Powder Metallurgy

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Lecture – 48
Sintering – 8

Hello everyone and welcome back again to this lecture series on Powder Metallurgy. So, right now we are in the final stage of the powder metallurgy process that is Sintering. And in fact, right now we are in a stage where we can actually demonstrate the unique abilities of the powder metallurgy process that we discussed in the beginning if you remember.

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So, this is what we had seen before when we started this course, when we discussed about what advantages and you know capabilities the powder metallurgy process can offer right. And one of them was this uniqueness of the process in terms of making materials by combining two or three different materials into one right.

So, this is something that we can demonstrate right now taking the example of some materials where you have more than one powders mixed together and looking at how the sintering happens for that kind of powders and how do you get a single material at the end of the sintering process. So, that is what we are going to talk about in this particular lecture as to how different materials can be combined into one by the powder metallurgy process.

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So, when it comes to sintering of mixed powders there could be three types of mixtures that you can consider; one; a mixture having different particle sizes or graded particle size. Second; a mixture having two or more metal powders for making alloys and thirdly you can have a powder for making composite, which is a material having a combination of two or more different materials. One of them is the matrix or the parent phase and second in the dispersed or the reinforcing phase.

So, here we will have the matrix powder plus the dispersion or the reinforcement powder which is to be sintered into one single material. So, all these mixtures will have their own characteristics and the sintering will differ depending on that.

So, if you talk about the first one that is a mix of different particle sizes, here it often results in a higher green density in the sense you have smaller particles to fill the voids between the bigger particles and give rise to a higher green density and that in turn will give rise to a high sintered density right.

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However, as the average particle size increases the sintered density will decrease. This is something that has to be kept in mind while dealing with powder mixtures having different particle sizes. And therefore, you have to consider different scenarios having you know different proportions of large and smaller particles. So, here we can consider two different scenarios.

First, at low sintering temperature and short sintering time. Here the densification benefit that you have due to the presence of different size of particles is dominant and the powder mixture will give rise to the highest density with little dimensional change.

So, in this kind of sintering condition you can achieve highest densification for this kind of mixed powder having larger and smaller particles, and as I said the dimensional change is minimum. But, when you are on the other side of the sintering cycle; that means, at high temperature side and long sintering time then the situation is going to change.

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Here, the benefit that you had at the lower temperature side is not that relevant. Densification in these conditions will be better when you have smallest average particle size. So, here the proportion of the smaller particles will play dominant role and this can be also demonstrated with the help of a plot like this, in which we can plot the fractional density with the percentage of large particles .

So, in a condition like high sintering temperature and long time, you could find the highest density and shrinkage for smaller average particle size. That means, when you are having a smaller fraction of the large particles, it will give rise to high sintering density and high shrinkage.

So, let us plot the shrinkage first and as you increase the fraction of large particles, the shrinkage will also decrease which also indicates a decrease in the densification and as a result you would see that the sintered density would also decrease as the proportion of large particles increase or in other words as the average particle size increases, something like this for the sintered density.

Whereas, the green density would vary with an opposite trend showing an increase with increasing percentage of the large particles. The trend of course, can change depending on the material that we are talking about. Here this was an example for iron powder having two dominant sizes. One bigger which is 66 micron and the other one the smaller size let us say about 4 micron. So, we have it has a mix of large particles like that and also smaller particles where there is a significant difference in the size.

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Now, let us go to next category that is a powder mix for making alloys. So, this is an alternative to pre alloyed powder which you know already alloyed with the alloying element that is needed in the final product. Here instead of having pre alloyed powder, the alloying element is mixed with the powder and that mix is finally, sintered for making the alloy.

And the advantages of that are several- these are as follows; It will provide a flexibility in controlling or altering the composition and the chemistry of the alloy which is to be made finally, can be easily altered by simply altering the proportion of the powders.

It is also easy to press because alloyed powders will be obviously, stronger than the elemental powders or the pure metal right. So, therefore, when the pure metal mix is used instead of the stronger alloyed powder it will easier to compress it. And as a result of that this will lead to higher green density and strength.

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And it also provides an opportunity for making unique microstructures, which may be needed for a particular kind of application or property. And ultimately it provides an improved densification. So, the idea of sintering is to actually densify the compact. So, let us talk about that has to how the densification happens in this case when you have two or different metal powders mix together for making an alloy.

So, here two things will happen. One is of course, formation of the alloy or the chemistry. So, here homogenization is an important factor because we need to maintain a particular alloy chemistry, a particular composition right. So, when the sintering happens, the powder which is mixed as an alloying element should be completely and homogenously mixed with the direct metal to form an alloy which is uniform in the chemistry.

So, apart from densification , the homogenization part also has to be considered. In fact, for a considerable portion of the sintering time this homogenization is dominant, post which the densification starts. And here you have you know first in the mixed powder or in the green compact you have compositional gradients because your steel in the green state and this homogenization part will happen only when the compact is heated to high temperatures.

So, these gradients that you have you know higher concentration somewhere and lower concentration in some other parts basically provides you a concentration gradient which will promote mass flow and that is what we need for the densification to happen in case of sintering. So, this will enhance the diffusional flux, which is going to be helpful for the densification.

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And the other aspect which is again beneficial for the sintering process is the creation of the vacancies at the interfaces between the metal powders . You have two different materials and there is an interface. So, that leads to creation of vacancies which is again good for the diffusional process to occur.

And this occur so, retards the grain growth. But, in order to achieve that homogenization the temperature and time cycle has to be controlled. Otherwise, there will be issues with regard to the final material composition and also dimensional changes and so on.

For example, if you have two materials having very different melting point; you know one is having much higher melting point compared to the other then if the temperature is not controlled it might lead to swelling and therefore, it will be difficult to maintain the dimensional tolerances. An example is aluminium being added to iron.

Iron is having a melting point which is much higher than aluminium. So, here you need to control the temperature not only to you know prevent this swelling, but also to prevent any unwanted reactions between iron and aluminium that can lead to formation of brittle intermetallics which are again detrimental for the properties of the material.

A perfect example of this kind of tray mix powder for making alloy is the copper tin porous bronzes where tin powder is mixed with copper to make bronze which is an alloy of copper and tin. So, tin here is the minor element or the alloying element and copper is the major. So, some amount of tin depending on the composition that is needed the final material is added in copper and that mix powder is sintered.

Here tin is a lower melting material with a melting point of 230 degree Celsius and the melting point of copper is much higher. So, this will also aid the sintering process in the sense that while being heated, tin will melt and give rise to liquid phase which will enhance the diffusional flux right, because diffusability is higher in a liquid compare to that in a solid.

But, this liquid that you have is transient because you know ultimately we are talking about a copper tin alloy, you know which is solid even at 800 degree Celsius right. When you have a single phase material, when the alloy is already formed it can remain solid till 800 degree Celsius right.

So, when the alloy is found you know the final material that you obtain at the end of the sintering process, it will be a solid. So, therefore, the liquid which forms during the heating is just a transient phase.

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So, as I said in this kind of alloying a large portion of the sintering period is dominated by the homogenization process.

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And the densification continues after the homogenization has completed. We can take another example to look more into this homogenization process.

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So, let us say we have a system of A and B where B is the alloying element and A is the parent metal in which B is added. And let us consider a spherical shape. So, particles of B are added into A and let us also consider that A and B are completely soluble into each other. You might know this kind of system is known as an isomorphous system or isomorphous alloy right.

There is complete miscibility or complete solubility. So, as you heat this mixture of powders A and B, B will start dissolving in A and you know the homogenization process as to distribution of B into A uniformly will start to happen as the compact is being heated . So, initially the homogenization is not uniform and there will be a steep gradient in the homogenization process or in the concentration.

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So, if you look at the concentration as a function of distance in the beginning that is time t equals to 0, there is steep gradient in the concentration and as the time increases the gradient decreases and eventually levels of. So, this is at **t1** and this is at **t2**, where **t2** is greater than **t1,** then you can see that as the time is increased the gradients are also becoming smaller .

And ultimately it will level off at a particular average value C_B, which is the composition of the alloy that we are looking for. So, this will happen on prolonged heating; that means, you can consider this as time infinity right when it becomes C_B, the average alloy composition.

And the homogeneity index can be given by an expression like this,

$$H \sim D_v t / S^2$$

where D_v is the diffusivity, **t** is time and the parameter **S** represents the scale of microstructural segregation. And this depends on the particle size concentration and microstructure of the powders.

And the homogenization behaviour can be shown with a plot like this, where the x axis is this term and y axis is homogenization. So, as this term increases the homogenization will also increase which is obvious from this equation and ultimately it will saturate at 1, which is complete homogenization.

And temperature will also have a significant effect on this homogenization process because the diffusion process itself is thermally activated. In fact, the diffusional coefficient or the diffusivity that you have , it increases exponentially with temperature and therefore, the temperature will also have a significant influence on the homogenization process.

So, this is how we can see the unique ability of the powder metallurgy process in combining different materials into one which is having better properties compare to the individual materials which are mixed into it. Now, the similar approach can be also used to make a composite material that is the third category that we talked about.

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Here you have a matrix material, let us say you have a metal and you are adding another phase which is completely different from it. So, in metal matrix composite you have the ceramic. You have a ceramic materials as the reinforcement. This will lead to an increase in the strength and hardness of the metal, right.

So, here you have an insoluble component mixed with the matrix material right. So, here the sintering approach remains the same, but the densification process could be different due to the presence of this kind of insoluble particles.

So, here you mostly have to look at how these insoluble particles bond to the metal during the sintering process right. So, although the basic mechanism is going to remain same, but the interface between this ceramic and the metal is going to play a dominant role in this case because here we have to see how this interface is created and how the bonding at that particular interface is occurring during the sintering process .

And only when a proper bonding is achieved between the metal and the ceramic particles, you can get a composite which is free of defects and also will have better properties compare to the individual materials and with that we come to the end of this lecture.

Thank you for your attention.