Processing of Non–Metals

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Module - 5
Polymer Matrix Composites: Processing
Lecture - 8
Injection Molding

Good morning to all of you, a very warm welcome to this lecture on injection molding. We have been discussing a series of lectures on Processing of Non-Metals. And in processing of non-metals in model number five, we are discussing the processing aspects of polymer matrix composites. So our focus is on the processing aspects as well as we are discussing the advantages, limitations and the application areas of the various processes. Just to take you back and summarize what we have already covered, we have covered the importance of polymeric matrix composites in various engineering applications. We have seen what are polymer matrix composites, what are the constituents of the polymer matrix composites, and how do they compare with the conventional engineering materials such as steel and other isotropic material.

We have also seen the classification of the various processes, which are used for fabricating or processing parts of polymer matrix composites. So, broadly the processes can be classified into three - that is the open mold processes, the closed mold processes and the others. So, we have seen few processes, we have seen the advantages, limitations and the applications of these processes. To name a few the processes which have already been covered, we have covered hand lay-up process, spray lay-up process, pultrusion, filament winding and compression molding.

So, in today's lecture, we would be discussing the details of the injection molding process. So, injection molding process has also got certain variants. So, we will try to address very briefly the variants of the injection molding process. Majorly our focus would be to understand the basic aspects of the injection molding process. So, we will first like to understand that in the broad classification of the processing of polymer matrix composites, this particular technique where it falls in which category it falls.

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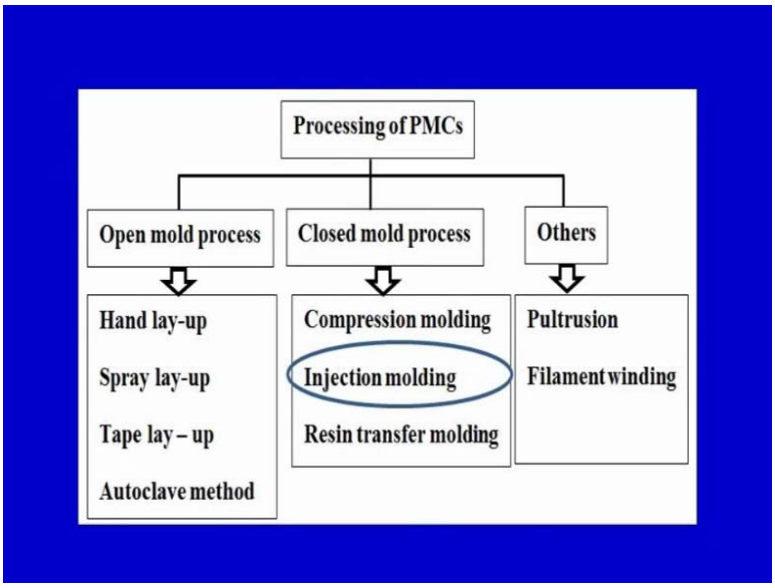

On your screen, you can see in case of processing of polymeric matrix composites injection molding falls under the category of closed mold process. So, we have open mold process closed mold processes and others. So, if again to revise and if we look into what we have already covered, we can see we have covered the hand lay-up process on your screen. We have covered the hand lay-up process and the spray lay-up process which fall under the category of open mold processes. In closed mold process, we have seen compression molding, and today we are focusing on injection molding. In others, we have already discussed pultrusion and we have seen filament winding in the last lecture. So, today our topic of discussion would be injection molding process. So, injection molding process is one of the most important processes, which is used for processing of plastics as well as processing of fiber reinforced plastics or polymeric matrix composites.

The basic details of the injection molding process we have already seen in the processing of plastics in a different module. But today our focus would be to incorporate the two constituents of the composite together. If we have to do the injection molding of simple or nascent plastics or only polymers, the process would be different. The basic principle would be same, but in case of processing of fiber reinforced plastics or polymeric matrix composites, wherever the world composite comes we have already understood that two important things have to go in order to make a composite material. Or the two important things you have to go into or to form into one particular thing that is called a composites

material. Now what are these two things again I am revising the two things are the matrix and the reinforcement.

The reinforcement in case of polymeric matrix composites is in the form of fibers, and the matrix is in the form of a polymer or a resin. So, the resin and the polymer have to mix with the fibers in order to make a composite material. So, what I need to emphasize here is that the process which we have already covered for processing of plastics that is injection molding of plastics. In that particular process, there was no incorporation of the fibers into the matrix, or there only the polymer products were made or the plastic products were made, and there was no fibers in the final product. But in case of polymer matrix composites, the matrix would be a resin, but it has to be reinforced, it has to be strengthened with the addition of fibers. So, we have to see that how fibers can be added into the plastic in order to make it a fiber reinforced plastic. So, this is one process which is a closed mold process in which the final product would be a discrete product, it would be exact duplicate of the shape of the mold that is used in the injection molding process.

So, we will get a large number of products may be 100 products per hour or may be 50 products per hour depending upon the production rate of the process. But injection molding is a very very important process, it makes discrete products as well as it is a continues process or we can in the other words we can say it is a automatic process. So, we will see today the basic details of the injection molding process, which the basic details already we have covered in the processing of plastics. But today our focus would be that how to incorporate the fibers and what additional issues and challenges are there when the fiber are put into the matrix or fibers are mixed with the polymer in order to make a polymeric matrix composites. So, with this particular background, we will start our discussion about the basic process that is the injection molding process.

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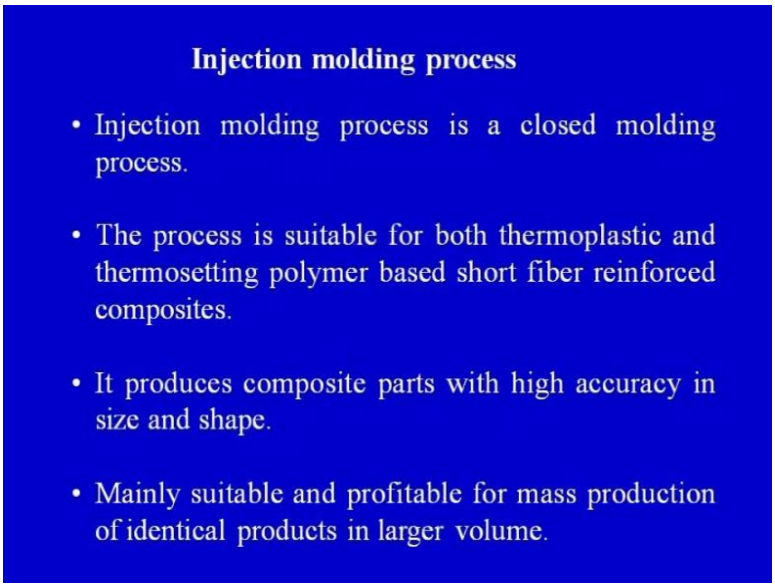

Now, injection-molding process is a closed molding process, which we have already discussed in the previous slide. In which we have seen the classification of the processes which are used for making polymeric matrix composite. So, injection molding falls under the category of closed mold. So, the mold in this case would be a closed mold. So, the process is suitable for both thermoplastic and thermosetting polymers. So, this particular process can be used, as we have seen the polymers can broadly be classified into thermoplastics and thermosets. So, there are processes which are only suitable for thermosets, and there are process processes which are suitable for both the thermosetting resins and the thermoplastic resin.

So, this particular process can be used to process parts out of thermoplastics also as well as out of thermosets also. And the short fibers reinforcement would be put into the matrix. So, we have the process is suitable for both thermoplastic and thermoset polymers based on the short fiber reinforce composite. So, important point to note here is that short fiber composites are made. They in a particular variant of the injection molding process, we can use continues mat also, but in most of the injection molding of composites short fibers reinforcement would only be use. This is an important point to note that incase of injection molding short fibers are usually incorporated, but the research work is going on in the direction of incorporating long fibers also in the injection molding process.

It produces composite parts with high accuracy in shape and size. So, the accuracy that we achieve in case of injection molding process is a comparatively good and the size or the dimensional accuracy is also good. So, we get a very dimensionally accurate and a very high quality product in case of injection molding. Mainly suitable and profitable for mass production of identical products in larger volume, so the same type of product now two important points needs to be emphasized in this particular bullet. If you see on your slide the last point mainly suitable for and profitable, it is suitable and profitable for mass production of identical parts in large volume. So, identical parts why there is a emphasis on identical, because in the total injection molding setup or injection molding machine, the cost of the mold is extremely important, and it is extremely higher. The molds that are used for making the composite parts are relatively costlier. So, when we are procuring a very costly mold for the making of composite products, the cost high cost of the mold has to be justified by the large volume of the products.

So, if we are changing the product or the design, the new mold has to be procured. So, identical product means that if one particular design has to be made in one lakh components or two lakh components or five lakh components then the cost of the mold is justified. But if we have suppose five components only the cost of the mold may not be justified. So, injection molding is particularly suitable when the part design is fixed or the product design is not changing to often. And similarly that cost of the mold or the cost of the machine is only justified when the volume of production is large. Volume of production large means that large number of components are being made of the same product design, because the mold is fix the machine is fix and if we have large volume of product of production we would be able to justify the cost of the mold and the cost of the machine.

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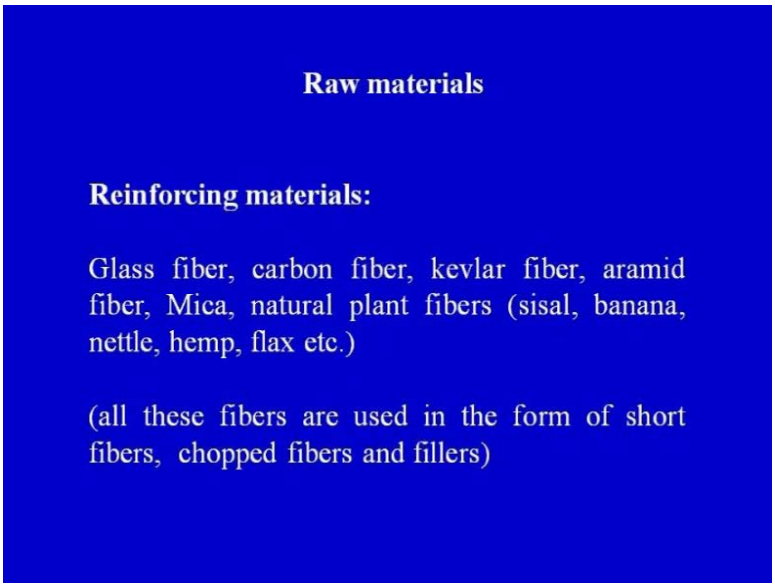

What are the raw materials, which are used. In raw materials, we have glass fiber which are the common raw materials which are used in making of polymeric matrix composites. So, we have glass fibers, carbon fibers, Kevlar fibers, aramid fiber, we have natural plants fibers such as sisal, banana, nettle, hemp. So, we have seen that a classification of the fibers also. We have synthetic fibers and we have natural fibers. So, we can think of incorporating both these types of fibers with the polymer in order to make a polymeric matrix composite. One important point I want to emphasize here is that the Kevlar and aramid are the same type of fiber one is that the trade name of the fiber. And cavalier and aramid, otherwise the two types of fibers are merely same. And all these fibers are used in the form of short fibers, short fibers and fillers. So, the fibers would be short in case of injection molding again.

I am emphasizing the research is going on in the direction of incorporating long fibers in the polymers, in order to make the fiber reinforce long fiber reinforce plastic products or polymeric matrix composite materials. But till today most of the work or most of the commercialized processes that fall under the injection molding process fall use the short fiber reinforcement only. Now, as we already know that the two important constituents have to combined together to make a composite materiel; one of the constituent is a reinforcement which is in the form of fibers. The fibers are short fibers in case of injection molding and we have seen what are the different types of fibers which go into

the injection molding product. So, the fibers are the carbon fiber, glass fiber, aramid fiber or these can be natural fibers like hemp, sisal, nettle.

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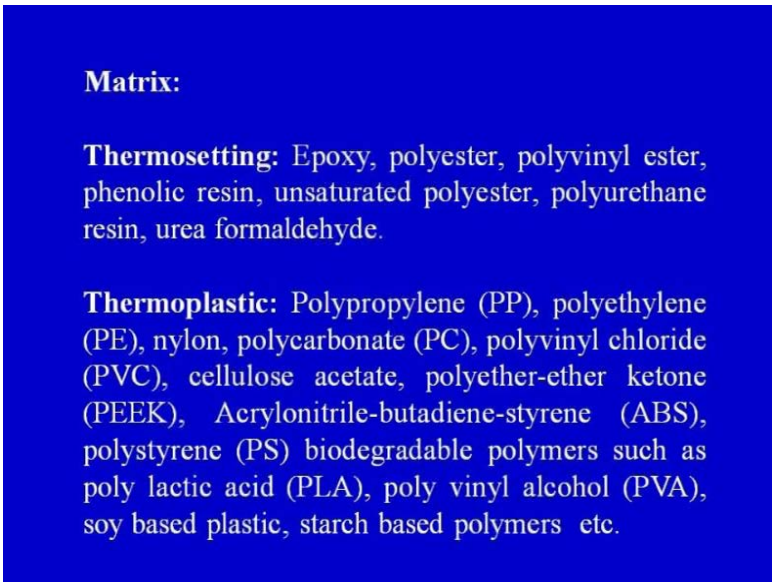

The second constituent is the matrix material, which is the polymer. In case of polymer matrix composites, so different types of polymers can be used which are broad classified as the thermosetting polymers and the thermo plastic polymer. We see different examples of the thermosetting and thermo plastic polymers. I will read out of few for you. In case of thermosetting, we can have epoxy, polyester, polyvinyl ester, phenolic resin, unsaturated polyester. In case of thermo plastics, we can have polypropylene, polyethylene, nylon, we can have acrylonitrile-butadiene-styrene, we can have polystyrene, we can have natural biodegradable polymers such as poly lactic acid, poly vinyl alcohol, soy based plastics or starch based polymers.

So, different types of polymers can be used now, the process would be adjusted according to the needs and requirements of a particular polymer. So, depending upon the needs and requirements of the reinforcement, and depending upon the needs and requirement of the matrix the process has to be adjusted. And one of the important parameters in context of the plastics or the polymers is the viscosity of the melt which we have seen in the properties of the plastics in one of the previous modules So, the viscosity is very very important of the polymer when it has to take the fibers and make a composite product. So, the viscosity is very very important criteria.

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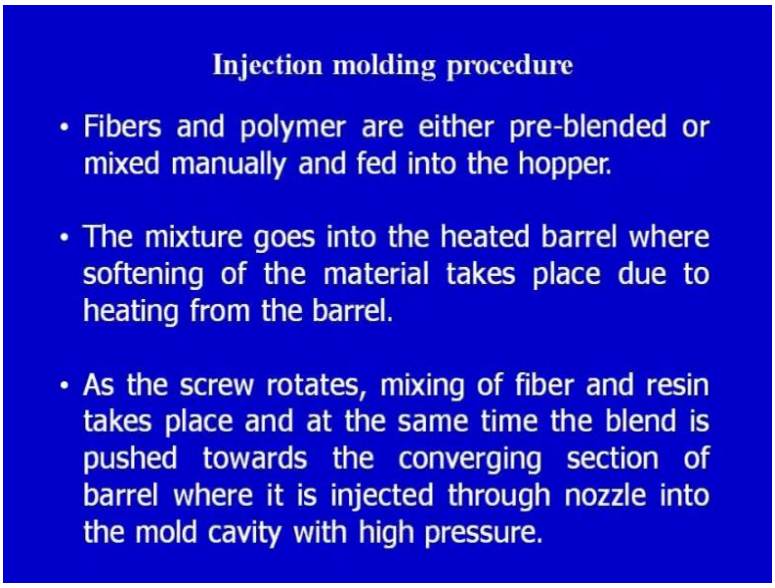

Now, the injection molding procedure, now we have seen that injection molding process falls under the category of closed mold process. We have seen what are the raw materials that go into the injection molding process, there is a reinforcement and there is a matrix. Matrix and reinforcement combine together to make a composite product. We have also seen that injection-molding process is a versatile process, it can use different types of fibers, it can use different types of matrices. It is suitable for different types of polymers. We have seen that it is very suitable when large number of parts have to be made and identical parts have to be made. So, it this particular process has got lot of advantages, and now we are going to see the process details that how the process actually takes place or how the raw material in the form of reinforcement and the matrix are blended together and converted or processed into the final composite product.

So, we will address this point by point. So, the first point is the fiber and the polymers are either pre-blended or mixed manually and fed into the hopper. Now, the first thing is the raw material that will go into the process. As we have seen in our lecture on processing of plastics and where we have discussed injection-molding process for plastics, we have seen the raw material is in the form of the pelletes or the granules. So, this pelletes and granule in case of simple injection molding or injection molding of plastics are made up of any of the polymer which we have just seen in one of the previous slides.

But in case of fibrous reinforcement or in case of composite products, what we need to do we need to pre-blend the matrix that is the polymer or the resin and the fibers. So, this pre-blending means that we will incorporate very short fibers into the pelletes or into the the other forms of the polymer that is available as I have already told pelletes or the granuals. So these small fibers would be there pre-blended or initially only before the process the raw material would be blended in such as a way that these polymers would be carrying the fibers. So, the fibers would be blended into the polymers and the raw material would be modified to suit to the needs and requirements of the injection molding process.

So, the fibers and polymer are either pre-blended or they may be mixed manually and fed into the hopper. So, the raw material comes from the hopper; in the hopper, we may pot pr-blended raw material in which the fibers are already present in the pelletes or pelletes of the polymer or we may manually mix the pelletes and the fibers and feed them through the hopper. So, that is one important point which differentiate between the processing of plastics and the processing of polymeric matrix composites by the same process of injection molding.

The mixture goes into the heated barrel where softening of the material takes place due to heating from the barrel. Now softening of the material here it the important point to notice that the softening of the matrix would takes place, matrix in case of injection molding of polymer composites is a polymeric material. Now, the polymer may be of different types. Now depending upon the properties of the polymer, it would get heated and it will soften or it will become we can say a from solid state it would come into a semi solid state. So, the mixture goes into the barrel, now barrel is heated all along the length. This we will try to understand in the diagram that what where is the barrel, but first we should understand that what is the process like. The mixture this pre-blended mixture of the fibers and the polymers goes into the barrel, and where it is heated and the matrix or the resin softens as the screw rooted.

Now, what is the role of the screw? The screw feeds the polymer melt into the mold. So, it acts as a injection mechanism, as the name suggest injection molding. We can have ram type of injection mechanism we can have a screw type of injection mechanism. These two mechanisms we have already seen in the injection molding of the plastics in one of the previous modules.

So, as the screw rotates mixture of the fiber mixing of the fiber and the resin takes place, and at the same time the blend is pushed towards the converging section of the barrel where it is injected through nozzle into the mold cavity at high pressure. So, the raw material is coming from the hopper, the raw material is either pre-blended that is the fibers are there in the polymer pelletes or they are manually mixed the short fibers and the polymer pelletes are manually mixed, and from the hopper the material is coming into the heated barrel. In the barrel, we have a screw type of feeding mechanism and in this barrel because of the heating mechanism the polymer will melt or the polymer will soften and the fibers would be incorporated into the polymer and then this is pushed by the action of the screw through the conversing section of the nozzle into the final mold.

So, this all we will see with the help of a diagram, but before we go to the diagram because in a short lecture all the thinks cannot be discussed in much more detail. So, by the time, we reach to the diagram at least the terminology should be clear that what is a barrel and what is a role of the barrel. And again we will revise the working principle of the injection molding with the help of the diagram. Now what is a barrel what is pre-bleeding, how the raw material comes, what is a hopper all these things are being explained with the help of these initial slides. At high pressure that material is now being injected into the mold. Now coming on to a specific case in which the natural fibers are being used as the reinforcement materials.

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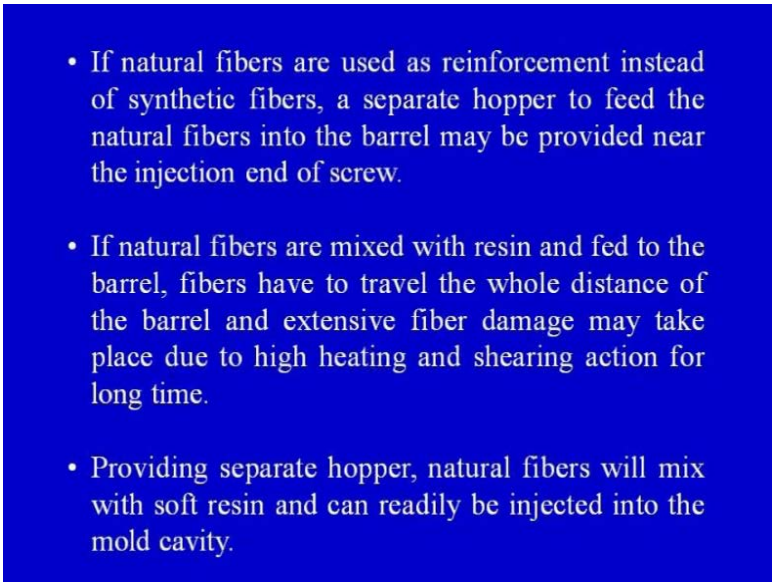

On your screen, I will read it for you. If natural fibers are used as reinforcement instead of synthetic fibers, a separate hopper to feed the natural fibers into the barrel may be provided near the injection end of the screw. So, if natural fibers are being used instead of synthetic fibers, a separate barrel may be used. Now why a separate not a separate barrel, but a separate hopper should be used. So, why a separate hopper should be used in case of natural fibers we will try to address this point. If natural fibers are mixed with the resin and fed to the barrel, fibers have to travel the whole distance of the barrel. So, I have already told the barrel will have a length. So, if we are feeding the natural fibers and the polymer in the form of pelletes together from single hopper only, now the polymer will melt or the polymer will soften and the fibers will have to travel the whole length of the barrel, and the barrel is also heated. And it would be made up of a metallic material. The screw would also be made up of a metallic material. The fibers will rub against to the screw as well as against to the barrel. So, the extensive fiber damage may takes place due to the high heating and shearing action for a long time.

So, we do not want the fibers to be damaged, because fibers are the main load bearing members in case of a composite material. And the fibers take the maximum amount of load, when the product is subjected to a mechanical environment or when it is subjected to different types of mechanical loading, the fibers are the main load bearing member. So, we do not want any damage to takes place on the fiber. So, again I am emphasizing that if we are feeding the natural fibers and the pelletes from the same hopper, and the fibers have to travel the long distance through the barrel, the fibers may get damaged.

So, therefore, the first point is very very important that we can use another hopper at the end of the barrel that we will try to understand with the help of diagram that near the injection point only we have another hopper where we have put very small size of fibers or short fiber. As soon as the polymer melt travels through the barrel, it get soften and just before the injection into the mold cavity, we are incorporating the fibers through a another hopper. In this way, the fibers do not get damaged.

Providing separate hopper for the natural fibers natural fibers will mixed with the soft resin and can readily be injected into the mold cavity. So, this important aspect has to be taken care of when we are using short fiber, short natural fibers. Incase of synthetic fibers this particular problem may not arise and the synthetic fibers such as the carbon glass or aramid may be manually mixed with the polymer pelletes or the pelletes in the

hopper only and from the hopper the from a single hopper and from there the fibers will travel with the polymer, the polymer would soften and they will travel the whole length of the barrel, finally being pushed into the mold cavity with the screw action. Whereas in case of natural fibers, we may emphasize the use of a separate hopper for the natural fibers just at the end of the barrel where the polymer is being injected into the mold cavity or the softened polymer is being injected into the mold cavity.

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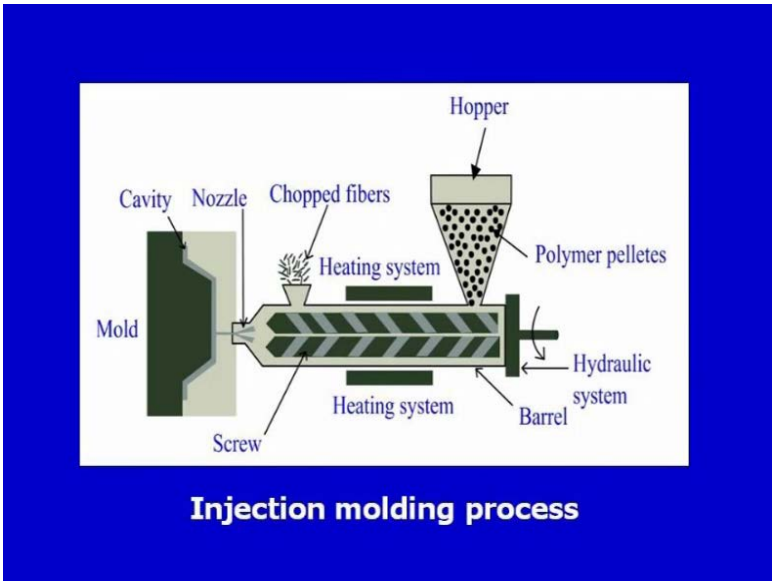

Now, we come on to the diagram. We have seen all the terminology which is there in this diagram we have seen there is a barrel, there is a hopper, there is a mold cavity. So, on your screen, now you can see there is a hopper, these are the polymer pellets, these black points - these are the polymer pellets, this is the raw material which would go into the barrel. This is the barrel, this long action; this is the barrel where the actual action would take place. This is the screw, you can see on your screen, this is the screw. So, we have a screw, we have a hopper, in which we have the raw material in the form of polymer pellets, and there is a hydraulic system. We have the heating system here you can see. The barrel is heated to soften the polymer, we have a screw for feeding, we can have a hydraulic ram system also for the feeding. This is the mold cavity this is the cavity, this is the final form of the product that we will get. This is the mold cavity, we have a screw.

So, as we have seen in case of the injection molding of the plastics, two types of feeding mechanisms are used either we can have a hydraulic ram system or we can have a screw

type of a system. So, both the systems can be used for feeding the raw material or injecting the raw material into the mold cavity at a high pressure. So, just to revise this process, what we have already seen. We have a hopper, the raw material in the form of polymer pelletes would be injected or would be sent into the barrel; and in the barrel, there is a heating arrangement throughout the barrel this barrel is heated. The polymer pellets will soften and here is the important point that I have emphasize the chopped natural fibers would be put in this small hopper here, and the fibers would be incorporated into the barrel at the fag -end of the barrel, this is the total barrel and this is the mold cavity. So, here only the fibers would be put into the barrel instead of putting the fibers along with the polymer pellets here.

If we put the fibers here along with the polymer pelletes, the fibers will have to travel this distance and this is what we want to avoid specifically in case of chopped fibers, so that the fibers may not get damaged. So we will use a polymer pellets here, and the screw will rotate it will feed the polymer melt the fibers would be incorporated here, at this particular point the fibers will mixed with the soften polymer, and this will be pushed at high pressure into the mold cavity.

Now, this is my mold cavity along the arrow and this is the final product that we would get. So, this is the mold, this is the one part of the mold and this is a another part of the mold. The mold is in two parts that we have already seen in the injection molding of plastic. So, mold is in two part; one of the parts is stationary, other part is movable. So, we have the mold in two parts we have the raw material and a process to heat the polymer and a process or we can say element to feed the fibers.

So, again I want to revise that in this diagram we can see that we have polymer pelletes in case of synthetic fiber let me differentiate between the synthetic fiber then the natural fiber. In case of synthetic fiber the fibers may be impregnated or may be pre-blended in the polymer pelletes as the raw material that is one important point. In case of polymer pelletes, we have pre-blended fiber short fibers already present and then we are feeding through the hopper into the barrel and this raw material will get softened and simultaneously it would be pushed by the screw feeder, and finally, it would be injected into the mold cavity at high pressure. Now the main difference between the synthetic fibers and the natural fibers which has already been explained. In case of natural fibers, we do not want the fibers to rub against the screw and the undertake the shearing action

and we do not want the fibers to rub against the barrel. So, we would be incorporating the natural fibers at the end of the barrel where the matrix in the form of polymer has already soften and fibers are incorporated here and the fibers as well as the polymer is injected into the mold cavity with the help of the screw feeder.

So, we have two important modifications of the process. If we have synthetic fibers, we can a pre-blended raw material, we can manually mix the raw material in the hopper. If we have natural fibers then we can have the another hopper or a secondary hopper towards the end of the barrel, when the polymer has soften the fibers would be coming from the secondary hopper. They would be mixing with the softened polymer and this mixture would be pushed into the mold cavity with the help of a screw feeder. I think we have revise it two three time, the process would have become extremely clear for all the listeners.

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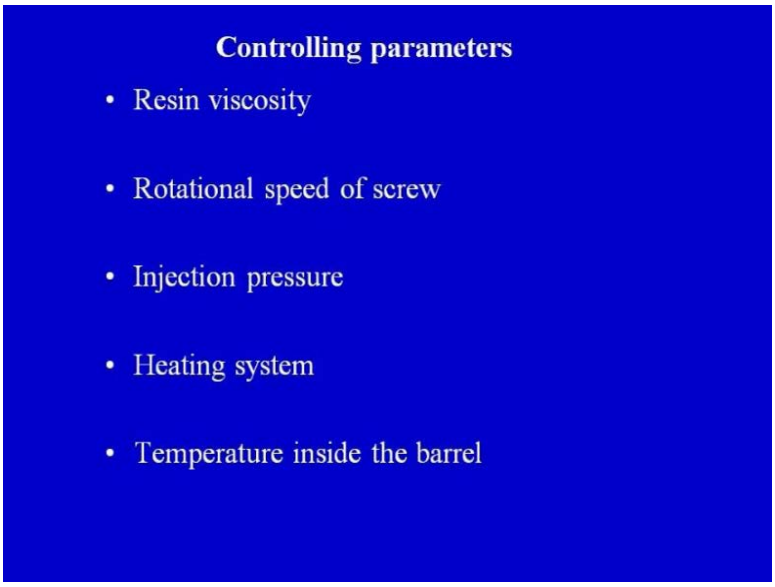

Now, what are the important controlling parameters. So, the important controlling parameters is the resin viscosity, which we have already discuss the rotational speed of the screw because that is also important if it is too fast the polymer may not have melted it may jam the screw also. If it is too slow, we may we not be able to generate the adequate pressure to push the fibers and the polymer into the mold. So, the rotational speed of the screw is also very important. Injection pressure is also important if we are using a ram type of the injection mechanism cylinder and ram type of injection

mechanism is use the injection pressure is very important. The heating system is also is very very important.

So, we can see that we have a length of a barrel. So, the temperature can be uniform throughout the barrel or there may be a thermal gradient along the length of the barrel. Because we see as the polymer is entering, it is at a particular suppose it is at room temperature. Now when it is towards the fag-end of the barrel, it has already attained some temperature, it has already softened and now it is ready to be pushed into the mold cavity. So, we may think or that may be certain situations where we would like to have a thermal gradient or we may have to like to have a higher temperature in the beginning and a lower temperature towards the end. Or on the contrary, we may like to have lower temperature in the beginning of the barrel or at the start of the barrel and a very high temperature at the end of the barrel. So, this heating system has to be designed in such a way that a proper temperature is maintained along the length of the barrel. So, depending upon the requirement we may have to chose or design the heating system of for the injection molding machine. The temperature inside the barrel as I have already explained, it is very very important. If the polymer does not soften properly, there may be certain problems which may arise in the final product.

For example, if the product has a complicate geometry, the mold cavity would be complicate and or a complex and we may when we are putting the polymer into the final mold cavity; at that particular point, the polymer is not able to the reach to each every corner of the mold cavity and may result in a defective product. So, the temperature in side the barrel is very very important, because viscosity is proportional to the temperature we have to maintain the temperature in such a way, so that the mold cavity is field appropriately and no part of the mold cavity is left without the polymer and the fiber. There for these are the important parameters all these parameters are related to one another, and these important controlling parameters have to be taken care of when injection molding of the fiber reinforced plastics or the polymeric matrix composites is being carried out.

So, again I will read out the important parameters which needs to be controlled in order to make a very good quality or a high quality, very precise, very accurate and you can say good quality product. So, resin viscosity, rotational speed of the screw, injection

pressure, heating system and temperature inside the barrel. So, these are the parameters or the elements which have to be taken care of in case of the injection molding process.

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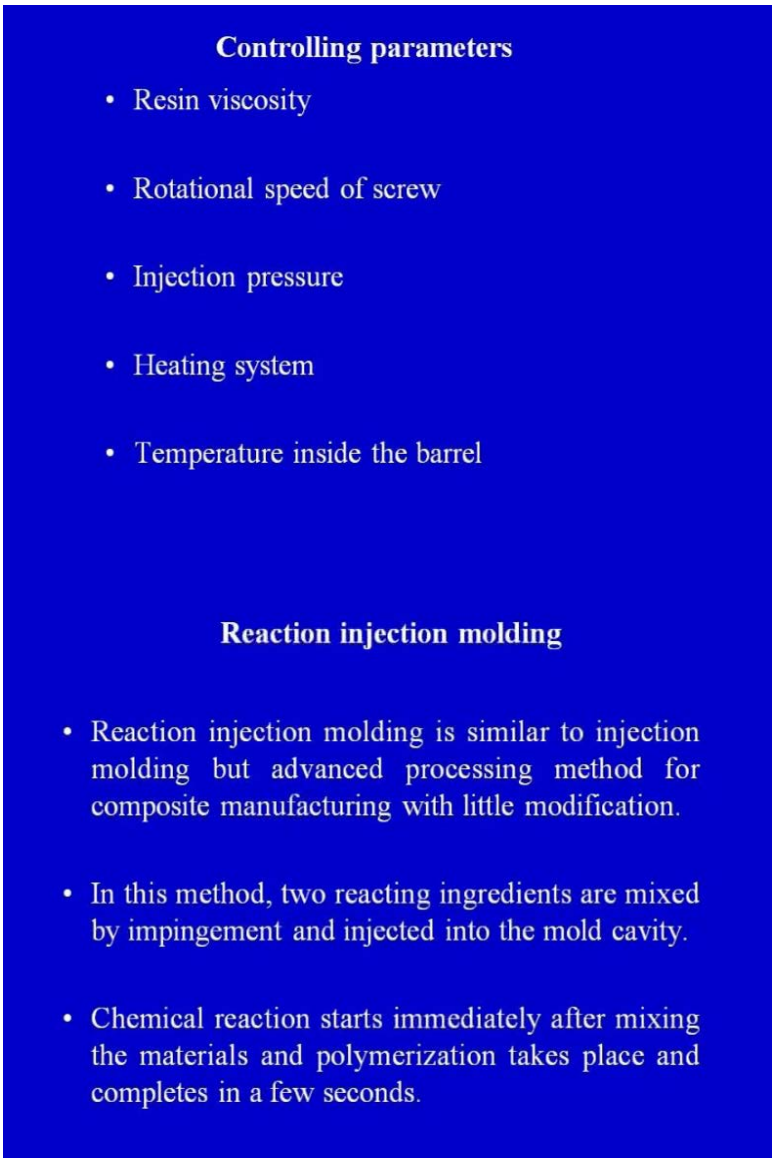

Now there is a another variant of the injection molding process. Now, what is this variant this is reaction injection molding which is similar to the injection molding, but it is advanced processing method for composite manufacturing with little modification. So, as I have already emphasize, it is a variant of the injection molding process only. The basic principle is same; the fibers and the polymers would be injected into the mold cavity, and in the mold cavity the final product would be formed. In this method, two reacting ingredients are mixed by impingement and injected into the mold cavity. So, reaction injection means, there would be a reaction that is taking place among the constituent, and

finally, the injection of this particular constituent into the final mold cavity. So, the mixture then finally is injected into the mold cavity.

So, we have a diagram understand the basic mechanism of reaction injection molding. So, a reaction takes place and after the reaction, the final product is injected into the mold cavity or the reaction product is injected into the mold cavity. Chemical reaction starts immediately after mixing the materials, and polymerization takes place and completes in a few second. So, it is a very fast process. So, the heat of the reaction is used for softening the matrix in case of reaction injection molding.

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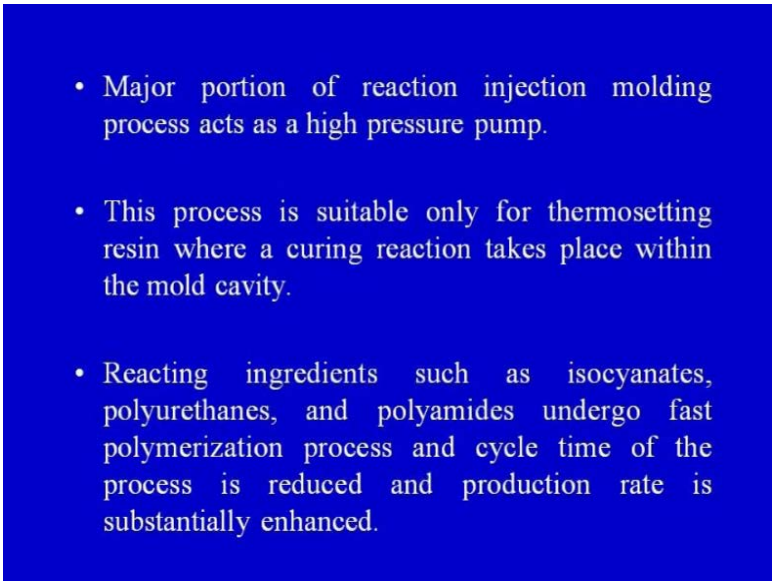

Major portion of reaction injection molding process acts as the high-pressure pump. So, during the reaction only high-pressure is generated and a temperature is generated which acts as a pump or which acts as a injection mechanism or which acts as the pressure for the injection. So, there is no external pressure that may be required; in some cases that may be required also, but in when the reaction takes place the heat that is generated automatically softened the polymer and the polymer then flows into the mold cavity.

The process is suitable only for thermosetting resin where a curing reaction takes place within the mold cavity. So, the final curing takes place within the mold cavity. Reaction ingredients now few examples have been given that which are the ingredients which can be used for reaction injection molding. Now reaction ingredients such as isocyanides, polyurethanes and polyamides undergo fast polymerization process and cycle time of the

process is reduced. If the cycle time is reduced, the production rate would automatically be high. So, if the cycle time is two minutes, we can have forty five to fifty products in may be in an hour, may be not in an hour, but in two hours, because there would be some time lack in between also. So, if two minutes are taken a cycle time is two minutes for one particular product to comes out, so for forty five products we may require ninety minutes, but because of some time lack or some additional process details or some process requirements we may be able to generate straightly lesser number then exactly multiplying it by two. But still if the cycle time is reduced, the production rate would be high. Instead of two minutes cycle time, if you reduce a cycle time to one minute we will be able to generate or produce or fabricate or process more number of products in the same time duration. So when these type of reaction takes place this particular process becomes a variant of the injection molding because here also the raw material is being injected into the mold cavity in order to produce the final product.

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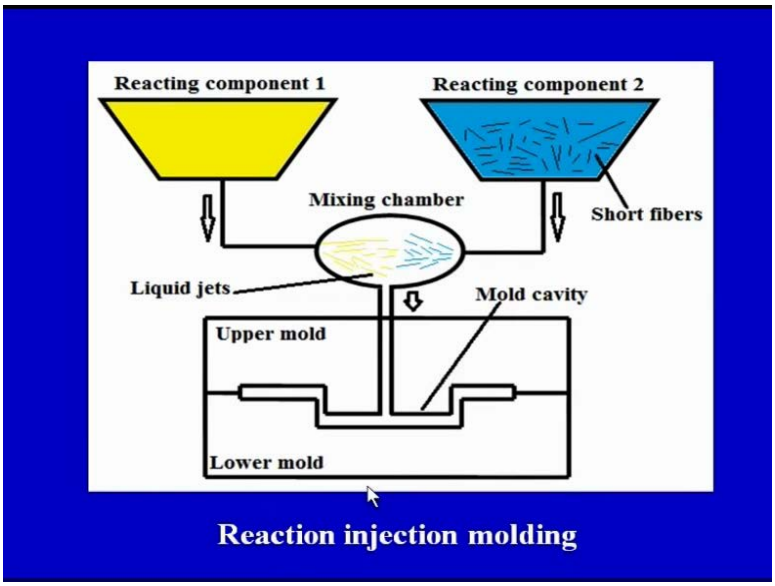

Now, on your screen, you can see the diagram. We have a reaction reacting component one which may be a matrix or may be a combination of two or three polymers and the reaction may takes place. Reacting component two - we may have short fibers, and we have a mixing chamber where the polymer is coming and the short fibers are coming they are mixing here and finally, they are being injected into the… this is upper half of the mold and lower half of the mold. The cavity generated between the upper half and the lower half of the mold is called the mold cavity. So, we have two important

ingredients that is the polymer and the fiber, and they are getting mixed in the mixing chamber, and finally, being pushed into the mold cavity. So, final product that will we will get out of this process would be this shape that your seeing on your screen that is the cavity generated between the upper half and the lower half of the mold which is usually called the mold cavity.

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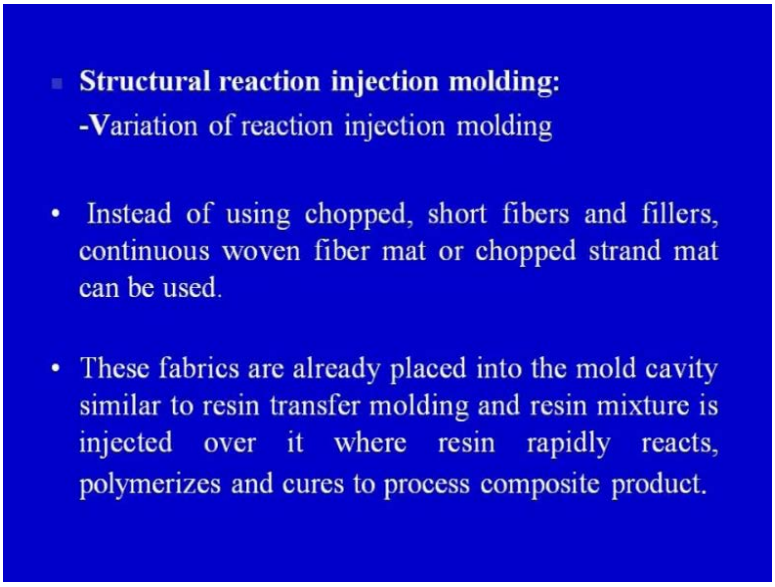

Then there is another variant of the injection molding process that is reaction in this is a another variant of the reaction injection molding that is the variation of reaction injection molding called as the structural reaction injection molding. Instead of using chopped short fibers and fillers continuous woven fiber mat or chopped strand mat can be used. Now this is one of the variants of the resin transfer molding also in which the fiber in the form of sheets is already placed in the mold cavity and the resin is injected at pressure. So, the reinforcement is already in place in the mold and the resin has to be injected. So, the these fabrics are already placed into the mold cavity. So, the continuous fiber fabric or a woven mat, these fabrics are already placed into the mold cavity similar to the resin transfer molding as I have already highlighted. And the resin mixture is injected over it, where resin rapidly reacts polymerizes and cures and to process the composite product.

So, in case of reaction injection molding, we are mixing the short fiber and polymer in a mixing chamber and then we are pushing this mixture into the final mold cavity. In case of structural reaction injection molding, we have already placed the reinforcement in the

form of woven mats or fabrics in the mold cavity. And we are injecting the resin only into the mold cavity, where it polymerizes cures, and finally processes the composite product. So, we have seen what is the basic detail of the injection molding specifically dedicated to fiber reinforced polymers or plastics or the polymer matrix composites. So, we have seen that what is the change which has to be incorporated into the basic process of injection molding in order to incorporate the fibers into the final product. So, we have seen two variants of the injection molding process also. Now what are these two variants, the two variants are the reaction injection molding and the structural reaction injection molding.

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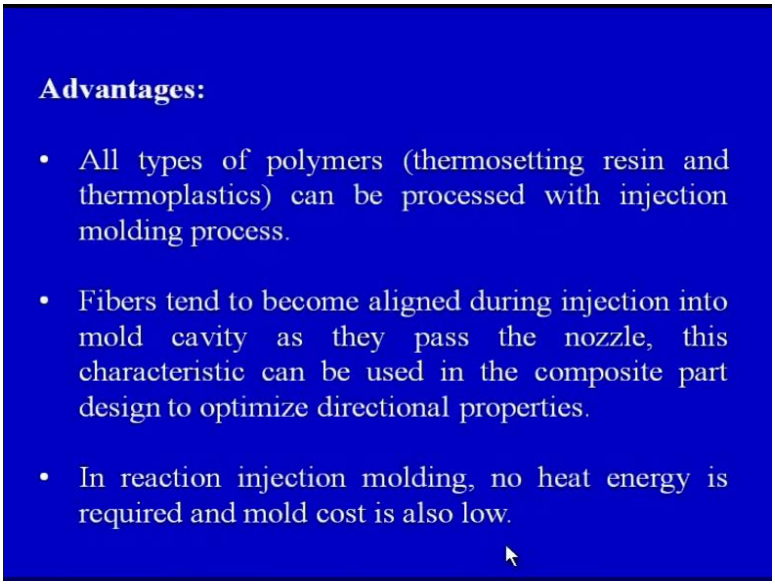

Now, what are the advantages of the injection molding process? So, on your screen, you can see all types of polymers thermosetting resin and thermoplastics can be processed with injection molding process which we have already seen. Fibers tend to become aligned during the injection into the mold cavity as they pass the nozzle, this characteristic can be used in the composite part design to optimize directional properties. If you remember in our lecture on filament winding, I have emphasized the role of fiber orientation, because we can have a particular winding pattern in case of a filament winding process. And the direction of the fibers dictate the properties of the final product which is made up of a polymeric matrix composite or a fiber reinforced plastic.

In case of injection molding also, when we are injecting the mixture of the polymer and the fiber into the mold cavity, the fibers tend to align in a particular direction. And when we have aligned reinforcement, the properties are different then the randomly oriented fiber orientation. So, in this particular case, there is a tendency of the fibers to align in a particular direction with and this particular process characteristics is particularly relevant to designers when they design products which are made up of the injection molding process. Because if all the fibers are in one direction, the properties would be different in that particular direction as compared to the transverse direction to the direction of fibers. So, we can have aligned reinforcement in case of injection molding process which would further dictate the mechanical properties of the processed part. In reaction injection molding no heat energy is required and mold cost is also low. In case of reaction injection, because the reaction is taking place the heat of the reaction is being used for softening the matrix, therefore sometimes additional heat may not be required.

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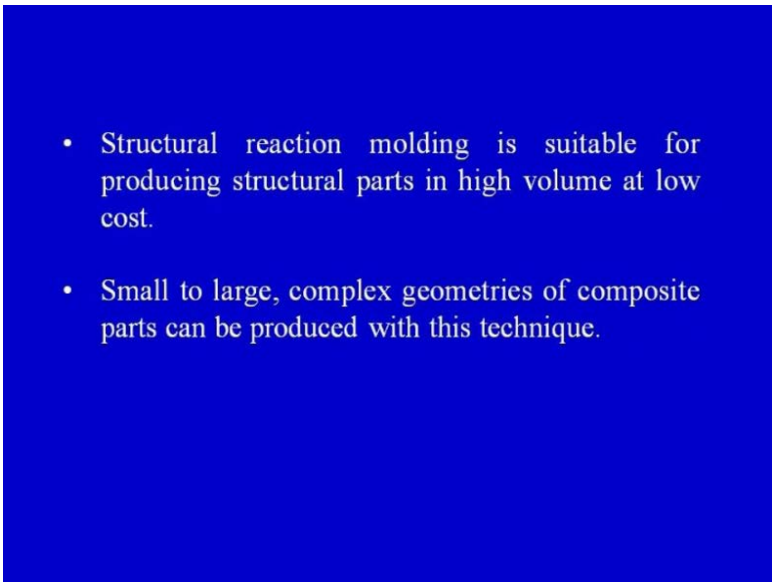

In structural reaction injection molding, it is suitable for producing structural parts of high volume at low cost. So, structural parts means the parts which can be used for the engineering applications in civil engineering or making different structural components. Why, because in this particular case, we are using a fabric or a woven mat type of reinforcement instead of a randomly distributed or an aligned type of short fiber reinforcement. So, we are not using short fiber reinforcement in structural injection molding, we are using a woven type of reinforcement. And as we have already seen the

woven reinforcement or fabric type of reinforcement always results in better mechanical properties as compare to the short fiber reinforcement in the polymeric matrix.

Small to large that is one important point, and complex geometries of composite parts can be produced with this technique. So, this particular technique of injection molding is suitable for small part applications also for larger parts also. Moreover even complex geometries now the geometry of the final product depends upon the shape of the mold cavity. So, if we are able to generate a complex shape of the mold cavity, we would be able to inject the mixture of the two ingredients that is the fiber and the polymer into the mold cavity, and the mold cavity the product would be made according to the details of the mold cavity. So, this particular process has another advantage that it can be used to fabricate fairly complex parts out of the composite materials specifically the polymeric matrix composite materials.

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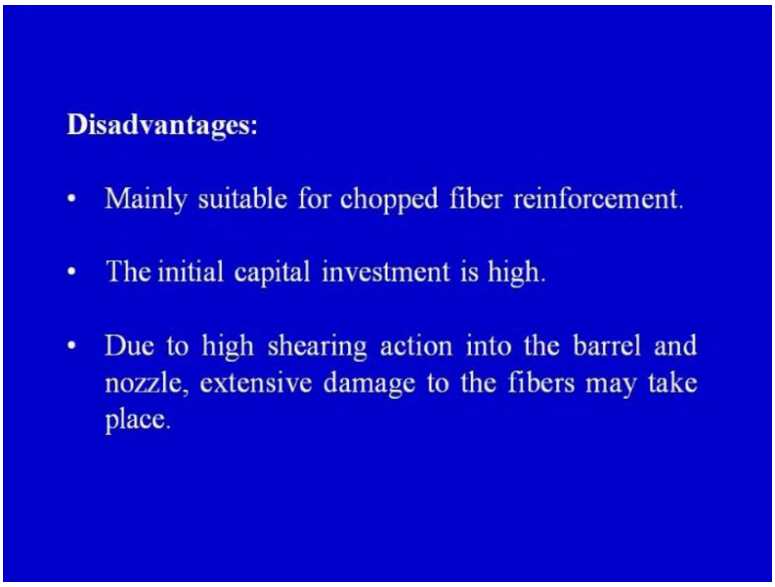

Now, what are the disadvantages of this process this is mainly suitable for chopped fiber reinforcement. Again I am emphasizing in today's lecture that the work is going on, people are working in the direction to incorporate long fibers also into the polymeric matrix and the work is in process. So till now, the commercial process available is used for short fiber reinforcement only. The initial capital investment is high, yes, because the cost of the mold is extremely high which I have already told and the cost of the setup

also is high as compared to hand lay-up process or the spray lay-up process and also in comparison to the compression molding process.

So, the cost - initial cost of the machine is high the cost of the mold is also very high. Due to high shearing action into the barrel and nozzle extensive damage to the fibers may take place. So, that we have already discussed specifically in case of natural fibers the damage to the fiber may take place. Therefore, we have put another hopper just at the end of the barrel where the matrix has already or the resin has already softened and with the polymer the fiber is mixing and the mixture is being pushed into the mold cavity. So, we tend to avoid the shearing or the damage to the fibers when they are travelling through the barrel, so that is one important disadvantage which has to be taken care of.

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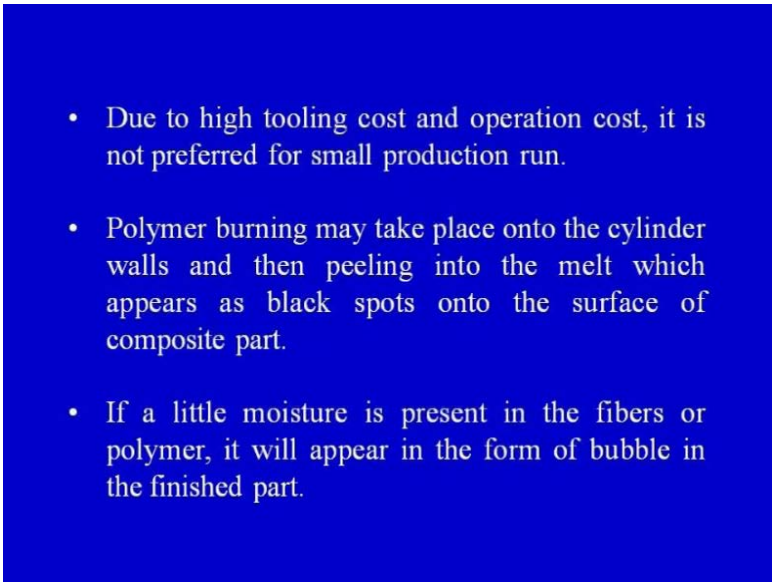

Due to high tooling cost and operation cost, it is not preferred for small production run which is very very clear. If we want to make only five products the process is not suitable; it is only suitable for large production runs where we want to produce a large number of parts or large number of identical parts. Polymer burning may take place onto the cylinder walls and then peeling into the melt which appears as black spots onto the surface of the composite part. Sometimes due to excessive temperature or excessive heating, the polymer may burn, and it may get the burned polymer may get stuck to the barrel. And during the next cycle this burnt part or this black part of the polymer may come again and peeling up peeling means that it would be scratched of the barrel by the

action of the polymer and it may come and mix with the polymer in the next next cycle. And the particular product which has been made after the burning of the polymer may have some black spots because of the peeling out action of this burnt polymer which was sticking to the barrel.

So, these are some of the difficulties which have been found in the injection molding process, and these particular things have to be taken care of. If you remember the controlling parameters of the injection molding process, we have seen the adequate design of the heating system and the temperature control within the barrel. These are two important controlling parameters, which have to be taken care of if we want to make a good quality product out of injection molding process. So, this polymer burning should be avoided or the peeling if the polymer is not allowed to burn there is no chance of the peeling out of the polymer layer from the barrel. So, this has to be avoided with the proper design of the heating system as well as with the proper control of the temperature along the length of the barrel.

If a little moisture is present in the fibers or in the polymer, it may appear in the final product in the form of in the form of voids or porosity; it may form in the form of bubbles also. So, the fibers as well as the polymer may be treated may be heated to a particular temperature before being used as the raw material. Before putting the polymer, pelletes, and the fibers into the hoppers we may under we may make these raw materials to undergo a specific treatment in order to remove all the moisture that is present, because if the moisture is present then it may appear in the final product in the form of bubbles or voids.

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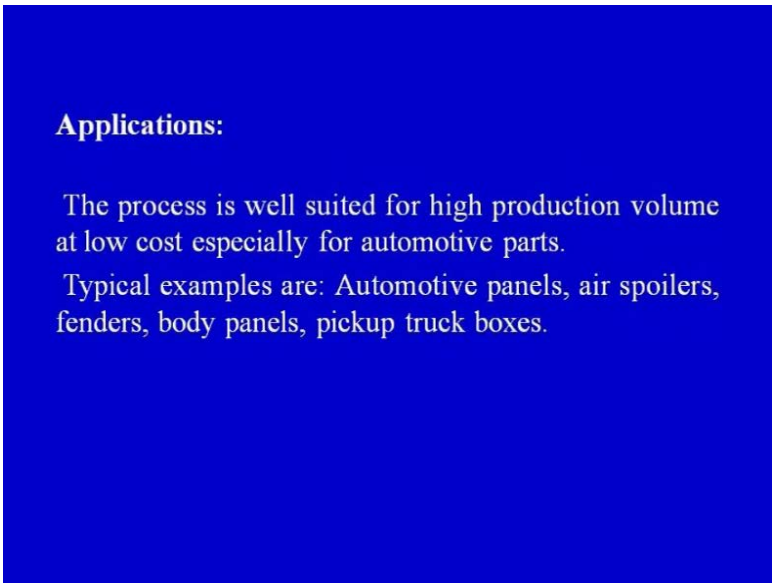

Now, what are the applications of the injection molding process? This has got very wide applications the process is well suited for high production volume at low cost especially for automotive parts. Typical examples are automotive panels, air spoilers, fenders, body panels, pickup truck boxes, and there are numerous other applications for which the injection molding process can be used. So, if in order to revise and if we see what we have discussed in the today's lecture, we have seen that what is the injection molding process and how it is different from the injection molding of plastics.

We have seen how the fibers are incorporated into the injection molding process setup, we can have a separate hopper for the fibers or we can pre-blend the raw material or we can have the pelletes, which are already pre-blended with short fibers. So, we have seen the process details we have seen what are the important control parameters or controlling important parameters which need to be controlled in order to make a good quality product. To name a few the temperature is important parameter viscosity of the polymer is also equally important the temperature gradient in the barrel is very very important the design of the heating system is equally important. So, there are few important control variables or control parameters which needs to be taken care of.

Finally, we have seen two variants of the injection molding process. We have seen reaction injection molding as well as we have seen structural reaction injection molding. And finally, we have seen that what are the advantages of using this process we have

seen what are the limitations of injection molding process, and finally, we have come to the application areas of the injection molding process. In our subsequent lectures, we would focus our attention on the other processes, which are used for processing the polymeric matrix composites.

Thank you.