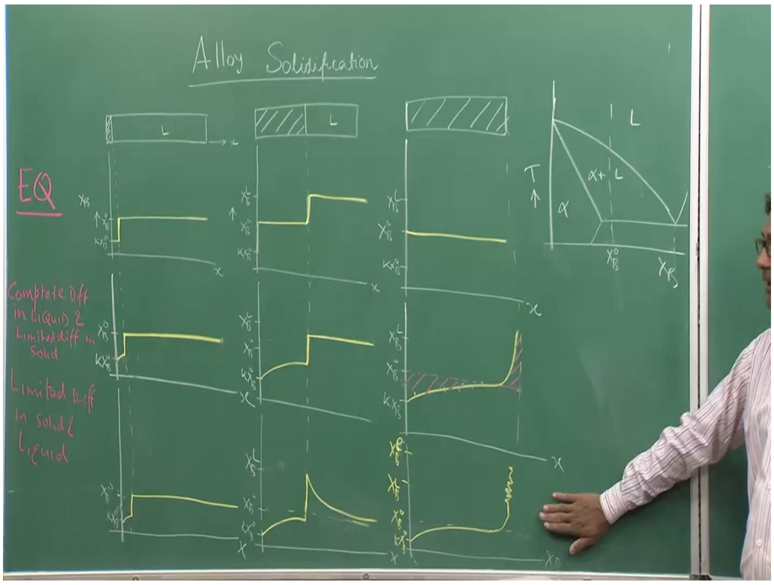

So, we have been discussing about solidification of the alloys x p 0. And I told you that the most realistic situation of solid profile is this one, the last one or the bottom one in this in these pictures. So, let us assume that we have a solid build up and the in this at the interface.

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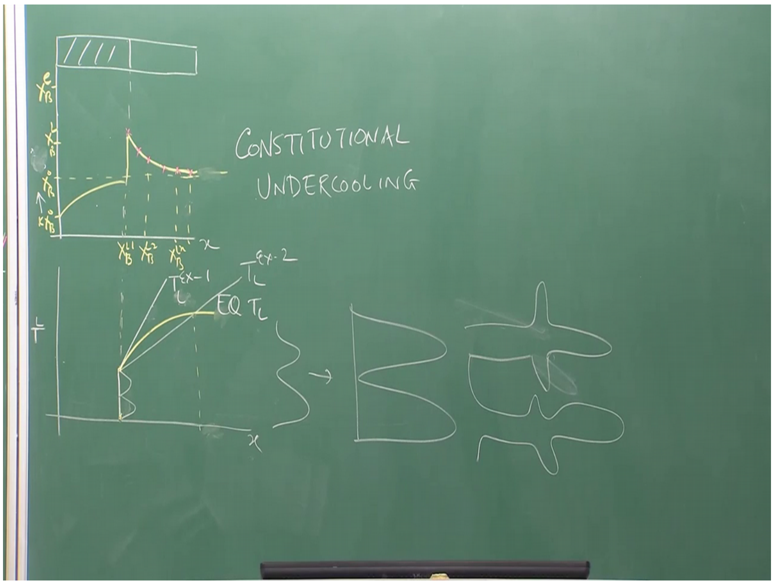

So, if draw that I need to draw it to explain is so this is my solid XB. And this is the distance. So, what I have drawn is basically solid profile, this is k v k XB 0 this is XB 0 this is XB L and this is XB e.

So, this is let me just draw it k XB 0 is here XB L and this is XB e. So, that why they are coming higher and this XB 0 and what I have done let me draw a line here. So, this is I am talking about intermediate case. So, this is the solid profile look like.

Now, how can I use this solid profile to discuss about the different growths forms? Well let us do that remember this is composition versus x profile distance, now I can actually take composition in the liquid. So, suppose this is my XB L 1, XB L 2 like that it goes on it actually goes much becomes flatter later on XB L n something like that. Now these compositions in the liquid will determine it is liquid temperature liquidus temperature.

Obviously because in a phase diagram this is liquidus, let us put it in color otherwise it is very difficult to follow. So, this is my liquidus and this is my solidus right it is the green one. So, as you clearly see the temperature this is a temperature versus composition plot; that means, for every any composition on these liquidus. I can determine the temperature if I know the liquid composition here, I know the temperature here that is a liquidus temperature. So, therefore, if I know the composition of this solute in the liquid this is what is given by this profile it looks like an exponential I have given the equation also it is exponential.

So, I can actually measure composition at each point on the liquid in the liquid, I can see here I can do that and then I can actually plot this compositions on this axis on the x axis of these on these phase diagram. So, by doing that I will know; what are the liquidus temperatures. So, actually I can see when the liquidus is very high temperature will be low right because that at these interface that composition is a very high there is a spike then slowly goes down. So, therefore, at the interface temperature will be very low because as you see here the liquid composition is here is composition is high temperature is lower.

So, as the composition increases and finally, it becomes same as XB 0, the temperature goes down right; so therefore, if I plot now here x as a function of T L, T L is my liquidus temperature. So, what will happen I am drawing for the liquid solid there is no liquidus temperature so; obviously, it will be very high very low here because this composition is slow and let us mark this as point this point. And then it will slowly increase right slowly it will increase, this is what it look like because composition is high liquid is slow composition is lower liquidus is higher that is very simple that is a direct correlation.

So, that is mass liquidus now this is my interface right. The question is this if this interface develops suppose say protrusion like this my another protrusion like that whether this protrusions will grow or not. If they do not grow the interface will move like a flat if they grow interface will break down and form dendrites that is what will happen. So, under what condition they will grow.

Obviously, this is my equilibrium liquidus temperature right. That is what I have done equilibrium liquidus why it is equilibrium liquidus because we are drawing it for the phase diagram and phase diagram tells you equilibrium informations actual situation may be defined. So, this is tells you because this is T x L versus distance plot. So, this any point on this curve will tell you the slope or the gradient temperature gradient in the liquid any point on this curve. Because this is a plot between temperature versus x, x is the distance.

Now, actual experimental conditions may not be following or it will not follow the equilibrium situation, because in actual experimental condition we may be extracting heat faster we have been cooling slowly we may be doing you know many other things actual experimental conditions actually vary.

Therefore, actual experimental condition the temperature gradient of the liquid can be modified can be changed. So, suppose if I impose certain experimental conditions and temperature getting a liquid looks like this. This is my experimental condition this is equilibrium T this is my experimental tl, tl experiments one under one experimental conditions my liquidus temperature it looks like that or basically temperature gradient has a this much value and I am this is basically given by this slope.

Now, if I have such a kind of situation; that means, the actual temperature gradient is higher than it the equilibrium temperature gradient. So, if there is a any kind of a protrusion forms in this till melt because temperature gradient is higher. Actual temperature is higher than the equilibrium temperature and because of that if there is at all any kind of a protrusion or any kind of a things form on the interface become little bit jiggered just like the once, which I have shown you in the last lecture, they will melt back they will be melt back and the interface will remain flat.

Therefore, this is the experimental condition in one, in which interface will regain flat it will not be at all forming any kind of features. But suppose let me draw this is a this is a wide line. So, that you do not forget this is my first condition. Suppose if I have I have a little other experimental condition in which the slope or the gradient is like this this is T L experiment 2, correct as you see here in the region from this plot to this pot, this point the liquidus temperature actual liquidus temperature of the sample that is the experimental T L experiment 2 is lower than the equilibrium liquidus temperature. So, because temperature is lower the liquid if, if there is a solid protrusion forms here, it is solid protrusion form here like this they will feel comfortable they will not melt back they feel that they are under cooled. Why they are under cooled because temperature is lower than the equilibrium liquidus temperature.

Remember anything below this equilibrium temperature solid can remain present because this is the region between alpha plus liquid anything above it is all liquids. So, above this temperature liquid can only remain will this temperature solid and liquid both can remain. So, because the temperature here is lower than the equilibrium liquidus temperature because of experimental conditions we are going to have develop this kind of suggestions. Or this kind of features from the surface and these features we will then grow as a time goes on this features will become bigger much bigger and finally, this features will become dendrites.

They will form dendrites. So, first interface fix downs it form cells do not have in any secondary arms or tertiary arms. Then secondary or tertiary arm forms they can dendrites that are what happens in the actual practice. Therefore, formation of alloy dendrites is something to do under cooling because composition or because constitutional. And this theory is known as constitutional under cooling theory this is has been described as a constitutional under cooling theory. So, therefore, without even going in to you know details of the different aspects we can simply explain why such a kind of things.

Such dendrites and cells form in the alloy dendrites, but this theory always have 2 problems. This theory is very simple and the elegant also very elegantly explain things very easily that whenever I have actual temperature gradient is lower than the equilibrium temperature gradient in the liquid, we will have serration formation on the surface interface and this parturition or serration, whatever you call they will grow into the liquid and that is how this dendrite growth forms will arise, but you know in undergoes 2 important things one the gradient is mainly because of compositional. So, if suppose I have a pure medal, I do not have any solid presence there will be no compositional gradient developed. And; that means, all the pure materials would grow by flat interface there will be no dendrites, but I as you seen in the last lecture in pure medal also we do see dendrites. And these dendrites because mainly because temperature thermal effects not because of compositional effects.

There is a number one drawback of this theory. Second draw back which is more important whenever you create you have flat interface as compared to a flat one the curved one or cells or dendrites will have a larger surface area interfacial area or interfacial area. And these interfacial area change will lead to change of the energetics of the system if I have to add total energy of system as a free energy decrease because of the liquid or solid transformation that is we have seen in the earlier lecture also, plus the energy because of this interface then only I will find the actual things will not be. So, simple, but these theory it completely under mines the effect of interfacial area they never consider the interfacial area at all. So, therefore, this theory is cannot talk about scale of micro structure whether smaller size dendrites will form or bigger size dendrites will form they cannot discuss because they are not considering they have not considered the effect of interfacial area.

So, these are the 2 basic problems of these theory already this was discovered long back 1954, but this has this problem. That is why this theory was discarded later on in fact, in 1960s 1963 64 65. This theory was discarded and people have described a new theory which I will just give a glimpses of that I will not discuss about much about this because that is a part of solidification does not part of the phase transformation. So, instead of thinking of a constitutional under cooling the main reason behind the dignity growth, we can simply think that I have a flat interface initially this is solid this is liquid and we there is always some fluctuation present in the interface in terms of temperature in terms of composition.

Temperature may not be uniform at present of interface a interface is microscopically not small may be thickness is small, but the length is not small. So, there will be always some fluctuations with the temperature or composition or may be some other elements like oxygen nitrogen in the environment.

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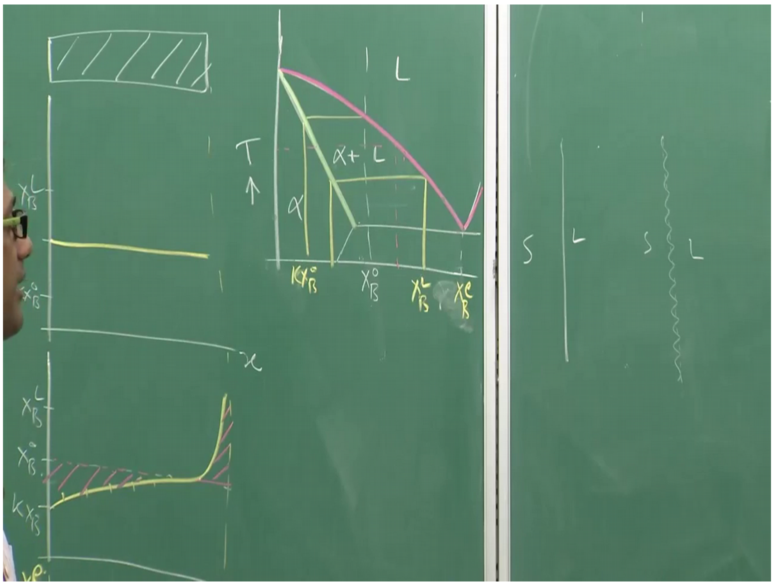

This fluctuations can lead to interface perturbed interface will become perturbed; that means, I can develop some sinusoidal perturbations on this surface, you see this is a sinusoidal curve you can also have co sinusoidal or any other such kind of perturbations now the question is this fine because of compositional change or temperature grad temperature variation according to interface certain kind of perturbation has developed acceptable understandable.

Now, question is that under what condition these perturbations will grow they will they had 2 choices either this perturbation will vanish the interface will remain flat or this perturbations can grow and form again cells and dendrites. So, that was done much later and that explained why dendrites form and why this growth forms are present in the actual solidified materials. Well then, there are many other things which I will not be I will not be able to discuss you because that takes lot of time, that is this theory is well known and this theory is there in the literature. So, you can even with books also you can read it in this book also, it is there it details talks about this theory and discuss about that. So, before I complete this today lecture. Let me just introduce you a new things which you will discuss today.

As a part of liquid solid transformation which is very widely present in the different alloy systems that is the eutectic solidification. Remember we are all discussing about single phase solidification. So, far whether it is a pure medal or it is an alloy we are only discussing about single phase solidification, but multi phases also be important as a part of your curriculum multi phase is means only eutectic solidification present. So, I will spend about 5 6 minutes today. And the next lecture eutectic solidification before we simply in complete this part of these course liquid to solid transformation move ahead for the other things. So, eutectics are very common in the actual practice we use many eutectic alloys right, we use lat10 as a solar material we use aluminum silicon as a cylinder blocks of the engines in the cars and the trucks or we use cast iron these are all eutectic alloys.

So, therefore, it is important that you have some idea how eutectics solidifies in the this materials; obviously, eutectics are much more complex than you think about it, than we actually suppose, but they have must more complex it will eutectic solidification can vary from one system to others. So, we will be not able to discuss in details that much that whether liquid solidification, aluminum silicon alloy is distinctly different from the cast iron or not that is not possible for me to discuss, but I will give you a generalized to eutectic solidification. So, that you have some idea about it and then you can build on it later on as you know, the classical eutectic phase diagram is little bit different from what

I have drawn, I have all drawn part of the phase diagram. So, eutectic phase diagrams are actually very widely present in the literature.

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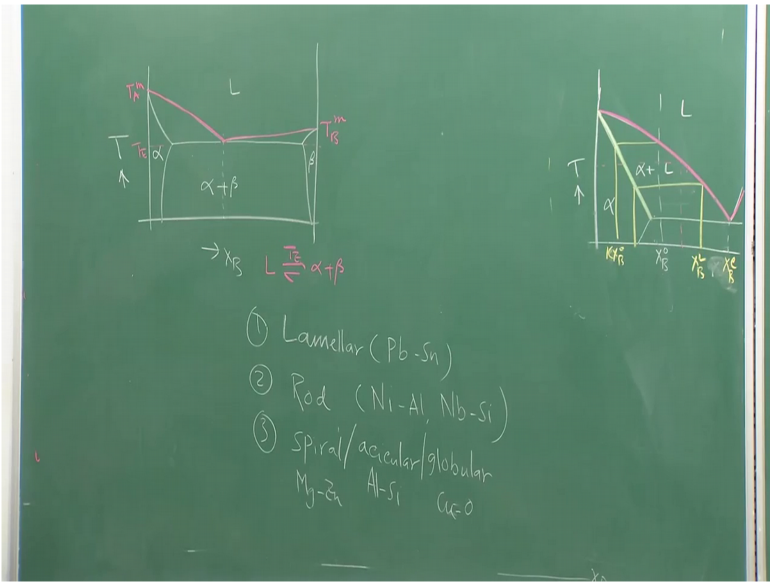

You will find many phase diagrams where eutectic is widely present the simplest eutectic phase diagram with 2 terminal solid solutions it is like that. So, alpha beta the 2 terminal solid solutions and eutectic is basically the lowest melting solid in this phase diagram as you see here both the liquidus is going down. And they are meeting at a point whose temperature is lower than the melting temperature of pure A and melting temperature of pure B.

So, therefore, eutectic reaction is basically liquid going to alpha plus beta, when at the temperature T e. It happens the T e is basically given by this line this invariant line we know that. So, eutectic is a very classical phase you know reaction what us it tell these particular reaction tells you that from the liquid 2 solid phases simultaneously form 2 solid phases are directly forming together from the liquid depending on the how this solid phases will be this to be in the micro structure. You can have different kinds of morphologies, the classical one which is present in the led tin or others alloys is basically lamellar. I will show you all this picture. In the next lecture, lamellar you can also have rod type; that means, one of the phases will be like a rod either alpha or beta whichever volume fraction is little one.

You can also have spiral or acicular eutectic or globular spiral eutectic is find in magnesium, zinc, system acicular is aluminum silicon. And globular is find in copper oxygen Cu2O. So, lamellar is basically led, tin. Rod is basically nickel, aluminum or aluminum silicon, there are many other morphologies. I am not discussing about that the important ones are these you can also have eutectic (Refer Time: 21:01) keep micro structures.

So, those are actually very special cases, but these are actually routine normal things normally we find most of the eutectic say lameller type, like led tin is one classical example. Or rod type normally rod type eutectic forms in one of the phases is basically volume fraction is low. You can also have a spiral if suppose one of the phases both the phases have different thermal expansion coefficients, then we will have a spiral eutectic. Very simple if I it have a by metallic rod of suppose say 2 metals, and if I start heating it up because of the difference in thermal expansion coefficients one will bent over the other. And there is the one that is the way spiral eutectic forms you can also have a acicular eutectic, one of the eutectic phases fibrous like silicon and aluminum silicon is basically of fibers, but the aluminum is a continuous phase you can also have a globular like one of the phase Cu2O is basically forms like a global in the continuous matrix of cu o.

So, these are all very classical things which are found in the literature. And the books I will show you some of these slides in the next lecture. And then I will try to develop a theoretical foundation, where you can actually use the use the theories to explain the formation of a eutectic.