**Power Metallurgy**

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**Lecture - 18**
**T-T-T diagram: Formation of Amorphous solids**

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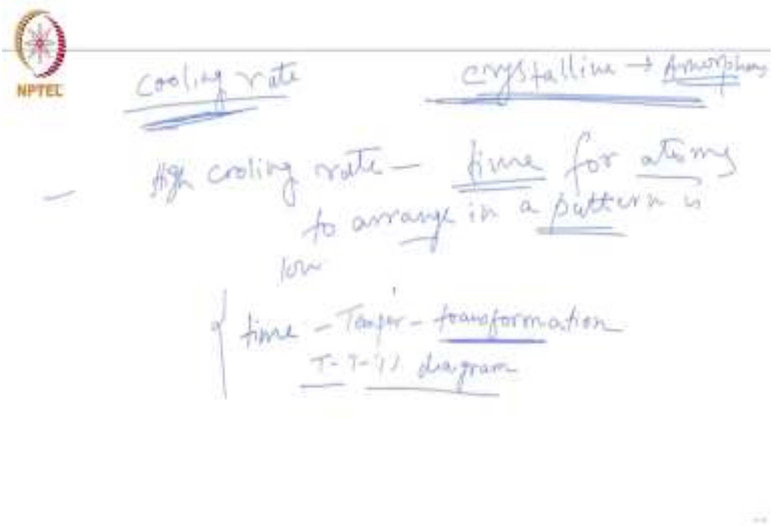


Hello and welcome back again. In the last class, we were discussing about this T-T-T diagram which stands for Time - Temperature - Transformation diagram.

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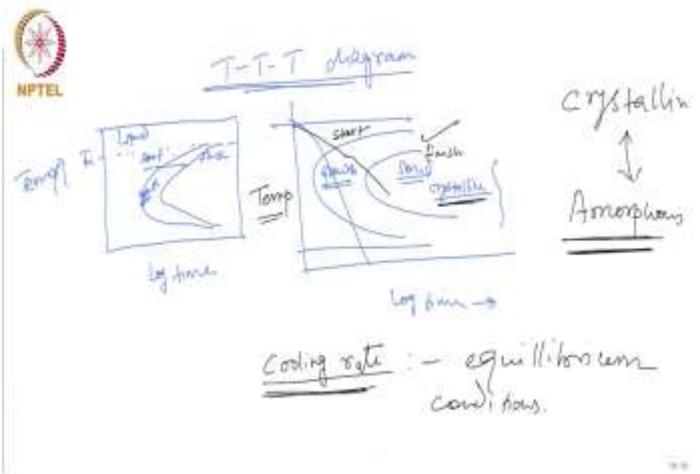

In order to understand this crystalline to amorphous transition during the solidification process in atomization. So, this T-T-T diagram as you can see from here is in the form of this kind of C curves like this as you can see over here. It shows 2 C curves; one for the start or the beginning of the transformation, and another is for the completion of the transformation.

So, in order to start any transformation, you have to enter this zone right; that means, the cooling rate has to be such that, it passes through this curve here to start it and then, to finish it, it has to pass through the finish curve as well like that.

So, those kind of cooling rate, where both of these C curves will be intercepted can only be obtained in equilibrium conditions. Like how you are generally encounter in case of the conventional casting process.

And therefore, if you have that kind of cooling rate which is sufficiently low or low enough to go through both of these curves that will lead to a crystalline solid at the end of the solidification process. Now, our point of discussion here was, how this crystalline structure can be changed to an amorphous structure at the end of the solidification process and what could be those conditions that can lead to this change.

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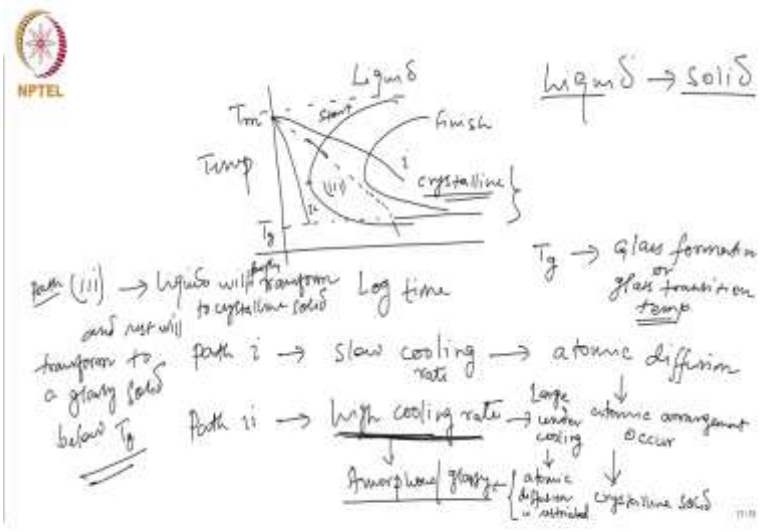


So, that again can be understood with the help of this T-T-T diagram. So, here the process is solidification; that means, we are talking about a transformation from the liquid to the solid phase. So, therefore, this temperature is the melting point. Now, once you cool below the melting point, then the solid will start forming as we have seen before right.

And, as it solidify through these two curves, a crystalline solid will form. So, in order to avoid the formation of this crystalline solid and make it amorphous, the cooling rate has to be such that, this nose is avoided right. That means, I am talking about a cooling rate like this; a steep cooling rate like that, where the nose of this C curve is not at all intercepted right.

So, if we have a cooling rate like that consequent undercooling would be so high that the atoms will not have enough time to arrange themselves into a particular pattern, and therefore, the solid which will form will be an amorphous solid.

So, if we call this as path **i** and this is path **ii** of cooling; then as we discussed, path **i** is a slow cooling path which allows enough time for the atomic diffusion to take place and atomic arrangement to occur leading to formation of a crystalline solid ok. On the other hand, as you can see path **ii** is a high cooling rate path. And, this also ensures that it does not intercept the nose of the C curve.

And as a result of this, the solid will be transformed into an amorphous or glassy solid, once it is cooled below this particular temperature which is known as glass formation temperature or glass transition temperature right.

High cooling rate generates large undercooling and as we have discussed before, this results in restricting the atomic diffusion and as a result, it solidifies into an amorphous or glasses structure rather than a crystalline structure, right. So, that is how based upon the cooling rate and the consequent undercooling, the solid can either take up a crystalline structure or an amorphous structure.

You can also have an intermediate cooling rate which is between path **i** and path **ii**. For example, like this which intersects the start curve, but does not intersect the finish curve as you can see here. So, let us call that as path **iii**, and for such a path which is intermediate between **i** and **ii**, the liquid will partly transform to a crystalline solid, because as I said it has actually crossed the start curve, right.

So, as it crosses the start curve, the crystalline solid will start to form. So, the first solids that form above this **Tg** temperature will be crystalline right. So, part of the liquid will transform to crystalline and as it goes below the **Tg** temperature; the rest will solidify as an amorphous material, right.

So, this is how the cooling rate or the different degrees of cooling rate will affect the final structure of the solid that forms from the liquid, it can be either crystalline, completely crystalline or completely amorphous depending on whether the cooling rate was slow enough or the cooling rate was very fast. And, when it is in between, under those intermediate conditions, it will be partly crystalline and partly amorphous in nature. So, it will be a mix of crystalline and glassy structure in the final solid that forms.

Now, the next question would be as to how this high cooling rate can be achieved. What can be done during the process to achieve a high cooling rate or a large under cooling, so that the crystalline solid does not form and it transforms to a glassy structure. So, a quest for that high cooling rate has actually given rise to a technology called Rapid Solidification Technology or Rapid Solidification Processing.

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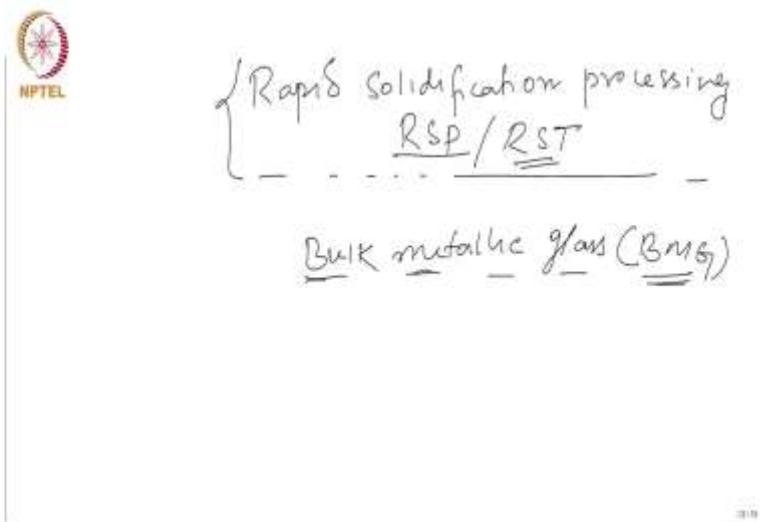


RSP or RST in short, which is a method of solidification that can generate very high cooling rate and lead to an amorphous solid. And, as I would have mentioned before, these amorphous metals can have very unique properties and when they can be made into large quantities or bulk quantities, these kind of metallic glasses are also known as bulk metallic glasses, which show some unique properties. BMG is the short form of Bulk Metallic Glasses. So, now let us see one of such rapid solidification process technique, which can generate this kind of metallic glasses.

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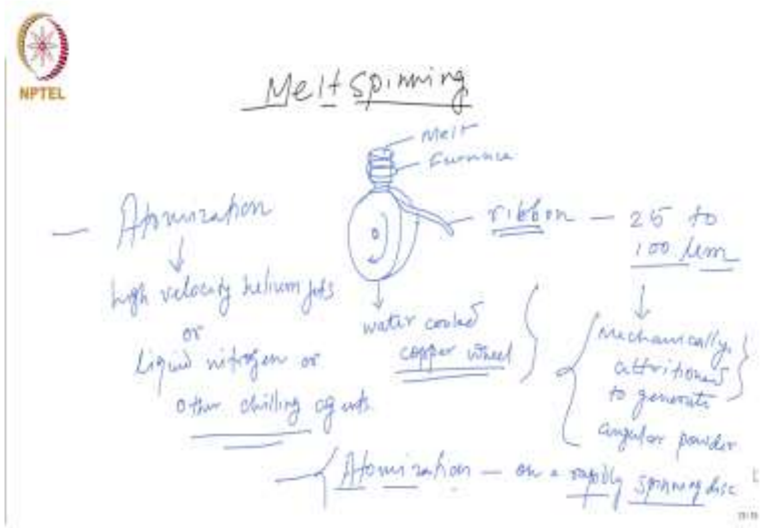


The technique goes by the name melt spinning, and it will be clear in a moment as to why the name is so. See, what is done here, the metal is first melted in a crucible and then, it is allowed to drop on a rapidly rotating wheel or disc, and as a result of that, it goes through a very rapid quenching, leading to a glassy material. So, the schematic of the setup, if you see it looks something like this.

This is the melt which is kept heated by these furnace coils and this is the water cooled copper wheel which is rotated at a very high rpm and as a result of that, when this melt falls on this rotating wheel, because of the chilling effect of this water cooled wheel, the melt almost solidifies immediately due to that quenching effect and due to that high very high cooling rate, it transforms into an amorphous structure.

So, once it is solidified on the wheel , it immediately gets thrown off due to the centrifugal force in the form of a thin ribbon, which has a thickness of 25 to 100 microns. And, since this is very thin, this can be easily broken down into smaller fragments to generate the powder. It can be mechanically attritioned to generate angular powder. It would be better, if the amorphous powder can be generated directly by atomization itself, instead of you know breaking it again into smaller fragments with the help of mechanical forces.

And in order to do that, the atomization process can include some means and measures to get that high cooling rate. For example, a very high cooling rate can be generated by high velocity helium jets or liquid nitrogen or by using some other chilling agents which can directly induce a very high cooling rate to the atomized droplets and make them solidify into a glassy structure. And, the other alternative would be to atomize on a rapidly spinning disc. So, this is similar to the melt spinning process that we discussed.

But in this case, it is the directly atomized droplets that are solidified on this spinning disc, which will provide that rapid quenching effect and lead to formation of a glassy or amorphous structure as the droplets solidify from the liquid state. So, that is the other alternative, wherein the amorphous powders can be directly generated by the atomization process in one step rather than going through more than one step like what we have seen in case of the melt spinning process, which involves a second step of mechanical attritioning to generate the powder from this thin ribbons which are generated by the process. So, this is a method which can be used to make amorphous metal powders in bulk quantities and therefore, you know this is also a process to make bulk metallic glasses, and with that, we come to the end of this my class today.

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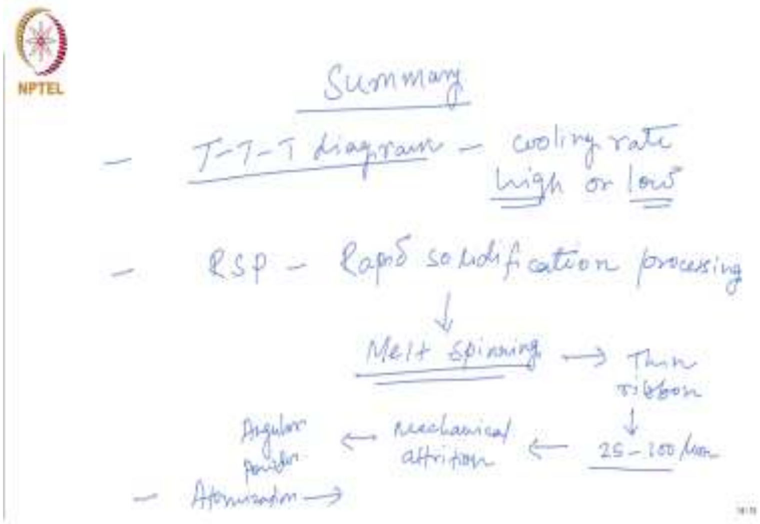

But, before we wind up, let us quickly summarize today's learning. Today, we have learned about this T-T-T diagram, to understand how the cooling rate will affect the final microstructure of the solid depending on whether we have a high cooling rate or a low cooling rate, we can have amorphous or a crystalline structure. And then, we discussed about a particular process or a particular technology called Rapid Solidification Processing or RSP in short which can generate amorphous metallic materials.

And, one such technique that we picked up was melt spinning in which the molten metal is allowed to drop on a rapidly rotating water cooled wheel made of copper and as the molten metal falls on this rotating wheel it provides a chilling affect and due to that it immediately solidifies in an amorphous solid which is thrown off from the wheel due to the centrifugal force in the form of a thin ribbon which is like 25 to 100 microns in thickness.

And, this can be easily broken down by mechanical attrition to generate angular powder. Then, we have also seen that the gas atomization process can be also modified to generate very high cooling rates and make amorphous powders and that can be done in two ways like how we have discussed today; one is through using some chilling agents like liquid nitrogen or other solid chilling agents or using a high velocity helium gas jet and the other alternative is to you know atomize this metal onto a rapidly rotating disc which provides the quenching affect leading to formation of amorphous powders.

So, with this, we come to the end of this class. I will see you again soon for the future classes. Till then, good bye.