Powder Metallurgy
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Lecture - 15
Dendritic growth in alloys

Hello everyone, and welcome back again to this lecture series on Powder Metallurgy.

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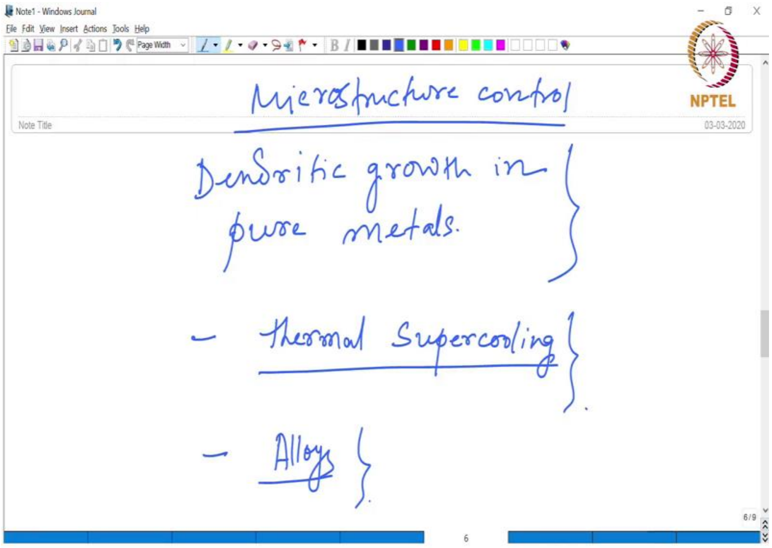

Microstructure control

Dendritic growth in pure metals.

- thermal Supercooling
- Alloys

In past few classes, we have been talking about the microstructure control in the atomization process, and in the previous class we learned about the Dendritic growth that takes place in pure metals.

Here, one thing that we have discussed is the fact that the driving force for the dendritic growth, in this case was thermal super cooling or thermal under cooling, which gives rise to conditions which are favorable for the growth of those dendrite arms.

Now, in metallic systems apart from pure metals, you also have the alloys. And, we have seen that atomization is a process which is also widely used for making alloyed powders and therefore, it is also necessary for us to understand that for alloys, what are those conditions, or what is the driving force for the dendritic growth that we are talking about.

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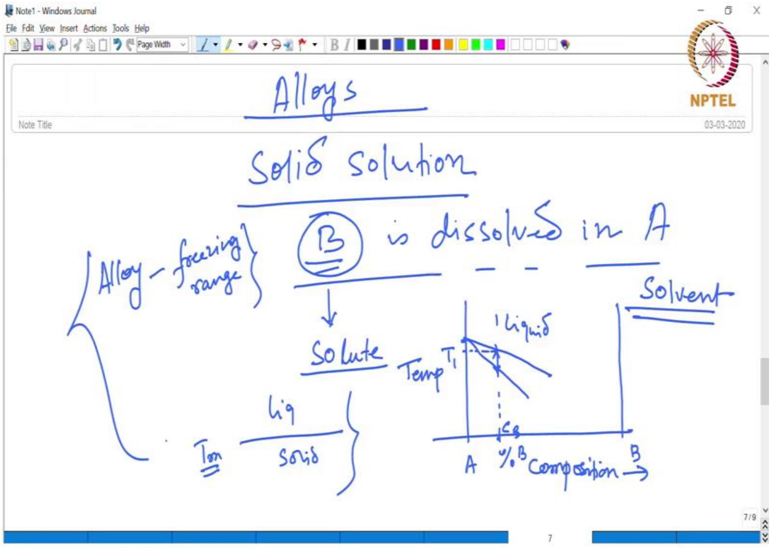

Alloys are different from pure metals in the sense that you have a second element which is dissolved in the parent metal. So, this is what we call as a solid solution, where a small amount of metal B is dissolved in A.

This we will call as an alloy of B into A or a solute solution of B into A, A being the parent phase, the main metal and B being the alloying element also known as the solute.

A is the parent phase or the solvent. So, different alloys might have a different alloying content in terms of the amount of B which can be dissolved. And that can be seen with the help of an equilibrium phase diagram which shows the composition as a function of temperature. So, this end is pure A and this end is pure B and composition is in terms of, percent B.

From the equilibrium phase diagram point of view, you will see that the melting point of the pure metal which is here, so that is T_m for the metal A.

That is going to be different for an alloy of a given composition. Let us say, this is the composition of the alloy. Let us say we call that as C_B a particular amount of B in A. That may be different, the melting point of that may be different from the pure metal, as you can see from here.

That is one difference that you can immediately note. The other difference being, the pure metal would solidify as and when the temperature is reduced below the melting point. It simply transforms from liquid to solid below the melting point.

But in this case, you can notice that for this particular alloy having this C_B composition, this is a liquid here then as it crosses this temperature; let us call that as T_1 it starts to solidify. The first crystals of the solid will start to form once this at T_1 temperature is reached and then it goes through this particular range, before it comes to the lower curve below which it turns into a complete solid.

So; that means, the alloy has a solidification range which is known as the freezing range. Unlike the pure metal the alloy would solidify over a range of temperature, as you can see from here. So, that is the biggest difference between the solidification of a pure metal and an alloy.

Due to that, the conditions which lead to a particular type of microstructure; in this case the dendrites, those conditions will also be different or the reasons or the driving force behind development of those conditions can be different, because of the different ways of solidification that you have between a pure metal and an alloy.

Let us try and understand as to what those conditions in case of an alloy are that lead to a development of a dendritic structure. In order to understand we will again take the help of this equilibrium phase diagram.

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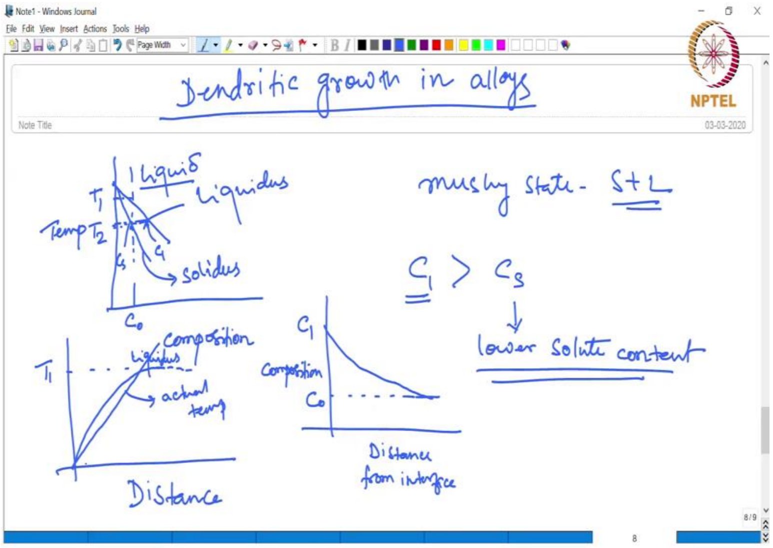
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mushy state - S+L

$C_l > C_s$

↓

lower solute content

Which has the temperature as the y-axis and composition as the x-axis. And let us say, we are talking about an alloy composition which is C_0. So, that is the average composition of the solid that we are looking at. And, now we are trying to understand here as to how this alloy will solidify as it is cool down from the liquid state.

When it comes to this upper curve a temperature of T_1, the liquid starts to or the solid starts to form from the liquid. So, above this curve all is liquid and below this curve the solid starts to form. So, this particular curve is known as liquidus.

And, when this is further cooled down and then when it comes to this temperature here, below that only it will completely transform into the solid. So that is why this curve is known as the solidus. So, any alloy that is solidifying has to go through this range starting from the liquidus and going to the solidus.

So any particular alloy having a particular composition will have its own liquidus temperature below which the solid will start to form. And as I said that is what we are trying to see over here, as to how this solid is transforming as the temperature is lowered.

So, T_1 is the liquidus temperature in this case, and as it is lowered the solid comes, so this is the solid plus liquid state which is in the middle in between these two curves. So; that means, here both the solid and liquid will coexist, which is a state known as a mushy state, where you have both the solid plus liquid coexisting.

Now, let us say this is further brought down to this temperature over here. And at this temperature T_2, the solid composition which is here is C_s and accordingly, the liquid composition is here which is C_l. C_s is the composition of the solid in terms of the percentage or the amount of the alloying element or the solute, and C_l is the composition of the liquid at this particular temperature T_2.

Now, what happens, you can clearly see from here, that you know C_l is greater than C_s; that means, the solid which is forming from this liquid having a composition of C_l is having a lower solute content. As a result of it, the liquid which is in contact of the solid or just in the close proximity or the liquid which is surrounding this solid which has just formed will be richer in the solute.

As a result of that the composition of the liquid at the interface, and the composition in the liquid away from the interface will be different. It is going to decrease as you move away from the interface.

So, if you plot that, composition as a function of distance from the interface, it will look like this. At the interface where the solid is forming from a liquid of composition C_l, that is what we have seen; that is higher compared to this average composition C_0.

As we increase the distance from the interface, the composition will decrease or the solid content of the liquid will decrease and eventually it will stabilize at the average composition C_0. And, as a result of this, composition variation from the interface, the liquidus temperature would also vary. Because, that also is a function of the composition.

And therefore, if you now plot the liquidus temperature as a function of distance, it will increase with the increasing distance and eventually will level of when the actual liquidus temperature of the alloy is reached; that is it will level of at T_1.

So, this is how the liquidus temperature would vary as a function of the distance. Now, if you measure the actual temperature of the liquid ahead of the interface and plot it, that would also you know increase with the increasing distance, like this. Let us try and draw this separately in a more cleaner space.

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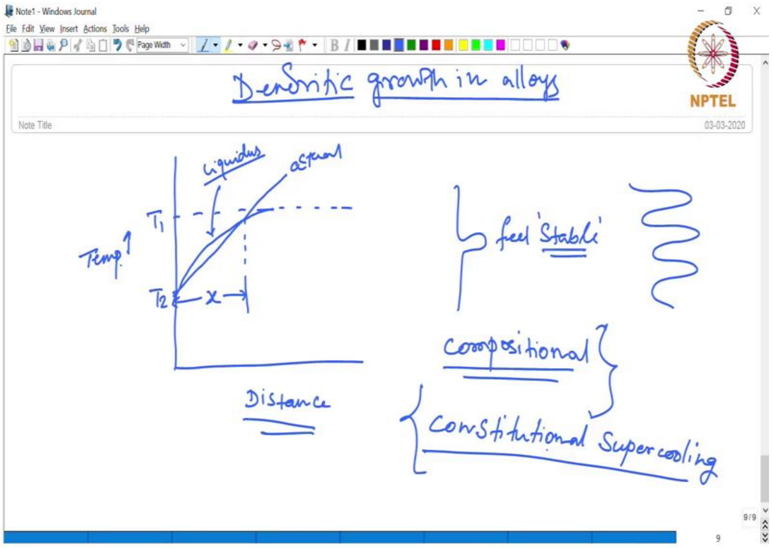
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This is the actual temperature, and this is the liquidus, which varies as a function of distance from the interface due to the variation of the composition as a function of the same distance.

Now, if you see between these two points; that means, from the interface to a particular distance; let us say, x. Within this distance, the actual temperature is always below the liquidus temperature. So, what does it mean is that if any protrusion forms in the interface, it will always be at a temperature lower than the liquidus, and as a result of that it will be it will feel stable. It will not melt back again into the liquid.

Because, as you can see from here, the temperature is below the liquid liquidus temperature where the solid is supposed to be stable. Therefore, anything any protrusion or perturbations that might occur in the interface, will feel stable and it will grow. So here, you can see, the driving force behind this is compositional, rather than thermal, like what we had seen in case of pure metals.

So, the super cooling which is being achieved here; that means, the temperature of the liquid being lower than the liquidus, That super cooling is achieved here due to the composition variation, as a function of distance from the solid- liquid interface. And, that is why this kind of super cooling is known as constitutional super cooling.

And this is the driving force for the development of dendrites, in alloys. Unlike the pure metals, where the driving force was thermal super cooling.

So, this kind of arms and can develop, because the liquid around it is super cooled. As we have discussed, the liquid is at a temperature which is below the liquidus and as a result of this, this kind of cells or this kind of arms which grow from the interface will be stable and then they will continue to grow as a solid phase giving rise to the dendritic structure that we have seen before.

So here, in case of alloys, the driving force behind that comes from the compositional reasons known as the constitutional super cooling unlike the pure metals, where it is thermal super cooling right. So, now, if I have to summarize this dendritic growth in alloys.

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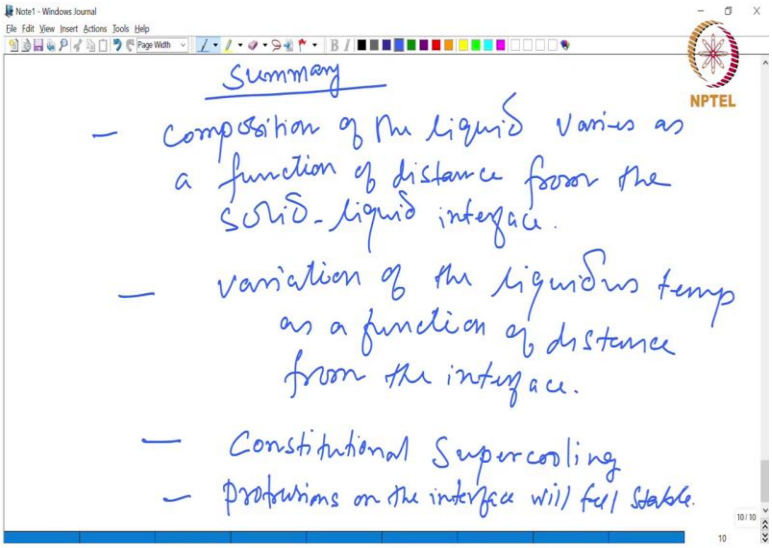

Summary

- composition of the liquid varies as a function of distance from the solid-liquid interface.
- variation of the liquidus temp as a function of distance from the interface.
- Constitutional Supercooling
  - protrusions on the interface will feel stable.

Here, we have seen that the composition of the liquid varies as a function of distance from the solid liquid interface. And, this results in the variation of the liquidus temperature as a function of distance from the interface.

And this in turn results in, what is known as constitutional super cooling. Because, this kind of super cooling is arising out of the composition variation ok. And as a result of this, any protrusions which developed in the interface will feel stable and thus grow into a dendrite ok.

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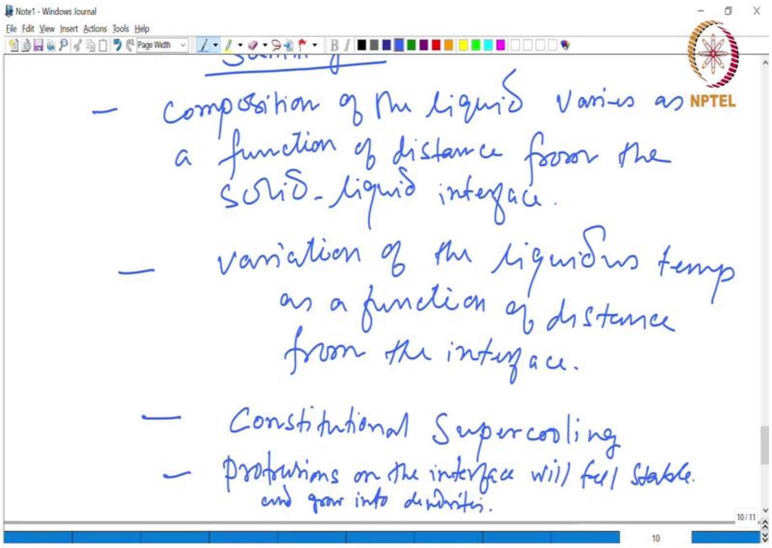

- composition of the liquid varies as a function of distance from the solid-liquid interface.
- variation of the liquidus temp as a function of distance from the interface.
- Constitutional Supercooling
- protrusions on the interface will feel stable and grow into dendrites.

So, in short, we can say that this constitutional super cooling of the compositional under cooling, compositional super cooling is the responsible force or the driving force behind the development of a dendritic structure in an alloy. So, with this we come to the end of this class.

Thank you for your attention.