**Processing of Polymers and Polymer Composites**

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**Lecture – 20**
**Injection Molding**

[FL] friends, welcome to our course on Processing of Polymers and Polymer Composites. So, we are currently midway in our course, we have to discuss or maybe have forty sessions in the course of half an hour each and today we are exactly 50 percent through. So, today we are having over lesson number 20 or session number 20 and the topic for today is of important very important very important commercial process that is injection molding. You may have seen and may recall that what we have covered in the previous sessions, we are currently focusing our attention on the second part of our course that is processing of polymer composites.

In the previous sessions maybe 1st 30, 13 sessions 1 3, 1st 13 sessions we have focused our attention on polymers, from 14th session we started our discussion on polymer composites and in polymer composites we have seen what are composite materials what are the fundamentals of composite materials, what is the classification of composite materials, what are the challenges in context of composite materials. We have also seen processes that are used for making the composite products and if you remember the very first process that we have seen was a hand layup process. And in hand layup process you have seen it is a manual process it a widely used process, the shape of the product is slightly limited we can make simpler shapes in hand layup process, but the size of the product is unlimited we can go for a very large size products in hand layup process.

Then we have seen modification of the hand layup process that is a spray layup process. In which short fibers are used there is a chopper gun or a spray gun through which our polymer and fiber and the catalyst are mixed together and they are spread on the mold. So, that is another modification of hand layup process then we have seen last in the last session a compression molding process which is a commercial process widely used process and is used for making number of composite products which are used in aircraft industry aerospace industry as well as in our domestic applications.

So, we have seen 3 processes. So, you summarize what we have covered, basically we have to see that how we can combine the fibers or the fibers and the polymers together. So, basically the process has to have some mechanism through which the fibers and the polymers can be combined together. In hand layup process we were using continuous fibers and we were laying up stacking of the mat of the fiber or the fiber mat, one above the other and then we were applying the resin after each layer. And then the 4 layers, 6 years, 8 layer layers were laid up in order to make a laminate and that laminate was our final product.

In compression molding also we have seen both thermoset and thermoplastics can be molded and we can get a product, which is a final product for any engineering application. So, basically we are combining the fibers and the polymer together to make composite products. Now, from the classification point of view if you remember from polymers side we have 2 major classifications, that is thermosetting polymers and thermoplastic polymers from the fibers point of view there is a classification based on the long fibers, woven mat form unidirectional long fibers.

So, from long fibers also there can be 2 3 types of arrangements. Then the opposite of long fibers is the short fibers. So, we can have short fibers also as in the example of spray layup process you cut the fibers into small small small small smaller fibers in the chopper gun and these fibers when impregnated with the polymer in the chopper gun is deposited on the mold. Surface and we have seen a video also a very good representation of making of boat large sized boats using a spray layup process.

So, the point that I want to make here is that from polymer point of view, as well as from the fiber point of view, there are lot of permutations and combinations that are possible and injection molding process that we are going to study today is mostly used for short fiber reinforced polymer composites. So, we cannot may use make use of injection molding process for very long fibers it will be use only for small fibers for making the reinforcement. And the polymer will be the thermoplastic polymer and if you remember we have already discussed the basic concept of injection molding in our discussion on processing of polymers.

So, the basic machine remains same the process almost remains same only difference that we have to introduce here is that how to combine the pellet us and the fibers together

otherwise the process remains same the process details remains same, the process equipment remains same, only thing is the means and mechanisms through which we are going to introduce the fibers into the polymer and finally, what are the intricacies that are involved in this mechanism and what will be the type of the product that we will get in the injection molding process.

So, basically we have to focus our attention on the last point that I have highlighted that is how the fibers and the polymers will be mixed together, this is also a closed mold process. Must I say that closed mold 2 processes we have seen hand layup and spray layup both are open mold processes. Last session we discussed compression molding process which is the closed mold process, now currently we will be seeing today injection molding which is also a closed mold process. So, till today we will have discussed 2 open mold processes and 2 closed mold processes.

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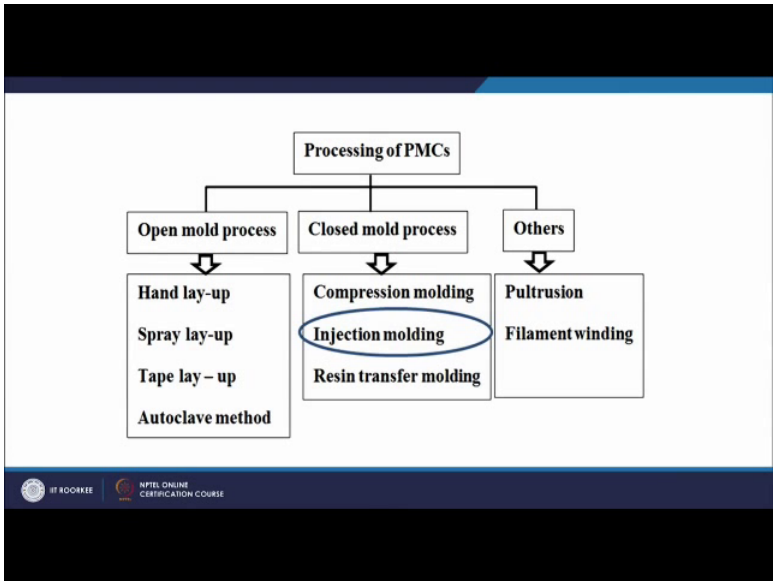


Now, let us first go through the discussion and the PPT this slide is common to all our presentations on polymer composites you can see, the open mold processes 2 we have already covered hand layup and spray layup and injection molding is going to be covered today and the last session we have covered the compression molding process.

Now injection molding let us try to understand it is step by step injection molding process the closed molding process already the process is suitable for both thermoplastic and thermosetting polymers polymer based short fiber reinforced composites.

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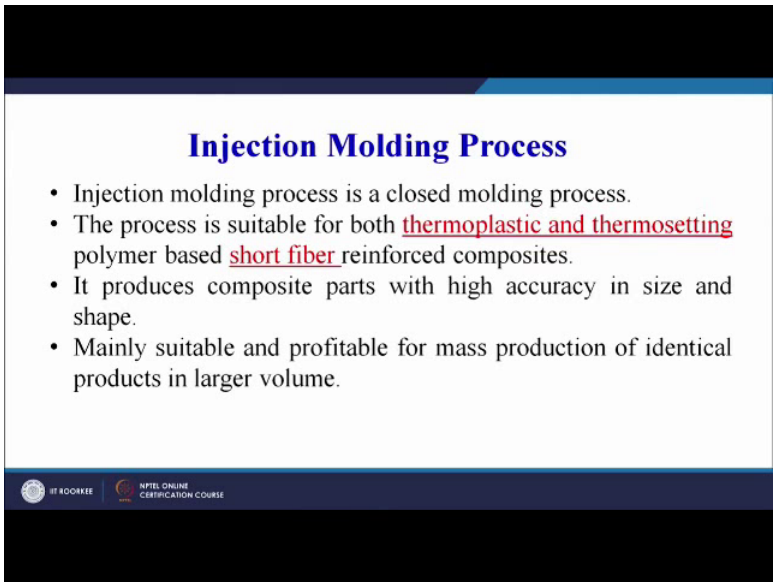


So, majorly maximum applications are there for thermoplastic based composites, but may be under special circumstances we may also go for thermosetting based polymers also, but most of the applications we will see that the process or the injection molding is used for making thermoplastic based short fiber reinforced composites it produces composite parts with high accuracy and shape. So, this is one thumb rule wherever we will have a closed mold process, there will be a you can say characteristic advantage that we will get very good surface finish and very high dimensional accuracy mainly suitable and profitable for mass production of identical products in large volume.

So, there are 3 things here mass production, identical products, larger volume; larger volume is not in terms of the volume literally, but it is in the term of numbers or products that we are going to make that are mass production of the large number of parts. Now the parts have to be identical, now what is the bottom line in this particular point is that last time also we discussed in our course on injection molding or in our session on injection molding, that the die or the mold is the most important part of any set up which is used for processing of polymers or polymer based composite.

So, the shape of the die the complexity of the die that is very very important and the cost involved is also most important to consider any particular process. Now in injection molding as well as in compression molding the cost of the die or the mold is very very very important. So, the if we are going to make small number of parts the cost of the die

will not be justified therefore, this process has to be used for large number of parts only why because the die is very very costly and even the initial investment required to procure or purchase a injection molding machine is relatively higher as compared to the hand layup or the spray layup process.

So, wherever we are going to make another point that is going to come up in the subsequent slide is that this process is not used for very large size parts. So, the point is that if the size of the product is not that large, the number of products required is large, the complexity of the shape or the die is not that we can say problematic means the shape is we can control the shape that is the shape is not very very complex and then short fibers have to be used we will easily think of only one process that is injection molding process.

Large number of parts size is not large complexity of the product is not very high and the short fibers have to be used for reinforcement, I think in the these 4 criteria we can very easily say that the exact process or the optimal process that should be used for such criteria is the injection molding process. So, this is an point that we should always keep in mind the die or the mold cause course cost is the very very important criteria when deciding to procure a injection molding machine.

On your screen you have a injection molding machine or a setup this is a schematic of a injection molding machine.

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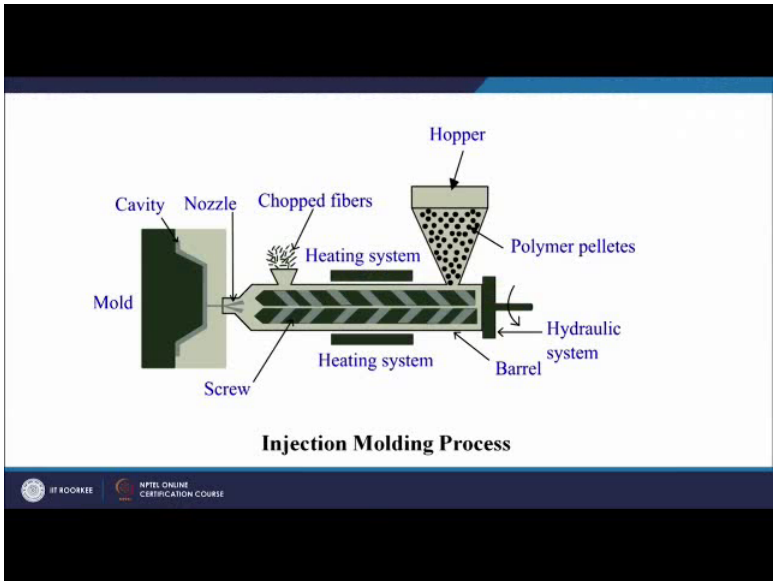

So, here we can see the first let us see the most costly part that is the mold their mold is in 2 halves this light gray color is one half of the mold, dark gray color is the other half of the mold, and when the 2 halves of the mold closed in between we get a cavity exact replica of the final product that we want to make. So, in between this is a cavity this is a product that we want to make.

Now, here you can see the other system more or less is same only addition is the chopped fibers; this is the chopped fibers that you see on your screen. Now as per the process details as we have already discussed we will put our polymer pellet us the black color polymer pellet us are shown here. So, these polymer pellet us we will put in the hopper and through hopper they will be coming into the barrel, now there is a heating system all around the barrel which will heat these polymer pellet us and they will be converted or there is the polymer pellet us will melt and they will be moved forward via the screw and here we can see there can be a hydraulic system or there can be a screw system.

So, here a screw is shown here the screw will rotate and it will push the polymer melt forward towards the mold or the die. As the polymer will move forward along the rotation of the screw we are feeding the chopped fibers from here these are the chopped fibers being fed from here. You can see they are small sized fibers and the fibers will mix with the polymer here and they will be pushed through the nozzle into the mold cavity the mold cavity is generated between the 2 halves of the mold as we have already seen. So, this is the process of introducing the fibers just before the polymer is going to enter into the mold cavity.

And we have to ensure that the fibers are uniformly distributed inside the polymer and we get a uniform composite product so that is the basic process. Now there can be other variants of this process which the for which we do not have the diagrams here, but I would just like to briefly highlight what can be the other variants for extremely small size of fibers, we have these pellet us that are already available and in these plates the short fibers are pre impregnated. So, we have short fibers already in the pellet form and we get may be pellet us with glass fibers, for that we need not have this mechanism of introducing our fibers here it will be a solid barrel without this mechanism.

So, the pellet us itself will have the fibers. So, there are extremely small fibers which are there in the pellet form. So, we will have a polymer also we will have a fiber also inside

the polymer pellet and it will be introduced directly from the hopper. Now these pellet us pre fabricated pellet us will have both fibers and polymer and when it will enter into the barrel the polymer will melt because of the heating system and this mixture of fibers and polymers will move inside the barrel and it will be pushed into the mold cavity by the screw or a piston cylinder arrangement.

So, that kind of flexibility is also available in which the fiber laden pellet us are already available from the market. Then there can be third mechanism or third variant of this process of introducing the short fibers into the polymers through the hopper only. We can introduce our fibers directly in the hopper, but what can be the problem you can just have a a thinking in this direction that if we put our fibers directly in the hopper what can be the problem. You can just think over it the problem basically will be that the fibers that are introduced at this point just below the hopper you will have the travel this much of distance, inside the heating, inside the barrel alongside along with the polymer and they will be heated.

Now, suppose we are using the natural fibers there is a tendency regarding the degradation of these natural fibers under high temperature, that is one we can say chance of failure of the fiber the degradation in the properties of the fiber, the second problem can be the fibers may get sheared by the rotation of the screw and this shearing of the fibers may reduce their length and may cause damage to the fibers and the fibers may not be able to achieve the purpose for which they have been introduced into the polymer.

So, basically there are number of studies available in which the fiber is introduced long with the polymer pellet us through the hopper, but it has been reported that there is certain amount of degradation in the properties of the fiber when the move through the barrel alongside the polymer. Therefore, the advanced version can be that you introduce your fibers just before the polymer is going to enter into the mold cavity. So, that the fibers do not travel a long distance inside the heated barrel. So, that is one maybe process modification which is being used.

So, I think we have seen the latest modification in the injection molding setup for introducing the fibers into the polymers. So, this is the most important thing we need to understand regarding the induction of the fibers into the polymer. Otherwise the standard injection molding process is well known most of you may be knowing for those of you

who are not knowing at least in this course the learners have got an idea, that what is injection molding of polymers in the last session in the maybe in our sessions on processing of polymers, we have covered the injection molding process in much more detail.

So, today I think I need to emphasize on this aspect only that how the polymer will be reinforced with the natural fibers or the synthetic fibers and how the fibers will be introduced into the polymer and I think I have try to explain this with 2 or 3 variants of the process. Now coming on to the procedure I have already explained. So, we will have a a glimpse of certain a finer points in the form of sentences. So, that we understand and we keep this in our mind we remember this for a long period of time that how the fibers are introduced into the polymer.

So, the fibers and polymers are either pre blended or mixed manually and fed into the hopper.

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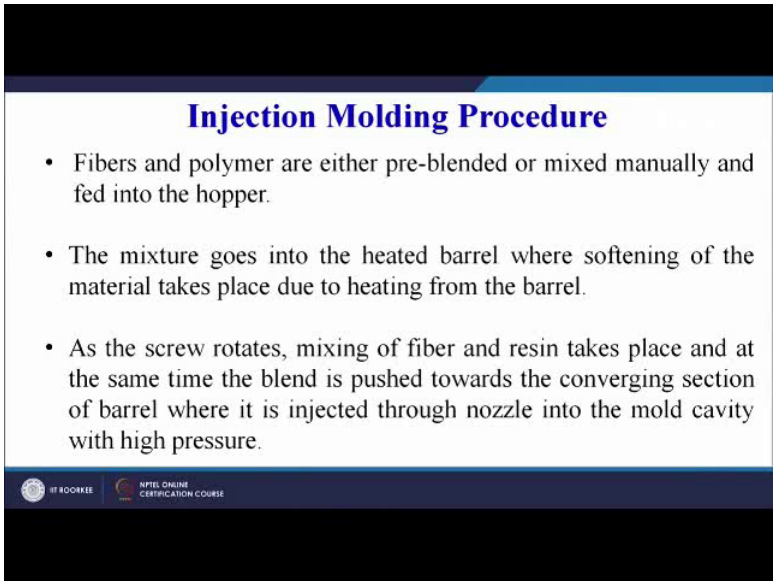


Now 2 points are important here Pre-blended yes there are pellet us which are available or pre blended pellet us are available which have the fibers very small sized fibers pre-blended into the polymer. So, directly then the process becomes very simple we have to buy these pellet us and directly put these pellet us into the hopper and then our process will automatically be running and the fibers and polymers will move through the barrel into the mold cavity and we will get our product, or the second point is we can mix the

fibers and the polymers in the hopper and then the fiber and polymer will come from the hopper into the barrel and then they will be pushed forward the because of the heat the polymer will melt and it will be pushed forward into the mold cavity, that is a another thing.

So, 2 variants third variant as we have already seen the diagram that the fibers are introduced separately, just at the end of the barrel just before the entry of the polymer into the mold cavity. So, that is another variant, but there the limitation I think it might have occurred to your minds also that what can be the limitation there, the blinding of the fiber and the polymer is getting very less time because we are just introducing the fibers before the entry of the polymer into the mold.

So, the fiber and polymer is getting very less time for having a handshake or for having a friendship or for developing a friendship. So, the time period maybe one of the limitations in that case, when we are just introducing the fibers before the entry of the polymer into the mold cavity so that can be one limitation there, but yes different methods have been used and have been found successful for different combinations of polymers and fibers. So, the mixture goes into the heated barrel where softening of the material takes place due to heating from the barrel all of you know that, as the screw rotates mixing of fiber and resin takes place and at the same time the blend is pushed towards the converging section of barrel where it is injected through the nozzle into the mold cavity with high pressure.

So, I have already explained from the hopper we get the raw material it enters into the barrel, a screw arrangement rotates this mixture and because of the heating arrangement the polymer may be is softened and then it is pushed forward and through the converging section at the nozzle the material is pushed into the pushed may be or as the name of the process, suggests injected into the mold cavity at very high pressure. Now why high pressures is required because the polymer has to go inside the mold and reach to the farthest corner of the mold.

If we do not apply presser the polymer may not have the velocity to enter into the farthest or the thinner sections of the mold and we may get a defective product. So, we have to optimize the injection pressure also in order to get a good quality product.

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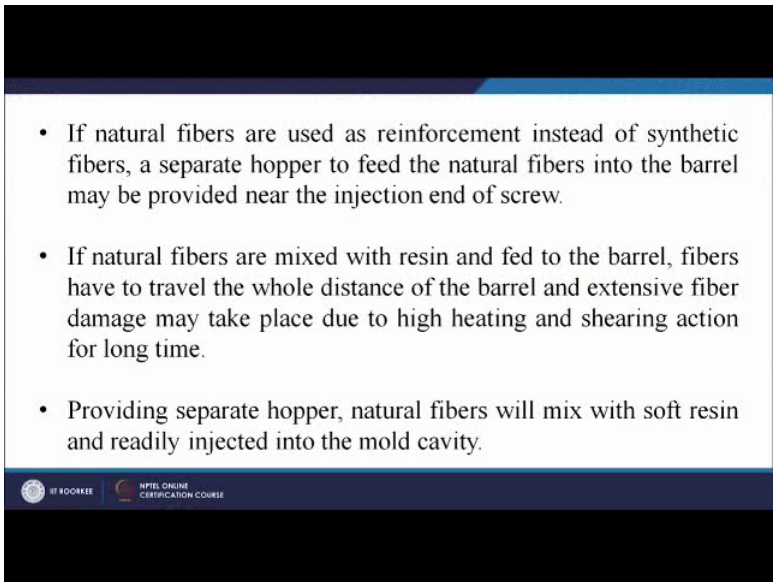


If natural fibers are used as reinforcement instead of synthetic fibers a special case because we know that in case of composites we can have synthetic fiber reinforcement, we can have a natural fiber reinforcement; a separate hopper to feed the natural fibers into the barrel may be provided near the injection end of the screw.

So, that I have already explained that we may introduce the fiber just at the end of the barrel. So, that the fibers and just mix with the polymer and enters into the mold through nozzle. If natural fibers are mixed with resin and fed to the barrel fibers have to travel the whole distance of the barrel and extensive fiber damage may take place due to high heating and shearing action for a long time. I have already explained that specifically for natural fibers that is one of the limiting areas or one of the limiting issues therefore, we try to introduce our natural fiber just at the end of the barrel, as was shown in our diagram, providing separate hopper natural fibers will mix with soft resin and readily get injected into the mold cavity.

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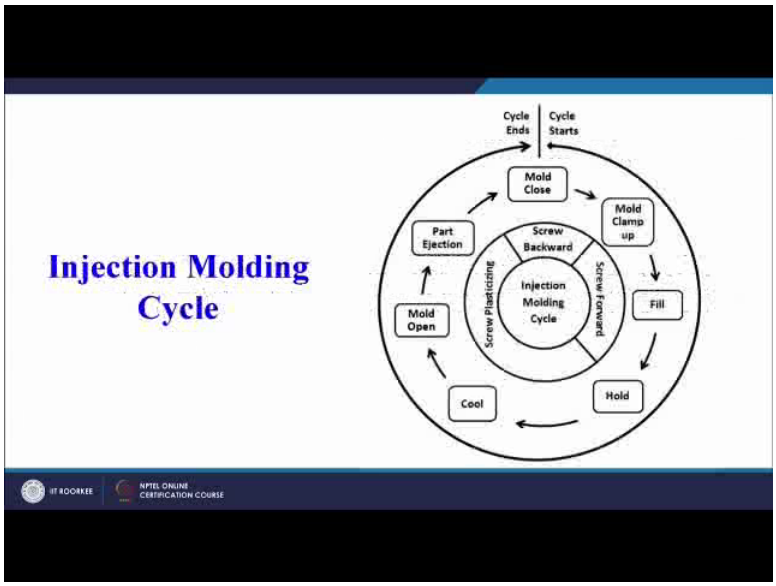


Now, this is a standard injection molding cycle just introduced to revise the concept of injection molding. So, on your screen you can see the cycle starts here the mold closes, as soon as the mold closes the cavities formed inside the mold or the cavity which is the exact replica of our product is forms formed inside the mold. So, the mold closes the cavity is now inside the mold the mold clamp up. So, a pressure is of light to keep the mold halves clamped then we have to fill the mold with the raw material.

Now, raw material in case of our injection molding process is combination of a fiber and the polymer. So, that is injected through the nozzle into the mold cavity then we have to keep the mold halves closed that is called the hold or the holding time in order to get a solidified or a rigid or a stiff product. So, we will give some time to the mold to remain closed. So, that the polymer filled with fibers inside the mold gets some time to solidify. So, we will keep the mold halves closed it will lead to cooling of the material inside and solidification of the material then once the material has solidified we will open the mold and the part injection will take place.

Now, part injection is sometimes facilitated with the help of ejector pins as the polymer has the tendency to stick to the metallic mold. So, if the material or the product may stick to the fixed half of the mold. So, there are 2 halves of the mold; one is a movable halve which will come and close the mold, other one is the fixed half. Now the material may have because of the shape complexity have a tendency to stick to one half of the mold.

So, wherever it has the tendency we can have a inject ejector pins, ejector pins which will be hydraulically operated or pneumatically operated we which will just give a tap to the part solidified composite part or product and it will fall down into the collection bin or collecting bin.

So, that is one thing that is part ejection and once the part has ejected the ejection will take place when the mold has opened up. So, once the ejection has taken place the mold is already opened, now the again the cycle will start the mold will close again we have the cavity inside the mold will be filled and the second cycle will start. So, there are these 3 to 4 steps which are automatic in nature and the process can be automated before that we have to do some optimization that at what pressure we have to push the material for what time we have to keep the mold closed.

What is the back pressure what should be the clamping force. So, these are the operating variables that we have to keep in mind, when we are designing the injection molding process for a specific combination of a polymer and a fiber. So, let us quickly see that how the composite products can be made.

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Here we have a Poly propylene pellet us this is a pellet form which is shown here, then we have chopped sisal fibers, this is one type of a natural fiber, the length of the fiber may range from 2 to 3 millimeter and this is a partially green composites this will be exact, we can say product that we want to make which is a partially green composite

because polypropylene is a non biodegradable polymer, but the fiber that we are using is a natural fiber.

So, when we combine these 2 in the hopper we can get a final product of this form this particular product will be made because of the shape of the mold.

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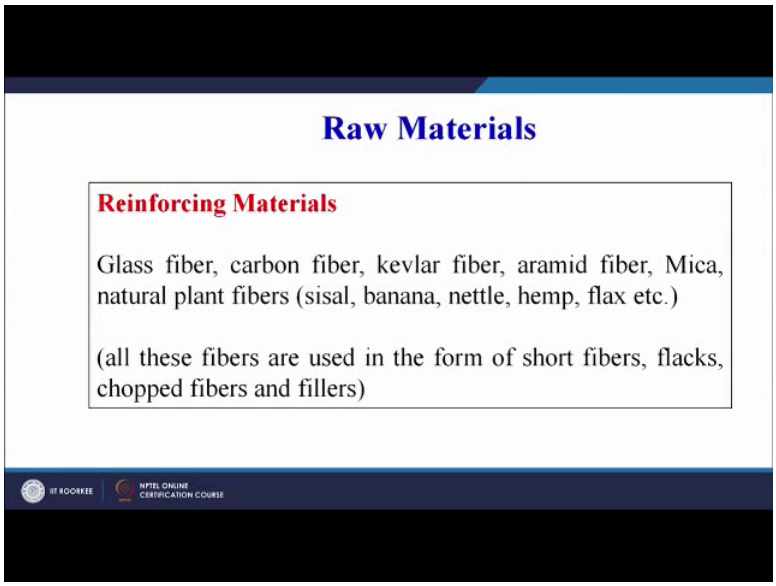


Now what are the reinforcement materials glass fiber, carbon fiber, kevlar fiber, natural plant fibers like sisal, banana, nettle, hemp, then all these fibers are used in the form of short fibers flacks chopped fibers and fillers I have already told injection molding process is well developed for short natural or synthetic fibers. From matrix point of view thermoplastic and thermosetting resins can be used from thermoplastic polypropylene; Polyethylene polycarbonate polyvinyl chloride and from thermosetting epoxy polyester polyvinyl ester can be used.

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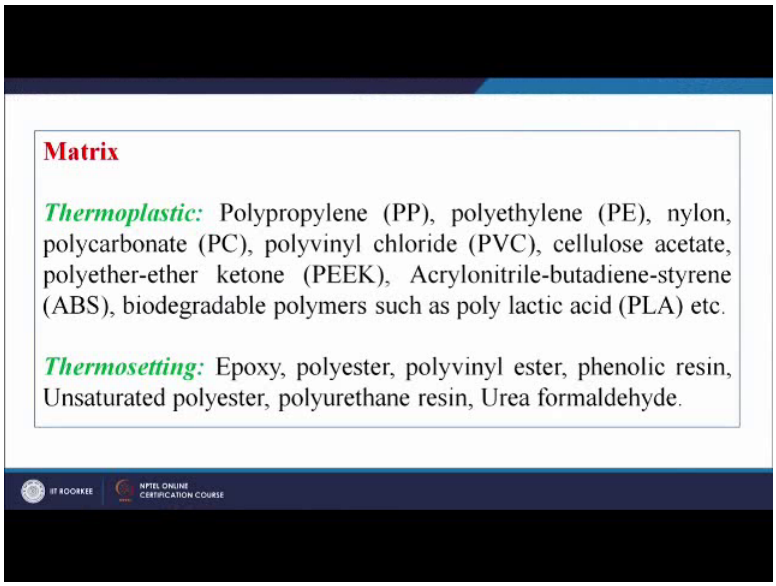


Now, Process Parameters.

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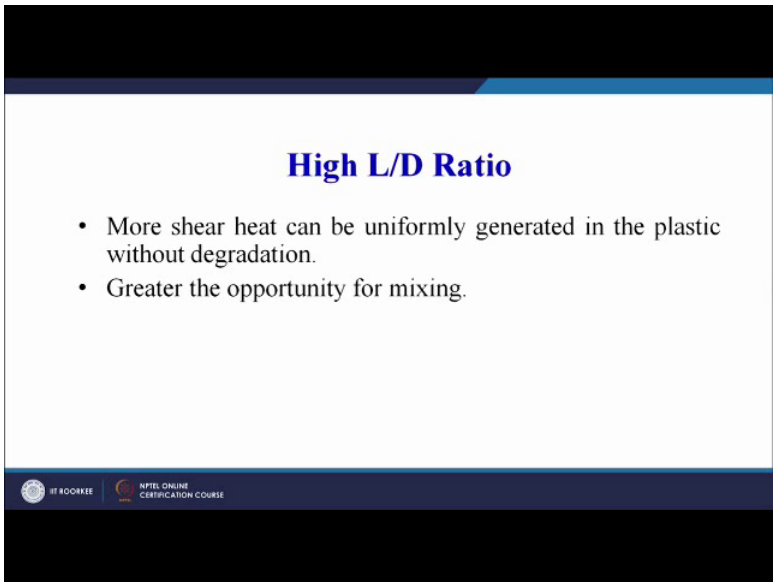


Quickly let us see high L by D ratio more shear heat can be uniformly generated in the plastic without degradation and it will high L by D ratio will lead a greater opportunity for mixing and in order to get the details of this points I would request all of you to refer to our discussion on injection molding that we have done for injection molding of polymers. Because the effect of the operating variables is more or less same in case of natural in case of fiber reinforced polymers as well as for neat polymers.

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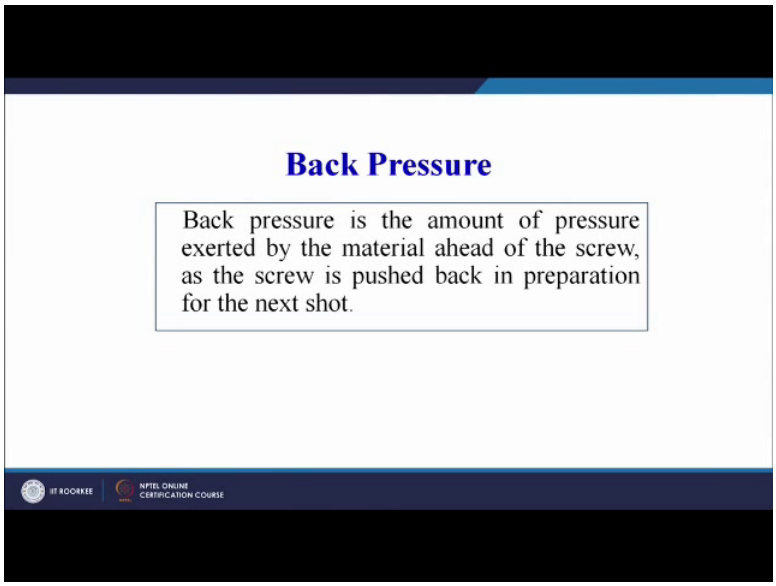


So, Back Pressure is the amount of pressure exhorted by the material ahead of the screw as the screw is pushed back in preparation for the next short of the next cycle.

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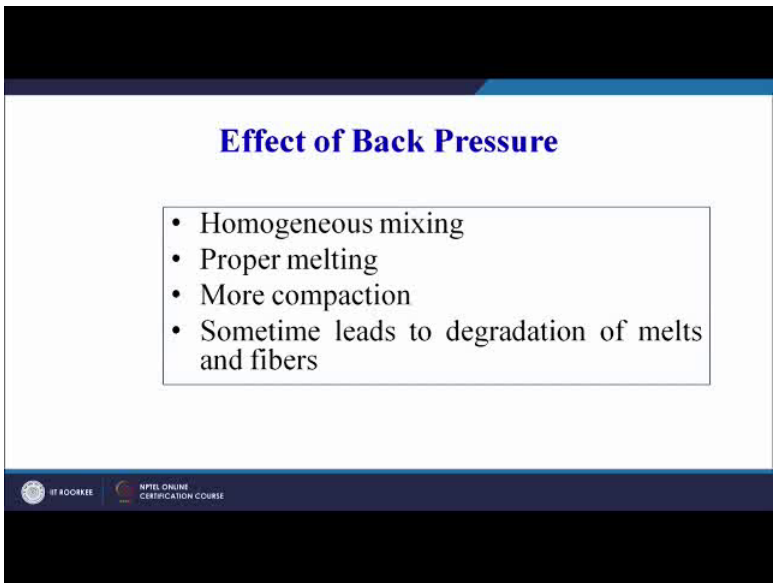


Then what is effect of back pressure it will lead to homogeneous mixing, proper melting of the raw material that is the polymer, more compaction and sometimes may lead to degradation of the melts and the fiber. So, we have to optimally select the back pressure. So, that no degradation of the fiber takes place.

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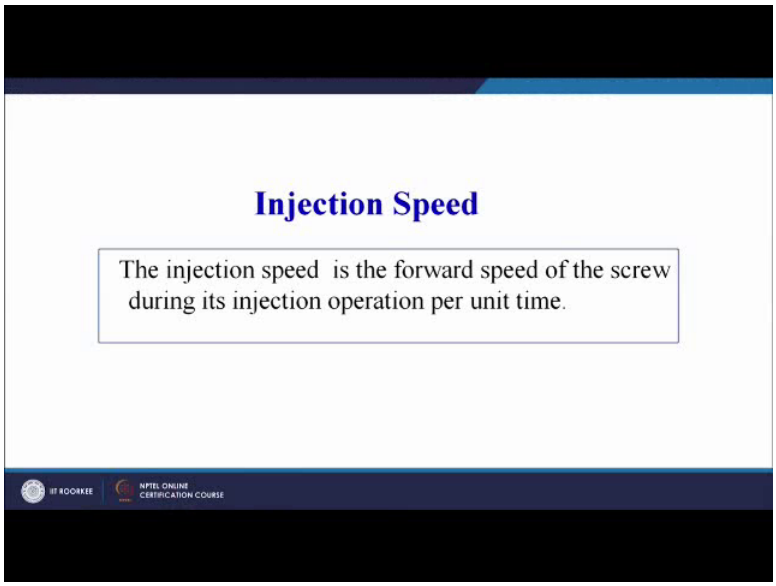


Injection speed is the forward speed of the screw during it is injection operation per unit time.

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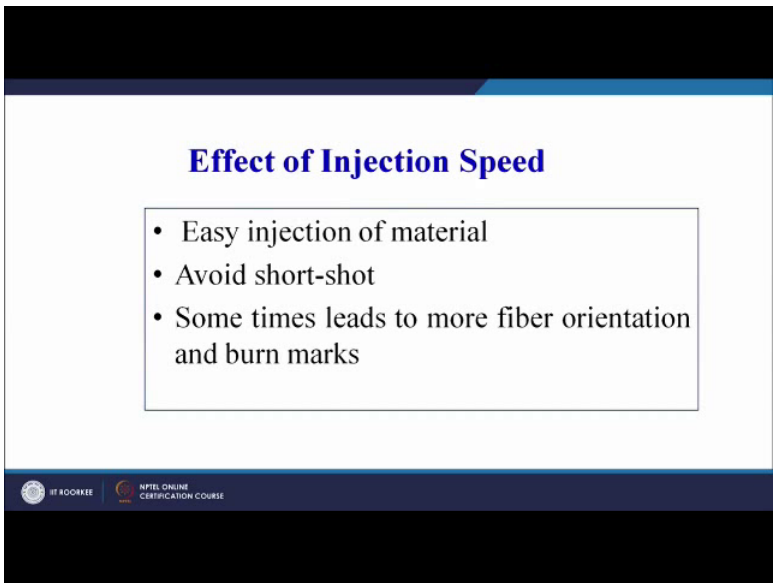


Now, what is the effect of the injection speed easy injection of material it will avoid the short shot that is the product may not be formed as per the dimensions sometimes leads to more fiber orientation and burn marks.

So, fiber orientation because a high injection speed we may get a defined fiber orientation so that sometimes maybe not desirable in case of a composite products.

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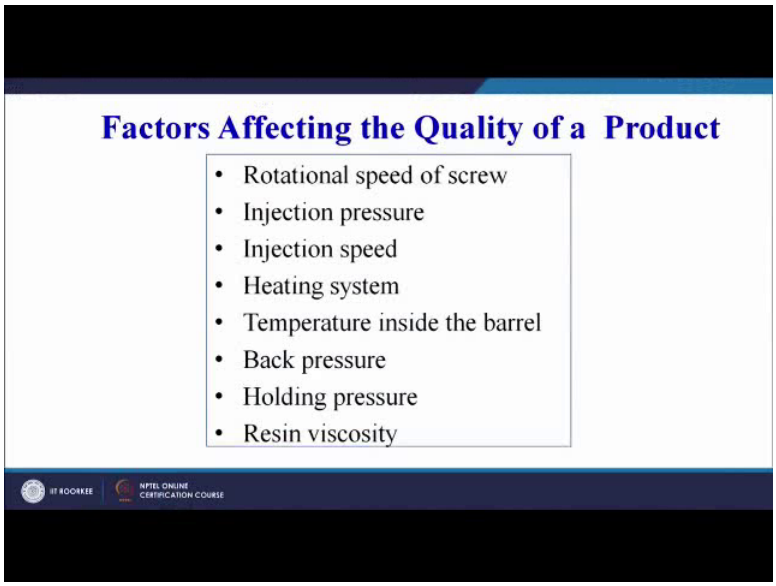


So, these are the factors that affect the quality of the product very quickly we can read these rotation speed of the screw, injection pressure, injection speed, heating system, temperature inside the barrel, back pressure, holding pressure, resin viscosity, and this list is not complete there can be other parameters also which can affect the quality of the product made by the injection molding process.

But certainly as an engineer we can keep these important parameters in mind that these are the parameters that we have to optimize that we need to optimize for a specific combination of a polymer and the fiber. So, that we get a good quality product. If you see in the previous 2 3 slides we have seen that a large combination of fibers and polymers is possible from polymers point of view we have seen a large list or a long list of thermoplastics and thermosetting polymers which can be used for injection molding. Then we have seen synthetic fibers and natural fibers which can be used for injection molding. So, therefore, we have to judiciously select all these parameters. So, that we get a good quality product.

In our next session we will discuss in detail regarding other variants of the injection molding process and we will try to understand that what changes can be done in injection molding in order to have or in order to develop products for specific applications.

Thank you.