Powder Metallurgy
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Lecture – 36
Powder compaction - 3

Hello everyone and welcome back this lecture series on Powder Metallurgy. So, in the first couple of classes we have been talking about Powder compaction and so far we have learned about the different aspects of the compaction process. In this class, we are going to talk about the material aspects as to how the material properties affect the compaction process.

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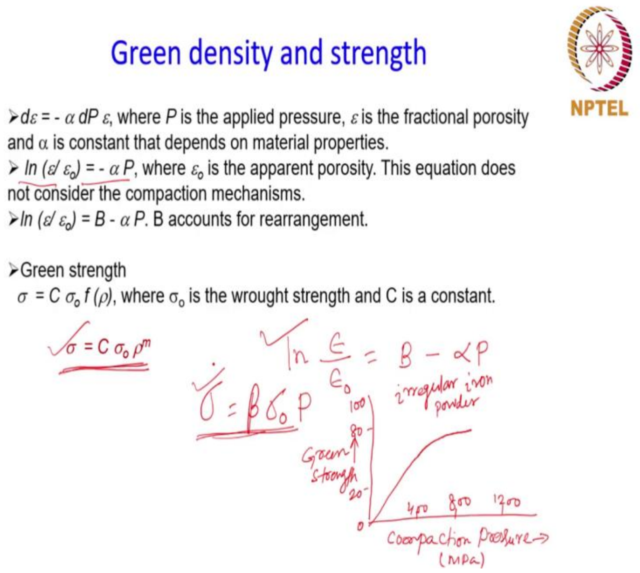

So, in the last class we discussed about the green strength and we have seen how it depends on the fractional density which is obtain after the compaction operation and $\sigma = C\sigma_0\rho^m$, is the equation which relates the green strength to the fractional density ρ. The green strength depends to large extent on the inter particle contacts which form during the pressing operation.

So, if there are any particle characteristics which lead to a better inter-particle contact (for example, the particle roughness) which may lead to mechanical interlocking, it will give rise to a higher green strength.

Similarly, smaller particle size which provides more inter particle bonding will also give rise to a higher green strength for a given green density. So, the nature of the particles will also have a great influence on the green strength and the surface conditions also will have a bearing because this interlocking that happens between the particles will depend on the surface condition.

A clean powder surface is always good for interlocking to happen through a cold welding kind of mechanism. And therefore, a clean powder will give rise to a higher green strength and for the same reasons when lubricants are added to the powder it might decrease the green strength because since there is a presence of a lubricant film on the powder particles, this interlocking will be adversely affected. And as a result of that, the particle bonding which happens by mechanical interlocking will suffer and as a result of that the green strength will decrease when the lubricant is present.

Now, if you want to correlate the green strength with the compaction pressure then you have to go back to the equation which relates the fractional porosity to the compaction pressure. So, if you remember this is the equation: $\ln\frac{\varepsilon}{\varepsilon_0} = B - \alpha P$, this we have already discussed before. So, now, in order to correlate the green strength to the compaction pressure, these two equations can be combined to come up with an empirical relationship.

And that might look like this: $\sigma = \beta\sigma_0 P$ where P is the compaction pressure, σ_0 is the wrought strength of the material and β is a material dependent constant which also depends on the powder characteristics. So, if you plot this equation you will get a plot like this (slide above) which will depict the relationship between the green strength and the compaction pressure.

So, let us consider a particular powder just to demonstrate this. So, let us say we are talking about iron powder which is irregular in shape. The green strength with respect to the compaction pressure will vary something like this (plot in above slide). So, at low compaction pressure there is a good correlation between this equation and the compaction behaviour of the powder, but at higher pressure this does not really follow the equation. The rate of compact strengthening is generally less than that will be projected by this particular equation. But nevertheless this plot will show a relationship between the compaction pressure and the green strength for a particular type of powder.

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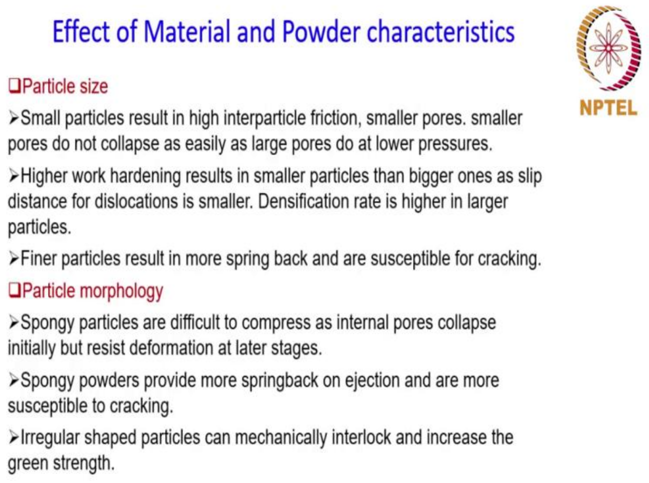

Let us see the effect of material properties and the powder characteristics on the green density and the green strength of the compact. Let us first talk about the particle characteristics.

So, the two main particle characteristics which will have a bearing on the densification during the compaction process are particle size and particle morphology. So, talking about the particle size, small particles will generally result in high inter-particle friction and smaller pores.

So, high inter particle friction as we have already discussed before would actually hamper the packing of the particles and small pores on the other hand do not collapse as easily as the large pores do, particularly at lower pressures and therefore this will also hamper the green density that can be achieved at a particular pressure.

And the small particles also go through a higher work hardening because the slip distance for dislocations is smaller in smaller particles compare to the bigger ones and that will also result in a lower densification rate compared to larger particles.

A phenomenon called spring back occurs when the compact is ejected at the end of the compaction process. It is basically some recovery that happens in the dimension of the compact as it is ejected from the die. So, finer particles will result in more spring back and are susceptible for cracking.

If the spring back is larger or the recovery is greater, there are chances that stresses will be developed in the compact and it might even crack under those stresses and finer particles are more susceptible for this kind of cracking.

So, this is how the compaction process and the density of the compact which can be achieved are dependent on the particle size. Now when you talk about the particle morphology, we have seen there are different kinds of morphologies generated by different fabrication routes which are used to process the metal powders. Spongy particles for example, are difficult to compress as internal pores will collapse initially but resist the deformation at later stages.

So, this kind of spongy powders will have lot of porosity and as you apply the pressure, before the compaction and densification starts, these pores will start collapsing. So, the pressure will go into collapsing these pores rather than compacting the powder or densifying the powder. But as the pressure is increased, the pores will also resist the deformation at later stages.

And spongy powders provide more spring back on ejection and therefore, are more susceptible to cracking. Irregular shaped particles on the other hand can mechanically interlock and this will increase the green strength. So, this is just an example of how the particle morphology will affect the compaction process and the green density.

Now, when you talk about material properties and their effect on the compaction process and the green density, basically there are two material properties which will come into force over here.

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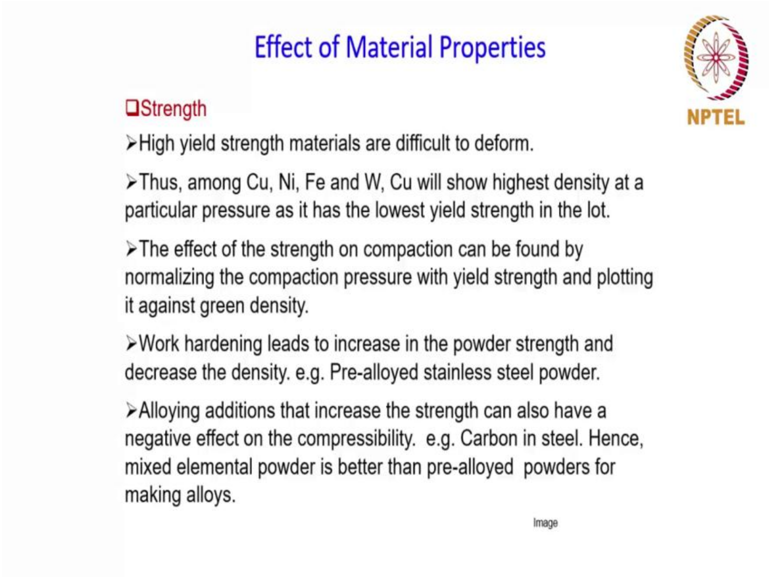

One is the strength and the other is the hardness, because these two are related to the deformation behaviour of the material and during the compaction as we have seen the powder goes through the deformation process. So, anything which relates to the deformation process will have a bearing on the compaction process as well. So, let us first talk about the strength and how it affects the compaction behaviour of metal powders.

When a metal has high yield strength, it will be difficult to deform which is quite obvious. Yield strength is nothing but the stress at which the material starts to deform plastically. So, higher yield strength means, you need a higher stress or higher load to deform the material and therefore, if the materials are compared, then the metal which is having the lowest strength, will give the highest density at a particular compaction pressure.

So, if we compare copper, nickel, iron and tungsten, copper will show the highest density because it has the lowest yield strength and this effect can be also shown graphically if you normalize the compaction pressure by yield strength and plot it against the green density (slide below).

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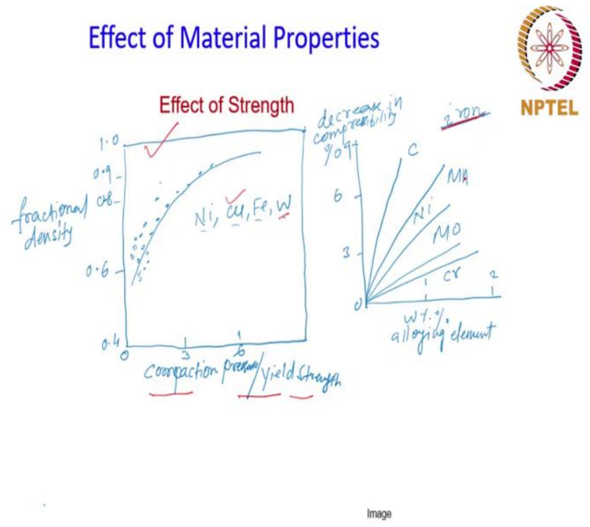

So, the x axis is the normalized compaction pressure and y axis is the fractional density. So, the plot might look like this (left side plot in above slide) and depending on the strength of the material, the data points may be below, above or on this curve.

So, if you talk about a particular compaction pressure or a normalized compaction pressure, materials like copper will have points which are above, because at a particular compaction pressure copper will have a higher fractional density compared to a higher strength metal like tungsten.

And therefore, it will lie above compared to the higher strength metals. So, if you compare this set of materials copper will always have a higher green density at a particular compaction pressure and with regard to the strength, alloying elements will have a very significant effect on the strength of a material.

For example, if you talk about iron powder, if you add different alloying elements, the strength of the material will change and as a result of that it will also affect compaction behaviour or the compressibility of the material. So, for example, if you talk about some of the alloying elements which are used in iron for making different grades of steel such as chromium, molybdenum, nickel, manganese and carbon of course, their effect can be observed.

Let us say we are plotting the decrease in the compressibility against the weight percent of the alloying element (right side plot in above slide). So, the y axis is decrease in compressibility given in percentage. So, for different alloying elements the compressibility will change differently. For example, chromium it may look like this, then above this you will have molybdenum, then nickel, then manganese and finally, carbon. Since all these alloying elements have their own affect on the strength of the material they will also affect the compressibility or the compactability of the powder.

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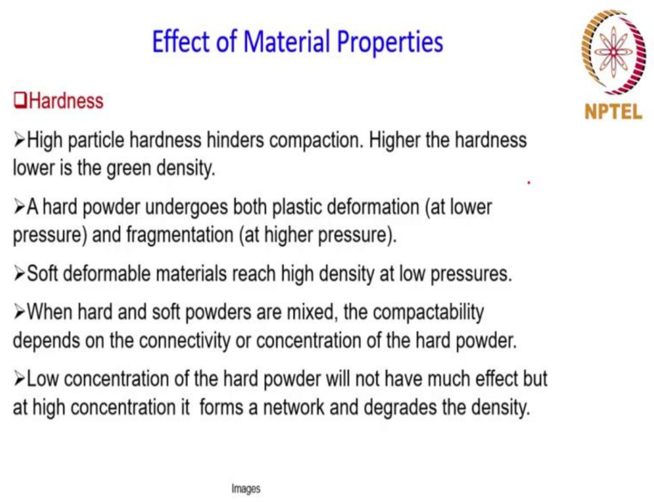

So, the next important property which has a bearing on the compaction and the green density is the hardness. High particle hardness hinders compaction because high hardness means it will have high resistance to deformation and therefore, a higher hardness will be detrimental for the compaction process.

And therefore, higher is the hardness, lower is the green density at a particular compaction pressure and a hard powder will undergo both plastic deformation at lower pressure and fragmentation at higher pressure.

Soft deformable materials on the other hand will reach high density at low pressures because these kinds of materials are easy to deform and they will easily form bonds with each other and therefore, a high density can be achieved at lower pressures. Now, if you mix hard and soft powders the compactability of this kind of mixture will depend on the connectivity or concentration of the hard powder. So, the hard powder will be dominating here in terms of deciding the compactability of the mixture.

Low concentration of the hard powder will not have much effect, but when the concentration increases it will form a network and these network of hard particles will degrade the density, which is quite obvious because as we have already seen it is difficult to deform the hard particles and it is difficult to compact them.

And therefore, if you have a network of these kinds of hard particles in a matrix of soft particles, it will hamper the compaction of the soft particles as well and as a result of that it will also degrade the density of the compact.

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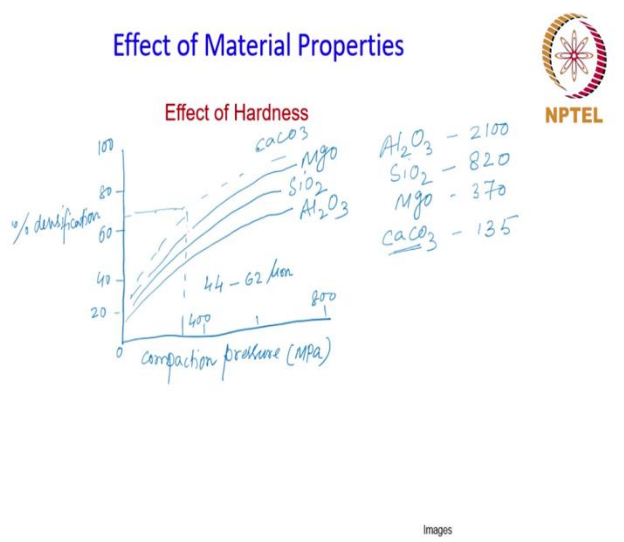

Let us see some examples and see how the material hardness effects the densification during the compaction process. So, let us say we are plotting densification against the compaction pressure and we are talking about a powder particle size in the range of 44 to 62 micron.

So, just to demonstrate this we will choose some materials which are known for their high hardness and we will also choose some material, which are having much lower hardness compared to harder materials.

For example, if you consider aluminium oxide or alumina it has a Knoop hardness of about 2100 and if you take a material like calcium carbonate that is much softer compared to aluminium oxide since the hardness is only 135. Then in between you may have silica which is having a Knoop hardness of 820, magnesium oxide with a hardness of 370.

So, if you plot this kind of materials you will find that the curve for the calcium carbonate will be at the top followed by magnesium oxide, then silica and finally, at the bottom you will have it for aluminium oxide. So, this tells you that at a given compaction pressure, the density for the soft material will be always higher compared to the harder material.

So, in this pack calcium carbonate is the softest and therefore, at any given compaction pressure, the densification or the fractional density will be highest for the calcium carbonate.

And aluminium oxide is the hardest in this pack and therefore, it will have the lowest density at a given compaction pressure. So, that is how you can see the effect of hardness on the densification which happens during compaction. So, before we finish this class let us take a moment to summarize it. Today we learned about the correlation between the material properties and the green density or the densification during compaction.

We have also seen how the green strength depend on the compaction pressure with the help of a plot. As the compaction pressure increases, the green strength will also increase which is obvious and we have also derived an empirical equation for that. The equation, $\sigma = \beta \sigma_0 P$ correlates the green strength to the compaction pressure P. Then we talked about the effect of particle characteristic on the densification process.

And here we talked about two characteristics of the particles; one is the particle size and another is the particle morphology and we have seen that it is difficult to compact smaller particles compared to larger ones and the primary reasons for that are as follows. Inter particle friction is high for the smaller particles and they also go through a higher work hardening compared to the larger particles and they result in more spring back and are also susceptible for cracking.

So, due to all such characteristics of small particles they are difficult to compact compared to larger particles and in terms of the particle morphology we talked about two kinds of morphology; one spongy kind of morphology and another was the irregular shape.

In case of the spongy particles because of the presence of lot of internal pores when the powder is pressed these pores will collapse in the beginning, but ultimately they will resist the deformation at later stages.

And these kind of spongy powders also lead to more spring back on ejection at the end of the compaction process and are also susceptible for cracking. Irregular shaped powders on the other hand can mechanically interlock and hence increase the green strength of the compact.

Then we talked about the effect of the material properties on the densification process as it happens during compaction and we have seen if the material has higher strength or higher yield strength it will be difficult to deform compared to a material which is having lower yield strength. And this we have also demonstrated with the help of a plot which shows the correlation between the fractional density and the normalized compaction pressure.

The compaction pressure is normalized with the yield strength of the material and we have seen a lower strength material like copper is easier to compact and will have higher fractional density compared to a higher strength material like tungsten or iron.

Then, we also talked about the effect of the alloying elements which influence the strength of the material and we took the example of iron and different kind of alloying elements which are added to iron for making different grades of steel. So, they will also have their own effect on the compressibility since they affect the strength of the material.

And then finally, we talked about the effect of hardness. And here also we have seen that higher hardness materials are difficult to compact compared to a lower hardness material because higher hardness means a higher resistance to the deformation process. And therefore, a soft deformable material will reach a high density at lower compaction pressure.

And this again we have demonstrated with the help of a few materials having different hardness some having higher hardness like aluminium oxide and some are of lower hardness and with a plot between the densification and the compaction pressure it can demonstrated that the lower hardness material will always have a higher density at a given compaction pressure.

And with that we come to the end of this class, but I am going to see you soon again with more of this course. Keep watching.