# Power Metallurgy

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## Lecture - 14
## Dendritic growth in pure metals

Hello and welcome back again. So, right now we are on this topic of Microstructure control for the atomization process.

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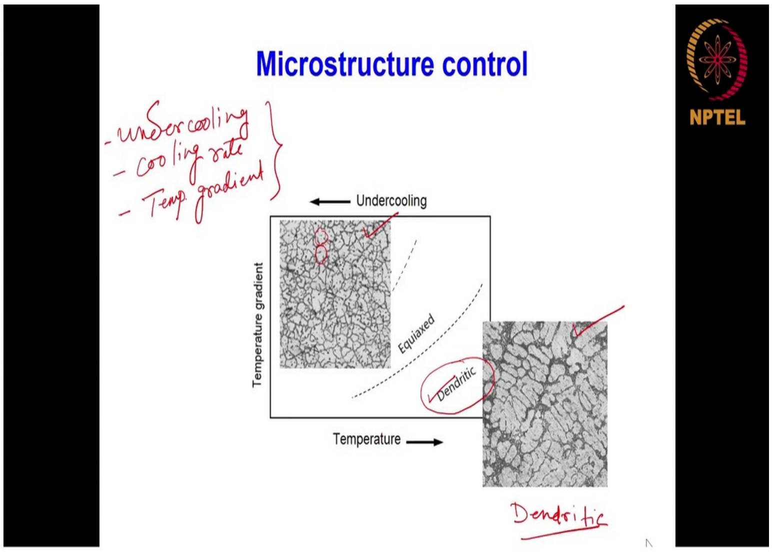


And in the previous class we talked about different parameters which actually control the microstructure of the powder which is generated by the atomization process. If you remember these were the 3 main parameters that we talked about, i.e. Under cooling rate and the temperature gradient. And how these 3 are interrelated to each other that also we have discussed. And then we had seen the effect of these parameters on the microstructure of the powder.

In one case, we have seen that it is dendritic which is here this particular microstructure. And that happens when the temperature is on the higher side and under cooling as well as the temperature gradient are both on the lower side. So, this corner. The conditions which prevail here in this corner that would lead to a dendritic microstructure.

And what are the different attributes of this microstructure and also some of the issues related to this kind of microstructure that also we have discussed.

Now, if you increase this under cooling or the temperature gradient, then we have seen that this dendritic microstructure will shift to an equiaxed microstructure which is here. An equiaxed microstructure is nothing, but it is internal structure of the material where the grains are more or less globular as we can see over here.

These are the grains. These you can see that these are more or less globular in shape and uniform in size or uniform in their growth as opposed to the dendritic structure which grows in a particular direction. But, in case of the equiaxed structure the growth is random in all direction and as a result these grains will grow uniformly in all directions leading to this kind of globular morphology.

Now, that we have been talking about these dendrites and they are shifting towards equiaxed. As it is also important to understand at this juncture as to why these dendrites form in the first place or what are those conditions during solidification that would lead to formation of dendrites in a metal while it is being solidified. That is what we are going to discuss in today's class as to how or why these dendrites form during solidification.

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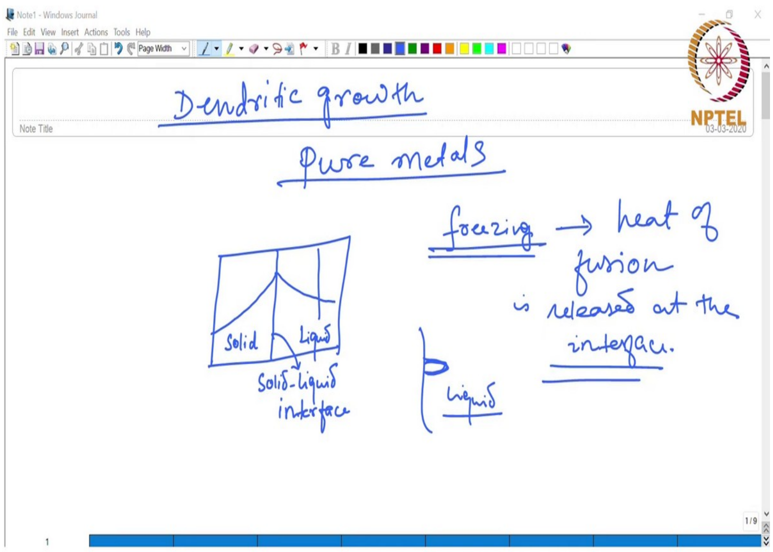


In order to understand this, we need to look at the temperature profile inside the liquid as it solidifies. That would give an idea about the prevailing conditions which are there during the solidification process and how that would affect the growth of the solid crystals. We will take the case of pure metals first the solidification of the pure metals and see what are those conditions which lead to dendritic growth.

Let us say the solid has formed from the liquid phase and therefore, you have this solid liquid interface (graph in the above image) and let us say right side of this interface is liquid and solid is growing on the left. Now, what happens when this solid is growing, that is freezing. That is the phenomena which is taking place.

This means that the heat of fusion is being released into the solid liquid interface. And as a consequence of this the temperature at the interface will be somewhat higher compared to a distance away from it either into the liquid or into the solid.

If you see the temperature profile as a function of distance from the interface either towards the liquid or towards the solid, it may look like this. Towards the solid anyway this is going to decrease as you increase the distance from the interface because that is the heat transfer direction.

But, in the liquid also you will notice that the temperature will decrease as you increase the distance from the interface. This is because of the fact I know that I said before that this heat of fusion is released into the interface and the liquid is actually under cooled or super cooled.

Considering these 2 aspects you can say that the liquid in front of the interface will be at a lower temperature compared to the interface. Due to this temperature profile the solidification behavior or how these interface would grow as more and more solid forms that will be influenced. Let us see how this temperature profile is going to affect that growth of the solid across this interface.

Now, that the temperature in the liquid head of the interface is lower compared to the temperature right at the interface. Any perturbations like this kind of growth if it develops here in the liquid since this part is cooler these kind of cells or these kind of perturbations will be will feel super cooled or will become stable because of the lower temperature in the liquid head of the interface. Now, let us say this solidification proceeds further.

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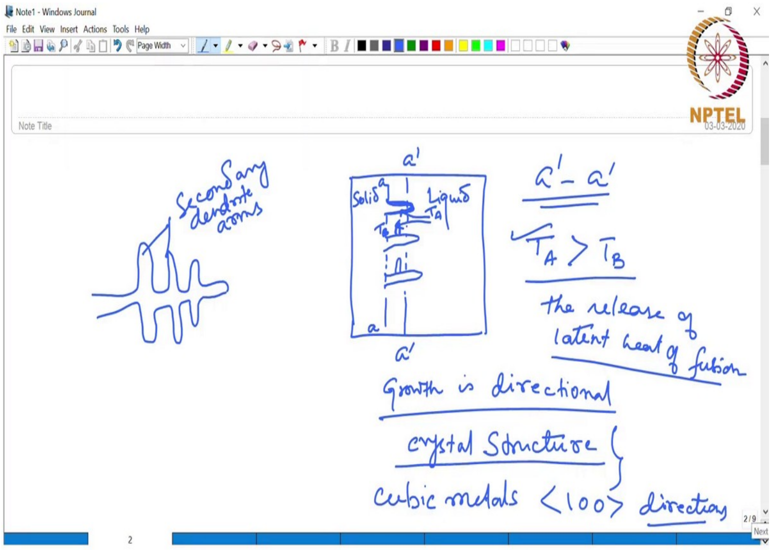


And more and more heat is removed and the solid is growing. And let us say this is the interface the solid liquid interface. Let us say at any location like this if a perturbation like this grows this will be in contact with liquid the surrounding liquid in contact with this perturbation is cooler and as I said as a result of that this will be stable this will not dissolve back again into the liquid.

And therefore, this will grow into the liquid and this might happen at regular intervals like this and this kind of branch will grow from this interface giving rise to that primary r of the dendrite.

You can see these growths of these dendrites is in a particular direction which depends on the crystal structure of the metal being solidified. The crystal structure of the metal would dictate in which direction this grows. For example, in cubic metals the direction would be the 1 0 0 crystallographic directions. Similarly, for other metals having different crystal structure the direction can be different.

Now, this is about the growth of the primary arm of the dendrite, but we have seen that the dendrite actually branches off and then you also have this secondary arms growing.

Now, we need to understand as to how these secondary arms grow from this primary branch that we have over here. In order to understand you have to again go back to the same fact that whenever the solid is forming the latent heat of freezing is being released.

Therefore, if you look at this section over here which is little away from this primary interface or the general interface let us say we call that as a and it's another section little away from it if we call that a'. Across this section if you see the temperature in between 2 consecutive branches of the cells; that means, the temperature over here and the temperature at the cell walls let us call that as $T_A$ and the temperature in between let us call that $T_B$.

$T_A$ is always going to be higher than $T_B$ because of the fact as I said the release of latent heat of fusion. This heat now is actually being released at this cell walls because this is now solidified.

And as a result of this heat being released on the walls that the temperature right takes to the walls will be higher compared to the temperature of a location which is away from the cell walls; that means, this temperature $T_B$. That is what I said $T_B$ will be lower than $T_A$.

So, as a result of that similar conditions will prevail which actually led to the growth of this primary r, but in the direction which is perpendicular to it. Now, because of the lower temperature adjacent to these cell walls these a secondary arm like that can grow from here or from these 2 here in the perpendicular direction.

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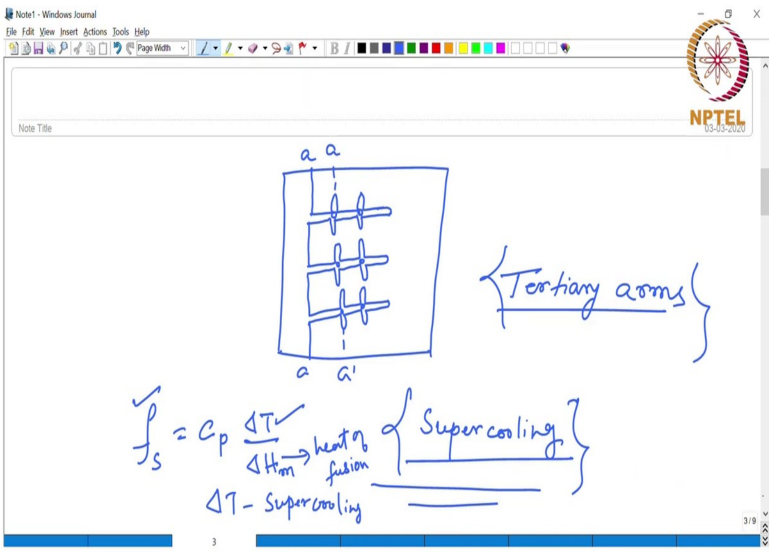

Now if we draw that separately (graph in the above image) like that across this a' section this secondary arms would grow and across this general interface which is a a the primary arms grow. So, like that you may also have the growth of the tertiary arms branching off from the secondary arms which will ultimately give rise to a structure that we have seen before in here.

Here you can also have more than one branches apart from the secondary branch sometimes in some of these dendrites you can also see a tertiary arm which can branch off from the secondary arms whenever those kind of conditions prevail which leads to a liquid head of the solid at a temperature lower than the temperature close to the solid or close to the solid liquid interface.

So, that is how the dendrites will grow as a result of this kind of temperature profile across the interface. The conditions that lead to dendritic growth that primarily depends on this super cooling of the liquid that is what we have seen whenever the liquid is super cooled; that means, the temperature of the liquid ahead of the interface is lower compared to that at the interface itself this kind of cells can grow and be stable in the liquid giving rise to a dendritic structure.

Therefore, it also means that for the dendritic growth to continue sufficient amount of super cooling is required in the liquid. So, in absence of large super cooling it is expected not to have complete dendritic growth because the driving force behind the growth of these cells or the dendrite itself is super cooling.

Unless otherwise the heat is continuously extracted from the liquid by external heat removal. Unless that is done this dendritic growth will not continue to completion because there will not be enough super cooling for the during the entire process.

And therefore, for the dendritic growth to complete totally and give rise to a complete dendritic structure an external heat removal is required. And the fraction of solid that can form when this is done when the heat is removed externally to the surrounding of this mold or this liquid metal which is being solidified. That is given by this particular relationship,

$$f_s = C_p \, (\Delta T / \Delta H_m)$$

where $f_s$ is the fraction of the solid that forms. $C_p$ is the specific heat of the solid $\Delta T$ is the super cooling and this $\Delta H$ is the heat of fusion.

From here again we can see that this $\Delta T$ and the solid the fraction of solid which forms they are directly proportional to each other and therefore, as I said a high amount of super cooling or continuous heat removal to the surrounding is needed for these dendrites to grow. Now, before we close today's class let us quickly summarize what we learned today. We primarily talked about the growth of dendrites in pure metals during solidification.

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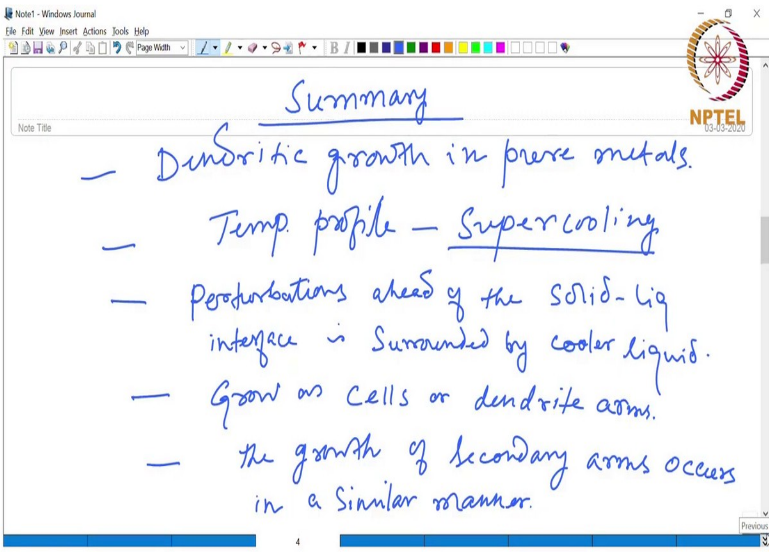


This happens due to the temperature profile which exist in the liquid giving rise to super cooling; that means, presence of liquid in front of the solid liquid interface at a temperature which is lower than the temperature of the interface.

When that kind of condition prevails any protrusions or any perturbations which grow on the interface will feel stabilized in the liquid and as a result of that they will grow as solids. That is how first the primary arm of the dendrite develops.

The perturbations as I said are in contact with the surrounding liquid which is at lower temperature and as a result this will feel stable and grow as cells or dendrite arms. Similarly, the growth of the secondary arms also takes place and this finally, leads to that dendritic structure what we have seen and finally, we have seen that for this kind of growth to continue.

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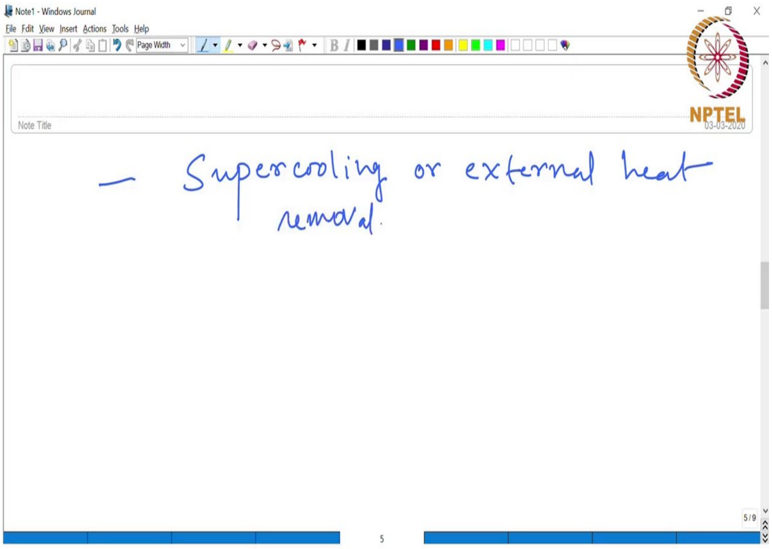


There should be enough super cooling in the liquid or external heat removal. With this we come to the end of this particular class. I am going to see you again soon for the next class.

Thank you.