Powder Metallurgy

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Lecture - 32

Powder mixing and blending

Hello everyone and welcome back. Right now, we are talking about shaping of powder or rather the preparation of the powder feedstock for the shaping process. And in the previous class, we have seen how the packing of powder is important and how the packing density can be improved. Today, in this class we are going to talk about the mixing and the blending process.

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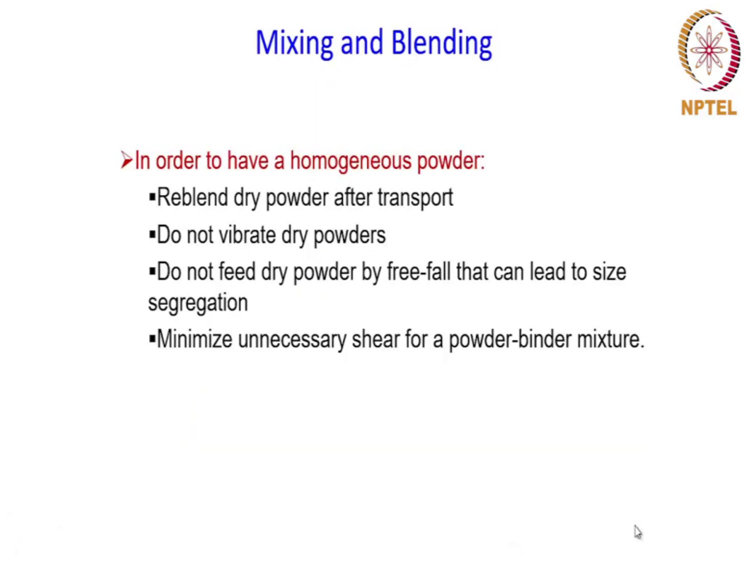

When it comes to mixing, the following things are recommended to get a homogeneous powder. Re-blend dry powders after transport. Do not vibrate dry powders, because as we have seen before one of the main reasons for settling down and segregation in powder is vibration and therefore, it is recommended not to vibrate dry powders.

Then, do not feed dry powders by free-fall that can lead to size-based segregation and minimize shear for a powder-binder mixture. So, these are the things that one can follow to reduce the in homogeneity in the powder and try and get the best possible homogeneity or a homogeneous mix of powder.

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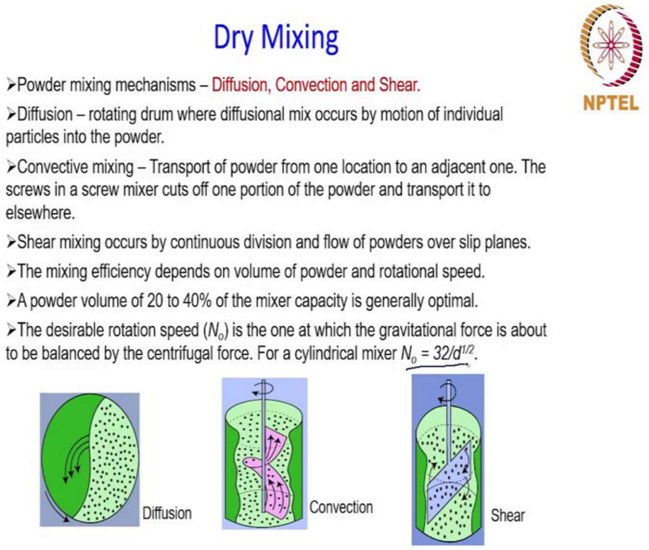

Now, powder particles can be mixed by different methods depending on whether it is mixing the powder alone or there is something which is to be mixed with the powder like for example, a binder or a lubricant.

Dry mixing is the process where only the powder is mixed, as the name itself suggests and in this case, there is a particular mechanism by which the mixing happens. There are primarily three mechanisms of dry mixing: diffusion, convection, and shear. And this also depends on what kind of mixture is used; the mechanism also depends on that.

Diffusion happens when the mixture is a rotating drum. And in this case, the diffusional mix between the particles occurs by motion of individual particles into the powder. So, what happens in case of a rotating drum like this, the rotation of the drum provides an inclined plane like this over which the powder particles stumble down and because of that it leads to mixing over the surface.

And the continuous rotation of the drum provides fresh powder to this inclined plane and hence, results into diffusional intermixing of the powder particles. So, that is about diffusion where the powder particles themselves mixed together.

Then, you have convective mixing wherein the powder particles are transported from one location to another for example, if you look at this screw mixture; in this case the screws in this mixture that you see over here will cut off one portion of the powder and transport it to some other location which is indicated by these arrows that you see over here.

So, due to that movement of particles from one place to another, it is kind of a convective mixing that takes place in a screw mixture. And shear mixing will happen when the mixture provides a plane over which there is a continuous divisional flow of powders like here that you see this blade for example, will provide that slip plane and across this plane, there will be continuous division and flow of the powder.

So, this blade itself will cut across this powder resulting in this flow of powders over this particular plane and that process is known as the shear mixing. Now, when you talk about the mixing efficiency that will depend on mainly two factors; one is the volume of the powder which is being mixed and the other is the rotational speed.

In this case, a powder volume of 20 to 40% of the entire mixture capacity is generally optimal. So, when the mixture is full up to point 2 or point 4 of the total capacity, then that can be considered as the optimal for a good mixing to happen.

And why it is only up to 40%, because as the powder fills this mixture, the relative motion of the powder will be inhibited, because as more and more powder particles come together, they themself will hinder each other’s motion.

And because of that when you feel more and more powder into the mixture the motion of the particles will be hampered and that is why you cannot really fill the entire mixture to its full capacity and then dry and mix it. So, it has been found that if you fill it up to 40% then the mixing will be good.

And the other factor as I said, is the rotational speed and the desirable rotational speed will be when the gravitational force is about to be balanced by the centrifugal force that is generated due to the rotation and for a cylindrical mixture, this can be shown as equal to this where d is the diameter of the mixture.

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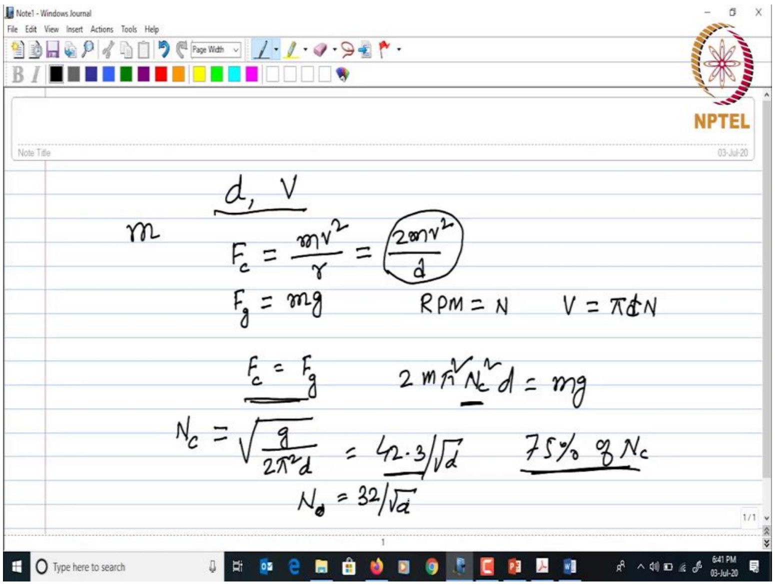

Let us say, we are talking about a cylindrical mixture whose diameter is d and let us say it is rotating at a velocity *v*. So, now, if you consider a particle of mass *m*, then the centrifugal force F_c will be,

$$F_C = mV^2/r$$

In terms of the diameter, it will be $2mv^2/d$. And the gravitational force F_g that is equal to,

$$F_g = mg$$

Where g is the acceleration due to gravity. And if the R M is N, then as you might know that V will be equal,

$$V = \pi dN$$

And the critical rotational speed will be when F_c will equal to,

$$F_C = F_g$$

if you replace v in terms of d and m, then we can write that.

m becomes N N_c, because this is the critical speed when f_c becomes equal to f_g. And from here, you can deduce N_c as,

$$N_C = \sqrt{\frac{g}{2\pi^2 d}}$$

Which will give this; $N_C = 42.3 / \sqrt{d}$

And approximately 75% of N_c is considered as the speed at each the centrifugal force and the gravitational force will just begin to balance each other and therefore, the optimal speed N_0 can be taken as the 75% of this value. And that will give N_0 as,

$$N_0 = 32 / \sqrt{d}$$

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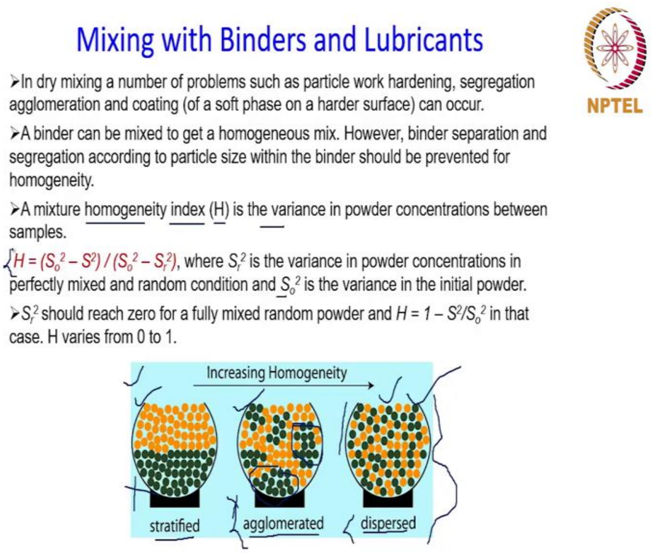

Now, as we have seen before as many times the powder is mixed with a binder, that is to ease out the shaping process when you mix the dry powder with some kind of binder, it makes the shaping abilities here in terms of helping the powder particles binding to each other. And sometimes a lubricant is also used to a reduce the friction between the die wall and the powder particles to improve the life of the die.

So, when there is something to be mixed with the powder, then we have to look at the other kind of mixing also apart from dry mixing. And you can also expect a number of problems in dry mixing for example, the particle work hardening since the particles are colliding against each other, they will deform and that can lead to work hardening and as the particle hardens, it might become difficult to pack them or compact them.

Then, segregation and agglomeration can also happen during the mixing process if it is not done properly or if the parameters are not optimum. And when you have a mixture of a soft and a harder phase together in one particular product or sample, then the soft phase can get deformed and get quoted on the harder phase leading to this soft phase on the harder particles.

So, all these problems can arise during the dry mixing and as a result sometime, there will be a need to mix the powder with a binder to get a homogeneous mix.

However, when you are using a binder you have to make sure that there is no binder separation and there is no segregation in the binder according to the particle size otherwise, it will lead to agglomeration again and the purpose of mixing a binder to get the homogeneous mix will be lost.

So, if we look at this image over here (image in above slide), it shows the homogeneity in terms of the mixing of two different phases for example, one being represented by this orange circles and the other is represented by this black circles. Left-hand side; that means, the mix over here is the extreme case or the most undesirable case where the two phases are completely separated from each other and this is a condition which is known as the stratified condition.

And then, comes this one (middle image) when you increase the homogeneity little bit more. Then, this 2nd phase is mixed with the 1st phase, but we can see there are pockets of agglomerations like this or this. So, this is not a complete homogeneous mixture, this is kind of an agglomerated mix. Our objective should be to get a complete homogeneous or a dispersed mix like this (last image) where all the particles are mixed with each other uniformly across the entire powder as you can see over here.

Left to right here in this image is the increase in homogeneity and that is something that has to be ensured and the mix that we are trying to get for a powder metallurgy process should be like this and not like other two cases of mixing.

So, how good is the mix in terms of the homogeneity that can be given by a parameter called the homogeneity index written as H and this is basically, the variance in powder concentrations between samples.

And this is given as this; *H* is equal to,

$$H = (S_0^2 - S2) / (S_0^2 - S_r^2)$$

Wherein S_r^2 is the variance in powder concentrations in perfectly mixed and random conditions and S_0^2 is the variance in the initial powder. Starting from a particular initial powder what homogeneity it is reaching after mixing that is what is given by this *H*.

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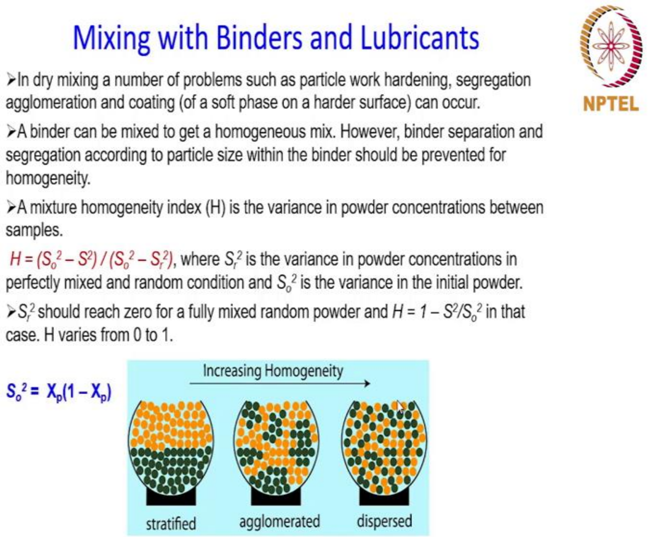

In the beginning, the powder binder mixture is a totally segregated system with variance S_0^2 given as,

$$S_0^2 = X_p (1-X_p)$$

Wherein X_p is the concentration of the major powder component. And as the mixing proceeds, it becomes more and more homogeneous as we have discussed.

And ultimately it should approach variant *0* when we have a homogeneous mixture or a perfectly random mixture when the final variance S_r^2 will approach 0 and, in that case, *H* will become, as you can see from here if you put S_r^2 equals to 0 then, *H* becomes this.

$$H = 1 - S^2/S_0^2$$

And the value of H varies from 0 to 1 where 0 refers to a segregated system and 1 corresponds to a completely uniform mixture. And if you see the kinetics or the progress of the mixing with respect to time.

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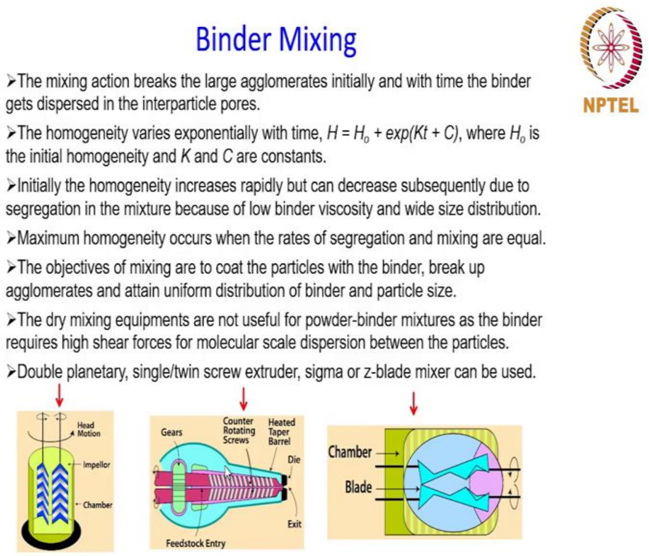

The mixing action first of all breaks down the large agglomerates and as the mixing proceeds with time, the binder gets dispersed in the interparticle pores. And therefore, we can say that the homogeneity increases exponentially with time and hence, the relationship between H and time can be given with an equation like this,

$$H = H_0 + e^{(Kt+C)}$$

Where t is the time and H_0 is the initial homogeneity and K and C are constants.

And during mixing, simultaneous segregation can also happen and as a result of that it kind of leads to a steady state beyond which you cannot expect anymore improvement in the homogeneity. So, the steady state will reach when the rate of segregation equals the rate of mixing. Initially the homogeneity increases rapidly, but it can subsequently decrease due to the segregation in the mixture if the binder has low viscosity and the powder has a wide size distribution.

The objective of mixing is to coat the particles with the binder, break up the agglomerates and attend uniform distribution of binder and particle size. So, it is not only about the binder and the powder that should be mixed together homogeneously, it is also about the particle size distribution. So, every portion of the powder in the container should be homogeneous in terms of the particle size distribution as well.

Now, if you have dry mixing equipment, these are not very useful for powder binder mixtures as the binder requires high shear forces for molecular scale dispersion between the particles. And therefore, we need to use other kind of mixtures which will affect more homogeneous mixing and provide that shear force to get this powder to be mixed uniformly with the binder.

For examples, the double planetary which is here, single or twin-screw extruder which is over here and sigma or z-blade mixture; all these can be used to impart high shear force for a proper mixing or a molecular scale dispersion between the binder and the particles. So, that is the advantage of having these kinds of mixtures where you have a certain kind of blade or impellers which will provide a high shear force.

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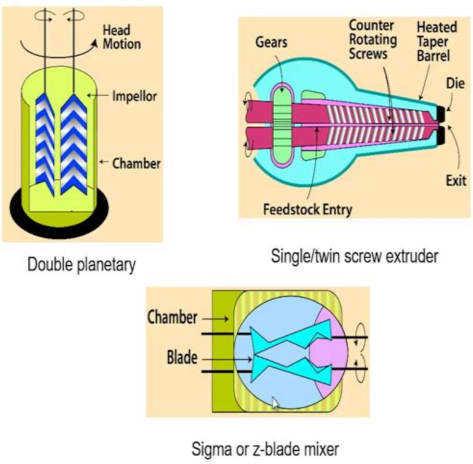
Mixers



This double planetary mixture for example, has these two impellers which rotate in the opposite direction to each other. And for the screw extruders, you have these counter rotating screws over here, to impart that high shear force. These screws are rotated with the help of these gears that you can see over here. And the powder is fed through this zone through this feedstock entry.

When the powder enters this chamber, it is subjected to high shear forces by this counter rotating screws. And when it comes out from this exit, it will be a uniform mixture between the binder and the powder.

Similarly, over here you can see these blades which are differently designed in order to impart that high shear force again. Here also, when the powder enters this chamber with the help of this specially designed blades, the powder is subjected to a high amount of shear and the binder will be mixed uniformly with the powder with the help of that. So, let us quickly summarize before we finish today's class.

Today we talked about this dry mixing and in this case, we have seen three different types of mechanisms of mixing and these are diffusion, convection, and shear. Diffusion happens in a rotating drum which provides an inclined plane like this over which the powder breaks and the particles fall giving rise to a flow over the surface and because of that diffusional mixing happens.

And then, you have convection in these kinds of mixtures where you have these screws which can cut off one portion of the powder and transport it to another place. And then sharing happens in a mixture like this where this kind of blades will provide a slip plane over which there is a continuous division of the powder and hence, the powder will flow over this slip plane and we will result in mixing. And there is a desirable rotational speed or an optimal rotational speed where you get maximum mixing or uniform mixing.

And then, we talked about mixing the powder with binders and lubricants. Here, the mixture homogeneity is given by a parameter called homogeneity index which is given by this relationship over here where these square terms that you see those are actually the variance in the powder concentrations S_0 is the initial variance and S_r is the final variance.

Our objective is to have a minimum variance at the end of the mixing so that we have a uniform mixture and that is what you can see over here. When it becomes 1, this will lead to a complete homogeneous mixture. And then finally, we also talked about the kinetics of the process in terms of the mixing time and we have seen that the homogeneity index varies exponentially with the mixing time *t*.

However, ultimately a steady state will reach when the rate of mixing will be equal to the rate of segregation that happens inside the mixture, while it is being mixed. And we have seen that if you have certain types of mixture like this double planetary, this screw extruder or this z-blade mixture; this will provide a high shear force which is good for homogeneous mixing between the powder and the binder.

So, with that we come to the end of this class, but I am going to see you soon again.

Thank you for watching.