Powder Metallurgy
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Lecture – 38
Powder Injection Molding – 2

Hello everyone and welcome back. So, right now we are discussing about the Powder Injection Molding or the PIM process which is primarily used for complex 3D parts and in the previous class we have discussed about the PIM equipment and the process cycle. So, we will continue on this and see the other details of the process in this particular class. So, in this lecture we are going to discuss the shaping process in powder injection molding.

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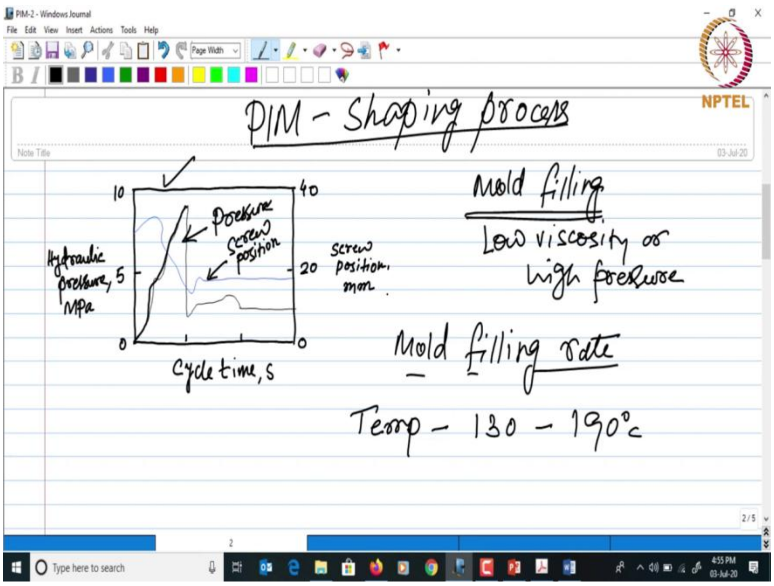

The shaping process depends on successful mold filling and for the mold filling to happen effectively high pressures or low viscosities are needed; now, the molding machine which is used for shaping the powder will have its own limitation in terms of the maximum pressure that can be applied and temperature on the other hand controls the viscosity and therefore, temperature and pressure become the primary control parameters in the molding process.

And apart from that mold filling rate is also important. So, in order to make sure that the mixture has enough viscosity it is heated to a temperature in the range of 130 to 190 °C and forward thrust of the screw in the barrel injects the molten feedstock into the die.

So, here is a diagram where you can see the relations between the screw position, the hydraulic pressure that is applied and the cycle time during molding. Due to an increased resistance to the mold filling the process requires a constant increase in the pressure as controlled by the screw position. So, both of these things are shown in the plot (slide above).

Due to the increased resistance to the flow of the powder binder mixture into the mold cavity, the pressure has to be continuously increased and the temperature also drops during the mold filling process and therefore, the viscosity increases.

And hence, it becomes all the more necessary to increase the pressure until the die cavity is completely filled and the molding pressure that has to be applied is dependent on the die geometry, binder and the powder characteristics.

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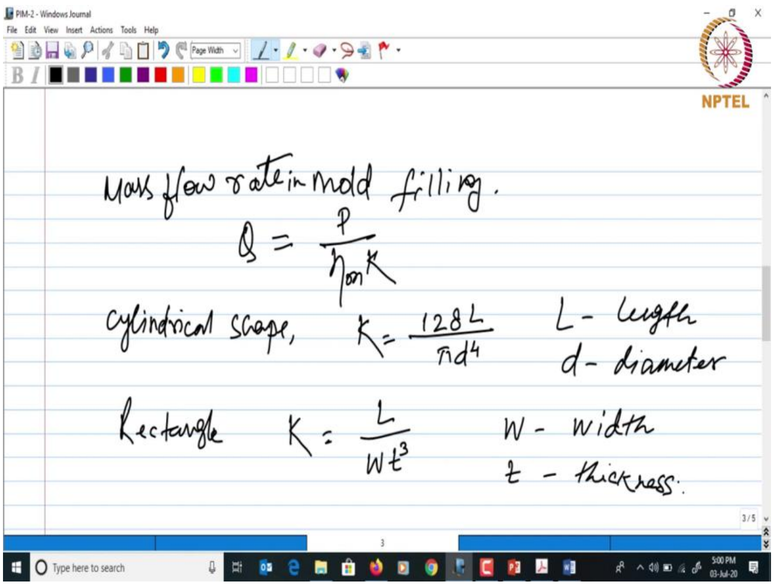

Now, if you look at the mass flow rate during the mold filling, that is also an important parameter that has to be looked at. Let us call that as Q and the relation of Q with the pressure P is given as this:

$$Q = \frac{P}{\eta_m K}$$

where η_m is the viscosity of the mixture and K depends on the mold geometry. For a cylindrical shape K is given as: $K = \frac{128L}{\pi d^4}$, where L is the length and d is the diameter of the cylinder.

And for a rectangular shape K is given as: $K = \frac{L}{Wt^3}$, where W is the width and t is the thickness. So, from here you can see that the mold filling rate or the mass flow rate during mold filling increases with the increased pressure and that is why a high pressure is always good for filling the mold.

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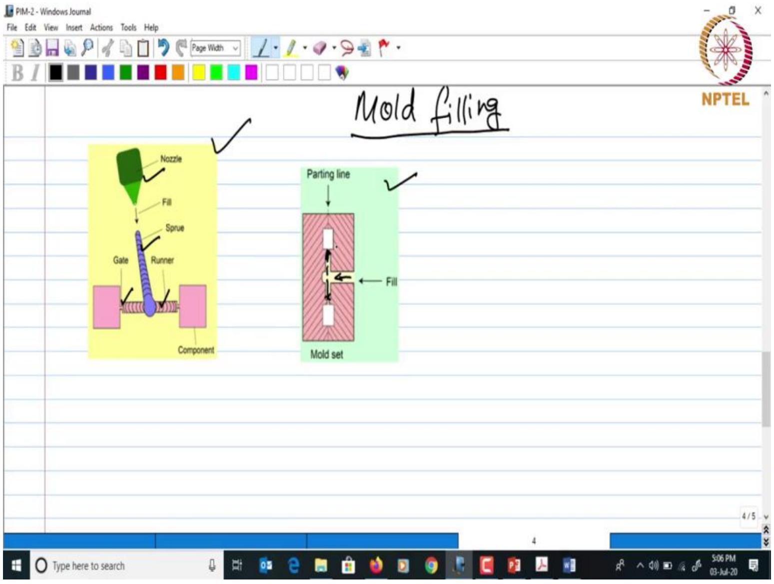

The picture in the slide above shows the flow path in the mold which is used in the injection molding tooling. Here it shows the location of the nozzle, the sprue through which the powder binder mixture flows into the die and before it enters the die cavity there is a runner and gate is the entry point to the mold cavity and a parting line can also be seen. So, the mold can be in two parts. So, across this line these two parts are divided and through the sprue, the powder binder mixture comes into the runner and then flows into the mold cavity through the gates; that is how the mold gets filled during the process.

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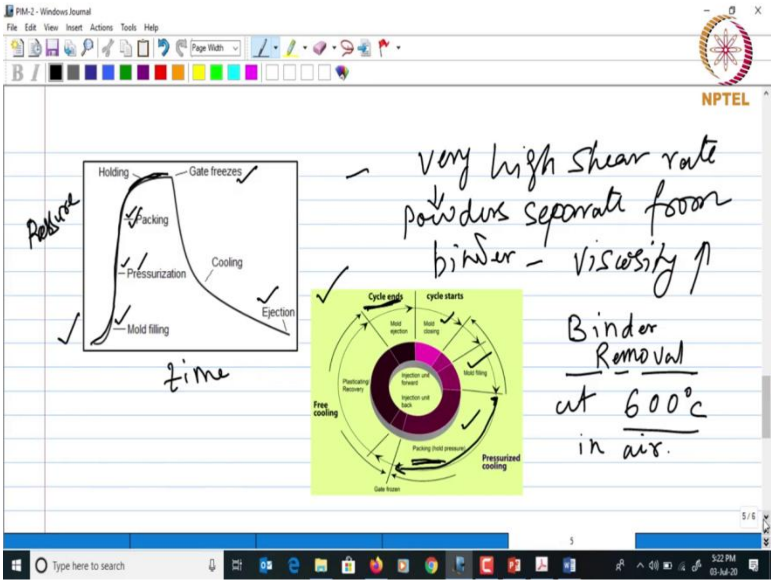

Now successful molding also requires low viscosity and viscosity will depend on the shear rate. If the shear rate is very high then the powders will tend to separate from the binder and the viscosity will increase and it will lead to non uniform mold filling because the mold filling depends on availability of a fluid mixture which can easily flow into the cavity to all the corners.

And therefore, if the viscosity is not optimum then the mold filling will not be uniform. Similarly, if there is a temperature drop which normally happens since the tooling is at a lower temperature, the viscosity will increase and that will also result in improper mold filling.

So, in order to make sure that the mold is properly filled the pressure it has to be continuously increased and has to be held. So, if you see the pressure with respect to time, it has to be continuously increased as the mold filling starts and then as you would have seen in the PIM cycle, after mold filling there is pressurization and then packing happens and the pressure has to be held when it reaches high pressure to ensure that the mold filling happens properly. So, this pressure hold compensates for the contraction and ensures that defect free components will form at the end of the PIM cycle.

And that is why it is necessary to hold the pressure when it reaches the maximum pressure. Not only to ensure that the mold filling happens effectively, but also to make sure that it takes care of the dimensional tolerances and compensates for the contraction that happens.

Because here the binder is in liquid condition; so, when it will solidify and the plastication will take place, then it will contract and as it contracts the pressure has to be held high in order to make sure that the contraction is compensated. So, that the dimensional tolerances can be maintained and a proper defect free component can be produced at the end of the PIM cycle. The slide above shows the same cycle. In this plot also you can see the processes which occur during this cycle starting from mold filling that begins after the mold is closed and as the pressure is applied, the packing starts to happen and this is the corresponding region of the cycle for the same and then the pressure has to be held.

And during this cold pressure period the gates are frozen so that no more powder binder mixture comes into the mold cavity and whatever has gone inside that is properly filled into the mold and effectively compressed so that a defect free component can be made at the end of the process.

During the whole pressure period the gate freezes and once the pressurization cycle is completed, the mold is allowed to cool down and once it is cooled the mold is opened and the compact is ejected when the cycle ends. Once it is ejected the next process that is to be followed is the binder removal process. The binder is actually a volatile matter and if it is not removed before sintering, then it will leave behind porosity as it leaves the component during the high temperature heating that takes place during the sintering process.

So, that is why before the component is heated to the sintering temperature, the binder has to be removed at a lower temperature to make sure that porosities are not generated due to the presence of binder.

Thermal Debinding means, removal of the binder by heating to higher temperature at around 600 °C in air atmosphere and the other process of binder removal is by using a solvent. A solvent can also be used to remove the binder partly so that the thermal and solvent removal processes can be combined.

A part of the binder can be removed by solvent process before the component is heated to remove the leftover binder and this can save on the heating time as well as the power requirement for the heating and that might ultimately lead to some cost saving as well.

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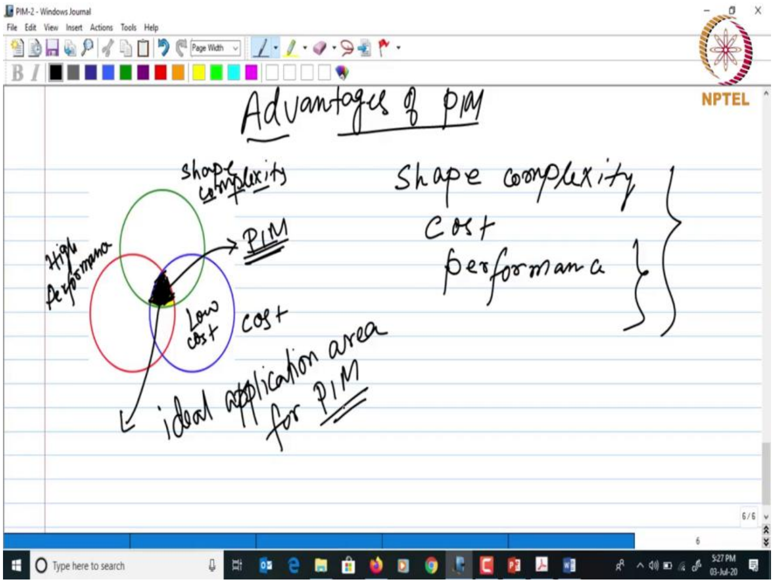

Now, if you talk about the advantages of this process, these are the three main considerations; the complexity of the shape, the cost and performance as to what will be the properties of the component which is made by this process and how it will perform when it is actually being used in that particular application for which it is made.

So, these three parameters can be represented by a Venn diagram like this, where these three circles represent shape complexity, cost and performance. So, there is a region which is the intersection of these three circles representing these three parameters and this intersection is actually the PIM region which means the PIM process can include all of these advantages into one single process.

So, complex shapes can be handled easily, it will be a low cost process and the performance should be high. So, all these can be obtained into one process if that process lies in this intersection. So, this is where the PIM process will lie and that is why it can provide all these advantages in one single process.

So, we can see this area is the ideal application area for the PIM process; that means, when all these three are needed into one single process, then the PIM process can be used.

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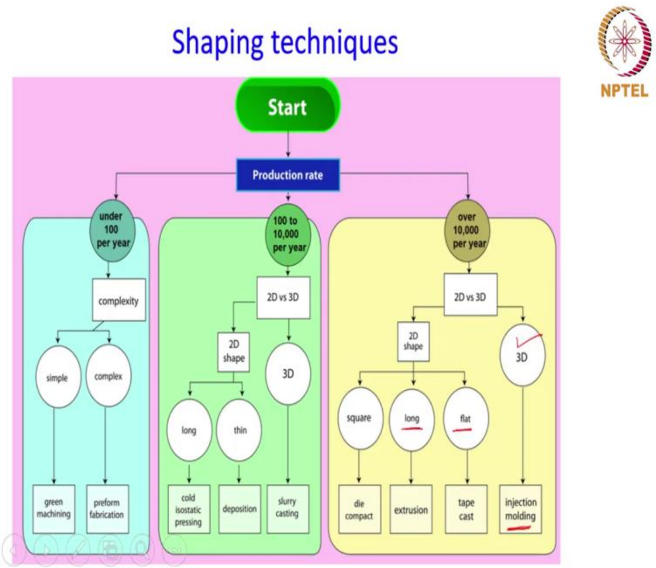

Now, let us come back to this diagram where it all started. So, from here you can see what kind of shaping techniques are needed for what kind of shapes and you can see injection molding is over here and it can be used for making 3 D shapes and complex shapes.

And now you can also see here that for other kind of shape complexity like for example, if you have a long product which is to be made or a flat kind of product that is needed for a particular application then these kinds of bulk shaping processes that we have discussed so, far may not be suitable. Rather you may need a process which can handle it in a different way in the sense that it will basically deal with wet powders in the sense that the powder will be made into some kind of slurry and then formed into the required shape.

In the injection molding also a slurry is made, but that was primarily through a binder which was melted to make that slurry, but in these cases it can be also mixed with some other kind of binder in an aqueous system to make the part in the required forms for example, in a thin tape.

So, all those also have to be discussed we will take that up separately, but for this particular class this is all I have, but before we wind up let us take a moment to summarize this lecture.

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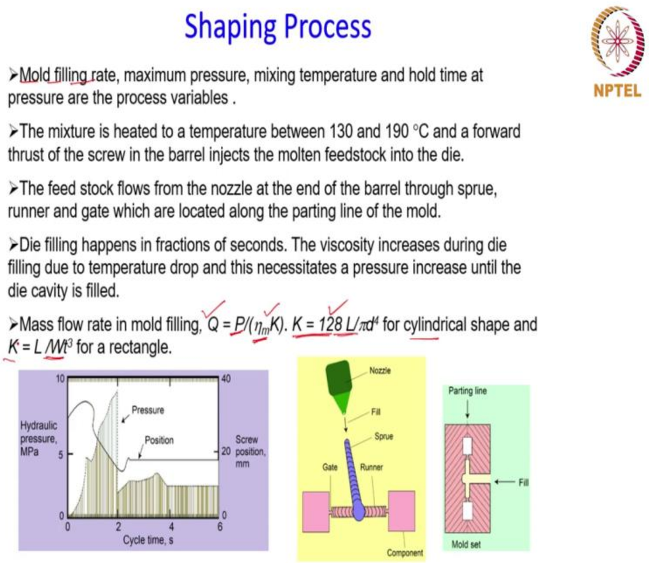

So, in this lecture we discussed about the shaping process that happens in the powder injection molding process and in this as far as the mold filling is concerned the two main parameters are the temperature and the pressure because pressure makes sure that the mold is filled, the powder is pushed into the mold cavity and it is completely filled and temperature on the other hand controls the viscosity of the powder binder mixture.

And apart from that the mold filling rate also has an effect on the process and this rate depends on the pressure, it is proportional to the pressure and inversely proportional to the viscosity of the mixture. The geometry of the part will also have an influence because how the mold will be filled that will of course, depend on the geometry of the mold.

So, the parameter K in the equation, $Q = \frac{P}{\eta_m K}$, takes care of the geometry, for example, for a cylindrical shape it is given by $K = \frac{128L}{\pi d^4}$ and if it is some other shape like rectangular shape then again accordingly depending on the dimensions, the K will vary.

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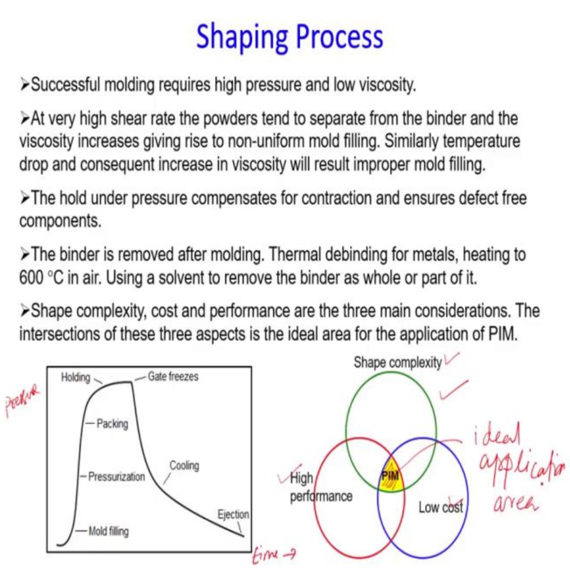

Then we talked about the process cycle again in terms of the pressure and the time, the pressure time cycle. As far as the pressure is concerned, there are two important things that need to be maintained; one is the pressure has to be continuously increased and second the pressure has to be held when it reaches the peak.

This is to ensure that whatever changes that occurred into the powder binder mixture due to a change in the temperature, will be taken care of and also the contraction that happens when the binder solidifies will also be compensated.

And finally, we discussed about the advantage of this PIM process with the help of a Venn diagram which shows that the PIM process can combine all the advantages like handling complex shapes, low cost and high performance. So, therefore, the intersection region becomes the ideal application area for the PIM process. So, with that we come to the end of this class.