Processing of Polymers and Polymer Composites
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Lecture - 25
Pultrusion Process

[FL] friends, welcome to lesson number 25 in our course on processing of polymers and polymer composites. Let us take a brief preview of what we have covered in case of polymer composites. We have covered the fundamental aspects of composite, classification of composite materials. Then we have seen the challenges in context of polymer matrix composites, and then we have tried to understand the basic principles of techniques that are used for processing of polymer based composites or polymer matrix composites, and sometimes also called as the fibre reinforced plastics. We have seen that the broad principle of any processing technique; that is used for processing of polymer composites is, that we have to combine the fibre and the polymer together.

The fibre is the reinforcing agent, and the polymer is the matrix that provides a bulk to the composite material. So, basically we have to see in every technique, that how we can combine the fibre and the polymer together, and we have seen that we can have either closed mould processes, or open mould processes. We have seen examples of both types, and we have seen that for closed mould processes, we have bettered control, better quality, and the processes are compression moulding, injection moulding, resin transfer moulding and there are other processes also these three we have already covered .Whereas, in case of open mould processes, we have seen that hand layup which is the most widely used process, then there is spray layup process which is used for short fibre reinforcement .

Today we are going to study pultrusion, which is another process, which is commercially used for processing of parts which have constant cross section or uniform cross section. So, we will see that it is a long product manufacturing process. So, the length of the product is not a limitation in case of the pultrusion process. Now let me try to explain you the name of this process; that is pultrusion .From where the word pultrusion is coming, just as a layman we can try to understand that, first three words or first three alphabets, if we remove pul and we put ex, the process becomes extrusion. So, in extrusion process we have seen, in extrusion of polymers we have tried to understand that, what we do in extrusion. In extrusion we put our pallet us in the hopper, and then we have seen the design of the screw also in case of extrusion process. We push the molten plastic through the nozzle into the die, and then it comes out as a continuous cross section.

So, extrusion process is a simple process for processing of polymers in which we take the pellet us in the hopper, bring them down into the barrel. The barrel has heating arrangement all around the periphery, and inside it got it has got a screw arrangement, and this rotating screw, helps in sharing of the polymer pallet us, heating of the polymer pallet us, and it pushes the polymer pellet us, molten polymer pallet, towards the exit. And the exit we have a die through which the constant cross section, product is coming out, and the length of the product is not a limitation. So, that is the process of extrusion. Now how pultrusion is related to extrusion. In pultrusion process the basic principle will remain the same. Only thing is that we have to see that how, the fibres can also be added along with the polymer.

And moreover we have to see that how the product will be coming out of the heated die. So, that is the only difference that we have to understand, which extrusion process does not have. In extrusion the material is pushed by the rotation of the screw. Here we will see the product is pulled out of the die. So, pulling action is designed in the machine, so that the product is pulled from the machine, and therefore, the name pultrusion. So, you can very easily remember that why we are calling this process as pultrusion. It is opposite of extrusion. In extrusion we are pushing the material. Whereas, in case of pultrusion; we are pulling the material.

So, that is the basic difference between the two from the name point of view, from the definition point of view, but otherwise we will see that in the process details, there are number of variations. And if you remember the extrusion process as applied to the metals, there also in almost all variants of the extrusion process, the metal is pushed, and then it comes out of the die and it takes a uniform cross section, and length of the product is not much a limitation in case of extrusion of metals. So, extrusion process is done for metals, extrusion process is done for polymers and extrusion process is also done for polymer composites, where we can put our fibres and poly pellet us in the hopper, and they can come to come into the barrel, because of the action of gravity and in the barrel.

Because of the heat the polymer melts, the fibres then travel this mixture of fibre and polymer travels with the motion of the screw by the rotation of the screw, and then it is pushed out of the die, and the final shape of the product depends upon the shape of the die. And finally, the material is pushed out and we get our product. So, extrusion process can also be applied for processing of polymer composites, and specifically short fibre composite, but here we are going to see pultrusion process. In pultrusion we will always get a product which will be continuous fibre, and the strength of the product will be very good, because on account of, or because of the continuous fibre reinforcements that we are able to achieve in case of pultrusion process. So, the name itself is clearly indicating, that if this is similar to extrusion, only difference being that we are going to pull the product from the opposite side. Now let us try to understand the basic intricacies of this process.

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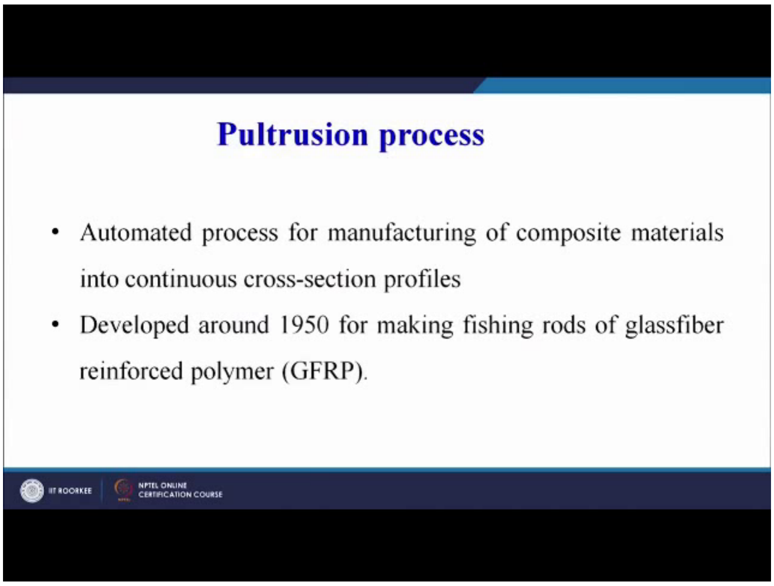

So, pultrusion process, it is automated process, we will also try to understand it with the help of a diagram as well as a simulation or the animation. So, automated process for manufacturing of composite materials into continuous cross section profile.

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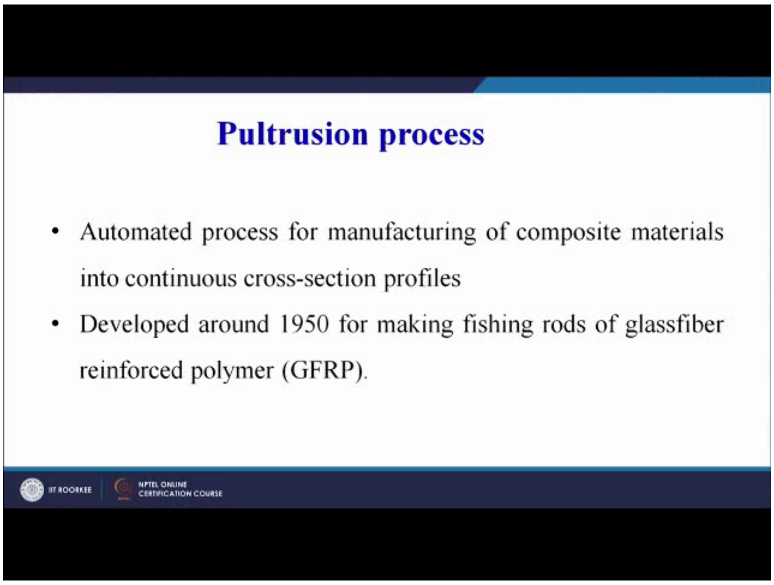

So, the cross section of the product that we will achieve from pultrusion, we will definitely be the uniform cross section. It was developed around 1950 just a historical perspective of the pultrusion machine. It was developed for making fishing rods of glass fibre reinforced polymers. So, glass fibre will be in the continuous form, and then it is the reinforcing agent is the glass fibre, and matrix in this case will be a polymer. So, glass fibre reinforced polymer fishing rods were made initially 1950 using the process of pultrusion.

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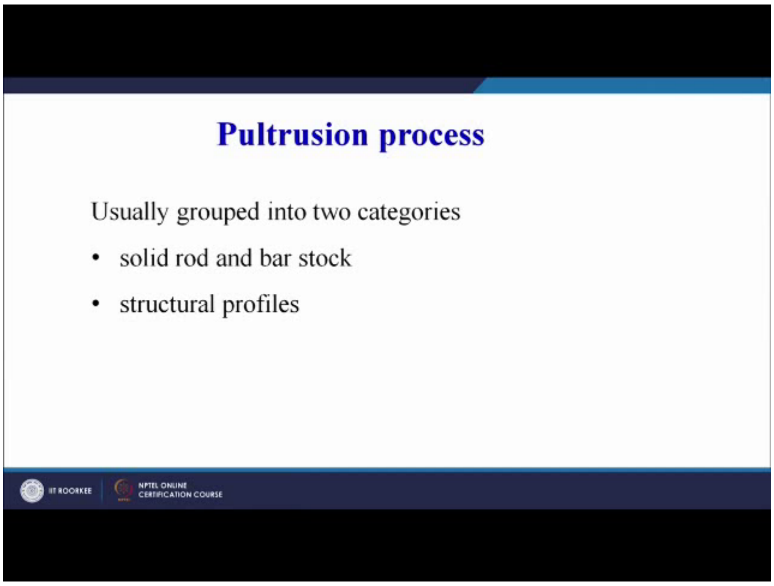

It is usually grouped into two categories; solid rod and bar stock as well as structural profiles. Now what are the raw materials that are basically used for pultrusion process. The reinforcement can be glass fibre, which can be e glass or s glass then.

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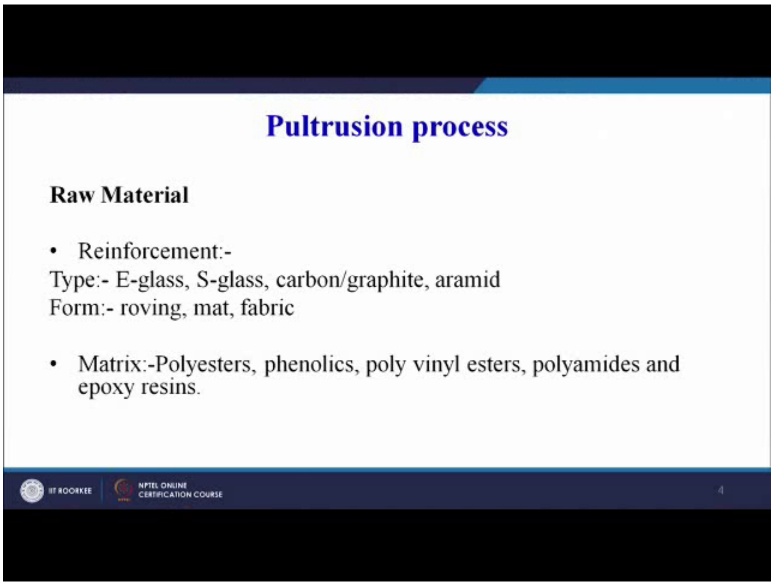

We can have carbon graphite fibres aramid fibres, and the form of the reinforcement can be roving, or in special cases can be in the form of a mat or a fabric also, but generally we used. Sorry generally we use the reinforcement in the form of rovings, which comes from we put mount this rovings on the creel, and from the creel the fibre filaments come and then they are preformed into a particular shape before feeding them into the resin tank. So, that we will try to understand it with the help of a diagram .

But the reinforcement in this case, can be in the mat form also, and the type of fibres are already shown. Matrix can be polyester, phenolics, polyvinyl ester, polyamides and epoxy. So, from the names, I think and today we are into our session number 25. The learners must be able to very easily guess that what type of polymer is being used here. So, all the examples mostly are thermo setting . So, therefore, we can say that pultrusion process is most commonly used for thermosetting type of resin systems. Now what are the steps forward in the pultrusion process?

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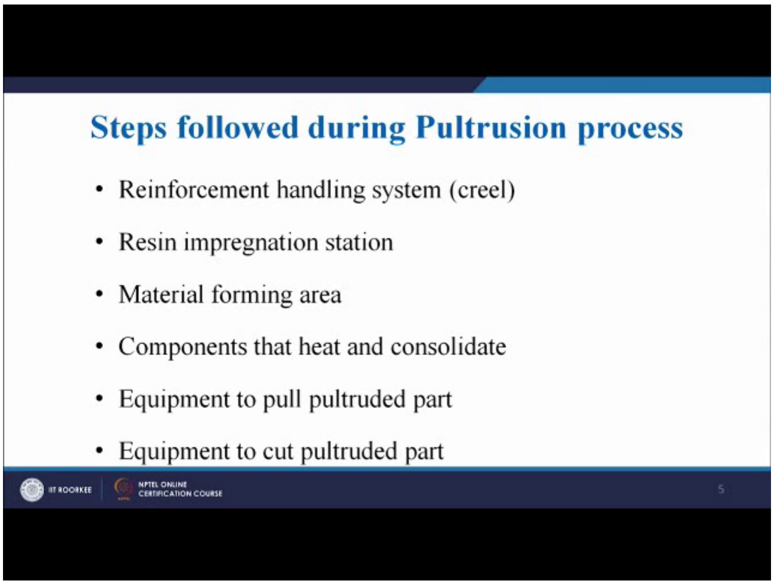

Let us first see the steps, and then we will go to the diagram. The first step is the reinforcement held handling system.

So, where we can see I have already used this word creel. So, the creel is used to mount the rovings, and from the rovings we will get our fibre which is the first requirement for the pultrusion process. So, reinforcement is in terms of fibre, the fibres can be glass carbon graphite fibre, glass can be e glass, s glass and the fibre is roving on a, we can say bovine or a creel, and this creel will help us, or the roving will help us to get our fibre for the process. Then the second stage is the fibres are coming from the creel. The second is the resin impregnation. So, we need to have a resin tank. So, here we are calling it as a resin impregnation station, where the fibres will get wet, the fibres will get impregnated with the resin; that is the matrix then the material forming area, that is we have to get a particular shape of the product, because we have seen that in case of polymer processing there were three basic steps.

First was melting of the polymer, second was deforming or giving shape to the polymer, third was the cooling stage. So, here also we have to give a particular shape. The fibres are random we can have the rovings, we can get the fibres in a particular direction, but finally, we have to make a solid rigid product, and for that we need to give a particular shape as per the design of our product. And to give that shape, we will have a particular die or a mould arrangement, then components that heat and consolidate. So, giving shape will not only make that product solid. What we need to do. We need to provide heat, we need to provide pressure, or we need to provide consolidation to this product.

So, that it solidifies, it becomes solid and rigid. The equipment to pull the pultruded , I think I have explained it in much detail, that how the pultrusion process is different from the extrusion process in pultrusion ,we are going to pull the material. So, there has to be a pulling mechanism which will pull the final product out of the machine. So, that is another arrangement that we have to provide. Then equipment to cut the pultruded part, as I have already told that pultrusion we can prove this long profiles, long profiles of uniform cross section. So, depending upon the requirement of the length of the product, we will have a cutting mechanism, which will cut the product as per the designed length

So, these are the various systems of the pultrusion process that we need to manage, control in order to get a good quality pultruded product.

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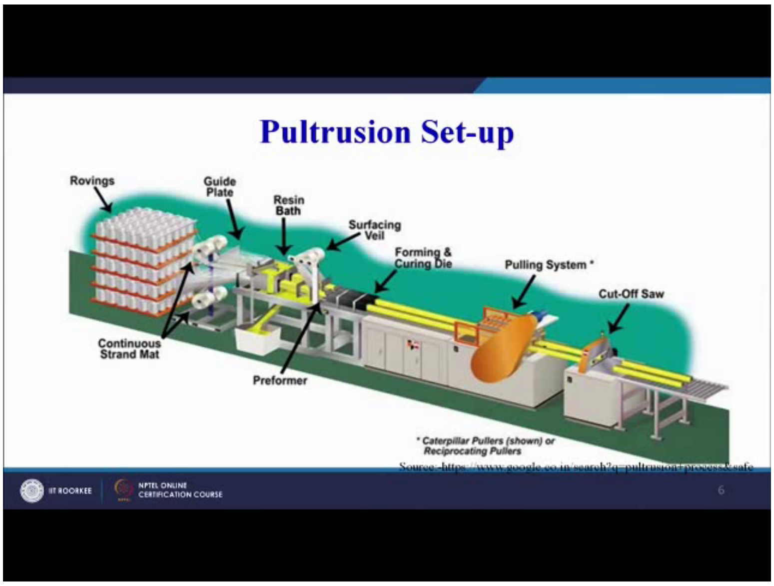

On your screen you can see image which is available at Google. These are the rovings, you can see on the leftmost corner, these are the rovings. So, many rovings are arranged here. So, the fibres or fibre filaments are coming from the rovings. Here we can see, a large array of fibres are coming from individual rovings. And finally, they are being guided by the guide plate into the resin bath. This yellow colour resin tank is there, which is providing the resin. So, the fibres will get wet in this resin, or they will get impregnated with the resin and.

Finally they will move forward. There is a surfacing veil, which we can says the top covering of the final product. So, that will provide a covering on top of the pultruded product. So, this is a surfacing veil; that is coming from this roll. In many cases the surfacing veil may not be there, we may get a directly pultruded product, because the forming die will give a very good surface finish to the product, but in specific cases we may opt for a surfacing veil, where we do not want the surface of the final product being exposed to the environment or being exposed to outside, maybe cooling, during cooling or cutting it is not damaged or the surface finish is not deteriorated during the pulling of the product . So, therefore, we may sometimes go for a surfacing veil, which is not a mandatory requirement. Once our fibres have come they have been impregnated in the resin system.

They move forward and there is a forming and a curing die. This is the forming and a curing die, in which we will supply heat also, and we will give a shape to our final product also. So, there are two jobs which have to be accomplished in the forming and curing die; one is the solidification, another one is the deformation. Rather we should say first one is the formation of the product, and followed by the curing that is a solidification. So, first is we have to give die a particular shape to the product, And secondly, we have to cure it. So, that that shape solidifies and become our final product. and then we can see the continuous profile, or you of uniform cross section this yellow colour profile, are coming out of the forming and curing dies and.

Finally there is a pooling system, which is continuously pulling these profiles from the forming and the curing die. And finally, there is a cut off saw, which is cutting the pultruded product as per the desired length. So, this is a caterpillar type of pullers, which are, it is a rotating type of mechanism which opposes the final product, out of the curing and the forming die. So, this is a, we can say a schematic representation of the pultrusion process. And here you can see another word that is pre former. So, before entering the forming and the curing die, the pre former will give a specific shape to the final product. the final shape is decided in the forming and the curing die .

So, basically you can see, as we have already tried to understand, there is a reinforcement management system here, or reinforcement system. Then there is a resin impregnation system, then there is formation and curing system, then there is a pulling system and then there is cutting system; so, basically for any manufacturing process, any processing technique that is used for processing of polymer based composites, especially fibre reinforced composites. We have to learn that how we can combine the fibre and the polymer together, and in this diagram we can see the fibre, and the polymer are getting combined, and after being passing through the pre former they are entering into the forming and the curing die, where the product is getting solidified and finally it is been pulled out of that die, and finally, cut as per that desired requirement or desired length of the product. Now this was the schematic diagram, let us try to understand the mechanism with the help of a animation, which will further make it clear that how the process actually happens.

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We can see here, this is the pultrusion setup. It is it is a large sized set up. So, here we see these are the rovings. Fibre yarns are pulled through a resin bath, wetting the fibres. This is a resin bath. Fibres are coming from here and getting wet in the resin impregnation system.

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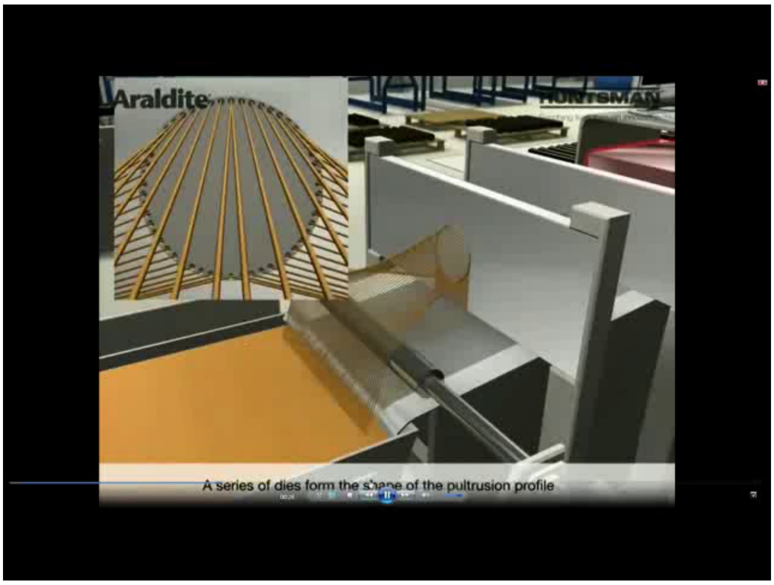

After being wet, a series of die forms the shape of the pultrusion profile. So, this series of dies can be called as the pre former as per our schematic diagram. So, these pre formers will give shape to the fibres, which are already impregnated with the resin.

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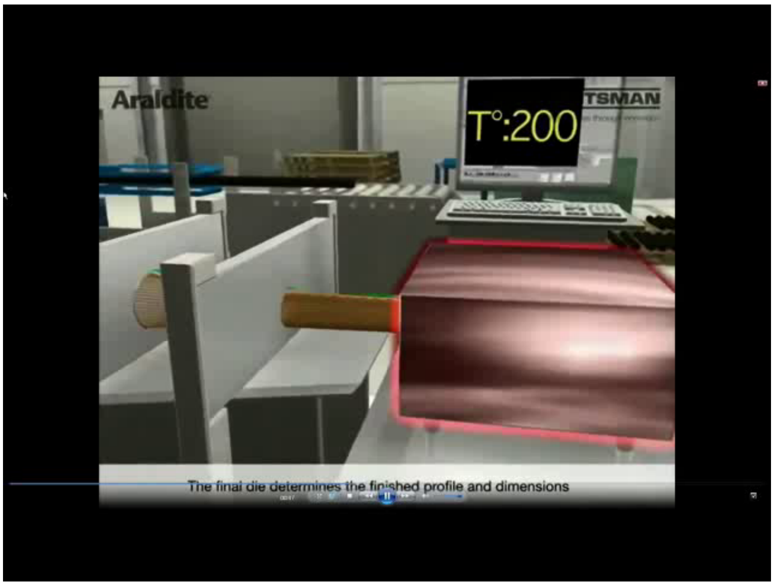

So, they are moving forward. There are two or three or series of these pre formers, and then finally, this is the die. We can see the temperature set is 200 degree within the die you can see.

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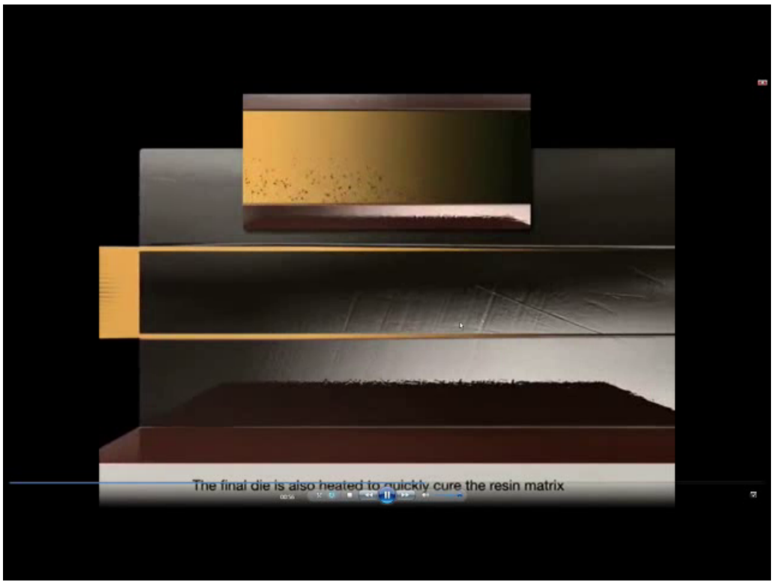

This is the movement, movement of the pultruded profile. Finally, the pultruded profile is coming out from here..

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Here it is hot as well as is giving the shape. This is the mechanism for pulling the material, it is continuous rotation of belts.

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And this is the cutting mechanism, where the saw cuts the profiled it or determined length, predetermined length.

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So, it is cutting the profile, and these are the final profiles, hollow profiles, or hollow cylindrical profiles made by the pultrusion process.

So, we can see, the video once again, just to have a overview, that how the process unfolds, and how the fibre and the polymer is combined together. The fibre is coming from this fibre stand. These are the fibre is moving. This is a resin bath. The fibres move through the resin bath. Then these are pre formers which are giving shape as per the final design requirement. And this is the final die, temperature is shown, it is a under hot condition, and this is giving the final shape to our product hot die and.

Finally the product is in pulled by these two belts. The product is being pulled out and finally, it will be cut by the cut off saw, as per the predetermined length. So, I think the process is absolutely clear now. So, we have different arrangements in the pultrusion process if you see. First of all we have the fibre arrangement, then the resin impregnation system, then the pre forming system, then the die forming and the curing die, then we have a pulling mechanism, and finally, we have a cutting mechanism. So, the whole system will help us produce profiles of constant cross section uniform cross section, and the length of the product is not a limitation in case of a pultrusion process.

Now, let us try to see the advantages of the pultrusion process, high throughput rate. So, the production as we can see is fully automated. So, we can produce at a very large volume.

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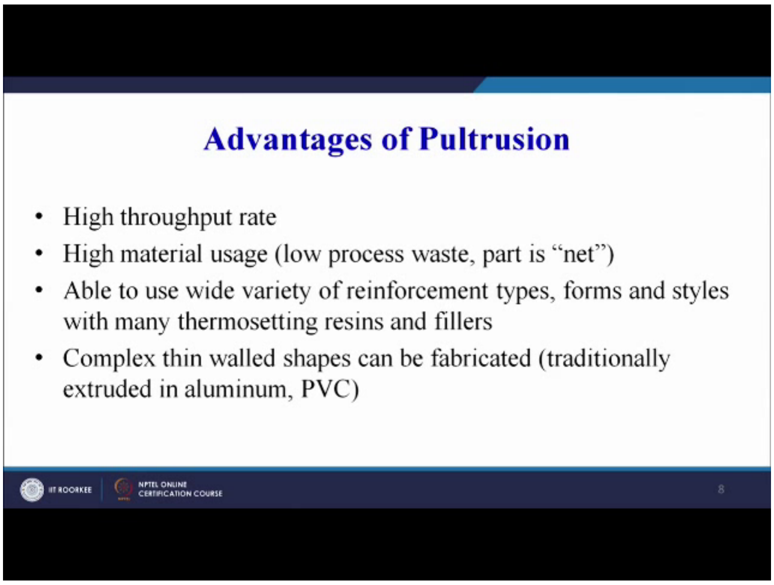

So, it is can be use our mass production, high throughput rate, high material usage, low process waste part is net. So, I think in the last or last to last session I have a tried to explain a near net part. So, near net part means, the final product is exactly the product which we have designed, and that we are going to use that it may not require any further processing. So, near net part is being produced

So, here once the near net part is produced, it means the fibre that we are using, the resin that we are using or the polymer that we are using, is getting utilized efficiently and effectively. There is no wastage of the material happening in case of pultrusion process. It is able to use wide variety of reinforcement types forms and styles, with many thermosetting resins and fillers.

So, the process is quite versatile. So, we can use different types of fibres here. And not only the types, but the forms of the fibres can also be different, and as you might remember that in a today's session only in the beginning I have told. There is a process can also be used for mat type of reinforcement. So, we can have mat type we can have roving type, we can have maybe cut out strands, but the it should be in the mat form. means the continuity of the fibre has to be maintained. And if we are able to maintain that continuity of the fibre, we can very easily pultruded the profile and get a final product. So, not only the types are different like urban glass or aramid.

But the form of the fibre that we can use, is also different. Then complex thin walled shapes can be fabricated, traditionally extruded in aluminium or PVC. So, we can get thin walled shapes, as final product that we have seen in case of our pultruded profile in the animation. The wall thickness was not that high. So, the complex thin walled shapes can be pultruded.

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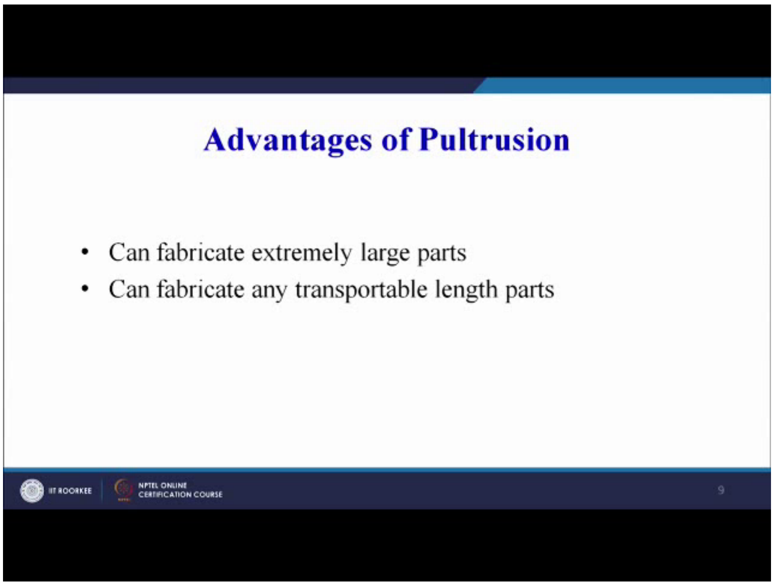

Can fabricate extremely large parts so large means here long, as well as the diameter can also be higher. So, it can help us to fabricate long uniform cross section products; can fabricate any transportable length part.

So, the length of the product that we can produce from the pultrusion process is not a limitation. Only limitation is the transportation. So, if we can transport large parts, the process is capable of producing large lengths of the product, using the basic principle of pultrusion. Now there are disadvantages also, limitations of the process also if you see.

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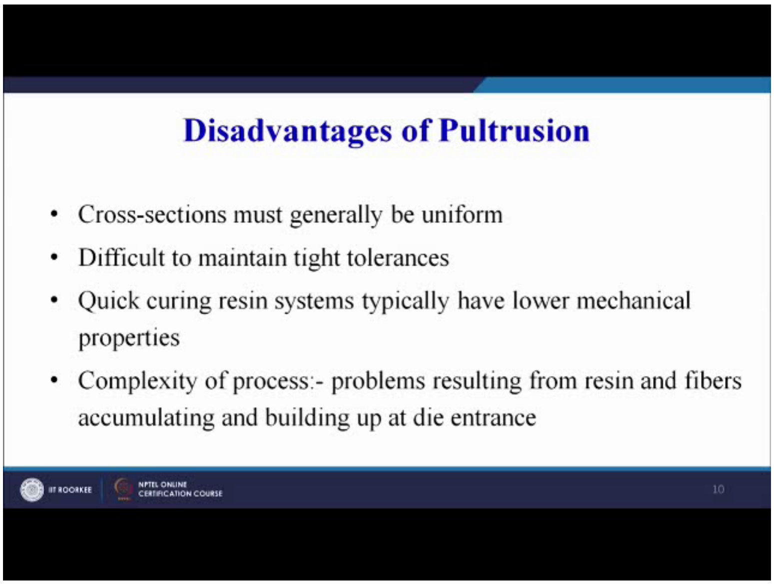

The cross section is one of the challenges. I have explained it in the beginning also that in this process is used for uniform cross section products only. So, if the cross section of the product is varying or it is wavy, it is difficult to process, using the pultrusion process of the cross section must generally be uniform in case of pultrusion; that is one limitation it also, it is difficult to maintain the tight tolerances; that is another limitation. The dimensional stability the tolerance limits sometimes may not be achieved as per the requirement or as per the design requirement.

Quick curing resin systems typically have lower mechanical properties. Now this point is important from the point of view, that we have to cure our resin in the designed length of the die only. If you see the fibres are coming and getting impregnated in the resin tank and then through the pre former, they are entering into the die. And finally, we are getting our final product which is solid. So, where the curing is taking place. Where the polymerization is taking place. How the product is getting solidified. So, that is solidification is happening only in that zone only. Starting from the pre former to the exit of the product from the curing die .

So, that is our major challenge. We have to ensure the curing solidification of the product within that designed the length only. So, the quick curing resins have to be used, and the resins which cure very quickly are typically having low mechanical property. So, that is also a limitation. And if you remember in hand layer process, which is also used for thermo setting type of plastic materials, we have seen that the curing may take even 24 days for the product to solidify. So, in there we are making a product may be in few minutes. So, we can see that the resin system or the polymer that we will use in this case has to be a quick curing system and.

The quick curing system will sometimes compromises with the mechanical properties of the product. So, that is another limitation, and very important limitation in case of pultrusion process. Complexity of the process that is also a limitation, problems resulting from resin and fibres accumulating and building up at the die and transient. If you remember the simulation that we have seen, there were a series of three former. So, though those pre formers are designed in such a way, that there is no build up of the fibres at the entrance of the die, and the product in sequence or in steps, takes the shape before it enters into the die or the curing die.

So, the problems resulting from resin and fibres, accumulating and building up at the die entrance have to be avoided, and it is a serious limitation in case of pultrusion.

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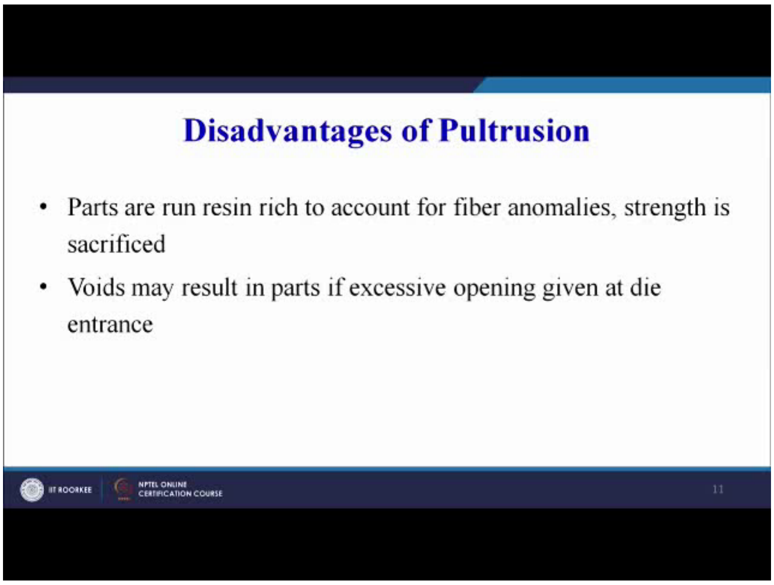

Parts are run resin rich to account for fibre anomalies strength is sacrificed. And this I have been highlighting in the previous processes also, and we have seen that wherever we have high fibre volume fraction, we have good mechanical properties, but in case of pultrusion, in order to avoid the problems associated with the fibre. Sometimes we tend to make a product which is rich in the polymer or the resin . So, resin rich products that we are making, will definitely sacrifice some of the mechanical properties of the final product. So, that is another disadvantage.

Similarly, the voids may result in parts if excessive opening is given at the die entrance. Now in order to avoid the build-up of the fibres at the entrance of the die, we may exercise a control that we may open up or give additional opening at the die entrance, but that will lead to accumulation of air, or maybe entrance of air and voids may be there. So, the voids may result in the paths, if excessive opening is given at the die entrance. So, that also is not, may be successful method for avoiding the build-up of the fibres, or the fibre anomalies, during the pultrusion process.

So, if judiciously we select all the parameters and we design our system in such a way, that although important limitations are taken into account, the product that we will get will be of good quality. And these are the limitations, theoretical limitations from understanding point of view. Whenever we design this process for a new combination of fibre and the polymer, but the process which has already been optimised for the specific combination of fibres and polymers, is being run successfully and commercially and.

We can see number of pultruded profiles all around us, may be in not very common in India, but in all the countries across the globe, the pultrusion process has been commercially used for manufacturing of uniform cross section, or products with uniform cross section. So, with this we come to the end of our session on pollution, and we will cover another process which is a specific process for making the raw materials, which can be used for further processing and making of the composite products

Thank you.