Processing of Polymers and Polymer Composites

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Lecture – 24
Filament Winding

[FL] friends, welcome to session 24 in our course on processing of polymers and polymer based composites. Just to have a brief review of what we have been covering. We have been focusing our attention on the processing techniques for polymers and polymer based composites, and the last few sessions our focus has been on the processing techniques for polymer composites. Just to review what we have covered till now, we have covered a most widely used process that is hand layup process, which is a open mold type of process. Then we have covered slightly advanced version of hand layup; that is a spray layup process.

Then we covered 2 important processes that fall under the closed mold processes, that is the compression molding process, as well as the injection molding process, and then finally, we have seen, the autoclave molding process as well as the resin transfer molding process. So, I think by now the learners have acquainted themselves with the processing techniques that are used, and what are the basic fundamentals for combining the reinforcement and the fiber. Sorry reinforcement and the matrix together. In all the processes if you see, our focus has been, to bring the 2 constituents together, and form a third material which we call as a composite material, and since our title is polymer composites.

So, we are not focusing our attention on metal based composites; like metal matrix composites or the ceramic matrix composites. This we have already understood in our discussion, when we have understood the classification of composite materials. So, our focus is on polymer based composites, and all the processes I will just list down, again hand layup, spray layup, compression molding, injection molding, autoclave molding, resin transfer molding. So, all these processes, the basic focus has been on how to bring together the fiber and the polymer together, the reinforcement and the matrix together, and to develop a material which has better properties, as compared to the properties of the individual constituents; that is the polymer and the fiber.

And in this series today our focus will be on filament winding process. Currently we are trying to understand the processes with the help of animations, videos. There are lot of content are these days; e content available, through the internet, through the Google, through the YouTube, through which we can acquaint our self, and we can improve, increase, enhance our knowledge. and we should be thankful to the groups the societies the companies the individuals, who are providing these type of content to us, and we are using that content for upgrading ourselves, and for improving our knowledge base improving our skills sets, and these videos are being covered in our course also and are really helpful for the learners to understand.

Otherwise maybe yes learner may just look at a video, may not be able to understand that what is actually happening, but when we club it with a little discussion on the process, and we add a commentary to the video. It becomes much more understandable, and that is the only purpose we are trying to get the best animations, best videos which are freely available on the various common platform; such as YouTube, and trying to use them with the running commentary to explain that how the process actually is happening.

So, as a teacher I am really thankful to the organizations which are providing this free content, and we are which is helpful for us to explain the basic concepts which are available in the textbooks. So, we are having the information from the textbook and the content which is freely available, clubbing them together to make the learners understand the basic fundamentals, or the fundamental behind the working of a particular process, and it has really been helpful. So, the audience has really appreciated these efforts and the understanding is much more clear with the use of this video content.

So, let us today our discussion primarily is on filament winding, which is one of the commercial processes. Why I am saying commercial, because the machines are available of hand in the market. If one wants to start making composite parts which need to be axis symmetric hollow parts, because this process is used for this type of cylindrical hollow parts only. So, if one wants to start the manufacturing plant or start of factory for this type of products, he can directly procure the filament winding machine and start manufacturing the product.

Therefore, I am saying that this is a commercial process, and the machines are readily available, but as learners we should know that; what is the basic working principle of this

machine. The second point we need to understand is, that what are the control variables, control parameters that we need to, keep in control in order to get a good quality product, how these parameters will affect the quality of the product that is also we need to understand, but that goes into the next level of understanding, in our course that is a twenty hour course on processing of polymers and polymer composites.

We may not be able to go to the second level of understanding, but definitely we will be able to address the primary level of understanding related to all these processes, and if the learners are attentive, they pay attention to the slides to, what is being discussed in the session, I do not feel that there is any issue that the learners will not be able to understand that what this process is. And we are also substantiating it, corroborating it with certain video content also, which makes the process even more clearer the understanding, even more clearer, and the working principle becomes absolutely clear to the learner once he goes through the video.

I will advise all the learners that please do not restrict yourself to the video that we are showing in our session, please look around for other videos, other channels of information which may be helpful to you for understanding of the process. So, let us now go through the process of filament winding step by step. Let us read the content on the slide.

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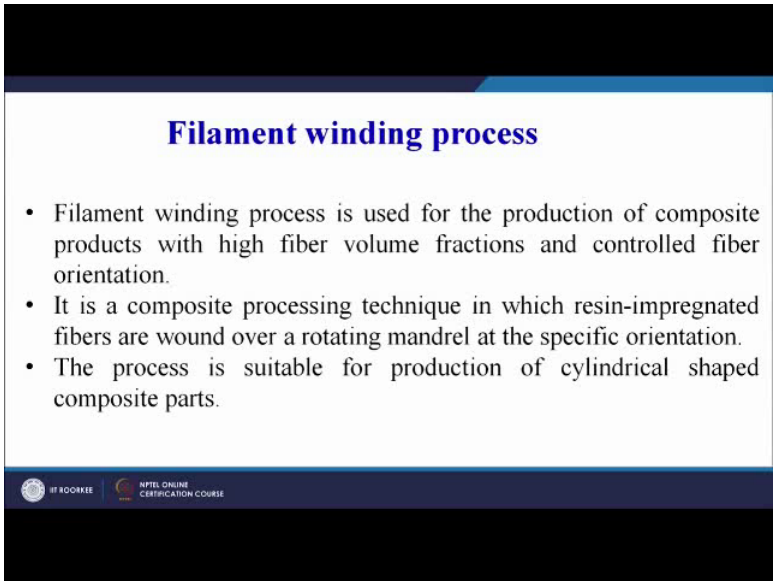

Filament winding process is used for production of composite products. So, it is a composite manufacturing process with high fiber volume fractions and controlled fiber orientation.

So, the important point to note here is, that we can get high fiber volume fraction. In the last session also on transfer molding, sorry resin transfer molding process I have emphasize the importance of the fiber volume fraction. So, if we have a high fiber volume fraction, the strength would be good, it is expected that it has to be good; why, because the fibers take most of the load, but too high fiber content also sometimes lead to deterioration in the properties now why, because some of the synthetic fibers are abrasive in nature.

If we have a very high fiber volume content; that means, the matrix will be lower in proportion or lower in volume fraction. And if matrix is less, there is every chance that fibers will rub against each other and may damage each other, therefore, leading to deterioration in the properties. So, always we have to optimize the amount of fiber and the polymer; that is going into the fabrication of the composite, but yes up to optimal level, we wish that we should have more fibers in the composite and less matrix in the composite in order to get better mechanical properties.

So, that is one important focus area of all designers that we should have high fiber volume fraction. And the processes that help us to achieve this high fiber volume fraction, are given importance or are given weightage as compared to the processes which lead to low fiber volume fraction. So, filament winding process that we are going to understand today, is one process which helps us to achieve very high fiber volume fraction, as well as we get a controlled fiber orientation. We will try to understand this with the help of a schematic, and we will see that we can control the direction of the fibers in the final product in the process, why, because the mechanism is such, that we can control the direction of the fibers of the angle of the fibers.

So, it is a composite processing technique in which resin impregnated fiber. So, this is one thing, that is different from other processes in this we will have resin impregnated fibers, they will be wound over the rotating mandrel at specific orientation. So, what will happen, the fibers will be coming from the creel, they will get impregnated inside the resin bath. There will be a a maybe a arrangement to keep the resin there, it can be a tub

arrangement, or it can be a flask arrangement. So, the fibers will get impregnated they will carry the resin and finally, they will be guided to a rotating mandrel, the mandrel will be rotating as all of you may be knowing the lath machine, on lath we have a rotating job, a similar type of mandrel will be rotating on similar type of machine ,and this will be wound over the mandrel rotating mandrel continuously.

So, this is the basic fundamental of the process or the basic mechanism of the process. So, it is a composite processing technique in which resin impregnated fibers are wound over the rotating mandrel at specific orientation. So, this one sentence, completely summarizes the whole process, because here we are seeing resin impregnated fibers, which means the fibers are already impregnated with the resin during the process, then there is a rotating mandrel and these resin impregnated fibers are getting wound over the rotating mandrel.

So, other parameters can be controlled, but this is the basic working of the process. The process is suitable for production of cylindrical shaped composite parts. So, axis symmetric large size cylindrical shaped parts can be made, by using the filament winding process.

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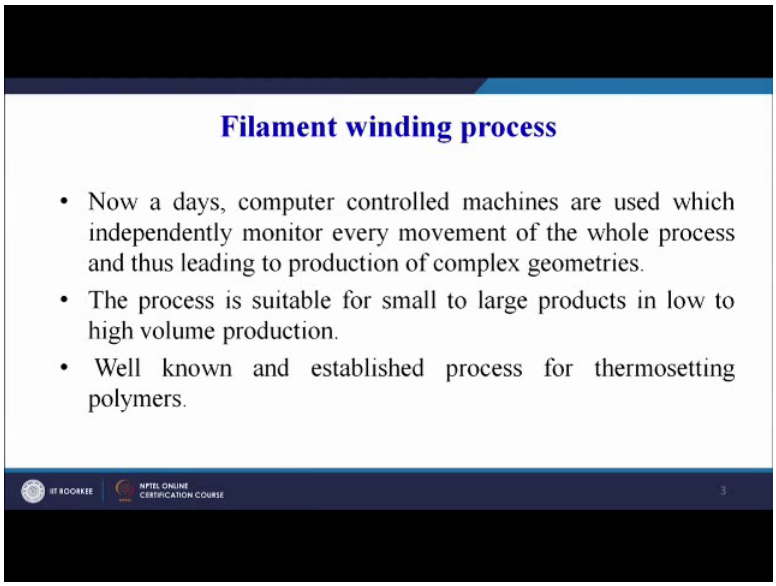

Now, nowadays computer controlled machines are used which independently monitor every movement of the whole process, thus leading to production of complex

geometries. So, now, there are number of movements involved in the filament winding process.

Now, what are these movements? The first movement is the movement of the fiber from the fiber creels. So, there are fibers creels, the fiber will move towards the resin bath. Now at the resin bath the fiber has to be wet completely, it has to be impregnated with the resin in the resin bath; that is one movement, just below the resin it has to move, and finally, this resin impregnated fibers have to move forward towards the rotating mandrel, and the mandrel is rotating at a fixed speed. Now these fibers have to wound over the rotating mandrel, and the rotation of the mandrel is another movement.

Now, the third movement which I have not emphasize till now, is the movement of the carriage; why, because there will be a length of the cylindrical shaped part that we want to make. Suppose this is the length, our resin bath is here. So, the fibers have to be deposited all along the length of the rotating mandrel. So, once the length is fixed, we have to ensure the movement of this carriage. So, that the fibers are deposited all along the length of the mandre. Thickness can be achieved by the time of the process. We definitely would like to have some valve thickness of the cylindrical part.

So, we will see that how many layers of this winding we want to have on our mandrel. So, depending upon that, we will decide on the time for the process. So, the process is high volume manufacturing process, it can be fully automated process also. So, this is process is suitable for small to large products in low to high volume production, as I have already said, well-known and established process for thermosetting type of polymers, because the polymer is available in a viscous form. So, the fibers go and get impregnated carry this viscous polymer with them, and then get wound over the rotating mandrel.

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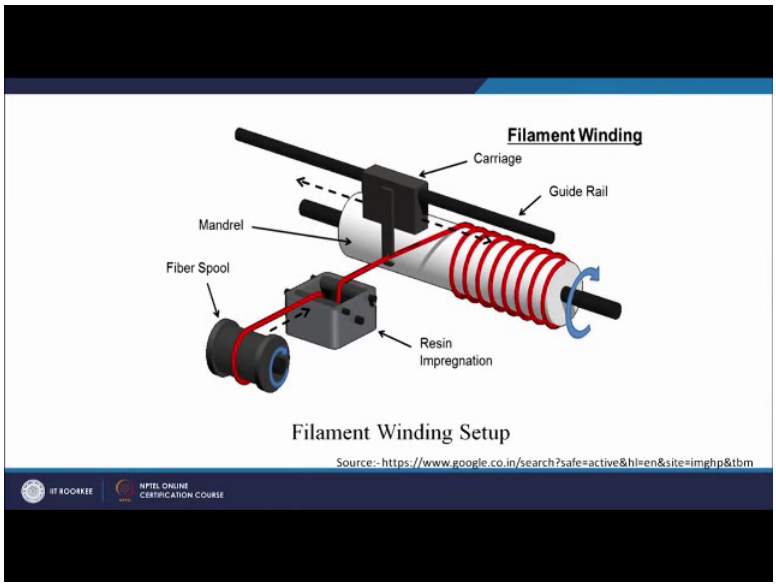

So, the process is most suitable for thermosetting type of polymers. I think this is the most simplistic type of schematic, which can explain the filament winding process available at the Google images. Here we can see this is a fiber spool, which will have the fibers; one red fiber is shown just to explain the process. This is a first movement dotted arrow, shows the movement of the fiber. So, the fiber will get a rotation, this is a another preliminary movement, this rotation by a sky blue color.

So, this is rotating fiber spool, the fiber is getting unwound, and it is moving towards the resin bath. This is showing the resin bath, these are the guide ways. So, the fiber will move down, the guide way allow it to move forward, but it has to get impregnated here. So, this tank is filled with resin. So, the fiber will get impregnated, it will carry the resin along with, we can see a black portion is shown here, which indicates the, fiber is carrying the resin along with it, and finally, it is getting wound over the rotating mandrel.

So, the rotation of the mandrel is shown with this arrow. So, the mandrel is also rotating, the fiber is getting unwound here, and it is getting wound here on the rotating mandrels, unwinding of the fiber winding of the fiber, and here it is getting the resin. So, basically in all processes related to processing of polymer composites, the fiber and the polymer has to be combined together either one way or the other way. And here we are having entirely different method or way of combining the fiber and the polymer.

So, the fiber is coming from the fiber spool or creel, and it is getting unwound here, it is getting impregnated with the resin here, and finally, it is getting wound over the rotating mandrel. So, we let us now see the movements. First movement is a rotation of the fiber spool or creel. Second movement is the movement of the fiber. Third movement is the movement of the carriage, as I have already explained. This is a length of the mandrel, and we have to wind the impregnated fiber all over the length of the mandrel and to ensure that, we have to provide movement to this carriage.

If this carriage is stationary we will not be able to wind the impregnated fiber on the rotating mandrel successfully. Therefore, a carriage is provided which will move along this guide rail, and it will keep on depositing the fiber that is impregnated with resin over the rotating mandrel. This movement of the carriage is also very important. So, there are three or four movement, movement of the fiber spool or creel, movement of the fiber, movement of the carriage, as well as the rotation of the mandrel.

So, you can see that there are number of movements. We have to synchronize these movements properly; otherwise we will get a defective product. So, if this movement, this four movement, the rotation of the mandrel, the movement linear movement of the carriage, the movement of the fiber, the rotation of the fiber creel or spool; these are not synchronized properly, we will get a defective product; therefore, the control mechanism has to be very precise and accurate in case of the filament winding process.

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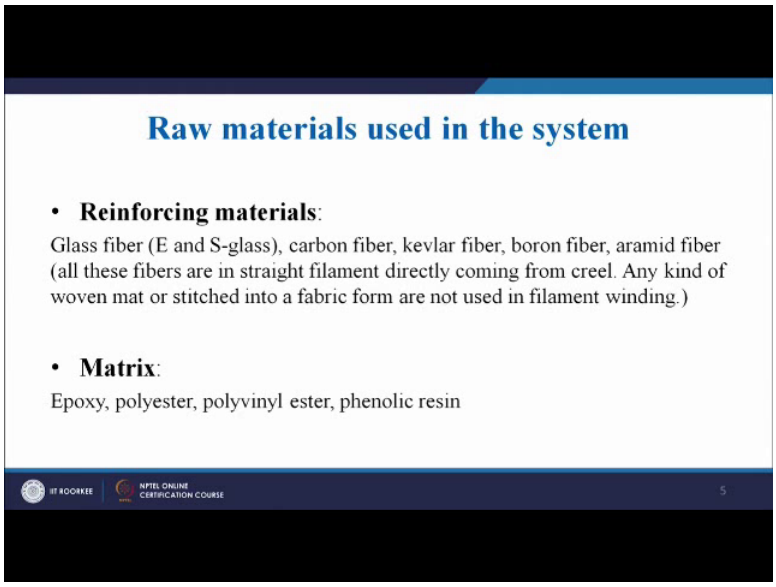

Now, what are the raw materials that can be used in this system; the reinforcing materials are again glass fiber, carbon fiber, Kevlar fiber. All these fibers are in a straight filament directly coming from the creel. So, they are in the filament form or the fiber from they are coming directly from the creel. Any kind of woven mat or stitched mat in the fabric form, are not usually used in the filament winding process, but yes the process can be modified in fundamental or the conventional system, the woven mat and chopped strand mats etcetera are not used.

But we can modify the process and we can try to use the similar process for the continuous fibers or the woven mat also. The matrix is epoxy polyester polyvinyl ester phenolic resin. As already explained this process is most suitable for thermosetting type of polymer. So, the raw materials that are going into the process are synthetic fibers in the filament or the fiber from, the creel form, and we are not going to use the woven mat form in case of filament winding process.

Let us try to understand this with the help of a video. The source is already given, the YouTube video again.

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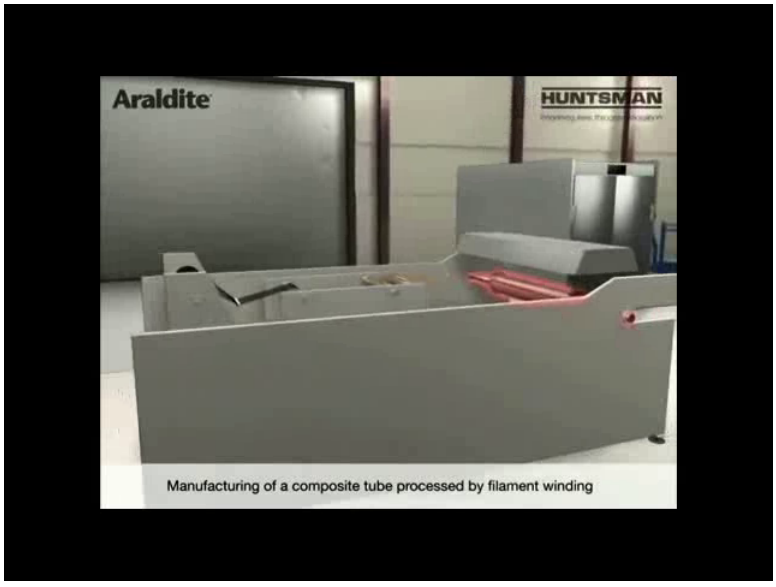

The videos from Araldite and Huntsman, manufacturing of a composite tube processed by filament winding, setup is shown on your screen. So, the fibers are impregnated in the resin bath.

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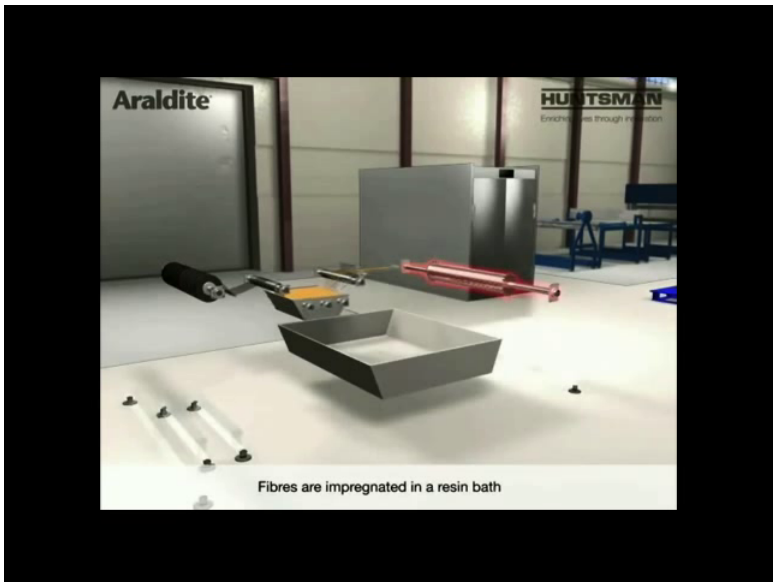

This is the fiber creel; the fibers are coming from the fiber creel. These are the fibers that are coming; this is called the pre former. The fibers are coming from here, they are going towards the resin bath, this is the resin bath continuous movement of the fiber, and they are here getting impregnated in the resin bath.

And then the impregnated yarns are wound around the rotating mandrel. Here we have the rotating mandrel, it is rotating continuously, and the fibers are getting wound over the rotating mandrel. The red color signifies that it may be under the hot condition or the heated condition. The impregnated yarns are cover the mandrel by the lateral movement, this is a lateral movement you can see, this is a lateral movement of the resin bath, or the carriage. Once the process is complete, the winding operation has been completed, the yarn is cut, it keeps on rotating.

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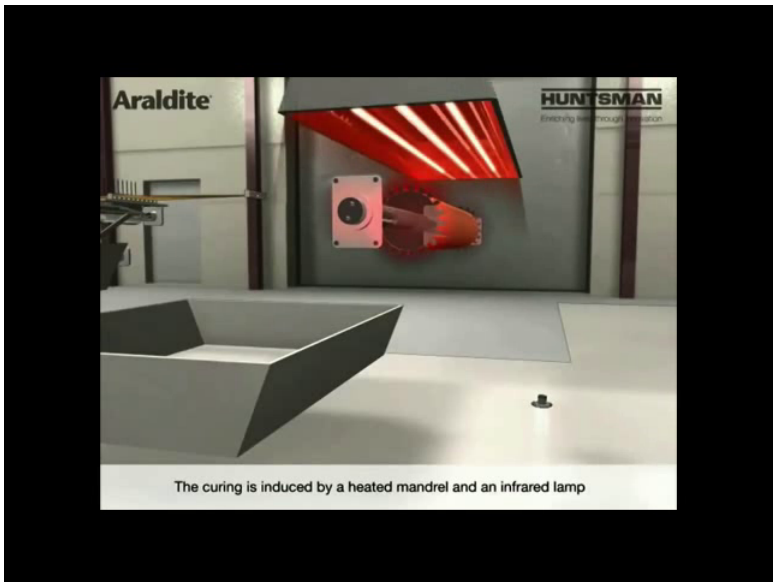

And finally, we will take this mandrel, hot mandrel for curing process. The curing is induced by a heated mandrel and an infrared lamp. So, the mandrel is also hot, and infrared lamp is used to further perform the curing operation. Now curing as all of, you know is the polymerization process, specifically in case of thermosetting type of resins. The curing is induced by a heated mandrel as well as the lamp. Now ones the tube is gelled, the mandrel is placed in oven for curing.

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So, this is a oven these are the mandrels with the wound composites. Once the time is over, it is taken out. Once the tube is gelled the mandrel is placed in an oven for cure, the when the curing process is over, the pins are removed by sawing the edges and the finished tube is de-moulded, we can see here the mandrel has been removed.

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And this is a final product that has been produced.

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So, I think the process is absolutely clear. Let us once again try to see the video, and try to understand the basic intricacies involved in the filament winding process. This is a

fiber creel, the fibers are coming. These are fibers are coming to the performer here, and they are going to the resin bath, and you can see the lateral movement of the resin bath.

The fibers are being impregnated by this resin, yellow color resin shown here. The fibers are getting impregnated, and the lateral movement of the carriage helps in that deposition of the impregnated fibers on the rotating mandrel. This is a movement of the fibers and this is a rotating mandrel, and the fiber, impregnated fibers are getting wound over the rotating mandrel. The red color signifies that the mandrel is hot, in order to ensure the curing process. The impregnated yarns cover the mandrel by a lateral movement; this is a lateral movement of the carriage being shown.

So, several lateral movements are made to achieve the desired thickness. So, we need to make a product of desired thickness, and therefore, several lateral movements are done. So, the time as I have told you, the time of deposition of this impregnated fibers on the mandrel will decide, the thickness of the product that we are going to get, or number of lateral movements can be done in order to increase the thickness of the product that we are processing, using a resin transfer molding. Once the requisite thickness has been achieved, we will cut the fiber input and then we will heat it with the infrared lamp, along with the mandrel we will put it in an oven, and after a requisite amount of time.

This is a curing process going on. Once it has cured, the mandrel along with the composite product will be taken out, after the curing. And then the pins are removed by sawing the edges, and the finished tube is demoulded, and we will get a long cylindrical product with the process of filament winding. So, this is the basic concept of the filament winding process. Now what are the main components. Now I think all the learners must be able to appreciate, and must be able to list, that what are the various important components are constituents in the filament winding process.

First one is the fiber creel, from where the fibers are getting unwound, and they move towards the resin impregnation system. And in resin impregnation system, the fibers get impregnated by the resin, and further they move towards the rotating mandrel. So, the carriage is responsible for the lateral movement of the resin bath. So, that we are able to produce a requisite length of the composite product. If we do not have a carriage, we will not be able to achieve the desired length of the composite product.

So, the carriage will ensure the lateral movement of the resin bath. So, that the fiber is deposited at the requisite required or designed angle on the rotating mandrel.

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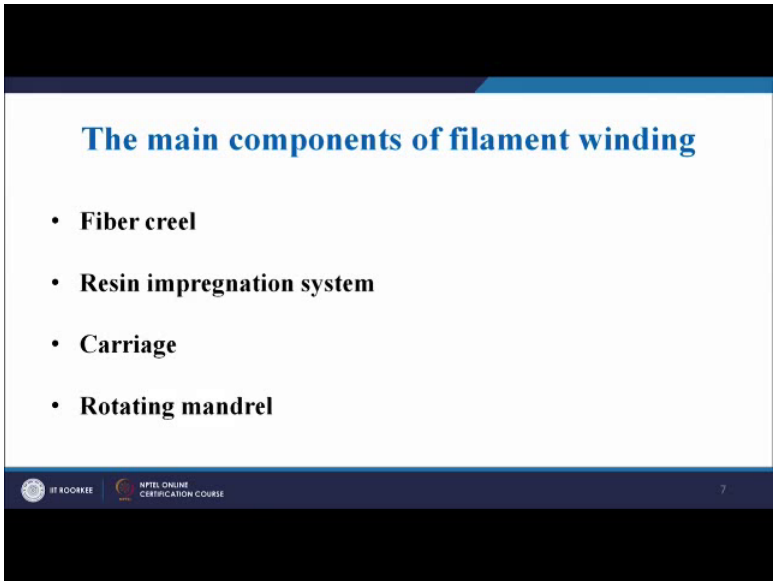

Then finally, the rotating mandrel is the final component which takes the fiber or wounds winds the fiber; that is impregnated in the resin bath, and that is coming from the fiber creel.

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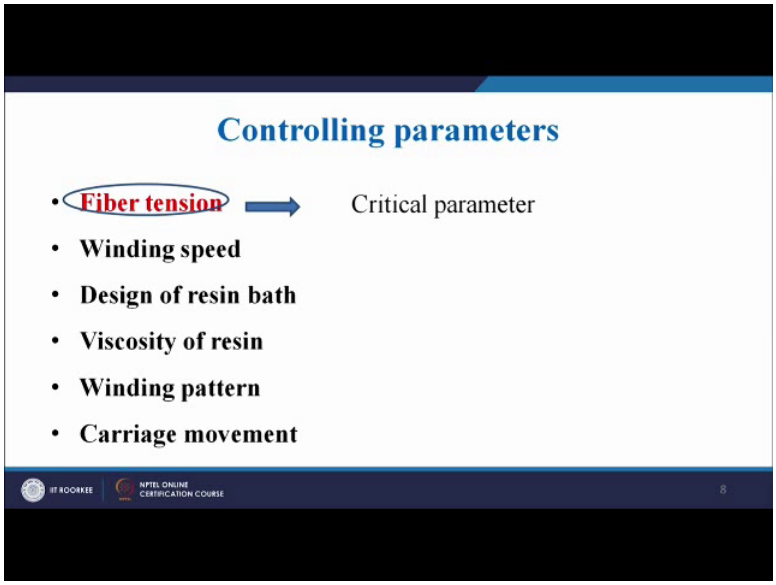

Now, what are the important controlling parameters. First one is the fiber tension, winding speed, design of the resin bath, viscosity of the resin winding pattern, carriage

movement. So, all these are the important design guidelines or parameters which have to be selected judiciously in order to make a good quality product using the filament winding process.

Out of all these parameters you see one parameter has been highlighted as red, and why this has been highlighted as red, because this is the most critical parameter. Now why this is critical, that we are going to understand in the subsequent slides, but prior to that, the other parameters I will just list out the winding speed; that is the rotation of the mandrel: the design of the resin bath, where we are keeping our matrix or the polymer, the viscosity of the polymer, the winding pattern, and the carriage movement, the lateral movement of the carriage; all these are equally important parameters and must be designed selected judiciously. So, that we get a good quality product.

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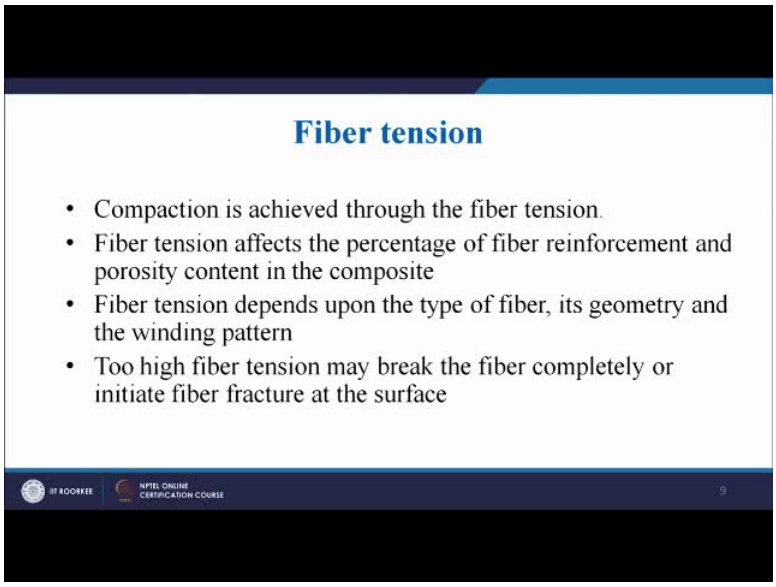

Fiber tension is slightly more important why, because the compaction, because we are not applying any external pressure on the composite product being processed here. So, the tension of the fiber will lead to the compaction of the composite product, and compaction is achieved through the fiber tension. Fiber tension affects the percentage of fiber reinforcement, and porosity content in the composite. As we have already emphasized, that we can get high fiber volume fraction in case of filament winding process. Similarly in resin transfer molding process also; that is only achievable if we

have good fiber tension as well as the porosity will also be less if we have good fiber tension.

Fiber tension depends upon the type of fiber, its geometry and the winding pattern. So, that is another thing that we need to control. Too high fiber tension may break the fiber completely, or initiate fiber fracture at the surface. So, the fiber tension must not be too high, and must not be too low. It has to be optimal, and it has to be right fiber tension, which will help us to get the appropriate compaction, it will help us to get the proper winding pattern, it will help us to remove or to reduce the porosity content in our final product, in a way finally, leading to a good quality composite product.

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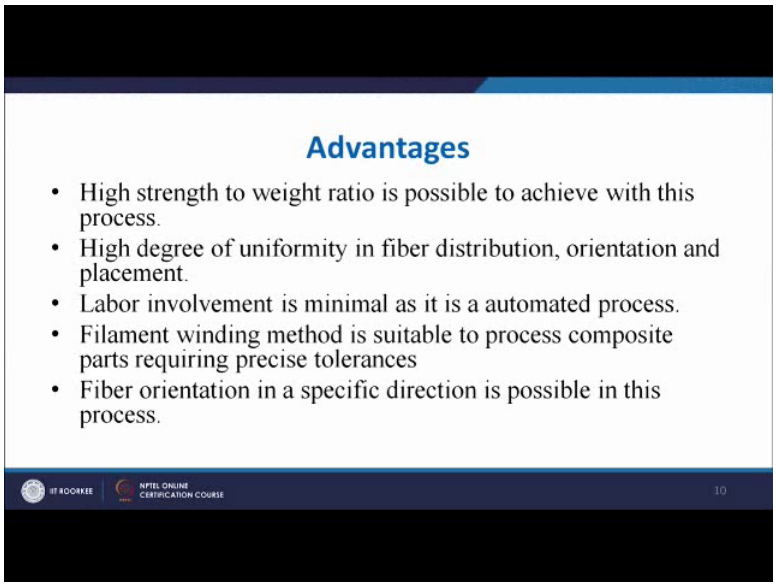

Now, what are the advantages of this process; high strength to weight ratio is possible with this process high degree of uniformity in fiber distribution, orientation and placement. Since we can control the rotation of the mandrel, we can control the movement of the carriage, we can control the movement of the fiber, we can control the fiber tension. Therefore, we are able to achieve good fiber distribution orientation and placement. Labor involvement is minimal as it is automated process. Filament winding method is suitable to process composite parts, requiring precise tolerances, as the quality control can be automated, we can get good product using the filament winding process.

Fiber orientation in a specific direction is possible in this process, which I have already highlighted.

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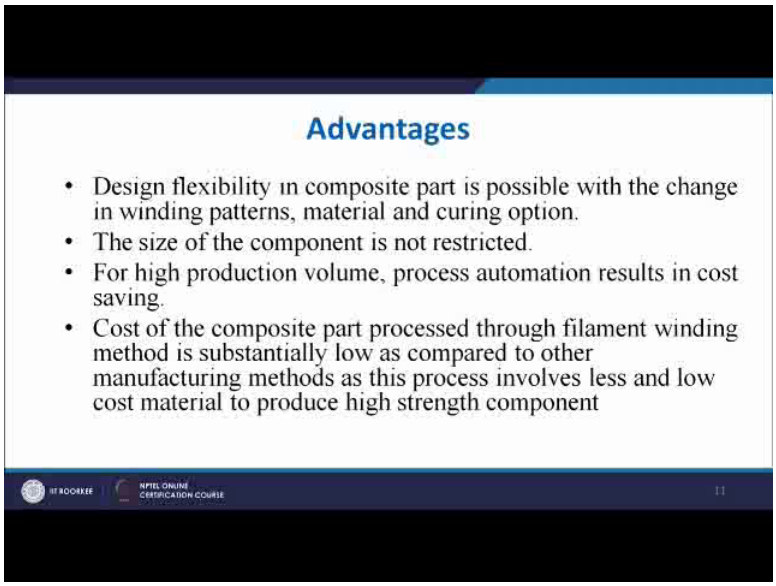

Design flexibility in composite part is possible with the change in winding patterns, material and curing options. So, that can lead to tailor made parts design flexibility is possible. The size of the composite is not restricted, we can have a long mandrel also, we can have a large carriage also. So, the model can be scaled up, and we can have a large size composite part, which can be made by the filament winding process.

For high production volume process automation results in cost saving, which is from the industrial engineering point of view. Cost of the composite part process through filament winding method is substantially low, as compared to other manufacturing method. As this process involves less and low cost material to produce high strength component. So, which is again from industrial engineering point of view, the cost of raw materials involved is less in case of filament winding process.

But there are no processes which has only got advantages. There are processes which have got disadvantages also.

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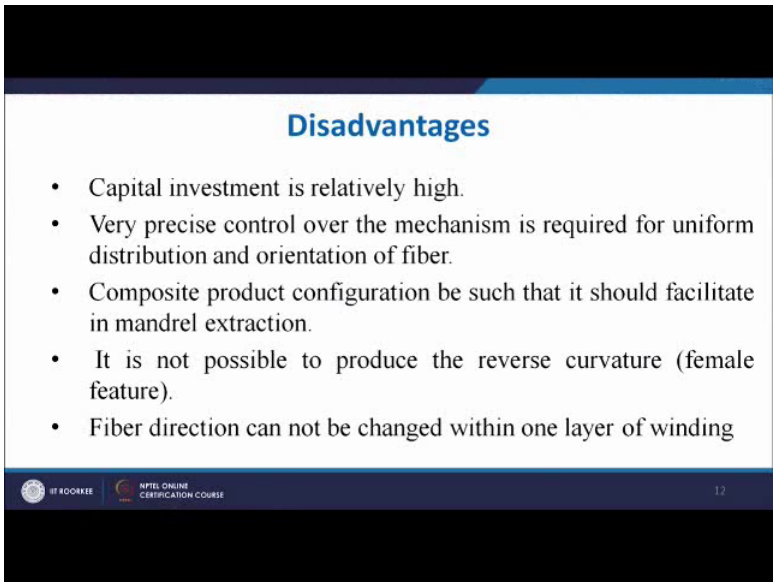

So, the capital investment as a cost of the machine is relatively high. Very precise control over the mechanism is required for uniform distribution orientation of fiber. So, the control is the key. If you control it precisely, you get a very good product. If you are not able to control it precisely, you may get a poor quality product, which can turn into a disadvantage also. Composite product configuration be such, that it should facilitate easy mandrel extraction.

So, as the mandrel has to come out, we are only making hollow parts, hollow cylindrical part, using the filament winding process. So, we have to ensure that the extraction of mandrel is also easy. Sometimes, some processes, some variants of filament winding process also use collapsible mandrel. So, which can collapse after the product has cured it has solidified the mandrel collapses, and it is very easy to remove the mandrel. It is not possible to produce the reverse curvature or the female features. So, this is one limitation, that is not possible in case of filament winding process.

Fiber direction cannot be changed within one layer of winding. So, for one layer of winding, the fiber orientation will remain same.

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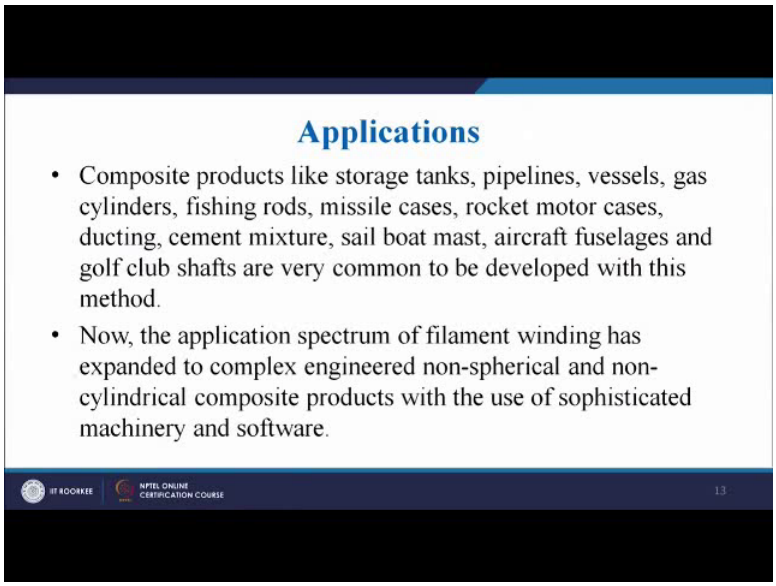

Finally coming to the applications, composite products like storage tanks, pipelines, vessels, gas cylinders, fishing rods ,missile cases, rocket motor cases, ducting, cement mixture, sail boat, mast, aircraft fuselages, and golf club shafts are very commonly developed with this method. So, all of the products mentioned here you can see, are axis symmetric in nature, and are most of them are hollow in nature. Therefore, the process of filament winding is most suitable for production of these composite products.

Now, the application spectrum of filament winding has expanded to complex engineered, non spherical and non cylindrical composite products, with the use of sophisticated machinery and software. As I have told you the concept of collapsible mandrels, the design of a universal mandrels. So, there are number of other parameters that have been changed, and the process has become even more versatile, more complex parts can be made using the filament winding process. So, with this, we come to the end of our session on filament winding. In next session we will discuss another process, which is used for processing of polymer matrix composites.

Thank you.