Processing of Non-Metals

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Module - 5
Polymer Matrix Composites: Processing
Lecture - 5
Pultrusion

A very good morning to all of you, I welcome all of you to this lecture on pultrusion. We have been discussing a series of lectures on processing of polymer matrix composites in module 5. The course is processing of non-metals, so in this particular lecture on pultrusion we are going to see that what is the process of pultrusion, what are the salient important points that are there in pultrusion, how the process is done. Secondly, we will see what are the application areas of the pultrusion process, what are the advantages of the pultrusion process, and finally what are the limitations of the pultrusion process.

Just to take you a few lectures back, we have started this particular module on processing of polymer matrix composites with the discussion on the challenge of selection of materials, that if we have to select a particular material for a particular application what is the criteria or what are the properties that should be kept in mind. In lecture number 2 we have seen the different aspects of materials that why and how the new and new materials are getting developed, and where do polymer composite fit into the broad family of material science and engineering.

In lecture number third, we have seen that what are the challenges in contest of materials for example, how the polymer matrix composites compared with the conventional engineering material such as steel, and what are the challenges for polymer matrix composites in contest or in comparison to the conventional engineering materials. And finally in the last lecture we have started our discussion on the processing aspects of polymer matrix composites, we have seen two very basic processes of processing the polymer matrix composites; that is the hand layup process and the spray lay-up process, while we were discussing the spray lay-up process we have left two or three important aspects that is the advantages, limitations, and the problem area with the spray lay-up process.

So, today we will start our discussion with the spray lay-up process. We will cover the things which are left in the last lecture and then we will carry forward our discussion in the pultrusion process or we will see what is the pultrusion process with the help of a schematic diagram. And we will see what are the important process variables in pultrusion process, what are the applications area of pultrusion, what are the advantages and limitation they are of. So, just to start this lecture, let us first focus on what we have left in the previous lecture.

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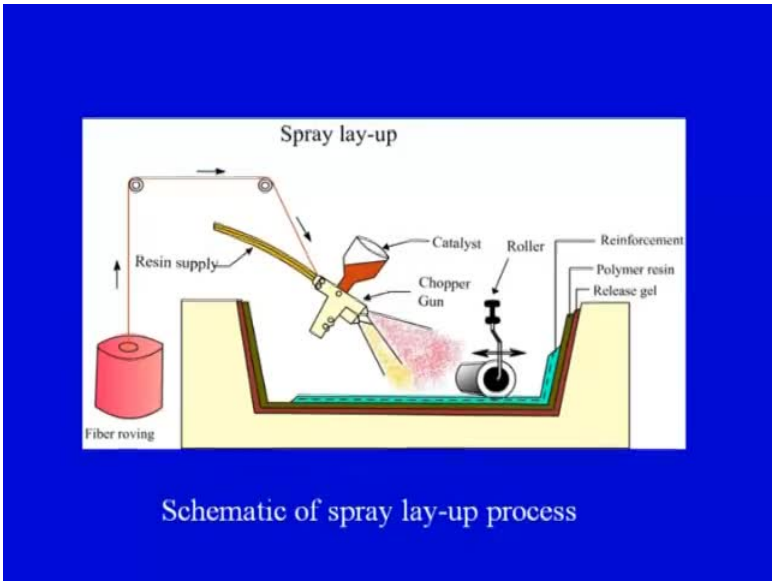

This is the photograph that we have seen in the last lecture, also this is the spray lay-up process. Again just to revise I will highlight the important aspects, there is a fibrous reinforcement and there is a resin supply with the, in the form of this tube, there is a catalyst or the hardener so resin hardener and fiber are getting mixed in this spray gun or the chopper gun and the mixture is getting sprayed on to the mold surface. This yellow colored component you can say this is the mold.

So, the final product will be made according to the shape of the mold, now this is our mold and in the mold we have first the release gel in order to facilitate the easy removal of the final product, we have a polymer resin and the reinforcement that is mixed here. So, this is you can say a simple diagram of the spray lay-up processing, we have fibrous reinforcement resin catalyst and a spray gun in which the material is getting mixed, the raw material is getting mixed and it is getting sprayed on to the mold surface and we

have a consolidation roller which will consolidate this sprayed material and it will also help in the removal of any air bubbles or excess resin which is present in the lay-up. So, this is the spray lay-up process in which our component is made according to the shape of the mold material.

So, here the component that will be coming out or the composite product that will be coming out will be of this particular shape. You can see on the screen as the arrow moves this is the shape of the material according to which the job will be made this is the shape. So, the process of spray lay-up has got certain advantages, it has got certain limitations as well as it has got certain application areas.

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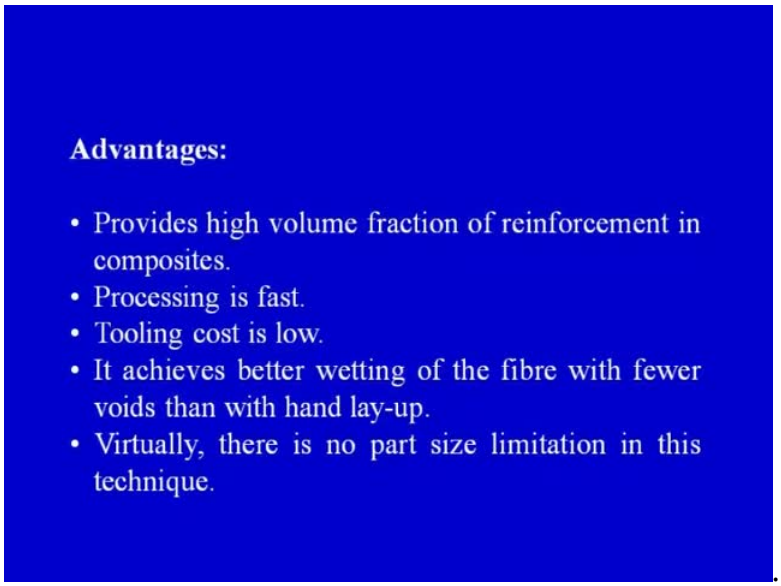

Now, what are the advantages of the spray lay-up process? The spray lay-up process provides high volume fraction of reinforcement in the composites. So, in the previous lectures we have seen that what do we mean by volume fraction so, volume fraction means the amount of fiber which is reinforcing the matrix phase. So, we may have 60-40, we may have 40-60, we may have 50-50, even 30-70, 30 percent of fiber and 70 percent of the matrix, 20 percent of the fiber and 8 percent of the matrix or 10 percent of the fibers and 90 percent of the polymer or the matrix. So, the fiber volume fraction we want that the fiber volume fraction should be higher, why it should be higher? Because in our previous lecture on polymer matrix composites we have seen, that the main load bearing capacity comes with the amount of the fibers present in the composite materials

because fibers are the main load bearing members in a composite. So, we want that there should be a higher fiber volume fraction for the composite, so spray lay-up process provides us that advantages that we can afford to have a high fiber volume fraction using this process.

The processing is fast, tooling cost is low, it achieves better wetting of the fiber with fewer void than the hand lay-up. So, the voids that are present in the hand lay-up process can be avoided by the spray lay-up process. Virtually there is no part size limitations in this technique so, we can even make a product of a size of this room also using the spray lay-up process basically, we require a spray gun a continuous supply of the fiber and continuous supply of the resin so we can do the spray and allow the composite part to cure, allow it to solidify and we will get a complete product.

Even a complete boat can be made using spray lay-up process even a combination of hand lay-up and spray lay-up process. So, again I am going to revise that what are the advantages of spray lay-up process it provides high volume fraction of fibers or the reinforcement in the composite, the processing is fast and the tooling cost is low and better wetting of the fibers takes place which means that the strength of the resultant composite would be very, very high and there is no part size limitation this can be used for very big size of the components or very big size of the composite products.

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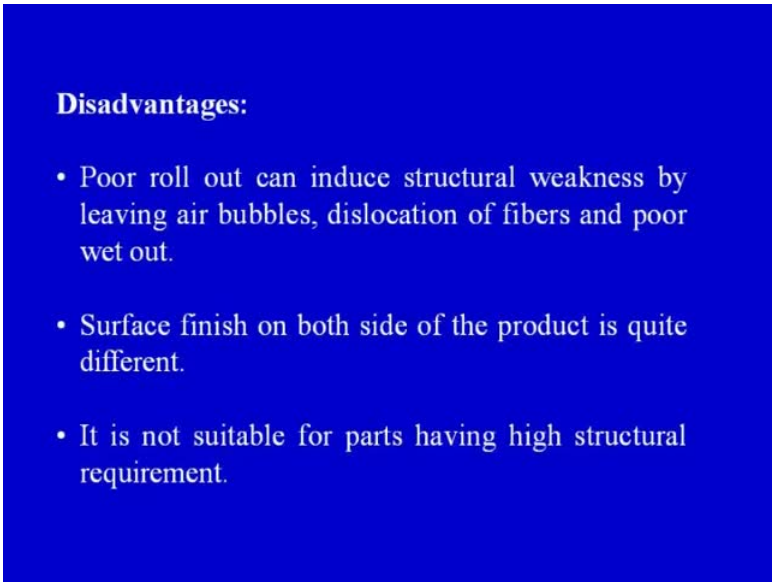

What are the disadvantages? Poor roll out can induce structural weaknesses by leaving air bubbles dislocation of fibers and poor wet out. So, sometimes the fiber may not get properly wet out there may be dislocation of the fibers, the fibers may be coming out of the matrix and there sometimes, there may be air bubble inside if the consolidation process has not been done properly.

So, all these factors will lead to poor mechanical properties of the parts which has been made by the spray lay-up process. Surface finish of the both side of the project product is quite difficult, because we can see, on one side we have the mold and on other side we are doing the spray. So, the surface finish on the side of the mold would be very high and on the other side the surface finish would not be good. So, only one side surface finish is usually possible with the help of spray lay-up process.

It is not suitable for parts having high structural requirements because the load bearing capacity of the discontinuously reinforced polymer composites is relatively low as compared to the continuously reinforced polymer composites. So, in this particular case we can see as the spray gun is been used from the spray gun, we are getting chopped fibers and the polymer. So, we are getting discontinuously or randomly oriented fibrous reinforcement in the polymer.

So, the load bearing capacity or the mechanical properties of these type of composite products will not be as high as possible with the hand lay-up process in which we have a continuous reinforcement or continuous layers of reinforcement in the laminate. So, here we can see this is one of the limitations of the spray lay-up process. Surface finish may not be good on both sides or may not be equal on both sides, on the side of the mold it would be good on the other side it will not be that good. So, these are some of the limitations there are chances of entrapment of air bubbles also that is another disadvantage of the spray lay-up process.

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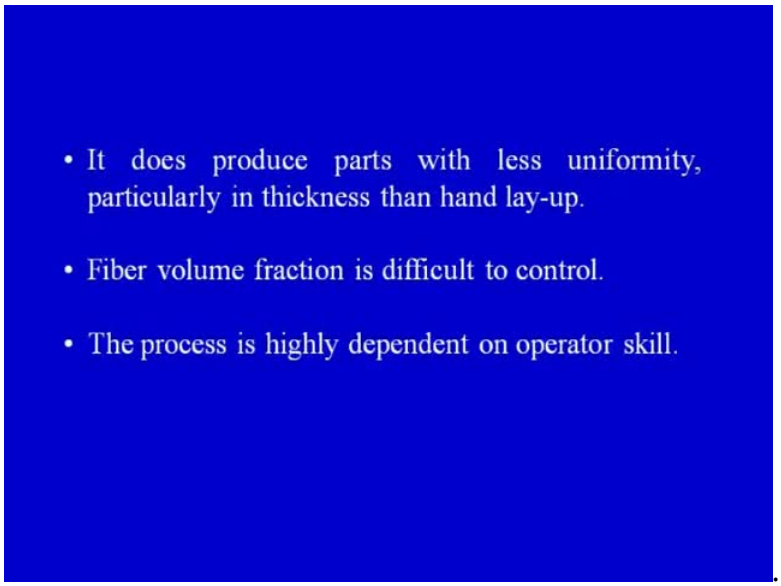

Another limitation of this spray lay-up process is it does produce parts with less uniformity particularly in thickness than hand lay-up. If you remember in hand lay-up we have taken suppose, an example of flat plate mold in which there was upper half of the mold and lower half of the mold. We were doing our lay up in between the two parts of the plate and then when we were putting that upper part on top of the bottom part, two part mold we were using, so the thickness was uniform on all along the mold. In this particular case when we are doing the spray the thickness may not be uniform, somewhere it may be higher and somewhere it may be lower. So, the thickness is an important uniformity of thickness is an important constraint in case of the spray lay-up process because it does not provide parts with uniform thickness.

Fiber volume fraction is difficult to control. Sometimes the fibers may get agglomerated at a particular place or at a particular location and at other place we place we may have place, we may have resin rich areas. So, we need in our composites product the fibers or the randomly oriented fibers should be distributed randomly all around the bulk of the matrix. But that is sometimes is not possible in case of spray lay-up process, all the fibers may get collected at the particular position forming a fiber rich area and on the contrary there would be other place where there would be a resin rich area.

So, which is not at all desirable, because we want uniform mechanical properties throughout the bulk of the composite that we are making by the spray lay-up process, the

process if highly dependent on the operator skill. So, that operational requirements or the operator skill is equally important. So, these are some of the limitations of the spray lay-up process but apart from these limitations this process has got wide applications in a large engineering structure and in other household applications.

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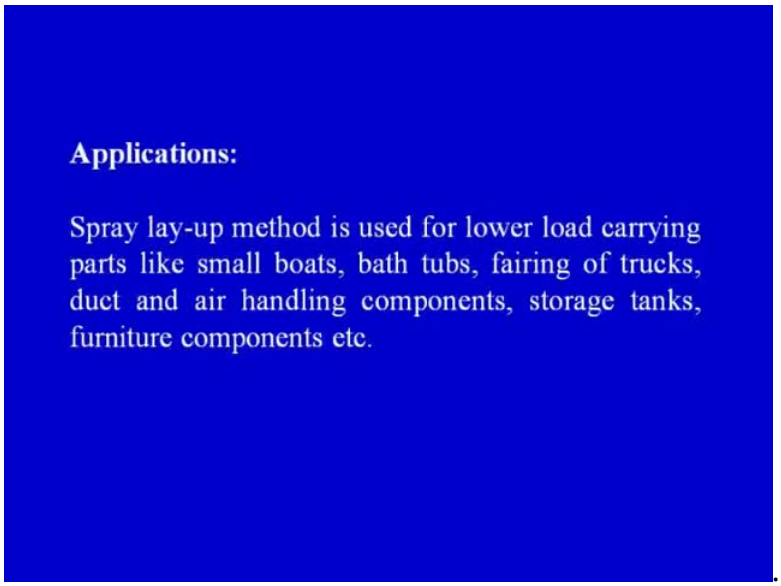

So the applications for spray lay-up process or the spray lay-up method is used for lower load carrying parts. Lower load carrying parts should be emphasized because again I am telling and we have already seen that the mechanical properties that we get from a spray lay-up composite is relatively inferior to the properties that we get from the hand lay-up products. So, a composite product made by the hand lay-up process would offer us better mechanical properties as compared to the product, which is made by the spray lay-up process.

The difference is because of the type of reinforcement that we are putting in the composite material. In case of hand lay-up we have continuous fiber, we can have continuous spread of the fibers in the polymer matrix. In case of spray lay-up, the fibers are chopped in the spray gun and we have small fibrous reinforcement or a short fibrous reinforcement which may not provide us a very good mechanical properties. Therefore, they are used in small boats, bath tubs, fairing of trucks, duct and air handling components, storage tanks and furniture components.

So, the components or the products by the spray lay-up process are such where too much of mechanical loading is not going to come. So, they are used for relatively medium mechanical loaded components where the loads are medium in nature or there are no load at all. So, spray lay-up has got its own advantages it has got certain limitations, but still it is one of the common processes which is used for the processing of polymeric matrix composites.

So, till now we have seen there are two important processes which are used, which are very useful and have got huge amount of engineering applications, these are the hand lay-up process and the spray lay-up process. And if you remember the classification of the processes for polymeric matrix composites there were three broad classifications that is the open mold processes closed mold processes and finally, the other type of processes. So, we have seen two processes in which the open mold processing is been done, so the mold is open in nature as in case of the hand lay up as well as in the case of spray lay-up. So now we will focus on our tension on some other processes which are used for fabrication or processing of polymer matrix composites. One of these important process is the process of pultrusion as the title of our lecture today that is the pultrusion process.

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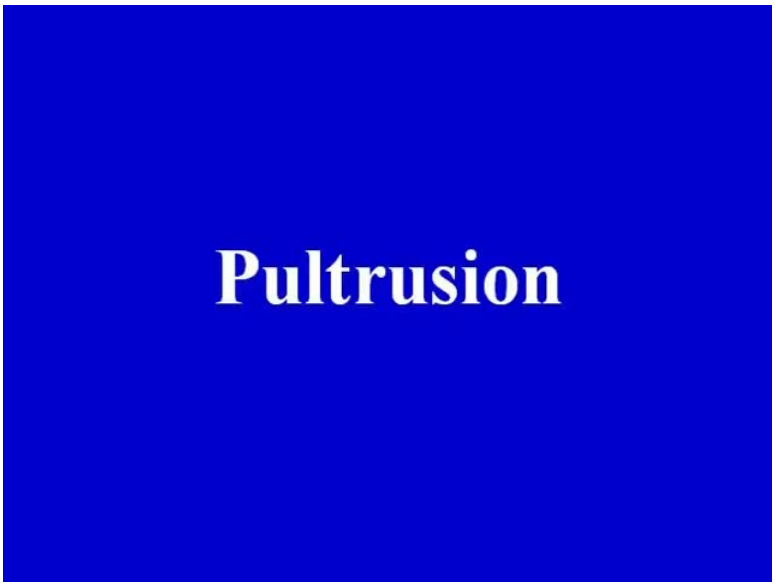

So, now we will see what is pultrusion. Pultrusion you can see is quite similar to the process which is used for metals that is called extrusion. So, extrusion and pultrusion is

one and the same thing we will see how extrusion and pultrusion are different in the subsequent slides. So, first of all let us see where pultrusion process comes in the overall processing techniques for the polymer matrix composites.

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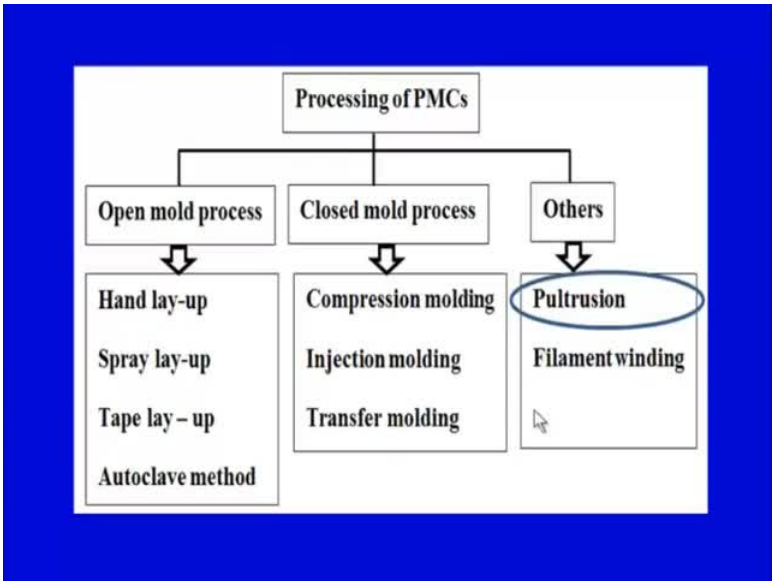

As I have already told, in case of processing of polymer matrix composites there are three broad categories open mold processes, closed mold process and the others. We have seen in our previous lectures two process that is hand lay-up process and the spray lay-up process, these two we have seen we have seen what is the procedure of doing this process or what is the process like we have seen what are the application areas we have seen what are the advantages and the limitations of these two processes.

So, today our focus would be primarily on the pultrusion process so, what is the pultrusion process and how it is done with the help of a schematic diagram we will try to understand that what is the process of pultrusion. And finally, we will see what are the application areas of pultrusion process, what are the advantages and limitations of the pultrusion process.

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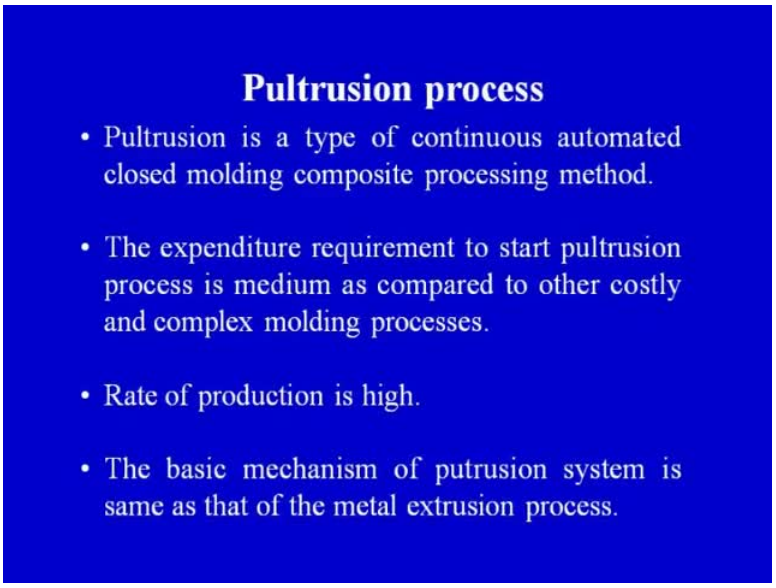

Now, pultrusion process has on your screen you can see, pultrusion is a type of a continuous, it is a continuous process, the product that we are going to get will be in a continuous form. Automated process, because the manual interference in case of pultrusion process is minimal, it is a completely automated process, closed molding composite processing method. So, here the mold is a closed formed mold which we call as die in case of pultrusion process.

So, first sentence has got two three important points that is pultrusion is a type of a continuous process, it can be automatic process as well as the die or the mold, in this form is a closed mold method. The expenditure required to start pultrusion process is medium as compared to other costly and complex molding processes. There are other very complex sophisticated molding processes but the expenditure or the infrastructural cost required to establish a pultrusion process is medium as compared to the more sophisticated processes used for the processing of polymer matrix composites.

The rate of production is high as its clear from the very first point that it is a continuous process therefore, the rate of production in case of pultrusion process is quite high. Whereas, the rate of production in case of hand lay process is relatively less and it is relatively medium in case of spray lay-up process but it is comparatively higher in case of the pultrusion process. The basic mechanism of the pultrusion process is similar as that of the metal extrusion process. So, in metal extrusion process what is done, we have

a raw material and it is extruded through a opening which is called as a die. A pressure is applied with the help of a ram on the metal and the metal comes out of the die opening in the desired shape.

The shape of the final product will depend upon the shape of the die opening. If the die opening is circular in nature we will have a cylindrical component. It can be a square, we will have a square cross sectional area of the final product. If it is a rectangular opening of the die we will have a rectangular cross sectional area of the desired component. So, depending upon the shape of the opening of the die, we will get the final product. So, the shape of the final product is depending upon the shape of the die. So, in metal extrusion process the metal is pushed through the die opening into the desired shape and the desired shape of the final product depends upon the opening of the die. This is the basic mechanism or the basic metal extrusion process.

Whereas in case of pultrusion process it can we can, if we divide the process into two parts pull and trusion, pultrusion so, means in case of pushing the metal we are now pulling the composite. So, from the name itself it is clear that here we are doing the pulling therefore, the name pultrusion process. So, pultrusion process is different from the metal extrusion process in one particular way. But the basic principle is same that the raw material is passed through the die in order to give it a required shape. So, we will see these points when we see the schematic diagram of the pultrusion process.

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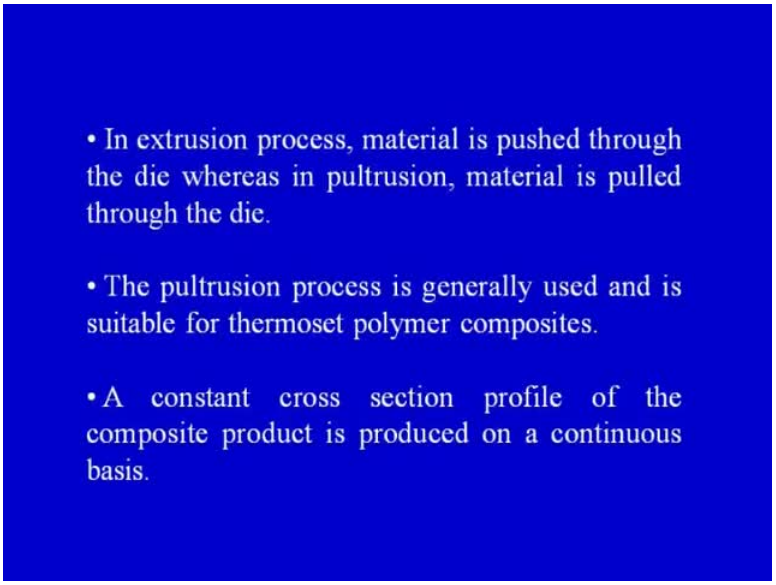

In extrusion process, the material is pushed through the die whereas in pultrusion material is pulled through the die. So, this is the difference which I have already explained on the previous slide, that in metal extrusion the metal is pushed through the die, through the opening of the die and the die opening decides the cross sectional area of the final product. In pultrusion, the raw material is pulled through the die and the shape of the material or the shape of the final product depends upon the shape of the die through which the material is pulled in the case of the pultrusion process.

So, the pultrusion process is generally used and is suitable for thermoset polymer composite. So, it is one of the important processes for polymer matrix composites. A constant cross section profile of the composite product is produced on a continuous basis. So, the two important points which are there to explain in this particular point is a constant cross section profile of the composites which is made and on a continuous basis. This point already has been highlighted that pultrusion is a continuous process, it will once the process has been started on a continuous basis we will get the output.

The output would be in terms of the final composite product which can have different profile. It can have a square cross section, it can have a hallow cross section, it can be a rectangular, it can be a circular, it can be in the form of rod or it can be in the form of tube depending upon the requirement, we can have different types of pultruded profiles but the profile would be coming out continuously and the first important point is a constant cross section so, the changes in the cross sectional area are not suitable for manufacturing by pultrusion process. So, if there are large cross sectional changes in the final product, then the pultrusion process is not that suitable, that we will see when we see the limitations of the pultrusion process. So, basically it is a continuous process, it is a automatic process and this process can be used for making different types of shapes

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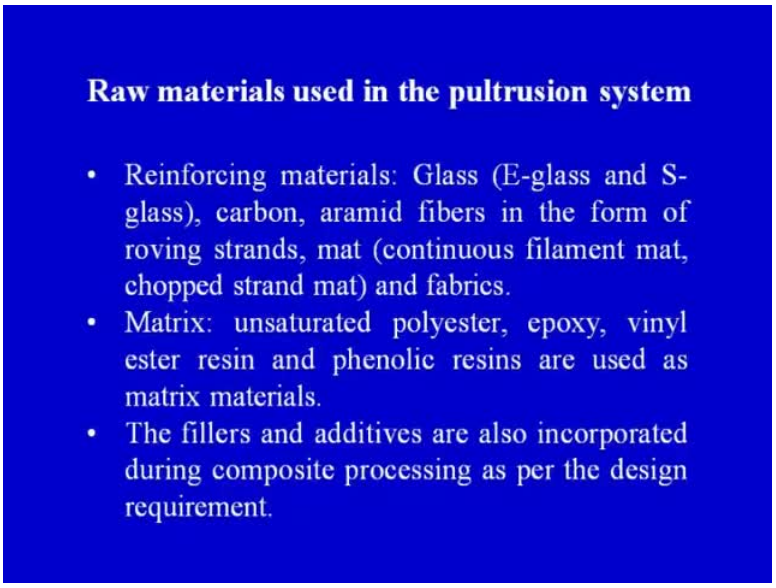

Now, what are the raw materials that go into the pultrusion system? Reinforcing reinforcing materials can be glass fiber, E-glass and S-glass carbon aramid fibers in the form of roving, strands, mats, continuous filaments are used chopped strand mats and fabrics can also be used. So, basically these particular points highlights two important things, first is the material of the raw material.

Material of the raw material means, that the fiber can be of different types, different types means on your screen you can see you can have glass fibers, you can have carbon fibers, you can have aramid fibers and now the shape of the reinforcement you can have it in the form of roving, you can have it in the form of a mat or you can have it in the form of a fabric. So, these are types of materials which go into the pultrusion process so, this is the reinforcing material then, what is the other important ingredient that is the matrix, now the matrix can be in the form of epoxy it can vinyl ester resin or phenolic resin.

So, different types of polymers can be used as the raw material different types of fibers can be used as the raw material and different shapes of the fiber are can be used as the raw material. So, we have a reinforcing material we have a matrix and when this reinforcing and the matrix will be combined together in the die, we will get a final product or we can say a final pultruded product.

The fillers and additives can also be incorporated during composite processing as per the design requirement. So, if the final composite product has to have some specific requirement, which have to be satisfied when the composite will be put to use in various engineering applications, we need to have certain additional requirements. For example, fire retardants or corrosion retardants or some colored pigments have to be added. So, all these additives can also be incorporated during the pultrusion process. So, this will also be the raw material that will go into the pultrusion system.

So, what are the raw materials just to revise, we have different types of fibers, carbon, graphite, Kevlar. We can have them in different forms, we can have rovings, we can have fiber mats and we can have different types if matrices depending upon the requirement of the final product and we can add certain additives into the resin system in order to give specific conditions and the requirements of the final product.

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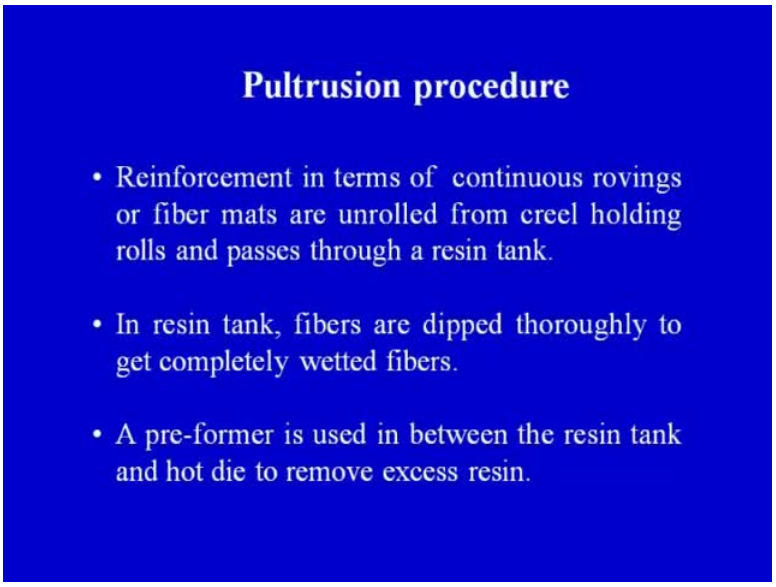

Now, what is the process or what is the pultrusion procedure, how the process is carried, so very simply the process is in three or four different stages. The first stage is the fibers are in the form of suppose rovings are put on the creels the fibers will come and they will get wet in the resin bath. The resin bath is the place where the resin and the catalyst have been put together, the fibers will get wet in this resin bath and finally, they will go pre-former, which will give a rough shape to the fibers and the matrix composition or the combination. From the pre-former the material will go into a heated die in the heated die

the polymerization or the curing process will start. As soon as the material is come out of the heated die it would be partially in the solid state. When it will be pulled through the pulling mechanism there are different types of pulling mechanisms, when it will be pulled through the pulling mechanism that desired length would be cut by the cut of saw or there can be different types of cutters, which can cut the composite product into the desired length. So, we will see this with the help of a simple diagram that how the pultrusion process takes place. In the pultrusion procedure reinforcements in terms of continuous rovings or fibers mats are unrolled from creel holding rolls and passes through the resin tank.

There are creels which hold the rovings and from which rovings the fibers will come out you can all of us have seen threads roll on the various types of rovings. In our house hold also we use needle and thread to stitch the cloths so, similar types of rovings are there on which the different types of creels are there on which we have the fibers. So, these the fibers will be coming and now these fibers can be wet in the resin tank. So, the first important point to note on your screen you can read the reinforcements in terms of continuous rovings or fibers mats are unrolled from the creel holding the rolls and passes through the resin tank.

So, first the fibers will come and these will then go to the resin tank in the resin tank fibers are dipped thoroughly to get the completely wetted fibers. So, first of all the fibers will be coming they will going they will be going into the resin tank and from the resin tank they will be picking up the resin. So, resin has to have the viscosity so that it is able to wet the fibers completely so that none of the fibers are left dry, so before entering into the pre-former so each and every fiber should get wet during the process of resin bath. So, when the fibers are going through the resin bath or the resin tank they should take the resin along with them and each and every fiber should get wet.

So, the second stage is in the resin tank fibers are dipped thoroughly to get the completely wetted fibers. A, pre-former is used in between the resin tank and the hot die to remove the excess resin so, when the fibers have been wet in the resin tank they will be going through the pre-former and the excess resin will be removed from there. Why do we want to remove the excess resin, as has been discussed in the process of hand lay-up as well as in the spray lay-up, we want to have a higher fiber volume fraction. So, in our final composite product we want that the fiber volume fraction or the proportion of

the fiber in that total composite should be higher why because the main load bearing member are the fibers. If the fibers are more the load bearing capacity of the resultant component would be higher, we do not want resin rich composite actually we want a fiber rich composites.

But, still the roll of the matrix cannot be undermined because matrix has got its own role it provides the bulk it avoids the fiber to fiber interaction rubbing and abrasion. So, matrix also has got its own advantages but on the whole we want a higher fiber volume fraction as compare to the volume fraction of the matrix. So, excess resin has to be removed and for that purpose pre-former is used and the pre-former is also used to give a shape because as the name suggest pre former.

So, it has to form the composite into the desired shape before it enters into the heated die. So, three steps we have seen the fibers will be coming from the creels and then they will be getting wetted inside the they will be wet inside the resin tank and after coming out of the resin tank they will go to the pre-former where the excess resin will be removed. And finally, this will finally, enter into the this combination of wetted fibers they have been wet by the resin which is present in the resin tank. Now finally, this combination of the fibers and resins would go into the heated die.

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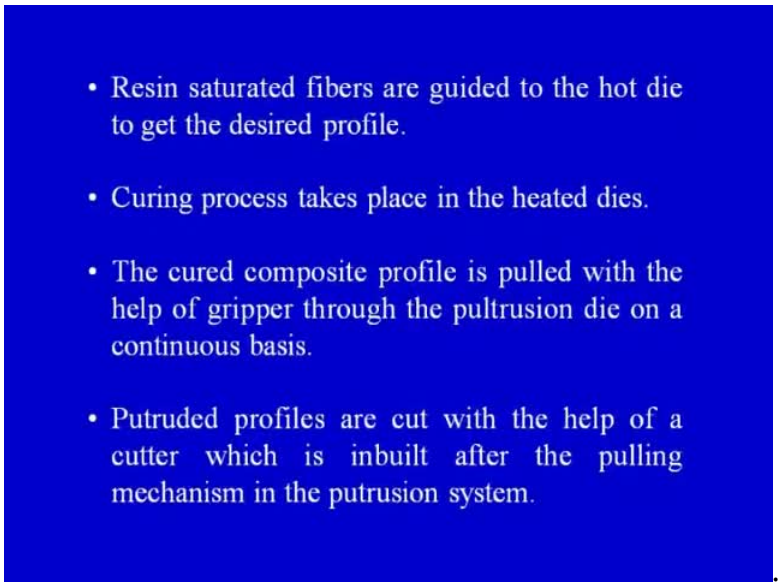

Resin saturated fibers so, the fibers which have undergone the wet bath in the resin tank are now guided to the hot die to get the desired profile. So, the final profile will be given

by the die but the pre-former will just give it the direction towards the die. Curing process takes place in the heated dies so the resin now will start to polymerize or the curing process will take place and the resin will start to solidify. Now, the important point is by the time this mixture of resin and fiber comes out from the die, it should have become solid or partially solid, so that the pulling mechanism is able to pull this material out of the die. If it would not have solidified the pulling mechanism will have difficulty in pulling this out of the die so the curing process takes place in the heated dies.

The cured composite profile is pulled with the help of a gripper through the pultrusion die on a continuous basis so, there will be a continuous pulling of the pultruded profiles which have partially solidified or solidified in the dies itself. The pultruded profiles are cut into the desired length with help of a cutter which is inbuilt after the pulling mechanism in the pultrusion system. So, after the pulling mechanism we will have a cut off saw or a cutting mechanism which will cut the pultruded profiles into the desired lengths. So, the complete process can be explained with the help of a diagram also, but before we go to the diagram there are few other important points that we need to discuss.

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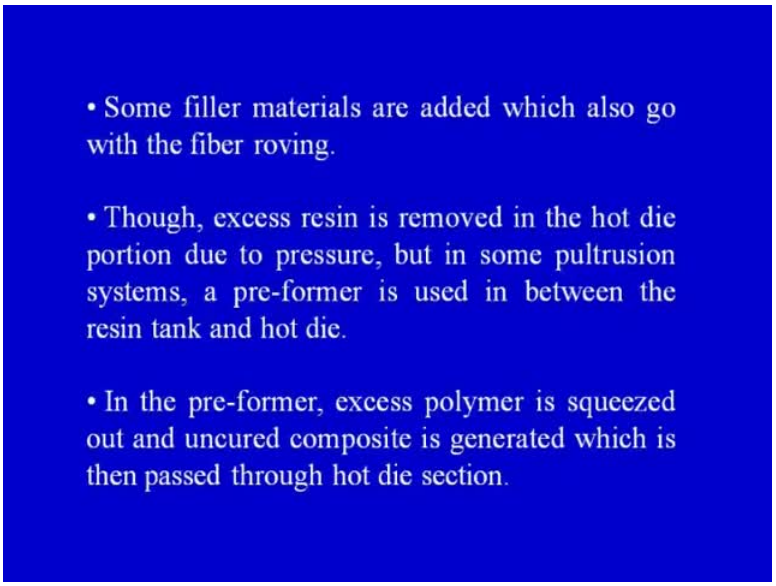

That is some filler materials are added which also go with the fiber roving. So, filler materials can be added they can be added in the resin bath also they can also be incorporated in the fiber rovings. So, sometimes there are different types of hybrid fibers also in which that there are different properties. So, we can have the reinforcement the

additional reinforcement also we can have an additional fillers that can be added in the resin. So, the raw materials can be modified to suit to the requirement of the final product. If the final product has got certain specific requirements, those can be incorporated in the material design stage only when we are selecting the fiber and the matrix we can add certain things, we can do some tweaking with the fiber and the matrix, so that we get the desired properties of the final product.

So, though excess resin is removed in the hot die portion due to pressure but in some pultrusion system a pre-former is used in between the resin tank and hot die, that we have already discussed the utility of using a performer. In the pre-former the excess polymer is squeezed out and the uncured component is generated which is then passed through the hot die section. So, this we have already seen in the previous slide it is just a revision to highlight the role of the pre-former that why a pre-former is used and we should lay emphasis on removing the excess resin before entering into the heated die because we want a fiber rich composite.

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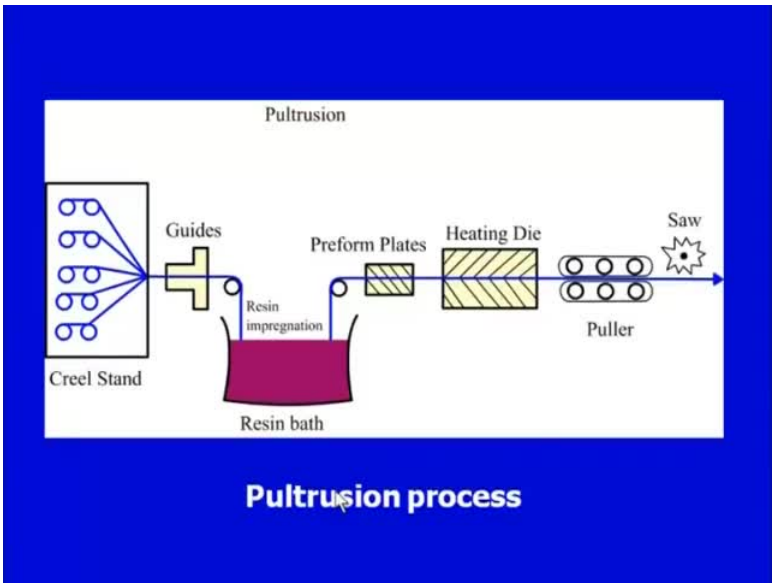

Now, this is a simplest diagram of the pultrusion process, you can see these are the fiber creels this circular portions this you can say this can be called as the this in totality can be called as creel stand. In this creel stand there are different creels and from these creels the fibers are coming. So, usually the diameter of the fiber is very less suppose in case of glass fiber the diameter of the individual fiber may be ten microns may be eight micron

to twelve microns. Therefore, these fibers cannot be handled so, the fibers usually are in the form of strands and each strand may have number of may be hundreds of fibers bound together. So, these are fiber strands which are coming 1, 2, 3, 4. So, these are the fiber strands which are coming from the fiber creels and these are the guides to give them a particular shape and this is the resin bath or the resin tank.

The resin impregnation takes place these particular fibers will get wet in this resin bath and after they coming out they will be carrying the resin along with them and then it will go through the pre-former or the perform plate which will give it a desired shape and the excess resin will be squeezed out at this preformed plates and then we have a heated die through this die this particular preformed composite system will pass and then there is a pulling mechanism. There are different types of pulling mechanism being used in different pultrusion system like, one of the important pulling mechanism is the cater pillar type of pulling mechanism. So, this is a pulling mechanism which will pull the composite product out on a continuous basis and then there is a cutoff saw which will cut the product into the desired length.

So, just to revise the process once again the fibers will be coming from the fiber creel the fiber here you can see this is on the conti the continuous basis the fibers are coming from the fiber creels. The guides are there to give a direction to the fibers. The fibers finally, in the final form will get resin impregnated here. So, this is a resin bath, in the resin bath we will have a polymer and we will have a catalyst which would be mixed together in the required proportion. This resin bath, the role of this resin bath is to do the impregnation of the fibers which are passing through this resin bath.

The fibers will get wet and the wet fibers will come out of the resin bath and they will be going through the pre-former plates. In the pre-former plate the excess resin would be squeezed out the performer, will give the desired shape to the fibers and the resin. Finally, these preformed parts will preformed part will go into the heated die where the process of curing will take place and the solid composite product will be pulled out by a pulling mechanism. And finally, it will be cut to the desired shape by the cutoff saw.

So, the process I think with the help of the stages or the points as well as with the help of the diagram, we have seen what is the process of pultrusion. So, basically there are two important points in any composite manufacturing process, we have to blend the two

things together the fiber and the polymer has to be mixed together in order to form a composite product. In hand lay-up process we have seen the lamination is done alternate layers of the fiber mat and the resin are placed together and then it is compressed with the help of pressure.

It is allowed to cure the resin cures and the composite laminate is got. In spray-lay up the resin and catalyst are coming from the two different sources, the fiber is coming and all these three ingredients are getting mixed in the spray gun and the mixture of resin catalyst and fiber chopped fiber is getting sprayed on to the mold surface and we get a composite product after curing of the resin. In case of pultrusion again we have to blend the fiber and the resin together or the fiber and the polymer together.

In this particular case we can see the fiber is coming from the creels it is been guided into the resin bath, in the resin bath it is picking up the resin the fibers are getting wet and they are go into the pre-former excess resin is removed from at the pre-former stage and the complete you can say the desired shape of the resin and the fiber system is then input into the heated die where it gets its final shape and the curing takes place inside the heated die and finally, we get the composite product out. The composite product is pulled by the pulling mechanism there are different types of pulling mechanism and finally, the desired length of the profile is cut by the cutoff saw. So, this is the, you can say one of the automated process of processing the polymer matrix composites.

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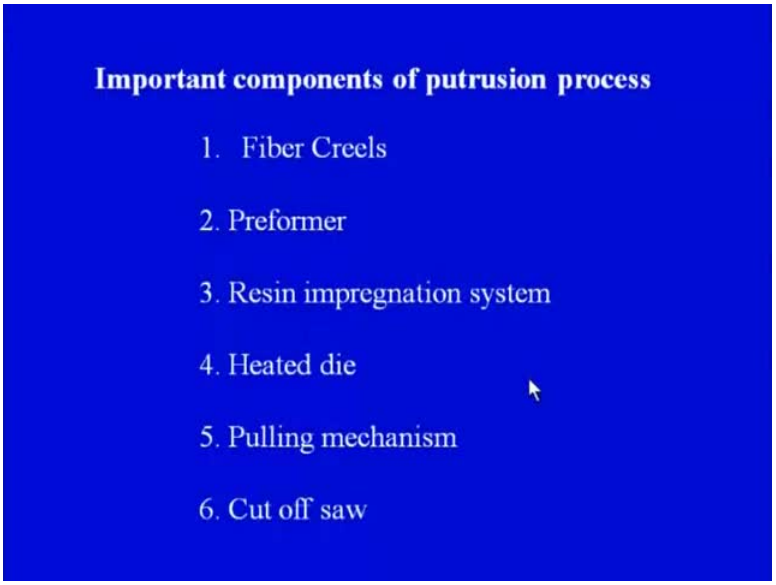

Now, what are the important component of the pultrusion process? On your screen you can see, we have fiber creels, we have pre-former resin impregnation system, heated die pulling mechanism and the cut off saw. So, starting from the fiber creels going through the resin impregnation system, pre-former heated die and the pulling mechanism and finally, the cut off saw. Now depending upon the type of the composite product being developed, depending upon the production rate, depending upon the quality desired, we have to see and we have to design all these important components of the pultrusion system.

What type of fiber creels are required? How many fiber creels are required? What type of pre-former is required? What should be the shape of the performer? How much resin should be prepared for the particular length of a profile? What should be the length of the die? What type of heating element should be put in the die? What type of pulling mechanism should be designed in order to pull the final composite product out of the pultrusion die and at what distance the cut off saw should be placed? All these are the decisions which have to be taken when we are designing a pultrusion system for a particular type of a composite material.

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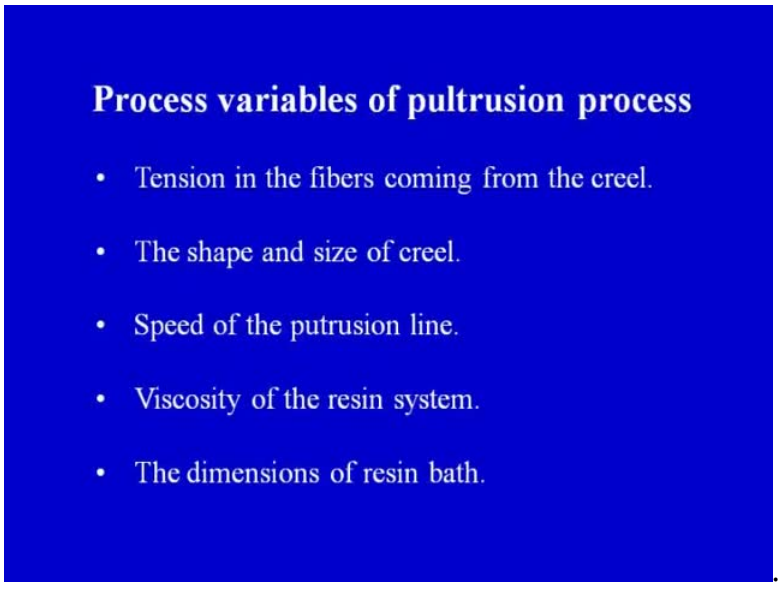

Now what are the process variables of the pultrusion process? What are the things which we need to control during the pultrusion process? The tension in the fibers coming from the creel so, we have to see that there is a adequate tension in the fibers when they are

coming out of the creel. The shape and size of the creel is also equally important. The speed of the pultrusion line may be in terms of centimeters per minute or meters per minute. So, that speed of the pultrusion line is also equally important at the rate at which the pultruded product or the pultruded profile is coming out of the heated die that is may be called as the speed of the pultrusion line.

The viscosity of the resin system so, there should be optimal viscosity of the resin system. The fibers have to get wet inside the resin bath. So, the viscosity should be optimal, so that all the resin, all the fibers that are entering into the resin bath should get wet. There should not be even a single fiber which is not wetted during the during the flow of the fibers through the resin bath. So, the optimal viscosity of the resin bath has to be chosen. The dimensions of the resin bath are also equally important. So, there are few things which are also designed, which also have to be taken care of when we are selecting a pultrusion process for making a pultruded profile for any particular engineering application.

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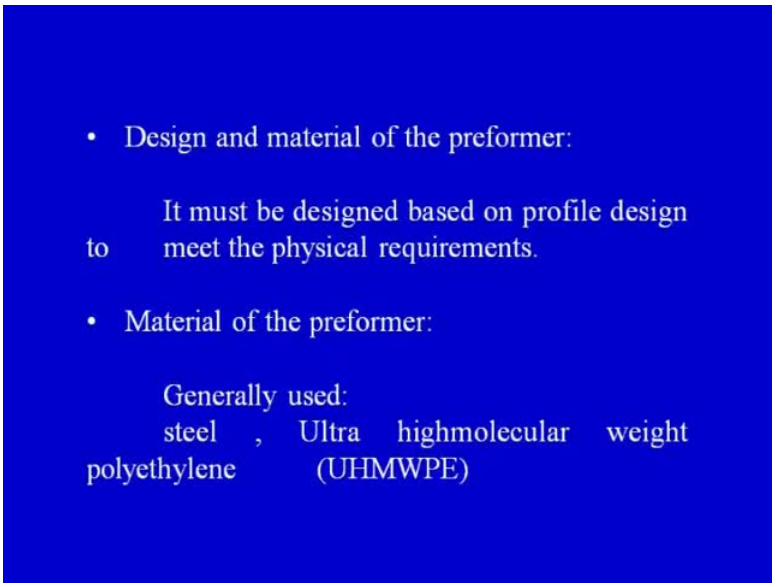

Another important point that has to be taken care of is the design and material of the pre-former. Now, it must be designed based on the profile design to meet the physical requirement. So, pre-former as we already have seen in the diagram also it gives the rough shape to the fiber and the resin system before it enters into the die. So, the shape of the pre-former is important, so that it is able to guide the fibers and the resin into the die

system and able to give the rough shape to the rough shape to the input that is going into the heated die. Because the die is the place where the final curing will takes place and the final shape of the product will be generated or made. But the pre-former acts as a input to the heated die. Now, what should be the material of the pre-former? It is generally used steel ultra-high molecular weight polypropylene polyethylene, sorry is also used we can use a pre-former of steel or we can use pre-former of ultra-high molecular weight polyethylene. So, the material is also specified or the other materials can also be used to make the pre-former.

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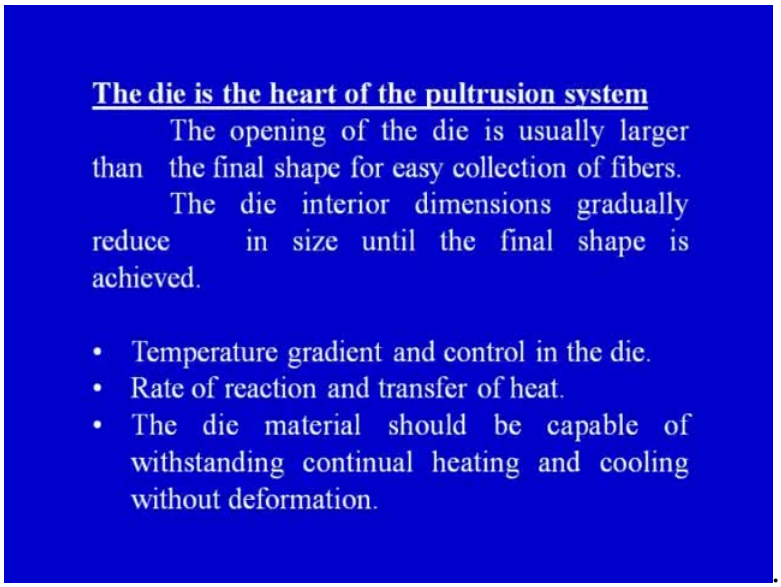

The pultrusion die is the heart of the pultrusion system so, this is the most important part of the total pultrusion system because the final formation of the composite products takes place inside the die only. So, the opening of the die is usually larger than the final shape for easy collection of the fibers. So, as we have already seen in the diagram the fibers and the resin they go through the pre-former and then they enters into the die. So, the opening of the die is made slightly larger in order to intake the fiber and the resin system. So, the fibers enter into the die and gradually the size of the die decreases and finally, it reaches to the exact size of the final pultruded profile that is desired.

So as you can see on your screen, the opening of the die is usually larger than the final shape for easy collection of the fibers. The die interior dimensions gradually reduce in size until the final shape is achieved. So, the final dimension of the die towards the

output where the final product has to come out is exactly equal to the final shape or the final desired dimension of the final product.

The temperature gradient and control in the die is also equally important. Because as soon as the raw material in the form of resin impregnated fibers enter into the die they encounter a certain temperature and as and when they move forward in the heated die the already heated fibers are moving in the die. So, towards the end they may get overheated also, there has to be a proper thermal gradient or proper temperature gradient along the length of the die; that we have to see that we have to establish and control, that what should be the temperature gradient inside the length of the die. So, the temperature gradient and control in the die or the temperature control in the die is also equally important.

Also we have to see that the product or pultruded profile or the pultruded product which is coming out of the die is finally, in the form in which it can be used or it should be in the solid state otherwise the pulling will become a problem. The pulling mechanism would not be effective if the product that is coming out of the die is not adequate. So, we have to establish the temperature gradient inside the die in such a way that the proper curing of the pultrusion process or the pultrusion raw material takes place. The proper curing of the resin takes place inside the die that is our ultimate aim. Therefore, we have to control we have to establish a proper temperature gradient inside the die.

The rate of reaction and transfer of heat is also equally important. The rate of reaction means how the curing process takes place and how the heat is transferred to the resin from the heating element that has to be designed properly. The die material should be capable of withstanding continual heating and cooling without deformation. So, thermal shocks should be avoided in case of material. The material should be chosen in such a way that it can experience those thermal shocks caused by the constant or intermittent heating and cooling of the die so, the die material has to be appropriately selected.

Another important point to be noted regarding the die material is that some of the fibers may be abrasive in nature. So, the die material should have the wear resistance property. If the die wears out very fast every now and then after few meters of length being pultruded the die would require to be changed, which is not at all desirable, because the cost of the die is extremely high. So, it has to be taken into account either the jacket of

the wear resistance material is put inside the die actual die or the die is made of such a material which is wear resistance.

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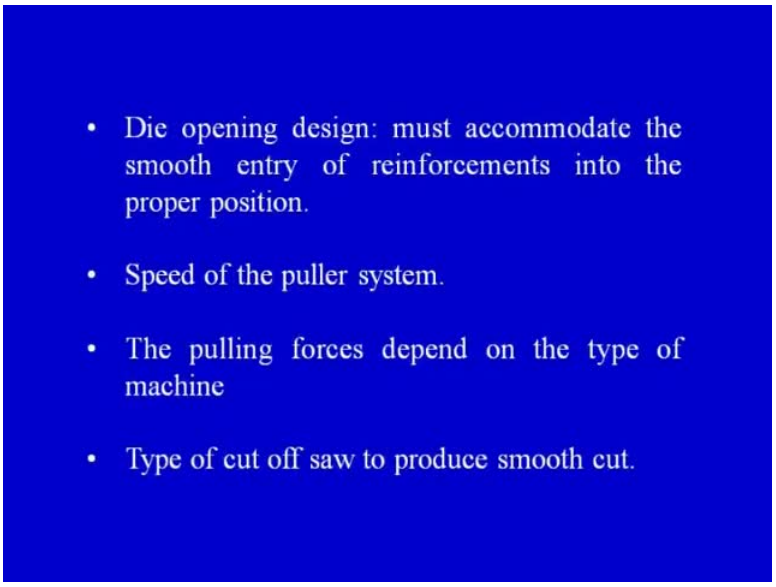

Then the die opening design is also equally important. Must accommodate the smooth entry then of the reinforcement into the proper position. So, the die opening design is very, very important because the raw material in the form of resin impregnated fibers have to get in the die and finally, the final product has to come out of the die. The speed of the puller system has to be designed properly. So, that we get the final pultruded profile which is having the desired shape as per the design requirements. The pulling force is depend upon the type of the machine being used and the type of the pulling mechanism being employed to pull the final product out of the heated die. Also the types of the cut off saw there are different types of cut off saws available so, we have to judiciously select the type of cut off saw for the particular application.

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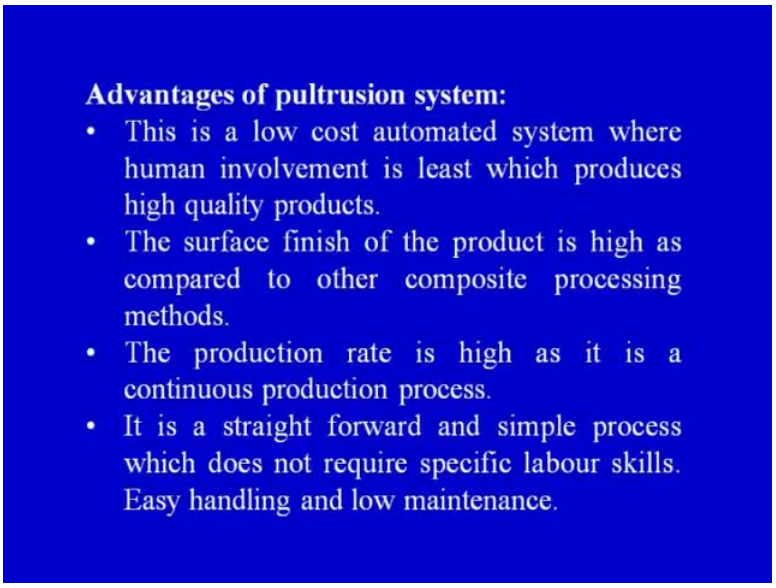

Now, what are the advantages of the pultrusion system? This is the low cost automated system, where human involvement is least which produces high quality products. So, there is nothing much to explain it is a automated system human interference is less and the and the quality of the product is good. The surface finish of the product is high as compared to other composite processing methods because the finish of the die is directly duplicated on to the finish of the final product. The production rate is high as it is a continuous production process. It is a straight forward and simple process which does not require specific labor skills, easy handling and low maintenance process.

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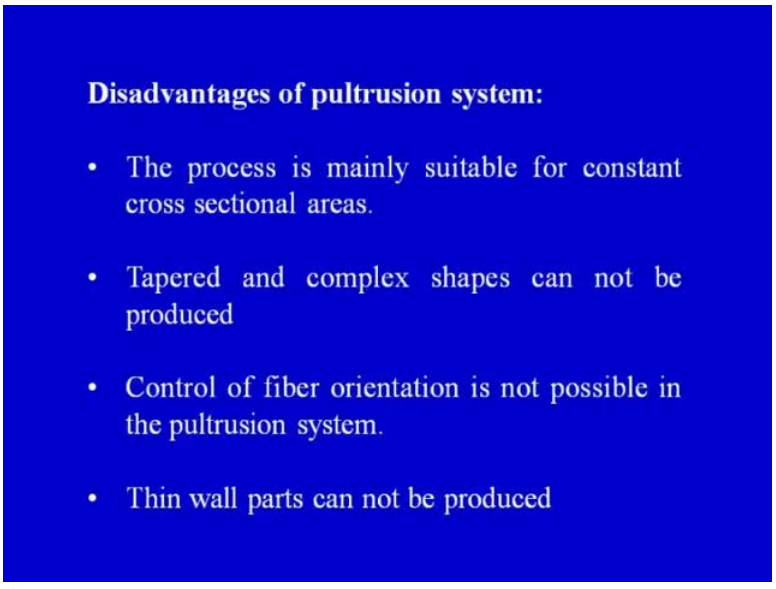

Now what are the disadvantages of the pultrusion system? The process is mainly suitable for constant cross sectional areas. These points have already been addressed, where the cross sectional area of the product is changing quite often that type of products cannot be manufactured by the pultrusion process. So, the process is mainly suitable where the cross section of the product is constant. Tapered and complex shapes cannot be produces by the pultrusion system. Control of the fiber orientation is not possible in the pultrusion system. Thin wall parts cannot be produced.

So, if there should be a adequate thickness of the parts which has to be produced by the pultrusion system. So, the very thin parts cannot be produced, fiber orientation cannot be controlled tapered and complex parts not possible. The process is mainly suitable for constant cross section only where the variation of cross section takes place that is not possible. For those types of products cannot be made by the pultrusion process where the cross section is changing.

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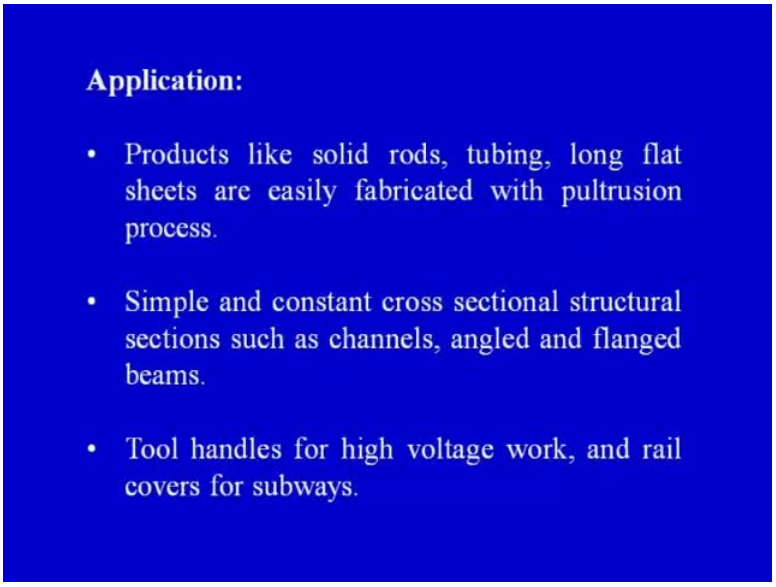

The application, the pultrusion process is used for making solid rods, tubing, long flat sheets can be easily fabricated. Simple and constant cross sectional structural sections such as channels, angled and flanged beams can be made by the pultrusion process. Tool handles for high voltage work and rail covers for subways can also be made by the pultrusion process. So, pultrusion has got a wide variety of applications where the constant cross section has to be made those type of cross section can easily be made by

the pultrusion process. Rods, flanges can be made different cross sectional shapes can be made on the continuous basis by the pultrusion process.

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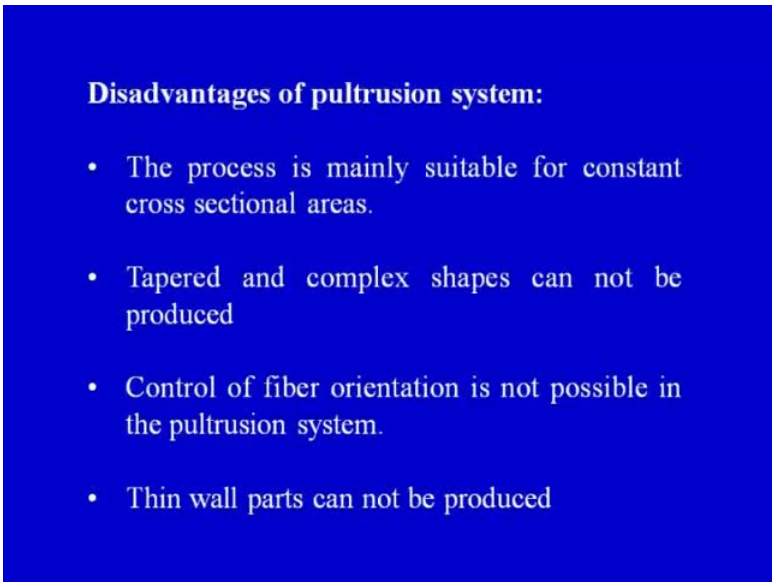

So, on your screen, you can see few examples of the product which can be made by the pultrusion process. Flat sheets, simple and constant cross sectional sections such as channels, angles and flanged beams can be made. So, pultrusion has got a wide variety of applications in the fabrication or in the processing of polymer matrix composite material or composite products.

So, with this we come to the end of this particular lecture on pultrusion. Just to summaries what we have already covered in this particular lecture we have seen we began our lecture with where we left in the previous lecture on the spray lay-up. We have seen very briefly what is the spray lay-up process, we have seen the advantages, limitations and the application area of the spray lay-up. There after we started our discussion on the pultrusion process, we have seen the process itself what are the important process variables or the control variable, which have to be taken into account while we are selecting a pultrusion process for a particular application.

We have seen the sequence of steps involved in the pultrusion process and finally, we have seen the advantages, limitations and the application areas of the pultrusion process. In the subsequent lecture on this particular module on processing of polymer matrix composite and the another name may be fiber reinforced plastics. This particular module

focuses on the processing of FRCS or the processing of PMCS, we would see other processes common processes, which are used for processing of polymer matrix composites.

Thank you.