Powder Metallurgy
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Lecture - 34
Powder compaction – 1

Hi everyone and welcome back to yet another lecture of this series. So, the main objective of the powder metallurgy process is to consolidate and densify the powder following a certain number of processing steps. So, once the powder is processed, the steps which are followed are essentially meant for densifying the powder. And the densification process basically starts with shaping the powder into a particular form by different techniques, alright.

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So, in this class we are going to discuss about shaping and compaction of powders.

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Now, as I would have mentioned before also powder metallurgy is all about shaping a loose mass of powder into a final product and the main requirement in most of the applications of powder metallurgy is to achieve a high density in the final product.

The powder densification can be achieved by the following processes, sintering a low density preform. So, in this case what is done is the powder is first compacted to give it a particular shape; so, that is what is the preform. This preform will have lower density and therefore, it has to be sintered by heating it to a particular temperature and holding at that temperature for a certain period of time to close the pores and get a densified product at the end of the process.

The second method is pressing to high density followed by sintering. So, in this case the compaction which is done we will give rise to a higher density compared to the first process and whatever porosity is left behind, that will be closed by sintering that will follow the compaction process. And then the pressure and the heat can be also applied simultaneously to densify the powder.

So, in the previous two cases what is done is first it is compacted by applying a pressure and then whatever porosity is left behind in the green compact as we call it is closed by sintering process, but in this case the pressure and the heat are applied simultaneously, right. So, the equipment which is used for that should have the provision of heating the powder and also pressurizing it simultaneously to densify it.

Powders that exhibit good sintering ability can be shaped by low pressure techniques, on the other hand many powders need to be pressed at high pressure to achieve densification. So, this will depend on the properties of the powder, particularly the hardness and the strength for the lower strength materials, the powder can be easily shaped by low pressure. On the other hand, if the strength is high, then the pressure applied should also be higher.

And the means of delivering the pressure , the pressurization rate and the mechanical constraints are the main process parameters in the process of shaping the powder and there are several methods available to shape and form the powder and a particular method is selected based on the requirements in the final product. So, let us see, what kind of methods are available and what factors are taken into consideration to select a particular shaping process?

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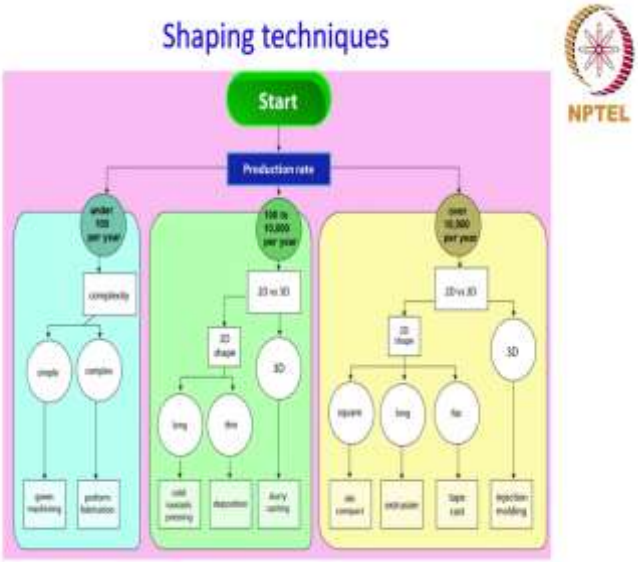

So, this is a diagram which shows the same. So, here you can see that the choice of a particular shaping process primarily depends on two factors, one is the production rate and another is the shape of the product and its complexity.

If the production rate is under 100 per year, then depending on the complexity of the shape a particular shaping process can be chosen. If the product shape is simple, then a green machining can be chosen to shape it and on the other hand, if the shape is complex, then preform fabrication will be needed.

And for production rate in the range of 100 to 10,000 per year, the choice of a particular shaping process will depend on the shape of the product and here you primarily have to look at whether it is 2D or 3D.

For the 2D shapes depending on what kind of products you are talking about. For example, whether you are talking about a long product or a thin kind of product a particular process can be selected. For a 2D long product, cold isostatic pressing for example, can be chosen and for 2D thin products, deposition processes can be chosen. On the other hand, if it has to be a 3D kind of shape, then the slurry casting process has to be chosen.

So, these processes we are going to take up separately and discuss about them in more details. Now, when it comes to high production rate over 10,000 per year, then again depending on whether it is 2D or 3D and the complexity of the shape a particular shaping process can be selected.

For example, for the 2D shapes, you can have this kind of product shapes, square long product or flat product. For the square shape a die compaction process can be chosen to shape it. For long products, extrusion is the process that is to be used and if it is a flat product, then tape casting has to be used. And for 3D shapes in this category, injection molding is the process which needs to be used.

So, these are the different processing methods which are available to shape the powder, depending on the production rate and complexity of the shape. So, as I said we are going to discuss about all these in more detail.

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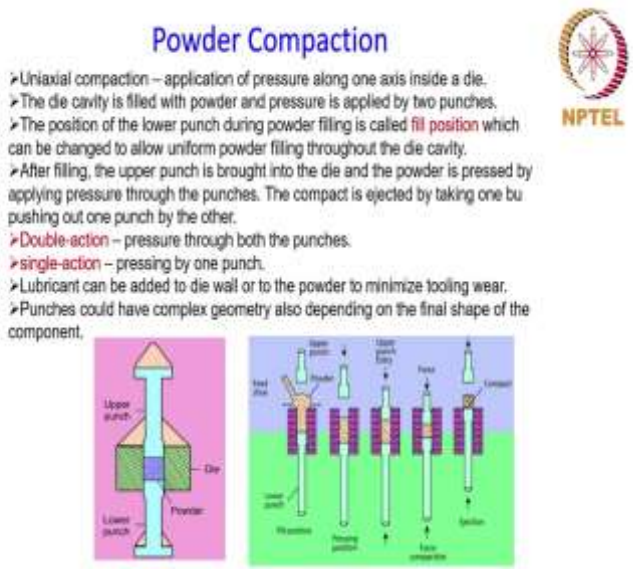

So, first we are going to start with powder compaction. Conventionally, powders are pressed by uniaxial pressing or uniaxial compaction, which is basically application of pressure along one axis inside a die. So, what is done here is that, there is a die and the die cavity is filled with the powder and pressure is applied by two punches, ok.

So, here is a schematic of the die and the punches. This is the die, the middle part that you see over here, in which the powder is filled. And then you have two punches, one the upper punch and the other one is the lower punch, ok. So, with the movement of these two punches, the pressure is applied on the powder, which is here in the die cavity and it is compacted to give it a shape.

And this is the sequence of events which happened during the compaction process. The position of the lower punch during powder filling is called the fill position, which can be changed to allow uniform powder filling throughout the die cavity. So, this is what you can see over here, this is the position of the lower punch, the fill position where the powder is being filled into the die cavity.

Now, after the powder is filled into the die cavity, the upper punch is brought into the die and the powder is pressed by applying pressure through the punches. So, here is the next set of events after the powder is filled. So, this is the upper punch and this is brought into the die cavity to press it as I said and once the upper punch is in contact with the powder, the pressure is applied uniaxially through these punches.

So, when you apply a force either through one punch or through both the punches, the powder which is in between will be pressurized and it will be compacted. And at the end of the compaction, the compact is ejected by pushing out one punch by the other .

So, for example, here you can see the ejection is done by pushing the upper punch by the lower one and the compact is ejected from the upper end. Similarly, if the lower punch is pushed by the upper punch, then the compact can be ejected from the lower side also.

Now, as far as the application of the pressure is concerned, there are two ways in which it can be applied. The pressure can be applied through both the punches and in that case it is known as the double action process and when it is applied by only one punch, then it is known as single action process. So, the name itself suggests whether it is through two punches or whether it is through a single punch.

And in order to avoid the die wall wear and tear and improve the life of the die, a lubricant is used and the powder lubrication process we have already discussed before while talking about the preparation of the powder feed for the shaping process.

So, when the powder is lubricated it will minimize the tooling wear; that means, it will minimize the wear and tear of the die and the punches as I said. And depending on the final shape, which is required in the component, the punches could also have complex geometry.

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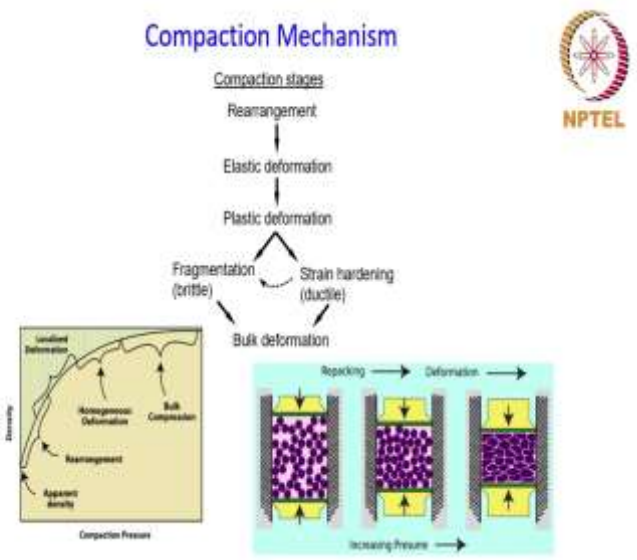

So, now let us see the compaction mechanism as to how it actually happens, when the pressure is applied into the powder. It basically happens in three stages as you apply the pressure. First in the beginning the powder particles will rearrange themselves. So, that is the rearrangement process. And as the pressure is increased, the powder particles will start to deform.

So, at lower pressure, the deformation will be elastic and as the pressure is increased further, the powder particles will eventually deform plastically and when that happens, when the plastic deformation begins, then depending on the nature of the powder, it can either go through fragmentation or strain hardening.

Fragmentation will happen for powders of brittle nature and on the other hand, strain hardening will happen for ductile powders, which can accommodate the plastic deformation. And after this, once the plastic deformation has begun, the bulk deformation process that is the deformation across the entire compact will start and the powder will start to densify to give it a particular shape and density at the end of the process.

So, this is a pictorial of the same thing, the same phenomena which is being described over here. So, here you see as the powder particles are filled and then the pressure is applied, they repack and rearrange themselves and once this rearrangement happens, the deformation process will start, when the powder particles will start to deform and make contact with each other and the pores in between them, will start to collapse and the powder will start to densify.

So, that is what you can see in this particular pictorial over here. So, here in this direction the pressure is increasing and with increased pressure the different kind of phenomena that we have described here, you can see in terms of this kind of schematic.

And this plot that you have over here, they shows a relationship between the compaction pressure and the density which can be achieved in the compact and here again you can see depending on this different kind of phenomena, that happens at different presses. How the density is changed? That can be seen from this particular plot.

So, in the beginning when there is no pressure, this is just the apparent density and we have already discussed this as to what is the apparent density? And how you measure it?

Apparent density as you would have already known by now is the density which is the density of loose mass of powder without any vibration or any application of external pressure. So, that is what you get in the beginning when the powder is just filled in the die.

And then as it is being pressurized as the pressure is applied gradually, these different processes will occur. First the rearrangement at low pressure and then as the pressure is increased it will go through the elastic and the plastic deformation processes.

So, in the beginning the deformation will be primarily in the contact points of the powder particles. So, they will start to deform and the force in between them will start to close.

So, that is the homogeneous deformation process as it is called and once this deformation process has ceased, then the bulk deformation will start, that is when all the powder particles have made contact with each other, then the entire compact will start to deform as the pressure is increased. So, that is the bulk deformation or the bulk compression that happens at high pressure during the end of the compaction process.

So, that is what you can see, probably from this schematic here, that here you know all the particles have made contact with each other and the pores between them are kind of filled now and now it has taken a shape and now if you apply a pressure on this, the entire compact is going to deform. So, that is the bulk deformation or the bulk compression process. So, these are the stages of the compaction process.

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Now, going into little more detail into the compaction mechanism, let us see what happens during each of this phenomena that we described in the previous slide. With the application of pressure, the powder goes through the following stages and the following phenomena as we have seen in the previous slide also.

First the rearrangement of particles, this is basically filling of large pores giving higher coordination number. Coordination number is nothing but, the number of particles that a particular particle is in contact with. Smooth hard particles have better rearrangement and the coordination number Nc is given by this particular relationship that you see over here.

$$\mathbf{Nc = 14\text{-}10.4\ \varepsilon^{0.38}}$$

Increasing the pressure leads to better packing, that is obvious as you apply more pressure, the particles pack together and the pores in between them will decrease and as a result of that, the porosity will decrease and it will also create new particle contacts.

So, that is how the whole rearrangement process occurs. Now, once the rearrangement is happened, then as you apply the pressure the deformation process will start. And this will primarily first start in the contact points, which will undergo elastic deformation. As the pressure is increased at high pressure plastic deformation will occur. And the gap

between particles will collapse allowing new contacts to form and hence the density will increase.

The interparticle contact zones become flattened with a circular profile as you apply more pressure. And the green density is related to the diameter of this circular profile by this particular equation, that you see over here.

$$R=D\left[1-\left(\rho_0-\rho\right)^{2/3}\right]^{1/2}$$

Where D is the particle diameter, ρ_0 is the initial density when R was equal to 0.

So, green density is one parameter which will have lot of bearing on the following processes, which are carried out after the compaction process, because this is the density which decides how much porosity is left behind and accordingly the rest of the densification will depend on the green density.

The next stage as we have seen is the fragmentation and bulk deformation. Metal powders when they go through plastic deformation process will work harden, particularly at high pressure in the range of 50 to 100 mega Pascal. And densification at this stage will occur by fragmentation due to work hardening or brittleness as we have discussed before.

When this bulk deformation starts depending on the nature of the powder, they can either work harden or fragment brittle powder for examples, we will go through the fragmentation process and the ductile powder will work harden as I told you before also. And at extensively high pressure, which is more than 1 Gpa, bulk deformation will start to happen and increase in the density with pressure will not be significant.

So, when the bulk deformation starts, that is basically deforming the entire compact and therefore, the pore filling and the collapse of the pore, which was happening before, that does not really happen in this case, because it is simply the deformation of the entire compact which has now formed and therefore, there will be not significant improvement in the density of the compact.

To summarize this class, we can say that, the powder shaping process is all about giving the loose powder a particular shape and the main objective of the powder metallurgy

process is to achieve a high density in the final product. And these are the different processes which can be applied to densify the powder and what kind of process will be chosen that will depend on the type of the powder or the material properties.

For example, powders that exhibit good sintering ability can be shaped by low pressure. On the other hand, there are many powders which will need high pressure for the densification to happen.

And there are several methods by which the powder can be shaped and which shaping process is to be chosen that primarily depends on two factors one is the production rate and another is the complexity of the shape.

For low production rate and simple shapes, simple processes like green machining can be applied and for complex shapes in the low production category a preform fabrication can be taken as the shaping process. And then for the high production rate, which is you know up to 10,000 or more than 10,000 per year.

The choice of a particular shaping process will depend on what kind of shape is needed in the final product, whether it is 2D or a 3D shape and also depending on what kind of geometry you are talking about for example, whether it is a long kind of geometry or whether it is a thin product. Depending on such parameters or the geometry of the product, a particular shaping process can be chosen.

For example, for a long product, the cold isostatic pressing technique can be selected to shape the powder and for high rate production again depending on the complexity of the shape a particular process, such as die compaction, extrusion, tape casting or injection molding can be chosen.

Then in this class, we have discussed about the powder compaction process and also the mechanism as to how it happens. Powder compaction is nothing but, pressing the powder inside a die cavity. So, this is one of the simplest powder compaction processes which is done uniaxially; that means, pressing the powder along a particular axis inside a die.

So, this tooling that you have for this uniaxial compaction basically consists of a die cavity in which the powder is filled and two punches, one upper punch and one lower punch through which the pressure is applied. When the pressure is applied through both

the punches, it is known as a double action process, whereas, the single action process refers to pressing by only one punch.

Then we talked about the sequence of events as it happens during the compaction process. So, there are different stages as you could see from this pictorial over here from powder filling in the beginning to the ejection of the compact at the end of the compaction process. And often a lubricant is added to the powder or to the die wall, in order to minimize the wear and tear of the tooling to increase the life of the tools which are used for the compaction process.

Then we talked about the details of the compaction mechanism and we have seen that, there are various stages through which the compaction process goes through depending on the pressure which is being applied and these are rearrangement, elastic deformation, plastic deformation, bulk deformation which also includes fragmentation and strain hardening depending on whether the material is brittle or ductile.

And the details of each of these stages as to what exactly happens during each of these processes have been also discussed. Rearrangement happens primarily due to the fact that the powder particles pack together and new particle contacts are created between them and when these contacts are created , the pressure is increased. These contact points will start to deform and it will go through elastic deformation first and as the pressure is increased more, the plastic deformation process will occur.

And this parameter green density we have also discussed, this is a very important parameter which will dictate the porosity, which is left behind at the end of the compaction process and it depends on how the powder particles eventually pack together during the compaction process.

And bulk deformation and fragmentation is the stage of the compaction process, where the pores have already collapsed between the powder particles and the contact points have already deformed. Beyond that if more pressure is applied, then the whole bulk of the compact will start to deform and since there is not much of a pore closure at this stage, the increase in the density with pressure is not significant. And with that we come to the end of this lecture, but there is more to follow on this particular topic keep watching.