Powder Metallurgy
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Lecture – 37
Cold Isostatic Pressing and Powder Injection Molding

Hello and welcome back. So, while discussing about the shaping of the powder in the last few classes, we have seen that the uniaxial compression has its own limitation in achieving uniform grain density in the compact, as pressure gradients develop due to the unidirectional operation. And therefore, we need other shaping techniques which can apply the pressure uniformly and produce a homogeneous compact.

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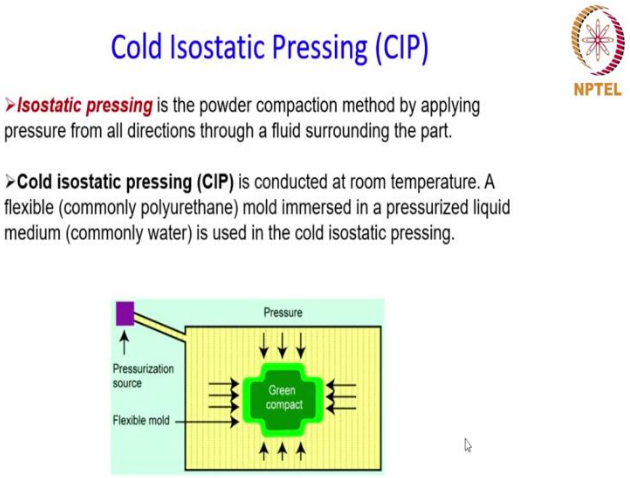

Cold isostatic pressing is a technique which can apply the pressure on the powder equally from all directions, and that is how it can overcome the problem of pressure gradients which develop in uniaxial pressing.

The technique is primarily based upon the principle that an object will experience equal pressure from all sides when immersed in a liquid, or in other words you can say that the liquid will exert equal pressure from all directions on the object.

And that is how the powder will experience the pressure uniformly throughout the mold without development of any pressure gradient. So, isostatic pressing is nothing, but the compaction of the powder by applying pressure from all directions through a fluid, surrounding the part, and the name cold suggests that it is conducted at room temperature.

In order to apply this liquid pressure onto the powder, a flexible mold is used. The mold is commonly made of polyurethane, and it is immersed in a pressurized fluid (which is commonly water) and pressed.

The schematic of the setup is shown in the slide above. The powder is filled in the flexible mold, and then it is immersed in a liquid which is pressurized with the help of the toolings which are there around it. So, apart from this flexible mold, the system will also have the toolings to pressurize and also to depressurize the system during the compaction process and the ejection process respectively.

So, the powder is filled in this flexible mold, and then it is loaded into the pressure chamber in which there is a liquid to pressurize it. And once the tooling and other things are brought in contact with this and the mold is closed, the pressurization system is switched on and the powder is pressed and compacted.

And when the compaction process is over, the system is again depressurized and the compact can be taken out from one of the ends, either from top or from bottom, depending on the shape you have in the green compact.

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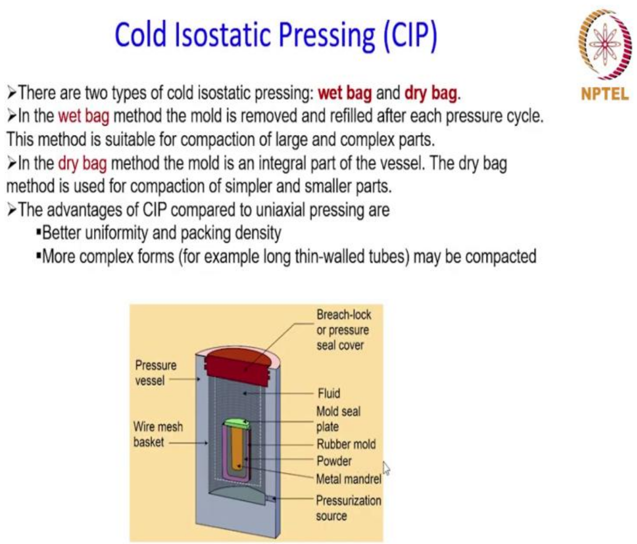

The cross sectional view of the pressure chamber or the pressure vessel of the cold isostatic pressing system is shown in the slide above. The flexible mold, in which the powder is filled, can be seen, and then surrounding it, there is a fluid to pressurize the powder. Then, there are toolings like bridge lock or pressure seal cover. Then, there is wire mesh. And then there is a pressurization source through which the pressure is applied to this flexible mold through the fluid. And then, you have the mold seal plate that is again the part of the tooling system, and if there is a part which is hollow in nature, then a metal mandrel can also be inserted through the mold to create that bore or the cavity.

There are two types of cold isostatic pressing or CIP, one is wet bag and the other one is dry bag. In the wet bag method, the mold is removed and refilled after each pressure cycle. So, here the same mold can be used again and again after each batch of compaction. So, once the compaction for a particular cycle is over, the mold is taken out cleaned and fresh powder can be filled again into it to do the next batch of compaction process. And this method is suitable for compaction of large and complex parts.

The dry bag method on the other hand has a mold which is an integral part of the vessel and in this case a thin flexible membrane separates the mold from the pressure fluid and keeps it dry and that is how the name dry bag. And this method is suitable for compaction of simpler and smaller part, contrary to the wet bag method which is suitable for larger and complex parts.

Now, the advantages of the isostatic pressing compared to uniaxial pressing are as follows: It provides a better uniformity and packing density which is obvious because here the pressure is applied uniformly or equally from all directions unlike the uniaxial pressing method in which the pressure is applied through an axis. And because of that, many a times pressure gradients develop and as a result of that the density of the compact will vary from place to place inside the compact.

And this kind of non uniform density is not good for the further processing particularly for the sintering process. And the other advantage is more complex forms, for example, parts like long thin walled tubes can be easily compacted by this cold isostatic pressing method. So, this was about CIP or cold isostatic pressing which can overcome the pressure gradient problem which is encountered in uniaxial pressing.

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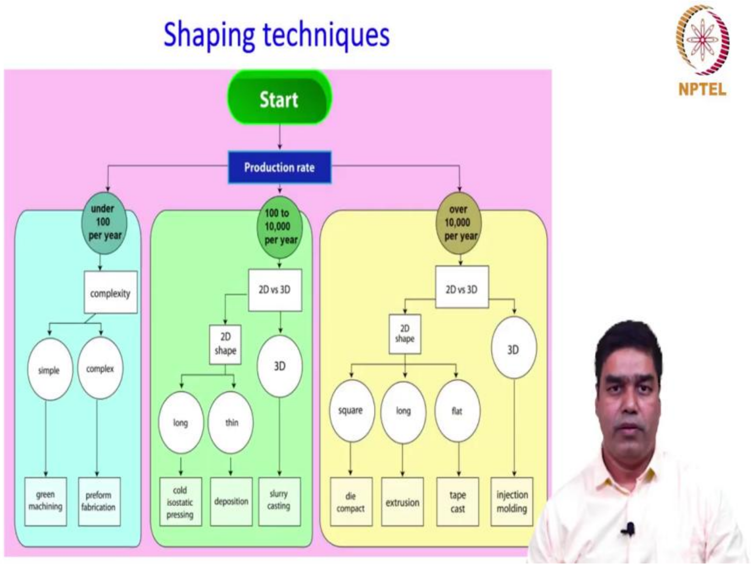

Now, there can be more complex shape parts where it is all the more necessary to maintain the uniformity, during the compaction process. So, as you can see from this diagram (slide above) powder injection molding is a process which can handle complex shapes including 3D parts and this is what we are going to discuss next.

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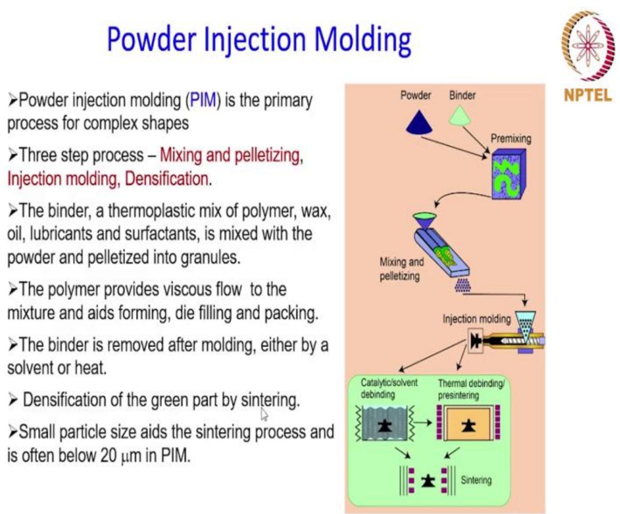

Powder injection molding is a process which can make complex parts including 3D parts, as we have seen before in that diagram which talks about the different categories of the shaping processes depending on the type and shape of the part. Powder injection molding or PIM is the primary process for complex shapes. And this process basically consists of three steps, first mixing and pelletizing, then injection molding, and finally, densification.

The three steps of the process are; (i) the powder is first mixed properly and then pelletized. So, mixing is done with the binder and then it is formed into small pellets which are loaded into the system for pressurizing this powder feed. So, that is the (ii) molding process, when it is actually being fed into a die cavity and pressurized and molded and also (iii) densification is achieved during the process.

The binder which is used here is a thermoplastic mix of polymer, wax, oil, lubricants and surfactants. And once it is mixed the powder it is pelletized into granules, so this is how the flowchart of the process is. You can see it from this particular diagram over here (slide above). The powder and the binder are mixed in a chamber and then it is first fed into the pelletizing chamber where it is pelletized into granules.

And, these granules are finally fed into the injection molding machine through a feeding hopper like this. So, we will come to this to see little more details as to how this exactly happens and how the process cycle goes. The polymer which is mixed provides viscous flow to the mixture, and aids the forming process, die filling, and packing. Once the powder is molded and densified the binder has to be removed because, if it is not removed it will leave behind porosity when it is heated for sintering.

The binder removal is done either by a solvent or by heating. So, if you heat it to a particular temperature and hold it over there for a certain period of time, then the binder will slowly evaporate out of the compact. And then it will be ready for the next step which is the sintering process for fully densifying it.

Small particle size will aid the sintering process and therefore, particle size below 20 micron is generally used in the powder injection molding process. So, if you look at this flowchart again (slide above) these pellets are fed into the injection molding chamber and then it is finally, fed into this die cavity where the mixture is pressurized and densified.

And once this green compact is removed from the die, it goes through debinding process or the binder removal process. And after that it finally goes for the sintering process where the final densification occurs.

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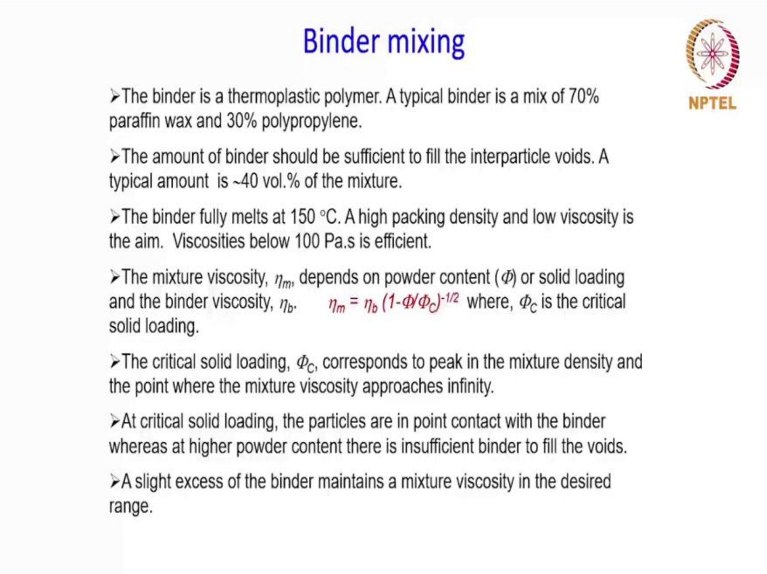

So, let us first talk about the binder mixing process before we actually go to the molding process because this is the first step. The binder basically is a thermoplastic polymer. A typical binder is a mix of seventy percent paraffin wax and thirty percent polypropylene. And the amount of binder should be sufficient to fill the inter-particle voids. A typical amount is about 40 volume percent of the mixture.

And the binder fully melts at around 150 degree Celsius, and here the objective is to achieve a high packing density and low viscosity. Viscosity below 100 Pascal second is efficient.

$$\eta_m = \eta_b(1 - \frac{\Phi}{\Phi_C})^{-1/2}$$

The mixture viscosity η_m, depends on the powder content or the solid loading which is written as Φ, and the binder viscosity η_b. So, this is the relationship which connects the solid loading or the powder content with the viscosity of the mixture which will be finally, obtained once the binder is mixed with the powder.

Here Φ_C is the critical solid loading, which corresponds to peak in the mixer density and the point where the mixture viscosity approaches infinity, right. So, that is how this critical solid loading is defined. At the critical solid loading the particles are in point contact with the binder, whereas at high powder content there is insufficient binder to fill the voids. So, this is what I said before also, the amount of binder should be sufficient so that it can spread out to fill the inter-particle voids and effectively create particle to particle contacts. So, if it is below that, then this purpose will not be served. A slight excess of the binder is used to maintain the mixture viscosity in the desired range.

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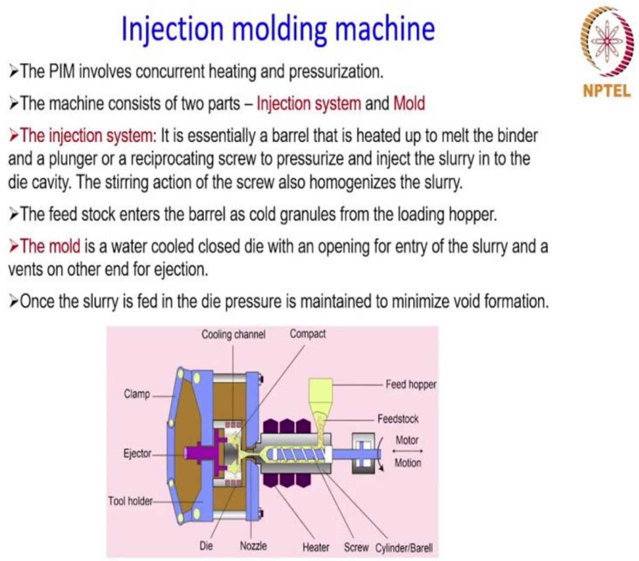

Now, let us see how this injection molding cycle goes. Powder injection molding involves concurrent heating and pressurization. If you look at the machine it basically consists of two parts, the injection system and the mold. The injection system essentially is a barrel that is heated up to melt the binder and apart from that it has a plunger or a reciprocating screw which is used to pressurize and inject the slurry into the die cavity, ok. So, the die cavity is the other part which is the mold.

The objective of having the injection system is to not only inject the powder binder mixture into the mold cavity. But also to homogenize it because the motion of the screw will also make sure that this powder binder mixture is agitated and it is homogenized before it is fed into the die cavity. As we have seen before the feedstock is fed in the form of granules which are first made in a mixing system.

And the loading into the barrel is done through a loading hopper. The granules are fed into the barrel through this feeding hopper over here. And now if you talk about the mold, it is basically a water cooled closed die system which has an opening for entry for the slurry from one end and vents on the other side for the ejection. So, the slurry goes from an opening on one side and then it is pressurized and the powder is compacted.

It is taken out from the other side, so that there is a vent and there are ejectors to take out the green compact from the die cavity. And then, in order to hold the die in place there are clamps and tool holder, and there are the heaters which are used to heat the powder binder mixture in order to melt the binder, so that it becomes fluid enough to go into this mold cavity and that fluid also helps in the compaction and the packing of the powder particles when they are pressurized.

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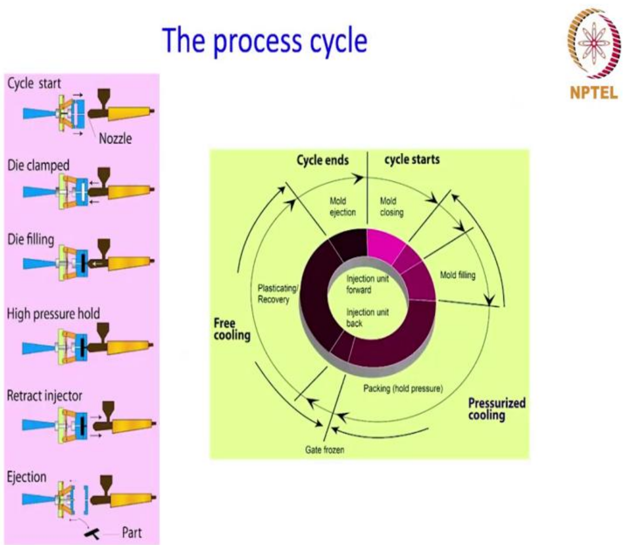

So, this is a schematic (slide above) which shows the process cycle from the start of the process to the end. At the start of the cycle the nozzle and the mold cavity (that is the injection system), and the die cavity, these two are kept ready and then the die is clamped and it is steady for the die filling process.

So, the powder is fed through the feeding hopper as the granules and then, the barrel is brought in contact with the die so that, the powder binder mixture can enter the die cavity through the nozzle. It is the die filling stage.

Once the die is filled by the binder powder mixture, the die cavity is pressurized to compact the powder. And at the end of the compaction process the injector is retracted and finally, the compact is ejected from the die cavity, and the green part or the green compact is obtained.

This also depicts the same process cycle in a different manner, but the stages remain the same. First, when the cycle starts, the mold is closed; the die is clamped. So, that is the start of the cycle and then the mold is filled by the powder binder mixture, and once the mold is filled it is pressurized for the packing to take place. So, here the pressure is held. So, that the powder can compacted and densified. So, at this stage when the pressure is held or at this pressure hold period, the gates are frozen and no more powder binder mixture enters the mold cavity. So, at the end of the pressurization cycle there is a free cooling, where plasticating and some recovery happens. And then after that once it is cooled down, the injector is retracted and the compact is ejected from the mold.

So, that is when the cycle ends with the final step which is the mold ejection process. And then it is again ready for the next cycle and starts again from the same process of mold closing and going through the other steps one by one as we have discussed. So, this is how batch by batch the powder can be compacted going through this PIM cycle.

Before we finish it let us take a moment to summarize it. So, in this lecture, we first talked about the isostatic pressing which is pressing a powder compact from all directions with equal pressure.

This is to overcome the unequal pressurization that happens in uniaxial pressing which also leads to pressure gradient in the compact during the pressing process and that in turn leads to density gradients which is not good for the powder metallurgy process as such as far as the dimensional tolerances and the sintering process of the compact are concerned.

So, here a liquid is used to apply the pressure on the powder from all sides uniformly and in order to do that flexible molds are used which are immersed in a fluid which is being pressurized. And there are two varieties of cold isostatic pressing, one is the wet bag process and another is the dry bag process. Wet bag process is primarily used for compaction of large and complex parts; whereas the dry bag method is suitable for compaction of simpler and smaller parts.

Then, today, we have started this process called powder injection molding. This is a suitable process for making complex shapes; the process primarily consists of three steps, mixing and pelletizing, injection molding, and densification. So, here the powder is mixed with the binder which is melted in a barrel by a heating it to a particular temperature.

And, the slurry which is obtained by this process is fed into a die cavity where it is pressurized to compact and densify the powder. And, the binder has to be mixed with a particular concentration and there is a critical solid loading which will give rise to optimum viscosity to the mixture, so that it can be properly fed into the mold cavity. And then, we had also seen the PIM equipment it basically consists of two parts, one is the injection system and another is the mold.

The injection system basically consists of a barrel in which the powder feedstock is fed through a feeding hopper. And it basically has the barrel in which there is a reciprocating screw which not only feeds the powder binder mixture into the mold cavity, but also homogenizes it. And as the feedstock enters the mold cavity, the die is clamped into place and the powder is pressurized to compact it and densify it.

The process cycle was explained with the help of a diagram (slide above). And, with that we come to the end of this particular lecture.

Thank you for watching.