Powder Metallurgy
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Lecture – 31
Powder packing

Hi everyone and welcome back to this lecture series on Powder Metallurgy. In the powder metallurgy process, the powder is formed into a shape and then it is densified to obtain a solid product. By now we have seen how the powder is fabricated and how it is characterized to evaluate the properties.

So, now, that we have the powder in hand, it is time for us to go to the next step of the powder metallurgy process and that would be to shape the powder. The first step towards shaping the powder is to get a powder feedstock, which can be then filled into a die or into a mold cavity to shape the powder into a particular form. Therefore, mixing and blending of powder plays an important role towards the shaping process and powder packing is important for the densification.

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This is going to be our topic today, powder packing, mixing and blending. Let us first understand as to what is meant by this powder packing and then we will go on to see this mixing and blending and talk about them in more detail as to why mixing and blending is necessary and so on.

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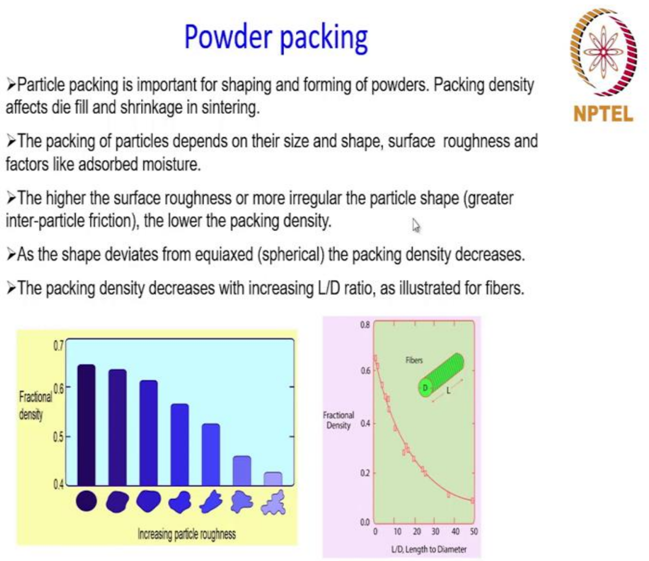

Powder packing refers to the packing of the powder particles together to give it a shape. For example, in a powder metallurgy process, the powder is filled in a die and then it is compacted. So, that it can be given a particular shape. Therefore, particle packing is important for this shaping process and for forming the powders and the packing density as to how closely this powder particle will pack together, that will affect the die fill and the shrinkage in sintering.

Sintering is a process which is the final step in the powder metallurgy process, in which the compact is heated to a higher temperature to close all the pores which remain after the powder is compacted and at the end of the sintering process what you get is fully dense product.

Since all the pores are closing during sintering, it also leads to shrinkage or some shrinking in the dimension of the compact. That also will be affected by the packing density, and that is why it is necessary for us to understand how the powder packing is and what are the factors which affect the powder packing.

When you talk about the packing of the particles, it will depend particularly on the size and shape of the particles and apart from that the surface roughness and the factors like adsorbed moisture will also affect the packing of the particle, because if you had seen before when we talked about the inter-particle friction, there we have seen that inter-particle friction depends on the shape of the particles, when you have a more irregular particle having high surface roughness, that would lead to a higher inter-particle friction also.

So, the higher the surface roughness or more irregular the particle greater will be the inter-particle friction and therefore, lower will be the packing density. So, you can expect the best packing density, when the particles are more regular in shape, like equiaxed or spherical and as the shape deviates from this regular shape, then the packing density decreases and this is something which is depicted over here in this diagram (left hand side image in the above slide).

Where you can see how the fractional density, which is the ratio between the actual density and the theoretical density, how that changes with respect to the particle roughness, which depends on the shape and morphology of the particles.

As I said when you have more regular kind of particles shapes like spherical or equiaxed, then the packing density is good and we will get a high fractional density as well, and as you deviate more and more from the equiaxed or spherical size, you can see here that the fractional density keeps on decreasing and for a particle which is very irregular kind in shape, the fractional density is very low.

That is how the shape of the particles will dictate the packing density, when the powder is compacted inside a die. And the packing density also depends on the *L/D* ratio or the length to diameter ratio of such particles. This is something which can be also called as the aspect ratio.

So, that would also affect the packing density as the *L/D* ratio increases, the packing density decreases, and this is illustrated by showing the packing of these fibers as a function of their *L / D* ratio. So, if you have fibers like this, with a particular *L/D* ratio, where L is the length and D is the diameter, then when you try and pack these fibers together to compact them, then you can see the fractional density of the compact decreases as the *L/D* ratio increases as you can see from this plot (right side image in the above slide).

A similar thing could also happen in powder particles when their aspect ratio or the *L/D* ratio of the particles increases. So, our objective should be always getting a good packing density or a higher fractional density and therefore, the question now would be how to increase the packing density of the powder particles?

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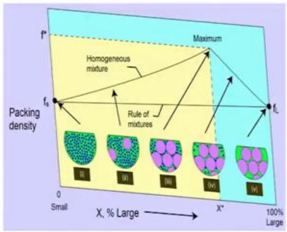
Improving packing density

- The packing density can be improved by bimodal particles i.e. using a mix of large and small particles.
- The smaller particles will fill the interstices between larger particles and improve the packing. The fractional density will depend on the proportions of large and smaller particles.
- The optimal weight fraction of larger particles (X*) depends on fraction of voids $(1 - f_L)$ between the larger particles. At maximum packing density large particle weight fraction is higher. $X^* = f_L/f^*$ and $f^* = f_L + f_S(1 - f_L)$

where, f^* is the optimal packing density and f_L, f_S are fractional packing density of larger and smaller particles respectively.



When you talk about improving the packing density, you will have to look at the particle size distribution. If you remember we have talked about this before, particle size distribution is about having particles of different sizes in a particular powder. And if you have two different sizes which are dominant, that kind of powder is known as or that kind of particle size distribution is known as a bimodal distribution. This kind of bimodal distribution of particle size is also useful for improving the packing density.

So, let us discuss that into little more detail as to why that happens and what is the mechanism behind that? So, when you have a mix of two different sizes of particles or two dominant two different dominant sizes, one of which is bigger than the other, then what happens is the smaller particles will fill the voids between the larger particles and improve the packing.

When you try and pack this powder by compacting it or applying a pressure, then whatever voids will be created in between the bigger particles, those will be filled by the smaller ones and as a result since these voids are getting closed, the fractional density or the packing density will increase.

And what will be the fractional density that will depend on the proportions of large particles or the proportion of large and smaller particles. This is something which is depicted over here in this diagram (image in the above slide), which is a plot between the packing density and percentage of large particles.

The optimal weight fraction of large particles, which is given us X* depends on fraction of voids between the large particles, which is obvious, and this fraction of voids is given by $1 - f_L$, where f_L is the fractional density of the large particles only; that means, the fractional density, which is obtained, when 100% large particles are present in the powder. Which is the right-side end of the plot.

Similarly, f_S is the fractional density, when only small particles are present; the fraction of large particles is 0. So, this is the X* is a fraction of large particle corresponding to the maximum packing density, that can be obtained, and how that happens you can see, from the above image. If you move from left to right, you are actually mixing some amount of larger particles into these finer particles.

Left to right is mixing larger particles into the finer particles and similarly if you move from right to left it is about mixing smaller particles into the larger particles, and corresponding to these two types of mixing, you get these two curves.

One for this one, where you are moving from left to right and the other is this one, when you are moving from right to left, and the intersection of these two curves is the optimum percentage or optimal fraction of large particles, which gives rise to a maximum packing density.

That can be given as like this, the X* or the optimum fraction of large particle is given as this,

$$X^* = f_L / f^*$$

Where f^* is given by the above relationship, wherein we have already defined the f_L and f_S, and f^* is the optimal packing density corresponding to this maximum as you can see over here.

At this point corresponding to the maximum packing density, the large particles will be in point contracts with each other and whatever voids will be created between them those will be filled by the smaller particles and because of that you get this maximum packing density.

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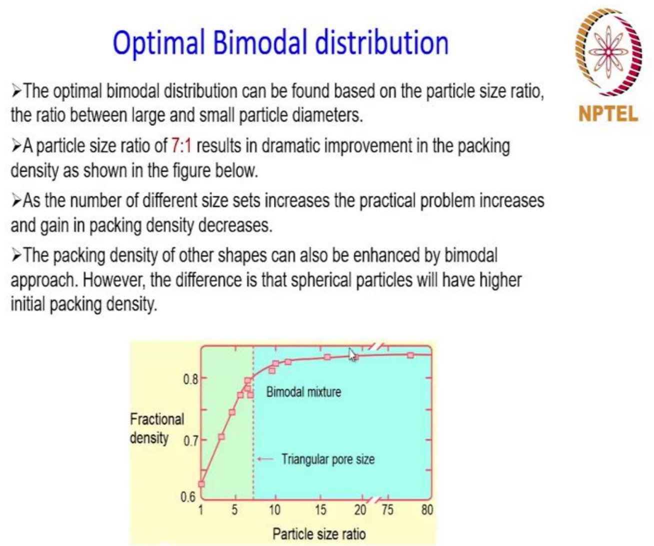

Now, when you have this bimodal distribution, you also need to look at what should be the optimal bimodal distribution in terms of the particle size ratio, which is a ratio of the diameters of the large and small particles. And this is what is being shown over here, the fractional density which depends on the packing density is plotted against this particle size ratio and as we can see from here the fractional density increases with the particle size ratio up to a point and then it kind of flattens off beyond a certain point.

And the other thing that you can note over here is that, when you reach this particle size ratio of 7:1 somewhere over here, you get a dramatic improvement in the packing density. This is because this particle size ratio corresponds to the size of the triangular pore which forms between the bigger particles.

As I said before when you pack these particles together, there will be a point when these bigger particles will be in point contact with each other and as a result of that, these triangular voids will be created in between them. When this particle size ratio is 7:1, that corresponds to the size of this pore, this triangle pore and as a result at this ratio, this triangular pore will be filled by this smaller particle. That is why at this particle size ratio, you get a huge improvement in the fractional density.

Apart from a bimodal distribution, where you have two dominant particle sizes, there could be more than two particle size sets also, but as the number of the different size sets increases; obviously, the complexity will also increase and therefore, there will be practical problems with particle size distribution where you have a greater number of different particle size classes.

This diagram (above image in the slide) over here this is regarding spherical particles where these triangular pores will form in between the particles, but the packing density of the other shapes can also be improved by this bimodal approach. However, the difference is that the spherical particles will always have the higher initial packing density, because of their regular shape as we have discussed before here, but nevertheless the packing density of other shapes can also be enhanced by this bimodal approach.

Generally, the powder sample or a lot of powder will have particles of different sizes and as a result of that it is important for us to have a uniform mixture, because the homogeneity of the mixture will also affect the packing density, and this is where the need of mixing will come, where you will have to make sure that the powder particles are uniform across the different locations of the powder or across the different locations inside the die.

The powder should be uniform in terms of the particle sizes which are present in the powder. So, the need of mixing is very clear here to get a uniform powder and that is what we are going to discuss next.

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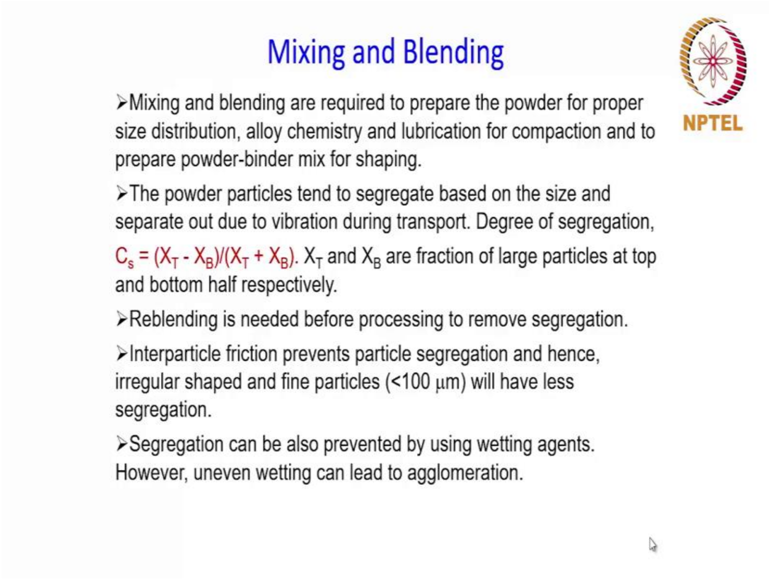

The mixing and blending of powder and see how this mixing and blending is done. what kind of equipment is used for mixing, what is the mechanism of mixing and so on.

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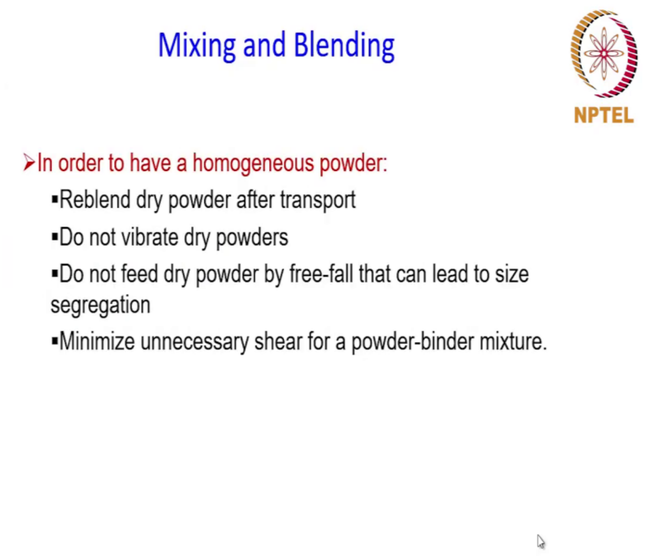

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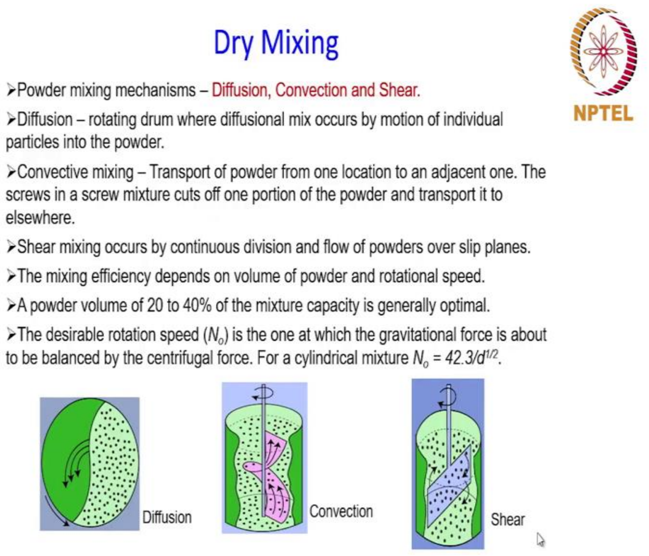

When it comes to mixing and blending, we can say that it is the first step in preparing the powder feedstock for the shaping process. As you all know by now, the powder metallurgy process is all about shaping a lose mass of powder into a product and in that process mixing and blending plays a very important role. Mixing and blending are needed to prepare the powder for a particular particle size distribution. For example, the bimodal particle size distribution that we talked about for improving the packing density.

It is also needed when the alloys are made by powder metallurgy process. In that case, two or more different metal powders have to be mixed and that is why for making alloys also mixing will play a very important role in making sure that, the powder feed is uniform in terms of all the metal powders which are mixed together. Compaction is the process which is used for shaping the powder and the powder in that case will be filled inside a die and a pressure will be applied to compact the powder.

So, to reduce the friction between the die wall and the powder particles a lubricant is used and while mixing the lubricant with the powder, there again you need to make sure that the powder lubricant mix is uniform and that is again will be made sure by mixing and blending the powder in the beginning of the process.

And then a binder also many times is used for the ease of the shaping process and here also we need to make sure that the binder is mixed uniformly with the powder. One of the main reasons for blending the powder is to eliminate the segregation as you all know by now, the powder particles tend to segregate during transport and this is something which is not desirable, because if there are segregations.

For example, if there are particle size based a segregation, then it will lead to variation in the properties across the compact, for example, the density can vary and therefore, we need to make sure that before the compaction process the segregation is removed.

Now, there could be three main reasons for segregation, and these are based upon the particle density, particle shape and the particle size, but more often they are not size based segregation is dominant.

Because, in a powder if you have small particles, these particles can pass through the voids between the bigger particles and tend to settle down at the bottom of the container, and that is why when you have a mix of different sizes of particles, the powder will tend to segregate, and this degree of segregation can be characterized by a particular parameter that you can see over here.

C_s is known as the degree of segregation and this is given by,

$$C_s = (X_T - X_B) / (X_T + X_B)$$

Where in X_T and X_B are the fraction of large particles at the top and bottom half of the container. So, to make sure that the powder is free of segregation it has to be re-blended before processing.

The other factor which will play a role in particle segregation is the inter-particle friction and as we have discussed before, the inter-particle friction depends on the shape of the particles, if the particle shape is more irregular, the inter-particle friction is also going to be higher and hence for irregular shape particles you can expect to have less segregation, because these inter particle friction will prevent these particles to settle down or go through those pores and settle down at the bottom.

And fine particles also, fine particles which are less than $10\ \mu m$ in size will also have less segregation. When you talk about removal of the segregation, then it can be removed, or it can be prevented by using wetting agents. This wetting agents basically are polar molecules.

So, when the powder is mixed with this wetting agents a thin coating of these molecules will form on the powder surface and as a result of that repulsive forces will be developed between the powder particles and the segregation will be avoided, but here when you are mixing the wetting agents with the powder, you have to make sure that it is mixed homogeneously, because uneven wetting, if the wetting agent is not distributed uniformly, then it can lead agglomeration again.

So, there again you can see the utility of mixing and blending to make sure that the wetting agent is also mixed thoroughly and uniformly with the powder. Let us take a moment to summarize today's class. Today we talked about this powder packing, mixing, and blending.

The powder packing density depends on the shape of the particles. The regular shape particles like the spherical and the equiaxed, once we will have higher fractional density or higher packing density and as the shape deviates more and more from the regular shape you can see from this plot that the fractional density will decrease. Then we talked about ways for improving the packing density and one of the approaches which can be adopted to improve the packing density is to use bimodal particle distribution.

So, in this case the smaller particles that you have in the powder will fill the voids between the larger particles and as a result of that, the packing density will increase, and for this mix between the larger and smaller particle there has to be a particular proportion of the large particles of the small particles at which you can get maximum packing density, which you can see over here from this plot, wherein this X^* is that optimal weight fraction of the larger particles that will give rise to the maximum packing density.

And this again depends on the packing density of the larger particles f_L and that of the smaller particles f_S as you can see from here, from this equation, wherein f^* is the optimum packing density. Then we also talked about a parameter called particle size ratio.

So, this is the ratio of the size of the large and small particles in case of a bimodal particle size distribution and here we saw that when the particle size ratio is *7:1*, you gain a huge improvement in the fractional density and this is because at this particular particle size ratio *7:1*, it corresponds to the size of the triangular pores, which are created between the bigger particles.

When this size ratio is 7:1, the size of the triangular pore corresponds to the size of the smaller particles and as a result the smaller particles will fill the gaps or the voids between the bigger particles and improve the packing density. And then finally, we talked about this, the importance of mixing and blending in the powder metallurgy process.

Mixing and blending will make sure that, the powder will have a required particle size distribution, a proper alloyed chemistry and proper mix of lubricant and the binder with the powder for the shaping process and it also helps in removing the segregation from the powder, which will help in making uniform compact, when the powder is being pressed and compacted and with that we come to the end of this lecture.

Thank you for your attention.