Powder Metallurgy
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Lecture – 12
Microstructure Control

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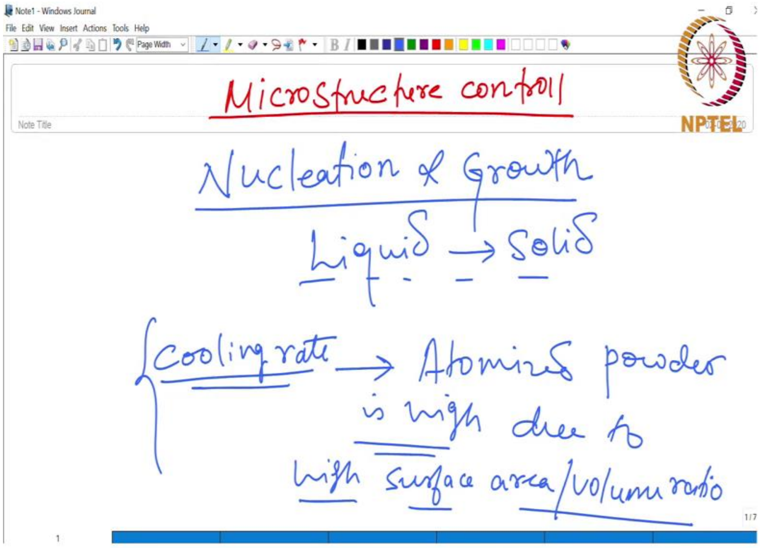

Microstructure controll

Nucleation & Growth

Liquid → Solid

Cooling rate → Atomized powder is high due to high surface area/volume ratio

Hello and welcome back again. In today's class, we are going to learn about this Microstructure Control in the atomization process.

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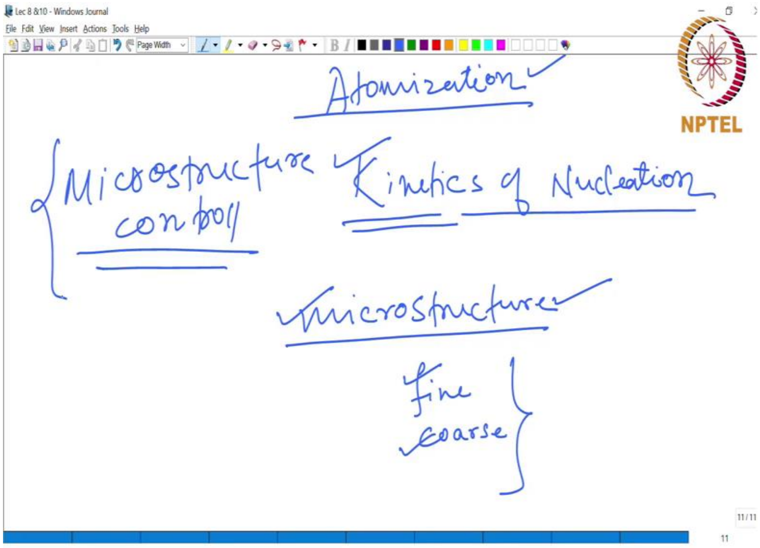

Atomization

Microstructure controll

Kinetics of Nucleation

microstructure

fine

coarse

But before we do that, it is good to look at what we have learned so far in terms of this nucleation and growth because that is what is the basis for the microstructure control, that you can exercise in case of the atomization process.

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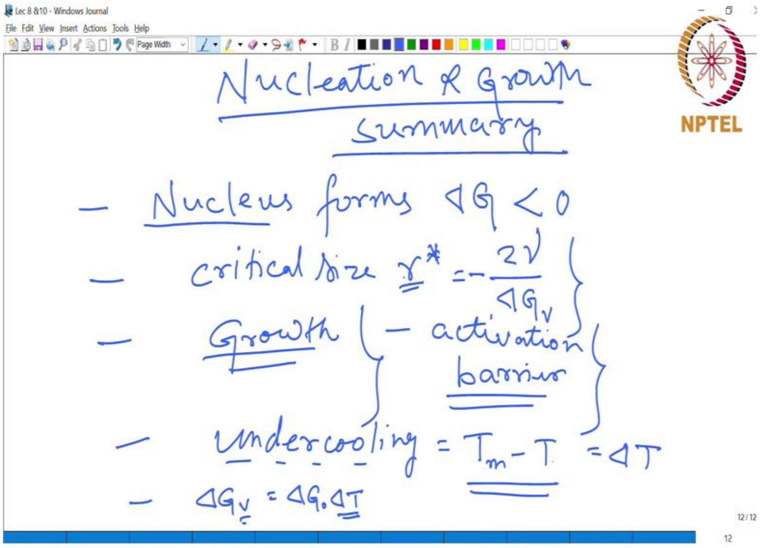

Nucleation & Growth
summary

— Nucleus forms $\Delta G < 0$
— critical size $r^* = -\frac{2\gamma}{\Delta G_V}$
— Growth (— activation barrier
— undercooling $= T_m - T = \Delta T$
— $\Delta G_V = \Delta G . \Delta T$

Let us go back and quickly summarize, here we have seen that the nucleus forms when the free energy change is negative.

Nucleus is nothing but the very first particle of the solid which forms from the liquid as the temperature is lowered below the melting point and for the nucleus to grow, it has to attain a critical size which is given by r*,

$$r^* = -(2\gamma/\Delta G_V)$$

Where gamma is the surface energy and ΔG_V is the volume free energy. Once it attains this critical size, the growth process will start, when the nucleus or the solid particles will grow to bigger size.

This growth process, to happen there is an activation barrier which has to be overcome this is because of the fact that the atoms have to move from the liquid and get attached to the solid.

So, for that attachment process, there is an activation barrier that has to be overcome for the solid to grow and that is why you need this under cooling when you cool the liquid below the melting point. You have that driving force to overcome this barrier and the solid will start to grow.

And we have also seen that this ΔG_V is a function of that under cooling. It is directly proportional to the under cooling and as a result of that when under cooling increases, ΔG_V would increase each in turn would decrease this critical size which is needed for the solid to grow which also means that the nucleation process becomes easier and as a result, when the under cooling increases the rate of nucleation would also increase.

And if you talk about the microstructure whether it is going to be a finer or a coarse kind of microstructure that is going to depend again on this nucleation rate, when the nucleation rate is higher the microstructure will be finer.

So, this is what we have for the nucleation and the growth process as it happens in atomization. Now if you look at this atomization process as such, one thing that you would have realized by now is that the cooling rate in the atomized powders; that means, the powders which are forming from the liquid in this process, the cooling rate in these powders is high because of their high surface area or due to the high surface area to volume ratio and this has a significant bearing on the size and microstructure of these powders.

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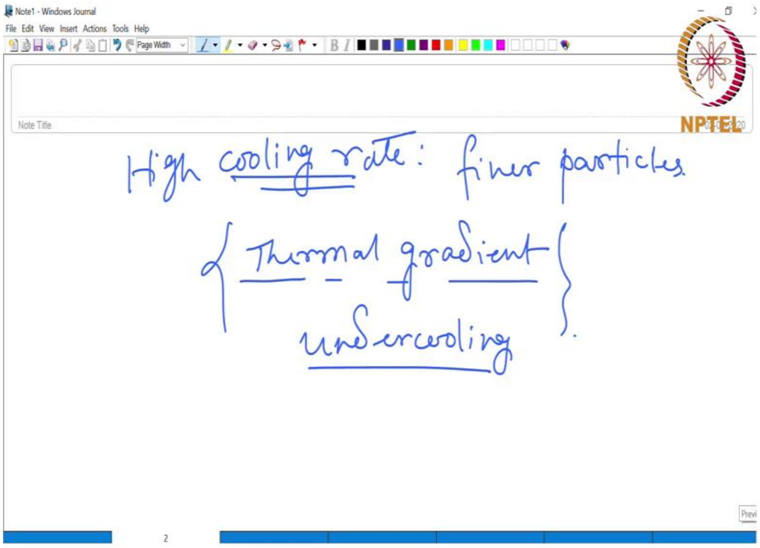

High cooling rate: finer particles

{Thermal gradient
undercooling}.

First of all, a high cooling rate will give rise to fine particles and this will also have a bearing on the thermal gradient in this solid particles which are forming from a liquid stream.

When the cooling rate is high that simply means that the surface of this powder particle is chilled, while the inner core is still much hotter. As a result of that from the surface to the core, there will be a huge thermal gradient that will be established when the cooling rate is increased. This thermal gradient is also a factor apart from the cooling rate and the under cooling which will affect the microstructure of these powder particles which are forming from the liquid stream. Now, in order to understand the microstructure control, the first thing that you need to understand as to what is that kind of microstructure that we are talking about.

And how it is affected by the following parameters i.e., the cooling rate, the under cooling, the thermal gradients and so on; If you talk about the cooling rate, as it its being one of the most significant parameters of controlling the microstructure of the powder.

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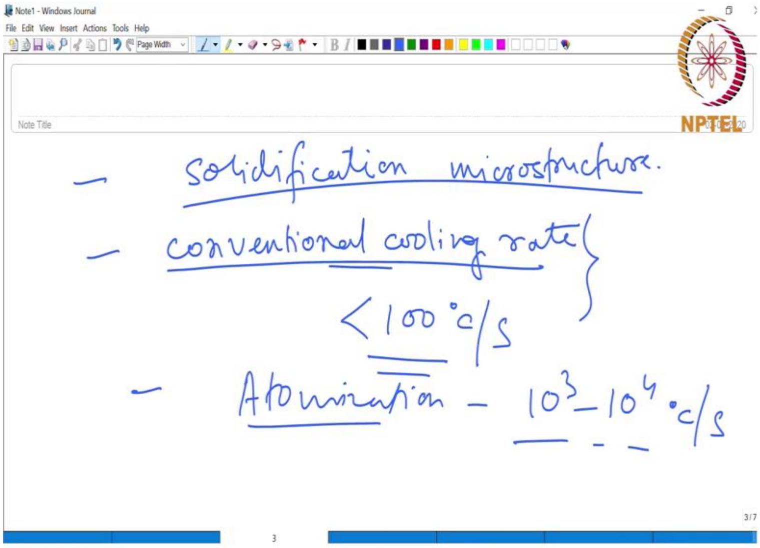

- solidification microstructure.
- conventional cooling rate
$< 100\ ^\circ c/s$
- Atomization – $10^3 – 10^4\ ^\circ c/s$

If you talk about that, in this process of solidification. The conventional cooling rates if you see like what do you see in normal melting and casting of metals, it is in the range of 100^O C per second or even lower.

In conventional melting and casting, the cooling rate is quite low; but in case of the atomization process because of the high surface area of the particles the cooling rate is in the range of 10^3 to 10^4 ^{O}C per second.

The order of magnitude higher in case of atomization compared to conventional melting and casting process. This is going to have a huge impact on the microstructure of the solid. Now, if you talk about the microstructure that this kind of conventional cooling rate will generate, then you need to look at those microstructural features, which will characterize this kind of microstructure.

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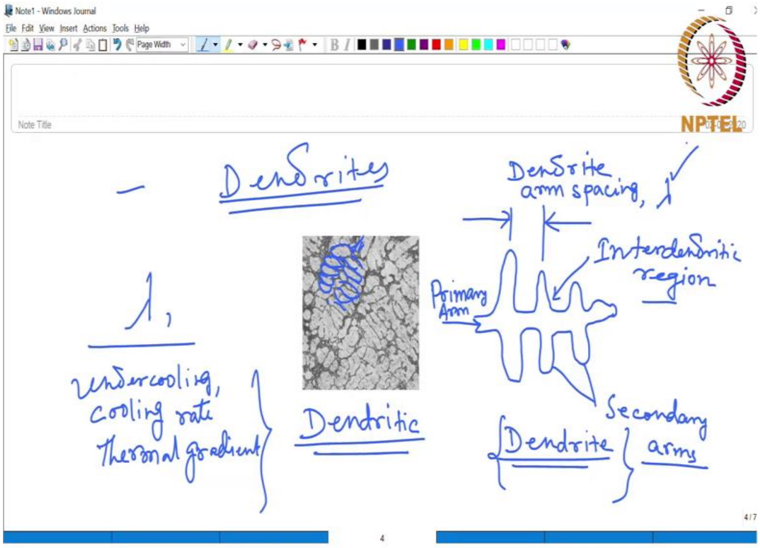

Now, in a conventional melting and casting after solidification, what you get in the microstructure is known as dendrites. What is a dendrite? From the above image it can be described more in detail.

This is an optical microscope image of a typical cast metal. You can see this kind of branches over here like this and this kind of structure. So, if you look from top to bottom, this side onwards looking down from the top, it looks more like this.

This structure is known as a dendrite and the origin of this term is from the Greek word dendrite which means a tree. So, if you look at this, it looks more like a pine tree, so that is how it is named as dendrite, because of its similarity with a particular tree.

There are certain features in this microstructure, the dendritic microstructure that are this central arm across which you have these branches grown that is known as the Primary arm of this dendrite is the main branch of this dendrite.

The branches which have come off from the primary arm, are known as the secondary arms and one parameter which can actually describe the size of this dendrite which is also used to describe the microstructure whether it is fine or coarse that is this dendrite arm spacing or the spacing between these secondary arms; spacing between two successive secondary arms.

This is generally written as lambda (λ). So, these are the parameters which will describe these dendrites and these features, or these parameters will also describe the microstructure of a solidified metal.

Now, in between these branches, you have this region which is between the dendrites and therefore, this region is known as inter dendritic region. Now, the picture of this dendrite is complete with all this labelling that you have for all these features of the dendrite. So, the size of the dendrites will be given by lambda and this lambda in turn is going to depend on all those parameters that we described before. i.e., the under cooling the cooling rate and the thermal gradient.

These parameters will have a significant influence on this structure of the dendrites or the size of this dendrite which is given in terms of this lambda. For example, if you correlate this lambda with the cooling rate, lambda in micrometre that is on this axis.

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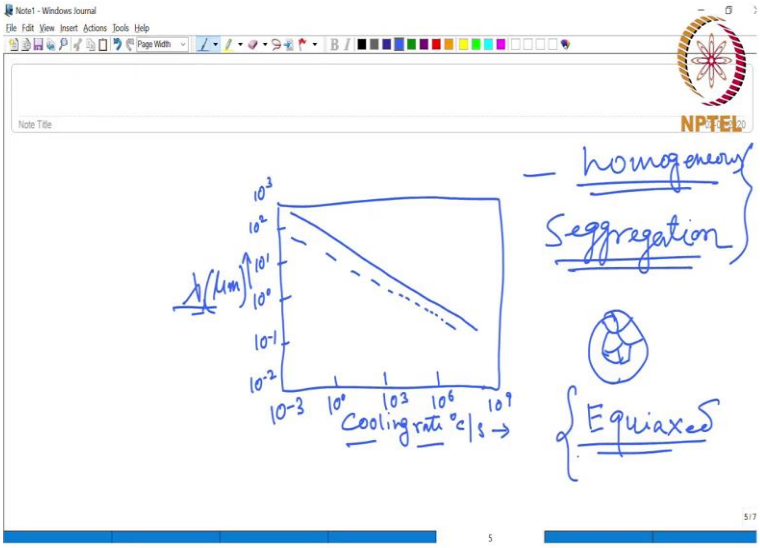

Let us say we are talking about cooling rates in the range from 10^{-3} to 10^{9} degree Celsius per second. As you decrease the cooling rate, this is going to decrease the dendrite arm spacing. So, as you increase the cooling rate, this will decrease linearly like this. So, for a different material, we will get a different line like this; but in any case, this is going to decrease with increasing cooling rate; the lambda is going to decrease with increasing cooling rate like this.

That is the first parameter that you can talk about or the first controllable parameter that you can tweak or you can control to control the microstructure to make it finer. So, if you can achieve a higher cooling rate, your dendrite arm spacing will reduce and ultimately, it will turn into a much finer microstructure which will also be more homogeneous. So, homogeneity is the other aspect of the microstructure that is also very important.

In case of this dendritic structure that you have what you can see over here, this inter dendritic region that you have that is the region which is going to solidify the last. And because of that, there will be a segregation of impurity and, the alloying elements if there are any alloying element in the material.

Those will be segregated in this last liquid to solidify right because what happens is in the liquid the solubility of any element whether it is an alloying element or if it is an impurity element, the solubility will be always higher in the liquid and it is lower in the solid.

Therefore, as the liquid is transforming into solid the solubility limit will also reduce and as a result, more and more of these dissolved elements will be rejected by the solidifying liquid. And therefore, all these rejected elements or the solutes will segregate in the last liquid to solidify; so, in the region which will solidify the last will have all these rejected solutes as the segregation. So, you can expect that the inter dendritic regions will have segregation.

And this is going to affect the homogeneity in terms of the chemistry of the material. Then if you talk about an alloy for example, in which you have another metal in a given amount. So, that particular amount is not going to remain the same, if you have segregation.

Therefore, the microstructure is also related to the homogeneity of the material. In this case, the powder which is forming and therefore, when you decrease this spacing; that means, this lambda the dendrite arm spacing, you can also expect the segregation to decrease right because as I said the segregation is mainly concentrated around these regions.

If these regions themselves shrink, then you can also expect the segregation to reduce. And as a result, as you make the dendrites finer and finer, you can expect the microstructure to be more homogeneous. So, controlling the microstructure has its advantages not only in terms of refining the material or the structure of the material, but also to make it more homogeneous.

Ideally, we want a microstructure, where all these dendrites can be eliminated and you can have a microstructure which is like more globular kind of structure; meaning you can have this kind of grains, where you do not see these dendrites rather the grains are in terms of this kind of globular structure.

So, this kind of microstructure, where these grains grow randomly in all directions without any preferential direction for growth is called equiaxed grains or equiaxed microstructure right. So, with that, I will conclude today’s class. I will see you again in the next class.

Thank you for your attention.