Powder Metallurgy
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Lecture - 02
Powder Fabrication Methods: Mechanical Fabrication

Hello everyone, and welcome back to this lecture series on Powder Metallurgy. This is the second class of this course. In the first one, we have seen the introduction of the powder metallurgy process. And while talking about the powder metallurgy process what we have seen is that the starting material is the powder. And then you take the powder to process it through a certain number of steps to finally get to the product which you want.

Hence, the powder has a lot of influence on this process, we need to first see how the powder is fabricated, because the fabrication process will actually influence what is that type of powder in terms of many of its characteristics and properties. So, today in this class we are going to see how powders are fabricated, we will be mostly dealing with metal powders here.

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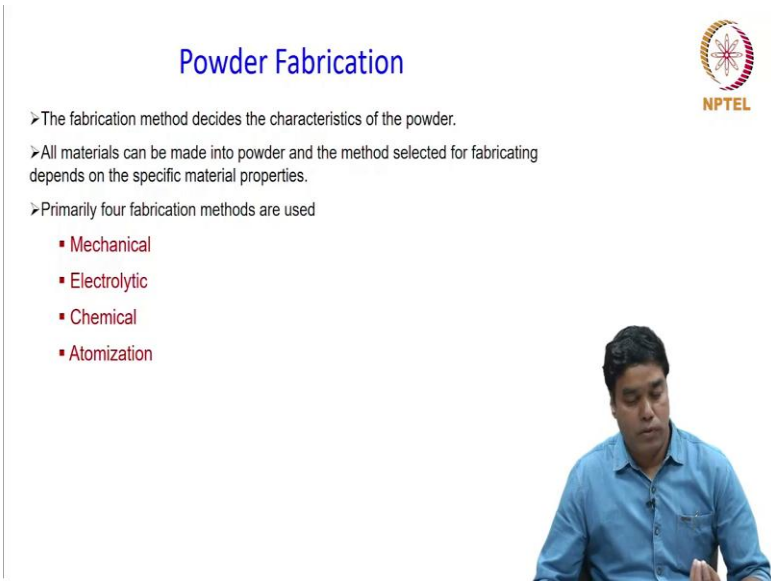

To start with we will see how metal powders are processed and manufactured. Talking about powder fabrication there are several fabrication methods which are available. And as you know the fabrication method will actually decide the characteristics of the powder, so that is why it is necessary for us to actually understand each of these fabrication processes, and see how they are done, and what kind of powders are obtained when you use a particular type of fabrication process.

One thing that we also know is that any material can be made into powder. And the method selected for fabricating depends on the specific material properties that you want. So, you can start with any material that you want, and then you can make powders out of it, and finally, you process the powders and get the desired product that you wanted.

So, as far as the powder fabrication methods of powder fabrication processes are concerned, there are primarily four types of processing methods which are categorized in these four different categories as you can see over here (diagram in first page/above diagram). Namely, these are mechanical, electrolytic, chemical, and atomization. So, we are going to take each of these individually one by one and discuss about them in more detail.

And you will also see in some of these categories there are several other processes, different types of processes that can be grouped into one particular type of fabrication method. So, all these we are going to discuss in detail in today's class. So, let us start with the first one which is the mechanical method of powder fabrication.

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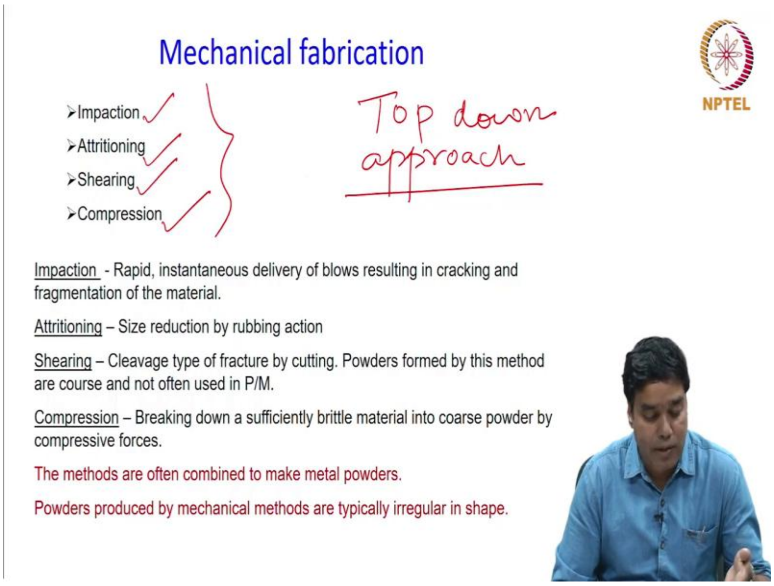

Mechanical fabrication or mechanical method of fabrication means you apply a mechanical force. And with the help of that mechanical force, you make small fragments from a material and make a powder out of it. So, this mechanical force can be applied by different means and ways.

As far as powder processing is concerned, there are primarily 4 methods by which you can apply this mechanical force and these are as follows impaction, attritioning, shearing, and compression. So, primarily these are four types of mechanical actions which are used to make metal powders.

Impaction is nothing but rapid, instantaneous delivery of blows resulting in cracking and fragmentation of the material. So, mechanical fabrication is known as a top down approach, which means you start with a bigger size material and break it down to smaller and smaller fragments till you get the powder.

For example, in case of impaction you apply these rapid blows or impact the material rapidly, so that it fragments and you keep on fragmenting it into smaller and smaller pieces, and finally you obtain the powder. Similarly, in attritioning, instead of impacting you use rubbing action. So, here the size reduction is by rubbing action.

So, you apply something on to a bigger chunk of material, you apply this mechanical force with the help some kind of impellers inside a container, and subject this material to high amount of deformation with the help of those impellers. And when the material rub against these impellers or against each other, they fragment into smaller pieces that is what is called attritioning.

And then you can also subject the material to shearing which is cleavage type of fracture by cutting. And in this case the powders formed are coarse and not often used in powder metallurgy. The powder which is made by shearing are quite coarse due to the cutting kind of mechanism, and that is why they may not be very useful in powder metallurgy processing.

Because in powder metallurgy processing what you need is a good packing characteristic, so that the powder particles can pack together and give you a compact which can be easily shaped and processed. In case, if these particles are very coarse or are very rough, then the packing characteristics are not very good.

Then comes compression which is nothing but breaking down a sufficiently brittle material into coarse powder by compressive forces. So, here as the name itself suggests you apply compressive forces on a material and break it down to smaller and smaller fragments.

And, while you want to achieve a particular type of powder often these methods are combined, so that you can get a particular type of powder or you can achieve certain properties in the powder. And the powders which are fabricated by mechanical methods are typically irregular in shape, that is the typical characteristics of powers which are made by this mechanical fabrication tool.

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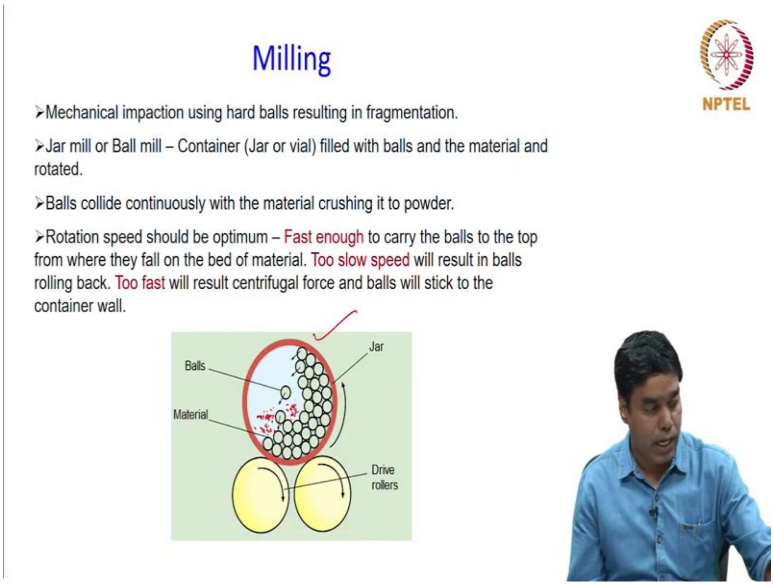

Now, if you go into details as to how this each of this method works. For example, if you talk about the impaction – the first type of mechanical method that we talked about. In this method, you have to impact the material rapidly with some force, so that it breaks down.

For example, in case of milling, you can impact the starting material which is much larger or much coarser in size with hard balls or hard metal balls. Hard balls made of any other materials which are very hard. So, with the help of those balls, you can impact the material and you can fragment it.

So, in order to do that you actually need a container in which you can fill these balls and the material together, and then you apply some kind of mechanical action, for example, rotation or some other movement, so that these balls can collide with the material and fragment it. So, in case of jar mill or ball mill, for example, you use a jar as a container which is also known as a vial and fill this container with the ball and material in a certain weight ratio.

For example, in case of ball mill as you could see in this image over here (above diagram), this is the schematic of the container in which you have these balls. And here you also will have the material along with the balls. Let say this is the material, which you want to fragment down into a powder.

If you rotate this container now at a given speed at a given rpm, then these balls will go up. And then as they reach the top they will fall again and crush against the powder or the material into smaller fragments or into powders. So, if the process continues the balls will collide continuously with the material and crush it into powder.

One thing that you need to make sure here is that the rotation speed which is used should be optimum. Because, if the speed is not fast enough to carry the balls to the top from where they fall on to the bed of material, then that whole purpose of the balls you know going up and then falling down on the material will not be served if it is too slow.

So, it should be fast enough, so that the balls can reach all the way to the top; and from there they can fall on the bed of material. Likewise, it should not be too slow also. Because if the speed is too slow that will result in balls rolling back and not really going to the top and falling on the material.

And if you are too fast on the other extreme, then it will result in centrifugal force and the balls will simply stick to the wall of the containers because of the centrifugal force. So, it should not be too fast, also it should not be too slow. It should be just fast enough so that the balls can be carried to the top and from there they should fall again instead of sticking to the wall of the container.

So, you need to optimize this rotation speed when you use this ball milling process.

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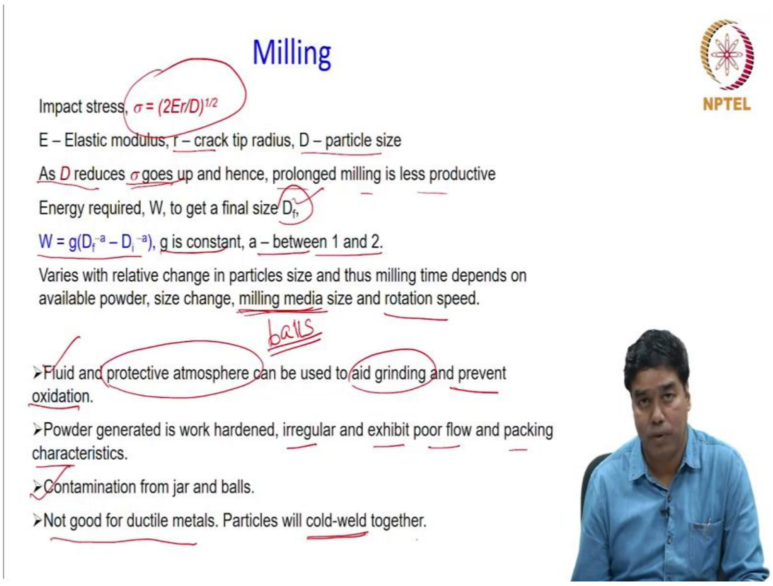

This is one type of mechanical action which can be used to make metal powders. And as far as the process parameters go, you can see here the impact stress (σ) is given by this equation over here.

$$\sigma = \left(\frac{2Er}{D}\right)^{\frac{1}{2}}$$

Wherein E is the elastic modulus of the material which is being processed; when the balls impact the material, it is going to crack. So, r is that crack tip radius. And D is the particle size which you achieve by breaking this material into smaller fragments.

So, from here one thing that you can notice is as D reduces, sigma goes up. So, that means, if you fragmented more and more and make the particle size smaller and smaller, then the stress required to break it down further will also increase significantly. And that is why prolong milling is less productive, since the stress requirement will significantly increase as the particle size goes down.

The energy (W) required in this process is given by the below equation.

$$W = g\left(D_f^{-a} - D_i^{-a}\right)$$

The energy (W) depends on the final size D_f of the material, g is a constant, and a is a constant which is in between 1 and 2. And this again varies with relative change in particle size, and thus the milling time will depend on the available powder, the size change, the milling media size and the rotation speed.

Milling media size is nothing but the size of the balls that you use. So, milling media means in case of ball milling are those balls which are used to impact the material, so that it can be fragmented. So, how this energy input will be that also depends on the size of the ball apart from the other parameters like the rotation speed, milling time and so on.

Also, in the case of the ball milling process at times if needed fluid and protective atmosphere can be also used to aid the grinding process, mainly to prevent the oxidation. So, if you have metal which is prone to oxidation, it should be also able to use a protective atmosphere, so that the oxidation can be prevented. And sometime a fluid or a liquid can also be used to aid the grinding process.

In that case what we call that milling process as wet milling where you have a liquid medium aiding the grinding process or this ball milling process. So, fluid or liquid can also be used to make it more effective. And the powder generated is work hardened because it is continuously impacted by those hard balls. And these powders are irregular in shape and they exhibit poor flow and packing characteristics.

The other issue with this process is the contamination that comes from the jars and the balls, because most of the time the jar and the balls are made of a different material than the processing material, because these balls and the jar also have to be very hard. So, more often they are not they are made from a different material which are very hard. So, there are chances that you know some contamination may come from the jar and from the ball into the material which is being processed.

And, the other limitation is that this process is not good for ductile metals, because what happens in case of ductile metals is that when you impact it with the balls instead of fragmenting because of their ductility, they will weld together which is known as the cold welding. So, instead of reducing in size, they will grow in size by welding together, that is why for ductile metal this process is not that effective because of this problem of cold welding.

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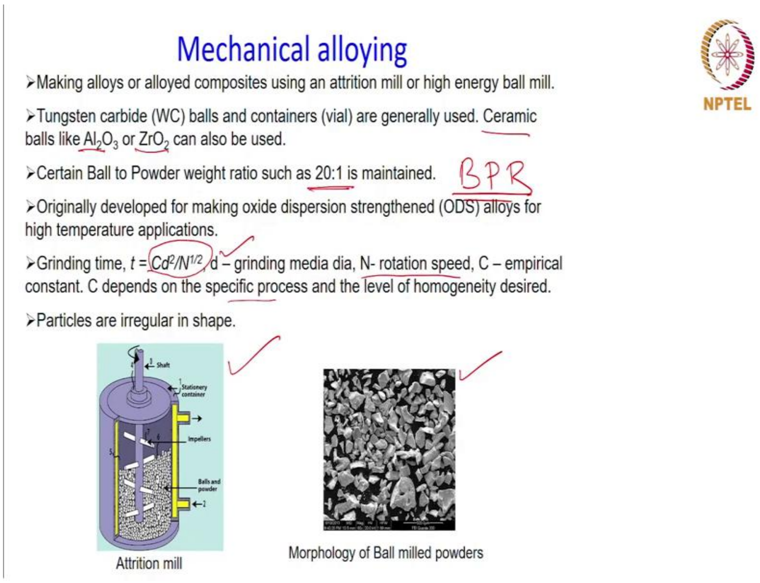

But one of the advantages that you have in this process of ball milling is that you can combine different materials, and you can make an alloy, or you can also make composites. If you are not making alloy and you simply want to combine two or three different materials, then we can combine them into a composite material.

Of course, in that case, you will have to use a high energy ball mill so that the energy input is high; because in that case you are actually trying to add a second material into the main material that you have. So, your energy input should be higher in that case.

And to input higher energy, you will have to use hard balls like tungsten carbide balls and also a container which are made of the same material. And, apart from that other hard materials like the ceramic materials such as alumina and zirconia can also be used as the milling media.

And in this case as I would have mentioned before also a certain ball to powder weight ratio has to be mentioned. For example, a 20 is to 1 weight ratio that means your weight of the balls is 20 times more than the material that is being used. So, that kind of ball to powder ratio which is in short known as BPR is used. So, that would depend on what kind of material you have. This BPR may vary from material to material.

And this process of alloying or mechanical alloying as it is called because you are using a mechanical force here to make the alloy. This mechanical alloying process was originally developed for making a particular type of material known as oxide dispersion, strengthened alloys in which you add fine particles and disperse them in a material to make it stronger. So, originally although it was developed for these ODS alloys, but now this process can also be used to make other type of materials including different types of alloys.

Grinding time or milling time (t) is a parameter which is depends on certain other parameters which are given here in this equation.

$$t = Cd^2/N^{1/2}$$

Wherein d is the size of the grinding media that means the size of the balls or the diameters of the balls; N is the rotation speed which is being used; and C is an empirical constant which depends on the specific process and the level of homogeneity which is desired.

And, in this process the powder particles which are obtained are generally irregular in shape which you can see from this scanning electron microscope image (above image) the powder particles are irregular.

The second mechanical method that we talked is attritioning. If you remember we had talked about that also before that is another method of applying the mechanical force. So, here what do you do? You use these impellers as you can see over here (above image - cylindrical one). And with the help of this impeller, you break down this material into powder. So, you have there are different parts in this attrition mill as you can see from this figure.

Here you have this shaft over here. And if you look at inside this jar which contains the material, in this shaft you have these impellers attached to it at different angles. And then you rotate the shaft, so these impellers will also rotate and they will impact or they will rub against this material, and break it down into smaller fragments, and give raise to a powder material.

And, along with this material, you can also mix hard balls, so that these balls can also be used to impact the material and break them down. And these impellers will help them in providing that agitation and the mechanical rotation or the mechanical movement. So, these balls can collide against the material and break it down into powder.

So, this is the process of attritioning which is done in this kind of attrition mill which basically has this container in which you have these mechanical impellers. And you load the balls and the powders again in a particular weight ratio, and then you start rotating the shaft which will rotate these impellers at high speed inside the jar. And with the help of that impact, you can break down the material. So, this is the process of attritioning.

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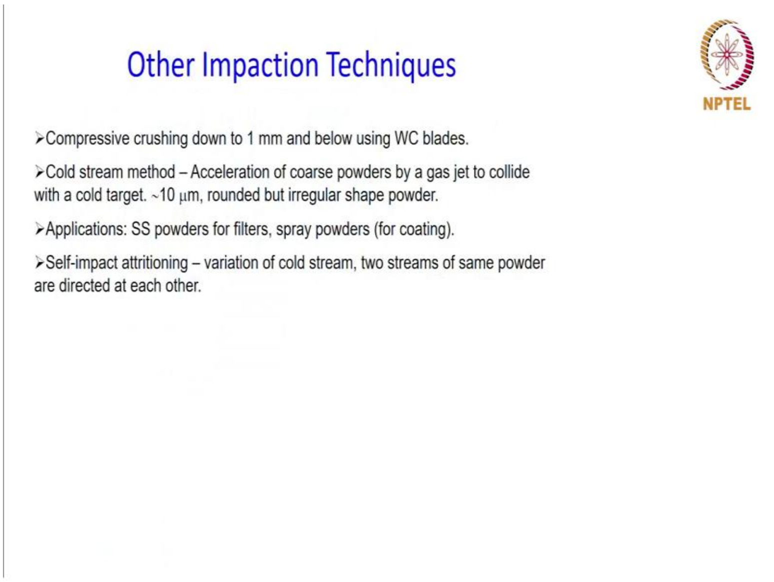

And the other impaction techniques which can be used are as follows. Compressive crushing is down to 1 millimeter and below using tungsten carbide blades. So, you can use a hard surface like this tungsten carbide blades, can apply compressive force to break down the material. Then there is a process called cold stream method which is acceleration of coarse powder by a gas jet to collide with a cold target. And in this case, you can achieve powders of size around 10 micrometers, and these powders rounded, but irregular in shape.

Application of this cold stream method is for making stainless steel powders for filters and spray powders for coating. And there is a variation in this cold stream method which is known as self-impact attritioning. In case of cold streaming, what is done these powders are made to collide against a cold target, but they can be also made to collide against each other.

So, in that case, it is known as a self impact attritioning where two streams of same powder are directed at each other with the high velocity. And when they collide at high forces or at high velocity, they fragment each other because of this collision. So, these are different methods of mechanical fabrication of metal powders. And with that we have come to the end of this class.

Thank you for your attention.