Processing of Non-Metals

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Module - 5
Polymer Matrix Composites: Processing
Lecture - 7
Filament Winding

Good morning to all of you, today we are going to discuss the process of filament winding which is one of the important processes used for fabricating part of polymer matrix composites, just to take back into certain aspects which we have already covered or just to revise or summarize. What we have already covered in this particular module. We have already seen, what are the basics of the materials like, we have seen that the selection of materials is an important aspect. We have seen, what are the factors that should be taken into account for selection of material for a particular application?

We have seen the importance of polymer matrix composites in today's engineering application then, we have seen, some of the important processes which are used for processing of polymer matrix composites. We have seen, the hand layer process, we have discussed the spray layer. We have seen, the process details related to protrusion and we have also discussed the compression molding process. We have seen, all these processes have got some specific application areas, we have also observed that, they have got certain advantages and certain disadvantages, visa vise one and another.

In today's lecture our focus on filament winding. So, there are so many processes, which are use for the processing of parts made up of polymer matrix composite, but, if there are certain specific requirements then, filament winding is used to start with just let us see, the name or the you can say title of the process, that is filament and winding, if you remember in some of the previous lectures, we have seen that are the composite material or the polymer matrix composite is made up of a polymer, which access, which is reinforce with the fibers. So, the fibers and the matrix they combined together to make a composite material. So, we have different processes to combine the fiber and the resin or the reinforcement and the matrix or the fibers reinforcement and the polymeric matrix. So, we have two important macro constituents, which we combined together to make a composite material. So, if we talk of the matrix part, we can have polymer as the matrix we can have ceramic as the matrix and we have metal as the matrix, but, in our module we are focusing on this particular module five, we are focusing on processing of polymer matrix composites.

So, no doubt there is the matrix is will always be in the form of a polymer and the reinforcement would always be in the form of certain fibers, fibers may be continues fibers, they may be discontinues fibers. The fibers may be aligned in one particular direction or they may be randomly oriented in the bulk of the matrix. So, the name sagest itself is filament and winding. So, we have a filament is one form, in which the fibers may exists. So, we have a fiber, which we are calling here as a filament. The filament is type of a fiber or the form of a fiber. So, we have a filament and it has to be wound over a particular mandrel in order to give it a shape, but, only fiber winding of the fiber or the fibers winding will not give us a composite material, because in composite as I have already discuss. There are two important constituents, which should be present. Now, what are these two important constituents? These important constituents are the reinforcement and the matrix the reinforcement is always in the type of, in the form of fibers and the matrix provides the bulk and it is a polymeric matrix in this topic or this is a particular module dedicated to polymeric matrix composite though in these discussions our matrix would always be a polymer or a polymeric matrix.

So, when we have a fiber in the form of a filament and that, we are winding over a mandrel suppose this is by mandrel and on this mandrel, if I am winding the fiber we can say it is a filament winding, but, the filament also has to have some matrix means, this individual filaments have to be coated or impregnated may be impregnated is the word. These filaments have to be impregnated with the matrix. So, what is the matrix? The matrix actually is the polymer. So, the two things when combined together, that is the fiber and the matrix or the resin the matrix and the resin is one and the same thing the re matrix is a more generic form and resin is one type of a matrix. So, when we have a resin and we have a fiber and when we combine them together, we get a composite. So, fiber incase of filament winding would be exist in the form of a filament and the matrix would again be a polymer. So, we can have thermo set polymer, we can have thermosetting polymer, we have seen that the polymers are also categorized into different categories and two broad categories of polymers are thermosetting polymers and the thermo plastic polymers.

So, today we will see that, how the filaments will get impregnated, how they will be wound and how we will get a product by the process of filament winding. So, we have already seen, there are number of processes, which have been already discussed and we have seen that each process has got its advantages. Each process has got its limitation and each process has got certain specific application areas. So, we will see filament winding, what are the specific requirements or what are the specific types of the filament winding or specific areas of application of the filament winding process. We would also see that, which the important control variables are in the filament winding process and finally, the advantages limitations and the specific application areas of the filament winding process, we would be seeing in the subsequent slides.

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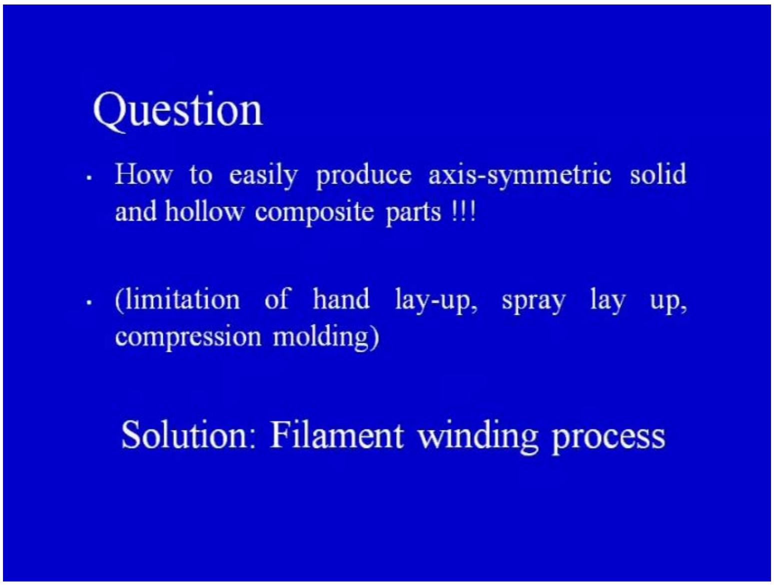

Now, the important question before we go to the discussion about the filament winding process, how to easily produce axis symmetric solid and hollow composite parts. So, we have an axis of symmetry and we have, you can say a hollow or a solid cylindrical or you can axis symmetric part. So, suppose I have to make a hollow cylinder or I have to make a solid cylinder and the material is fibers reinforce plastics or for that matter a polymer matrix composites. So, if I have to make a solid or a hollow cylinder or any axis symmetric job in which, I will have fiber and the matrix. The process that we are going to choose is the process of filament winding. That is the limitation of hand layup spray and compression molding.

So, when we have to make an axis symmetric component, it is difficult to process using the hand layup process or the spray layup process or the compression molding process. So, these three processes as you see on your screen have the limitation, that they are not much suitable for making an axis symmetric component out of a composite material. So, it is difficult with these processes to makes an axis symmetric component. So, axis symmetric components can be made by the filament winding process.

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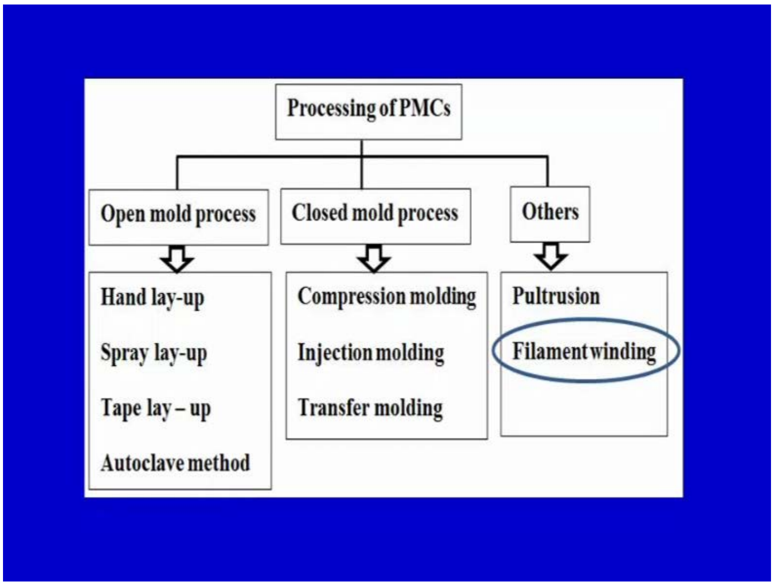

So, on your screen, you can see the solution of the limitations of the process that we have already discussed is the filament winding process. So, today we will see the basic procedure or the basic a sequence of operations in the filament winding process. The important control variable in the filament winding process as I have already told as we have been discussing in the previous lectures also our focus would be on the advantages limitations and the application areas of the filament winding process.

Now, this diagram again and again I am referring to each and every lecture, because this is relevant to the classification of the processes, which are used for making the polymeric matrix composites. So, we can see in poly processing of polymeric matrix composites we have three different types of processes, open mold process, the closed mold processes and the others. In others, we have pultrusion and filament winding in these series of lectures in module five on processing of polymeric matrix composites. We have already seen the hand layup process, the process itself the process details the control variables the advantages limitations and applications of the hand layup process similarly, for the spray layup process, which has already been cover. We have also seen the process of pultrusion that, what are the application areas of pultrusion and what type of composites products can be made by the process of pultrusion has already been covered.

We have also seen, compression molding in the previous lecture, that what is compression molding? What are the important or the critical parameters, which have to be taken care of when, we are processing the polymeric matrix composites using the compression molding process that has already been covered. So, in today’s lecture, our focus would be on the filament winding process, which falls under the others category of processing of p m cs.

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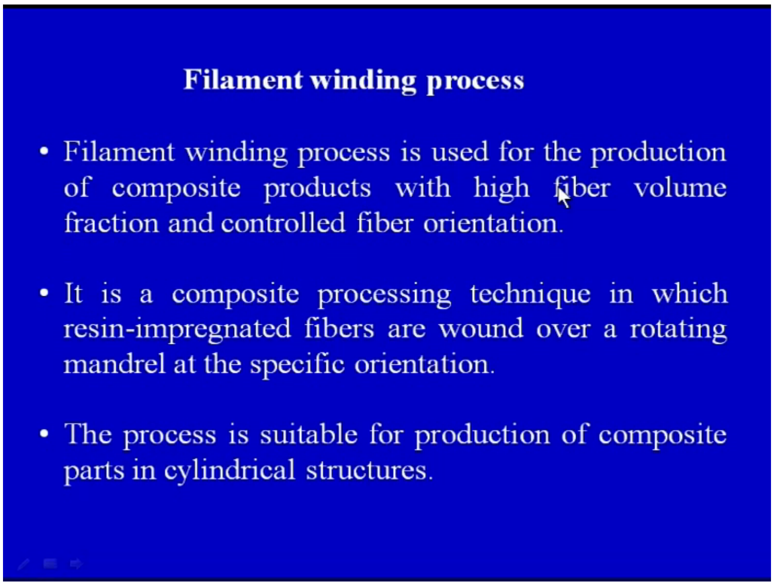

Now, the filament winding process is used for the production of composite products with high fiber volume fraction and controlled fiber orientation. So, there are two important points in this particular high light or the bullet, that is filament winding is used for production of composite parts that is obvious, because we are discussing it under the module 5, which is for processing of polymer matrix composite, but, the important point to note, in this particular point is the high volume fiber volume fraction, which can be achieved in the filament winding process and. Secondly, the controlled fiber orientation.

Now, the controlled fiber orientation is very important from the properties of the composite product point of view. The mechanical properties of the final composite product, which we are making out of the filament winding process, will depend upon the fiber volume fraction. When we are designing a particular component or a part, which has to be made by the composite material using the filament winding process one of two of the important points would be the fiber volume fraction and the orifice orientation, because the mechanical properties would depend on the fiber orientation. Now, suppose I have the fibers in one particular direction. So, let us try to understand the importance of fiber orientation in the properties of the composite products

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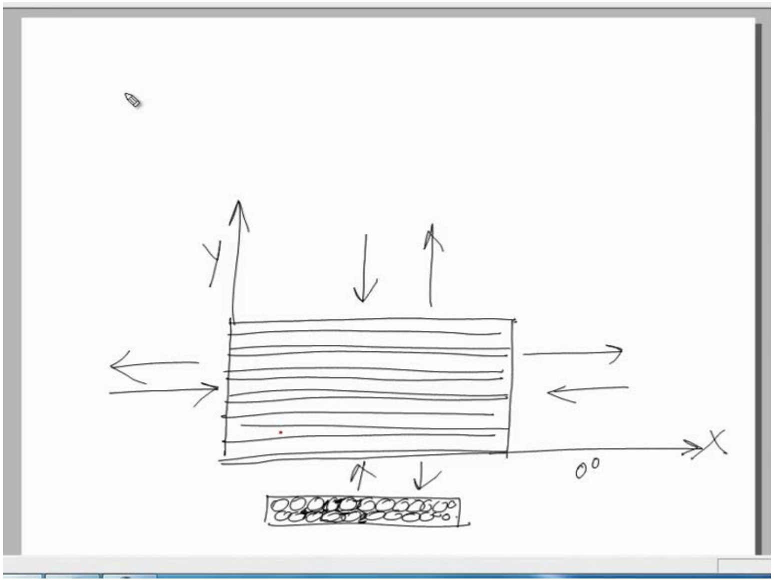

So, on your screen, you can see just try to understand that, suppose this is a simple composite part and we have all the fibers in one particular direction. Now, suppose we have and I blow up this particular area if I look it from this side. I have the fibers ends like this. So, these are the fiber ends and in between we have got the matrix material. The dark portion is the matrix material and we have a fiber ends.

Now, if this particular component is loaded, suppose in the under compressive loading. So, the compressive strength in this particular direction that is along the fibers would be different then across the fibers similarly, if we load this particular component under tensile loading, the tensile strength in the direction of the fibers would be higher than the tensile strength across the direction of the fibers, because this is the direction of the fibers, again I am high lighting, this is the direction of the fibers, all the fibers are in this particular direction. So, depending upon the (( )) this is called the fiber orientation. Now, suppose this is my axis x and this is my axis y. So, x and y axis we have the fiber orientation in this direction. So, this can be treated at 0 degree. So, all the fibers are oriented at oriented as 0 degree. So, fiber orientation plays a very important role in case of polymer matrix composites and incase of filament winding we are able to control this fiber orientation in our final product, as we have already seen that incase of poly incase of axis symmetric components made by the filament winding process, we can easily control the fiber orientation.

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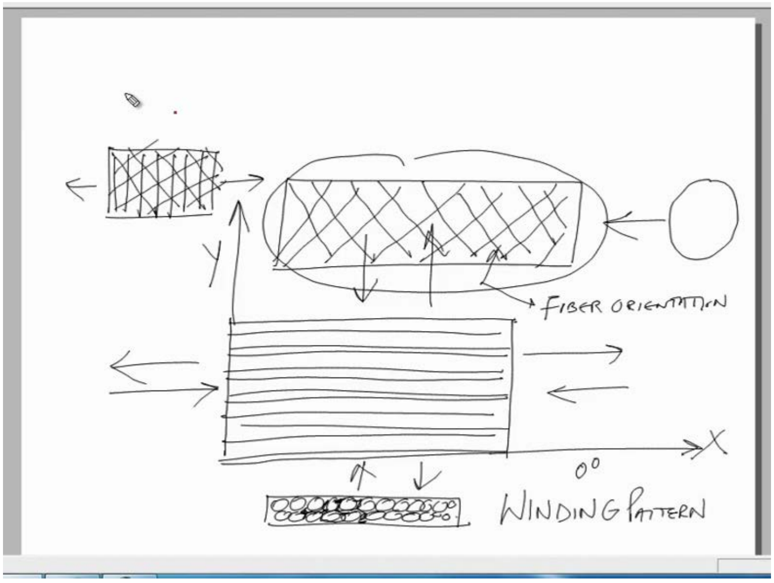

Now, let me show a simple cylindrical component on your screen you can see, we have a component like this. If I see it from this side, it is cross section is circular in nature. So, we can have a control over the fiber orientation all the fibers can be oriented in this version and similarly, they can be oriented in this version in the next layer. So, we can control the fiber orientation and this particular fiber orientation will dictate the properties of the composite material. So, this is what, this is nothing, but, what has been highlighted in the slide as the fiber orientation. So, all the fibers are oriented in one particular pattern. So, this may this is also called as the winding pattern. So, we can alter the winding pattern and we can properly dictate the properties of the filament wound composite product.

So, in this particular process of filament winding fiber orientation is the very important critical parameter which has to be taken into account, while designing the composite product or the part which has to be made by the filament winding process. So, we can also see that, if suppose all the fibers are in one particular direction. Now, this is again a circ cross part which has a circular cross section. So, if we have all the fibers like this and it is loaded in this particular direction, we will not get very high strength. So, it may fail at a very low value of the loading. So, if we have fibers wounded the different angles like this and fibers wound like this, the component will have higher strength as compare to the fibers wound earlier.

So, we have to see that how the filaments are going to be wound over the mandrel. So, we are still to understand the basic process of the filament winding, but, before going to the process details we should understand that, what we mean by fiber orientation, what do we mean by winding pattern, because these are the things, that would be coming up in discussion, when we will discuss the details of the filament winding process. So, in this particular explanation, I have tried to emphasize the importance of fiber orientation, because this is important in terms of the filament winding process. Now, let us see the procedure of the filament winding process that how the process actually takes place.

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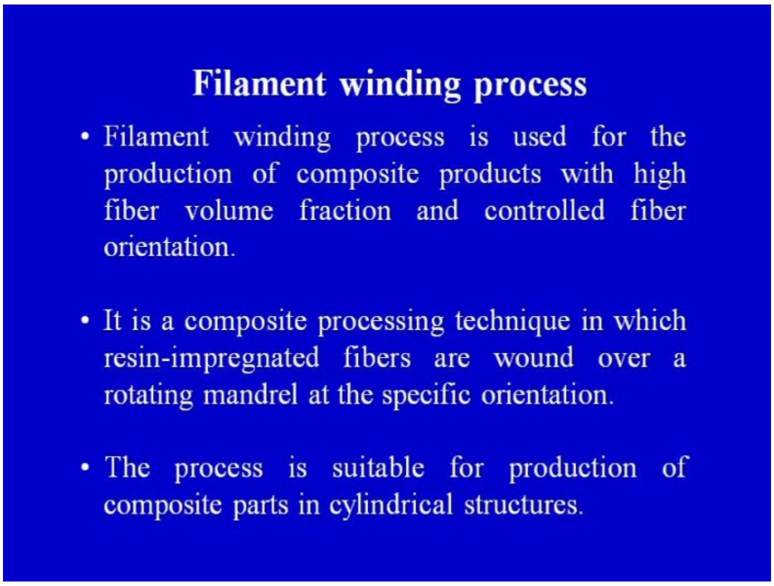

So, on your screen you can see, the filament winding process is used for the production of composite products with high fiber volume fraction, which we have already seen that, what do we mean by the fiber volume fraction and controlled fiber orientation, which I have explained just now, that is the fiber orientation has a very important role or is of great significance, because it dictates the final mechanical properties of the part made by the composite material. So, it is a composite processing technique in which resin impregnated fibers are wound over a rotating mandrel at the specific orientation. So, it is a vary, you can say it is simple to understand process in which a fiber or a filament gets impregnated in the resin bath and then it is wound over the rotating mandrel and the fiber orientation can be controlled easily.

The process is suitable for production of composite parts in cylindrical structures. This is one particular application of the filament winding process in which the production of cylindrical structures or production of axis symmetric components such a cylinders can be achieved.

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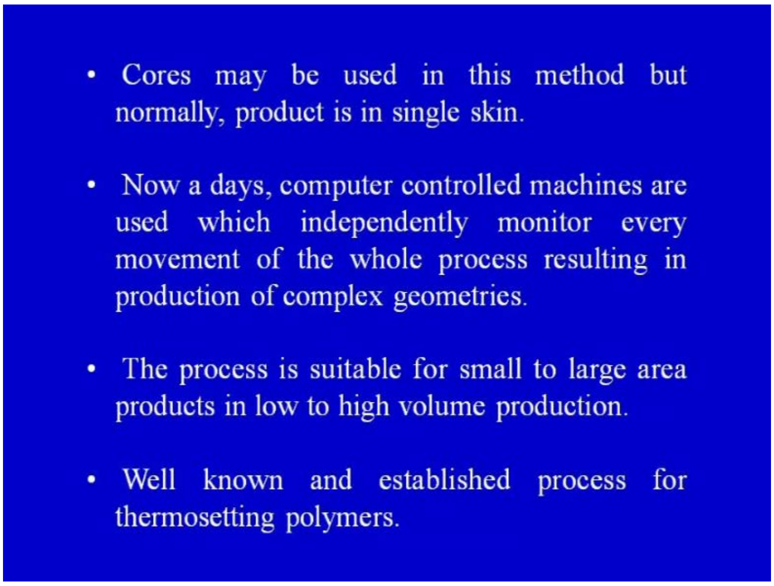

Cores may be used in the method, but, normally product is in single skin. So, we can have the cores as the cores is a very common term in casting, the cores can also be used in making the composite products but, usually this filament wound products are produced in the single skin mode only. That it will be have a uniform thickness and cores may not be used in the filament wound products.

Now, a day's computer controlled machines are used, which independently monitor every movement of the whole process resulting in production of complex geometries. So, earlier, when this process was designed. It was developed, it was used for axis symmetric component and the complex geometry of the axis symmetric components was sometimes a hindrance in the application of the filament winding process, but, with the development of sophisticated computer numerical control machines and with the help of certain further design guidelines or design modifications which have been noted and with the development of new and new materials, which are used for making in the mandrel. Now, this process can achieve fairly complex geometries.

Also the process is suitable from small to large area products in which high to low volume production can be there. So, filament wind process, winding process can be use for low volume production also, it can be use for high volume production also, but, as the experimental setup or as the machine has got a high infrastructural cost associated with. It is always suggested that, it should be used for a high volume production products and it is suitable from small products to the large products. So, very large products can be made.

So, if we just talk about the size of the composite products can be made by varies processes and compare varies processes. We can see that, hand layup and spray layup process can be used for very large products on the other hand filament winding process can also be used from low to large size of the products for from smaller to large size of the products, but, on the contrary compression molding can be used form low to medium size of the products and pultrusion process can be use for continuous products, but, the cross section should also not be very large. So, depending upon the size of the product, we can choose a particular process for a particular application. So, filament winding process can be used for small products also, it can be used for large products also and the volume of production can be low as well as it can be high, but, it is suggested that, it should be used for high volume production products only well known and established process for thermosetting polymers. So, this is a well establish process, specifically for thermosetting polymers.

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Now, coming on to raw materials which are used for making composite products as we have already discussed in our previous lectures, there are raw material is in the two forms, one is the reinforcement and another one is the matrix. So, reinforcement and matrix combined together to make a composite material. So, we have to provide a reinforcement here and we have to provide a matrix here and these two things, when they combined together they make a composite product and the filament winding process facilitates the combination of the fiber and the matrix.

So, what type of reinforcements can be used in the filament winding process on your screen, you can see what are the different types of reinforcing materials we can use glass fibers either e glass or s glass structural glass or we can have carbon fibers, we can use aramid fibers. So, different types of synthetic fibers can be use for the filament winding process fibers are in form of straight filament coming directly from creep and it can be kind of woven mats are not used in filament winding. It cannot be kind of woven mats or not suitable for filament winding, some machines may be developed specifically for using the woven mats, but, in general purpose filament winding machine. We are going to use fiber in the form of filaments only, which would be wound on the mandrel for making the composite product.

So, reinforcing materials are once again to revise we can have glass fiber either e type or s type, we can have carbon fiber, we can have aramid fibers have to be in the form of straight filament coming, which is coming from the creel woven mats are not suitable for filament winding process. So, reinforcement should not be in the type of the woven mats. Now, what types of matrix material can be use. So, matrix can be either an epoxy matrix, it can be a polymer matrix, we can use polyvinyl ester phenolic resin. So, there are different types of matrices like epoxy, polyester, polyvinyl ester, phenol resin and these types of matrices would be use in the resin bath and these resins would be used in the resin bath. The fibers would be impregnated and finally, wound over the rotating mandrel and finally, we can control the winding pattern and the fiber orientation what is ever we want to call.

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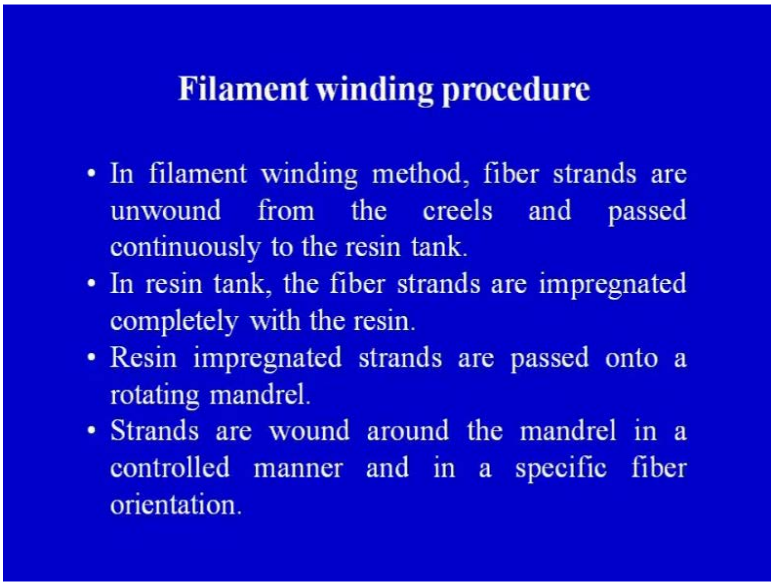

Now, filament winding process fibers strands are unwound from the creels and they are passed continuously to the resin tank. So, let us first see theoretically that how the process looks like and how the process takes place and then we will try to understand it with the help of a diagram. So, in a filament winding process as in the case of pultrusion process, we have the fiber roving’s which were placed on the creels and the fibers were coming and they were getting impregnated in the resin bath. The matrix or you can say polymer was in the form of a resin, which was put in the resin bath and the fibers got wet through the resin bath and finally, they were put into the performer and then forced into the dye and pulled by the pulling mechanism on the other side of the dye incase of pultrusion, but, in case of filament winding, the fibers are again coming in the form of filament from on we from the roving's or the creels and then these particular fibers are getting impregnated in the resin bath.

So, there are two things which have to be there in order to make a composite reinforcement and a resin. So, the reinforcement in the form of the fibers, which we in this particular case we are using as the filament and then, the resin are acting as the matrix the resin are available in the resin bath. The fibers are coming they are getting impregnated in the resin bath. So, now, we have the raw material ready we have the reinforcement in terms of fibers we have the matrix in terms of resin. So, the reinforcement and the matrix when they combined together (( )) they make a composite material.

So, now may raw material is ready, the fibers are there and the resin is there and the fiber is getting impregnated in the resin and the raw material is now ready for the final deform not I should not call our deformation, but, for the final winding on the mandrel or the final, you can say processing into the composite product. So, I have in a way using the process been able to combine the two things together, that is I the fibers are coming from the creels in the form of filaments and they are getting impregnated in the resin bath. So, the raw material is now getting ready and now when this raw material is getting ready it has to wound over the mandrel and the mandrel is also rotating. So, the load or there has to be adequate fiber tension. So, that the rolling takes place or the winding takes place over the rotating mandrel.

So, where we can see, in the very first point on your screen I again reading it for you, let us revise. In filament winding method fiber strands are unwound from the creels. So, the fibers are wound over the creels and when, we are making a composite product the fibers would be unwounded from the creels and passed continuously to the resin tank. So, they are getting impregnated in the resin tank, in the resin tank the fiber strands are impregnated completely with the resin. So, the fiber strands will pick the resin from the resin tank. Resin impregnated strands are passed onto the rotating mandrel, the resin impregnated strands. Now, the raw material is ready, we have the strands or the filaments and we have the resin. So, resin impregnated strands are passed onto the rotating mandrel. So, one thing is important to keep in mind, that the mandrel is rotating and it is causing attention in the fiber.

So, that the fibers are pulled and they are getting wound over the rotating mandrel. Strands are wound around the mandrel in a controlled manner and in a specific fiber orientation. So, the strands are wound around the mandrel. So, mandrel is rotating, it is pulling in a way, it is pulling the fiber from the creels once the process has started. Now, the mandrel is continuously rotating and the fiber is getting wound. Now, how to achieve this directional fiber orientation and how to achieve this fiber orientation, this will be achieved with the help of a carriage, that we will see in the process, when we will see the actual diagram of the process.

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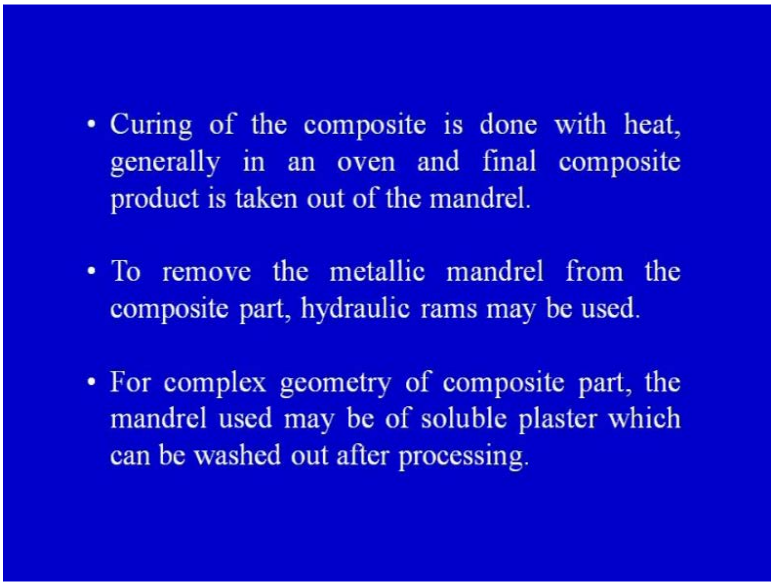

Curing of the composite that is the process of solidification of the composite is done with heat. So, we can have heating arrangement above around the filament wound product generally in a woven and the final composite product is taken out of the mandrel. So, we have to then finally, take out the composite product from the mandrel. Now, suppose this is a mandrel and I have wound the filaments or the fibers over this particular mandrel ultimately, I have got the length over the mandrel and I have got certain thickness over the mandrel. Now, may composite product as is from the top of the mandrel. Now, finally, this mandrel has to be taken out in order to get the hollow composite product.

So, finally, the mandrel would be removed and we will get the final composite product. Now, the important point to note is that the mandrel should easily be extracted from the composite product, which has been wound over the mandrel. So, the extraction of mandrel is also equally important and this also gives us an idea to select appropriate material for making the mandrel, sometimes we may make a mandrel out of a material which has a low melting point. So, that once the composite product is ready, when we heat the composite product for the curing process, the mandrel should automatically melt and come out also, sometimes we may suggest the use of collapsible mandrels that once the process is complete. The composite has cured and it has become completely solid, we can trigger the collapse of the mandrel and finally, the extraction of the mandrel from the composite product becomes easier.

So, the curing of the composite is done with heat generally in a woven and finally, composite product is taken out of the mandrel. I have suggested, I have given few ideas that how the mandrel should be chosen. So, that the extraction of the composite product becomes easier. To remove the metallic mandrel from the composite part hydraulic rams may be used which is another area or another important way of removing the mandrel from the composite product for complex geometry of composite part the mandrel used may be of soluble plaster, which can be washed out after processing. So, one other type of mandrel material is suggested here, which will help us in order to easily remove the mandrel from the composite product, because here the composite has been wound over the mandrel. So, the mandrel has to be removed later on in order to get the final composite product. So, how the mandrel can be removed, there are two three points, which have been highlighted here, which will help us to extract the composite product and we have to remove the mandrel on which, the final product has been wound.

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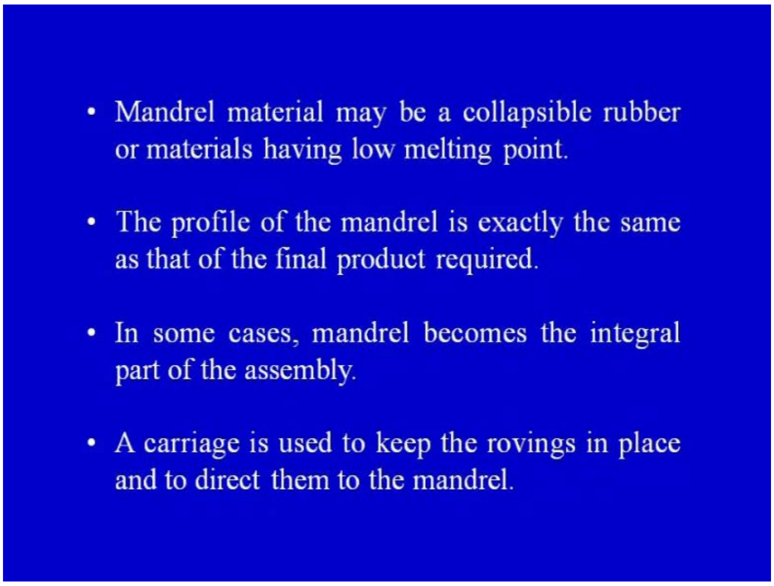

Mandrel material may be a collapsible rubber or materials having low melting point, which I have already highlighted, that it can be a collapsible material also the once filament wound product is ready over the mandrel, the mandrel make collapse and it may be taken out easily and the product is already solidified. It is in the form in which we have designed or we have required.

So, it can be they tron used can be put to the specific application. The profile of the mandrel is exactly the same as that of the final product required but, depending upon the shape of the mandrel we will get the final, we can control the inner cross sectional area of the final filament wound product, we can have a different shapes of the mandrel, because on top of the mandrel the filament winding is taking place or the product is been made on top of the mandrel. So, the inner details of the product, if we on want to a certain specific detail we can design the mandrel accordingly and that particular shape of the mandrel, we will doing the winding and later on the mandrel would taken out and final product would be ready.

So, the profile of the mandrel is exactly the same as that of the final product required. So that, two things should match and specifically, it is important that we are able to control the inner, we can say geometry of the final product. In some cases mandrel becomes the integral part of the assembly sometimes it may happened that we do not require removing and it is not a requirement to remove the mandrel, it has to be a solid product.

So, the mandrel will become a part of the final product. So, we have an inner core which is the mandrel and on that core we are doing the filament winding. So, on outer periphery, we have the polymer matrix composite of the fiber reinforced plastic and inner we have a core which is the mandrel. Now, the core material can be metallic. It can be other type of plastic, it can be rubber. So, mandrel can be of any material but, it will become an integral part of the material product. So, in this particular scenario, we need not remove the mandrel out of the composite product. It would become a part of the final product. So, inner core will be a mandrel and the outer periphery would be the fiber reinforced plastic or the composite matrix, which has been wound over the core.

A carriage is used to keep the roving's in place and to direct them to the mandrel. So, the fiber can control by the carriage and the final supply to the mandrel through the carriage, which we will try to understand with help of a diagram.

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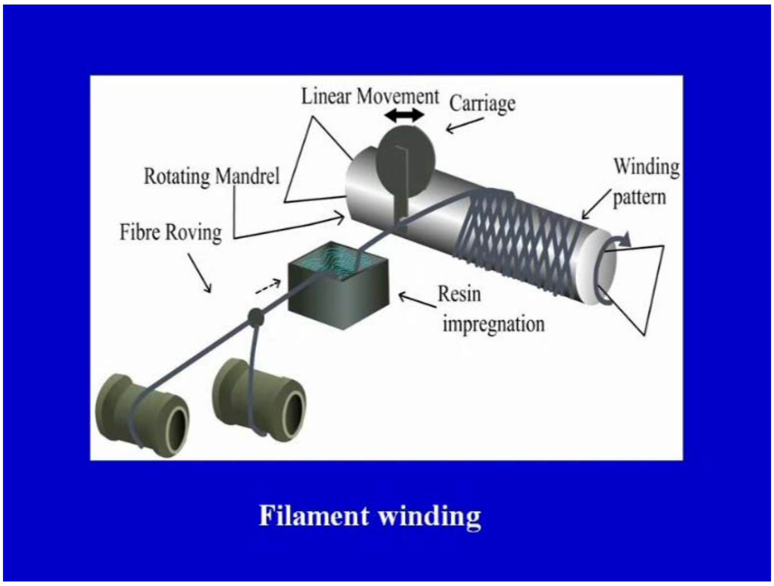

On your screen, you can see a very simplistic representation of the filament winding process. If we are able to understand this, we will able to design a filament winding set up on our own. There are few critical parameters, which have been taken in to account that would be would seeing in the subsequent slides. So, you can see here, these are the fiber creels on which we have the raw material in the form of the fiber. So, the fibers are coming individual fibers are coming or we can say this is the fiber roving, form the fiber roving we are getting the fiber and this is the resin tank where, we have the polymer. So, the reinforcement is in the terms of the fibers and the resin is acting as the matrix. So, we our reinforcement, we have a matrix and finally, we have to develop a composite material. Now, this is the rotating mandrel. So, this rotating mandrel is rotating, here we can see the rotation of the mandrel has been shown.

So, the mandrel is continuously rotating, the fibers are coming from the cranes and they are getting impregnated in the resin, but. So, this is resin impregnation of the fiber and finally, they are moving out after getting impregnated or here they carry the resin with them from these creels when, the fibers are coming they are dry fibers, when they get impregnated with resin. Now, they have the resin and the fiber. Now, the fibers are carrying resin with them in this particular area And then when this resin impregnated fibers they move through the eye of the carriage this is we can called as the eye of the carriage. This is a total carriage and this is having a linear movement along the axis of the rotating mandrel.

Now, this is the rotating mandrel and this is the axis of rotation. So, this particular carriage having a linear movement parallel to the axis of the or in the direction of the axis of the rotating mandrel. So, this linear movement would help us to control this fiber orientation. Here you can see, the fibers are in these directions also and the fibers are in this direction also. So, this is called the winding pattern, which I have explain in the previous slides I have explained, that the fiber orientation has got a very important role to play in the mechanical properties of the final product.

So, on your screen you can see, we have a specific winding pattern. So, with the proper design we can control the winding pattern that how the winding of the filaments would take place or the fibers would take place on the rotating mandrel. So, this is called a carriage and the carriage will have a linear movement creel. So, this winding pattern basically, will depend upon two movements. One is the rotation of the mandrel and another one is the linear movement of the carriage. So, if we are able to put are and optimal combination of the rotation of the mandrel and the linear movement of the carriage, we would be able to generate a finding pattern, which would result in very good mechanical properties of the filament wound product.

So, basically there are two important things that we need to control here, that is the speed at which or the r p m at which the mandrel is rotating and the movement of the carriage.

That is the speed at which the carriage is moving. So, we now need to have control over the two important movements that are there in this particular diagram. That is movement of the carriage and the rotation of the mandrel and a proper. We can say important combination has to be designed or develop between the rotational speed and the linear movement of the carriage in order to develop a very good winding pattern in case of a filament wound composite product. If we get a good winding pattern and good fiber orientation in different layers of the composite product or filament wound product, the final properties of the mechanical properties of the final product, which has been made by the filament winding process would suitable to our requirement.

So, we need to understand that, these are the two important things that is the winding pattern which further depends upon the rotating speed of the mandrel or the r p m of the mandrel and the linear movement of the carriage. So, there are few critical parameters that we have to take in to account, when we are discussing a filament winding process.

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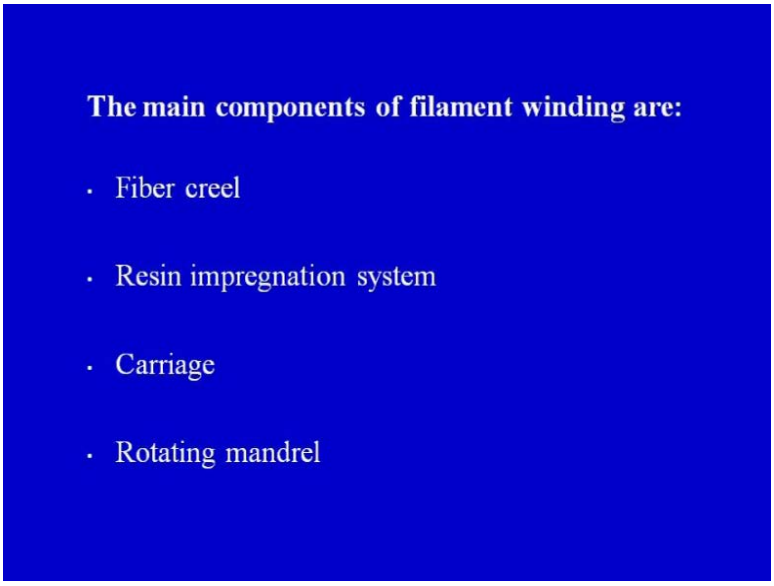

So, the main components of the setup or the filament winding machine are the fiber creels from which the fibers are coming. The resin impregnation system where, the fibers are getting with the impregnated resin that carriage which is having a linear movement and which is the final we can say point from where the fiber is going towards the mandrel or the rotating mandrel and the rotating mandrel. So, we have seen the rotating mandrel is also equally important, we have to see the geometry of the rotating mandrel, we have to see the material out of which the rotating mandrel is made and we have to control the speed of the carriage that the linear motion of the carriage has to be controlled. So, these are the few important points or few important elements of filament winding set up.

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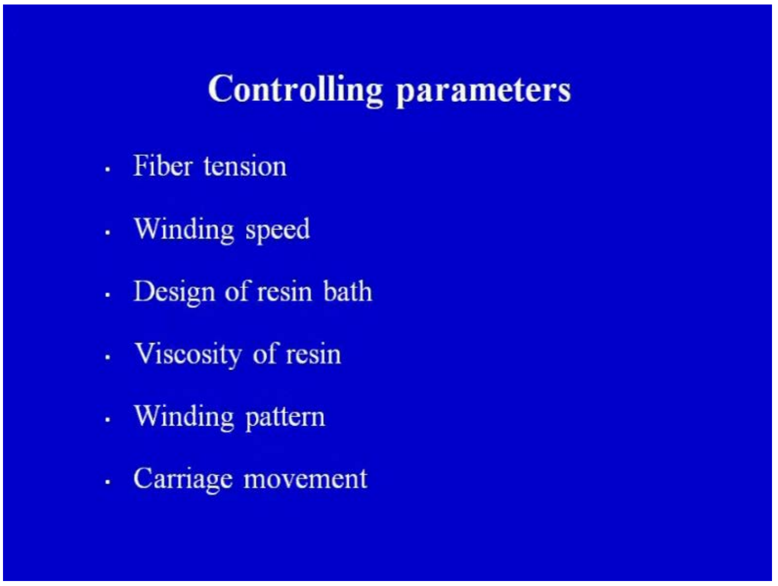

Now, what are the controlling parameters? So, there are few important controlling parameters in the filament winding process. So, these are the fiber tension, the fiber should have adequate tension if they have vary, if they are, you can say pooled very quickly or they are pooled at a very slow phase, it would affect the properties of the final product and if they are under very high tension. They may result in the final fractures of the fibers also. So, there as to be an optimal and the adequate value of the fiber tension, it should not be very high, it should not be very less, because the consolidation process. Now, we have seen in some of the previous processes let me highlight the word consolidation.

In some of the previous processes, we have seen like in hand layup process, how the consolidation is taking place, we have a two plates and we are applying the pressure on the top plate and we have doing the lay up on the bottom plate and applying the pressure with the nuts and the bolts assembly or we can had additional static lode on the flat plate mode. So, the consolidation taking place by the application of pressure or load in case spray layer, we are using a consolidation roller to consolidate the composite product, in case of pultrusion in the die we are having, you can say controlled temperature and cured curing is taking place as a cured product is coming out the consolidations is processing take place within the dye.

In case of compression molding, we are have a combination of the pressure and the temperature at the consolidation of product is taking place, but, in case of filament winding the consolidation will depend upon the fiber tension. So, if we have adequate tension optimal tension, it should not be very high it should not be very low. So, if we have optimal tension in the fibers when they are getting wound over the rotating mandrel, we will get very good consolidation of the final product. So, fiber tension is the critical parameter and we would be discussing may be one or two more slides on fiber tension. We have the winding speed or we can say this is the speed at which the mandrel is rotating. The design of the resin bath, how the fibers are getting impregnated. So, that is also equally important if all the fibers do not get wet, the final product that we will be getting would not be of the adequate properties and may fail it took to use.

So, that we have to design the resin bath in such a way, that each and every fiber should get wet, when it is passing through the resin bath. Viscosity of the resin is also equally important, winding pattern as I have already explain, that fiber orientation place or significant role in dictating the mechanical properties of the filament wound product. So, we have to see that we add attain a very optimal winding pattern. So, that the properties are as per our requirement and the carriage movement has to be controlled, because we cannot have a too fast carriage movement, for too slow carriage movement and if we have proper relationship between the rotating speed of the rotating mandrel and the linear movement of the carriage we can dictate or we can control the angle of orientation. So, we have to control the carriage movement, we have to control the winding speed, we have to control the viscosity of the resin and we have to control the winding pattern and most importantly are the fiber tension.

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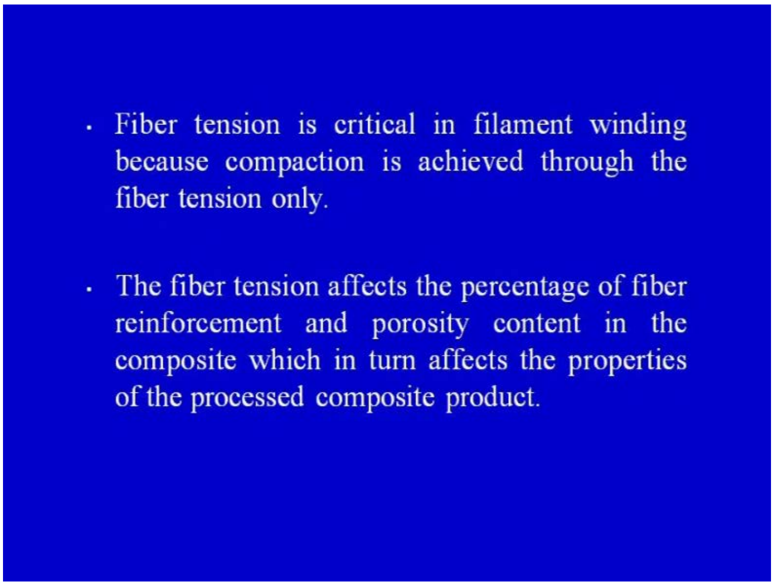

So, let us see, how the fiber tension places an important role in the consolidation process. So, fiber tension is critical in filament winding, because compaction is achieved through the fiber tension only. So, the important point the consolidation word has been replaced by compaction. So, the filament bound product would be very compact. It would be consolidated if we have an adequate fiber tension.

The fiber tension affects the percentage of fiber reinforcement and porosity content in the composite, which in turn affects the properties of the processed composite product as I have already explained the mechanical property is would certainly depend upon the fiber tension and the fiber tension would further dictate the fiber volume fraction, that is present or the percentage of fiber reinforcement in the final product. So, if we have fibers coming loosely and they are not getting wound properly on the rotating mandrel, the fiber volume fraction would be less and too much of resin will be there in the final product, but, we have adequate tension of the fiber, we will get a consolidation and we will get a very compact filament wound product. So, the fiber tension affects the percentage of the fiber as well as the porosity and wide content in the filament wound product. So, we have to appropriately and judiciously select the fiber tension during the filament winding process.

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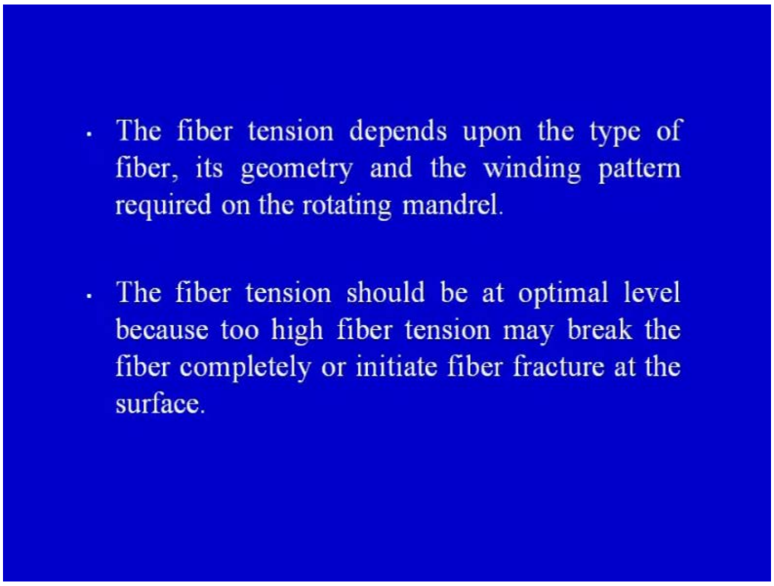

The fiber tension depends upon the type of the fiber, the geometry and the winding pattern required on the rotating mandrel. So, we have to judiciously and we have to very intelligently select the type of fiber. And on that type of fiber the fiber tension will depend, there may be some fibers if you apply lot of tension on them, the fibers may break also and then these types of reinforcements are not suitable for making composite products by the filament winding process. So, we have to choose the type of fibers in such a way that we can have a adequate level of tension during the process.

So, fiber tension is very important. So, if there are some fibers which cannot take that much of tension, their they have to be discarded for filament winding process means, the filament winding process is not suitable for making products by those type of fibers which cannot take the adequate amount of tension.

So, the fiber tension again to revise depends upon the type of the fiber, we have to choose those fibers only, which can take the tension and its geometry as well as the winding pattern required on the rotating mandrel. So, the winding pattern required is also very important. The fiber tension should be an optimum level, because two high fiber tensions may break the fiber completely or initiate fiber fracture at the surface.

So, I have already highlighted, I have already explain the two high fiber tension is also not desirable, because it may lead to the fiber fracture or the failure of the fiber before the actual winding process or the surface of the fiber may get degraded, because of very high tension. So, we have to judiciously and optimally select the fiber tension during the filament winding process. So, we have seen that, there are few control variables in the filament winging process which have to be taken care of.

Now, just to revise that, what are these important points or critical parameters which should be taken into account, while we are discussing the filament winding process. Now, these are the rotational speed or the winding speed that is the r p m of the mandrel, the linear movement of the carriage the tension in the fiber the resin impregnation system. So, these are three or four important critical parameters, which should be taken into account while discussing the filament winding process, because if any one of these parameters is not taken care of or is not give given due importance and attention then, the final product that we are getting using the filament winding process may not be of a very high quality. So, if for making a good quality product, we have to select the rotation speed, we have to select the translation or the linear motion of the carriage, we have to select the appropriate resin system and resin impregnation system and we have to provide adequate type of the fiber and the fiber tension should be optimal.

So, that we get a very good quality product.

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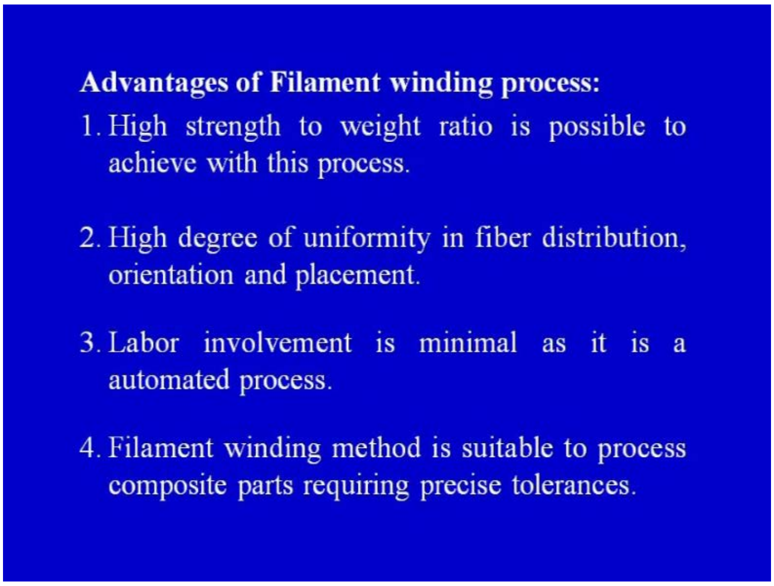

Now, what are the advantages of the filament winding process. So, we have been discussing the advantages and limitations of some of the processes like the hand layup, the spray layup compression molding pultrusion. So, vis a vis other process filament winding has got certain advantages and it has got certain limitations also. Now, we are going to discuss the advantages of the filament winding process high strength to weight ratio is possible to achieve with this process, because the fiber volume friction or the percentage of fibers in the final product is high therefore, we are able to achieve high strength, the weight ratio with the filament bound products.

High degree of uniformity in fiber distribution orientation and placement, because here we are having a continuous fibers reinforcement, we are able to control the uniformity in fiber distribution and orientation and placement is also good in the filament winding process. So, the orientation and placement is in context of the fibers the fibers orientation and the placement of the fibers in the matrix is optimally controlled in case of the filament wound products labor involvement is minimal as it is an automated process. So, it is very clear that, it is automatic process. So, the labor involvement is less.

Filament winding method is suitable to process composite parts requiring precise tolerances. So, far highly accurate and precise products filament winding process is suitable. So, we can see that, high fiber volume fraction can be archived strength to weight ratio of the products made by the filament wounding winding process is very good uniformity in fiber distribution fiber orientation can be archived by the filament and winding process. So, there are certain advantages, which are not available with the other processes which we have discussed till now.

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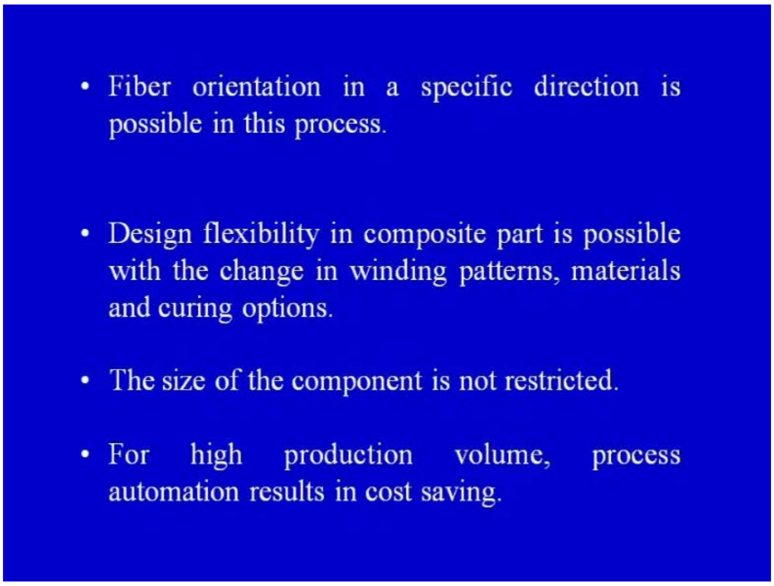

So, fiber orientation in a specific direction is possible in this process as we can see that, the winding pattern will depend upon the rotational speed of the mandrel and the linear movement of the carriage. So, we can dictate the fiber orientation in the filament wound product design flexibility in composite part is possible with the change in the winding pattern materials and the curing option. So, it is a versatile process, we can choose the raw materials, we can dictate or design the winding patterns and we can adequately choose the curing options. So, because of all these options available with the engineers, the filament winding process can be used for a verity of composite products.

The size of the composite component is not restricted. So, a large size component can also be made and a smaller size component can also be made by the filament winding process. So, high production volume process automation results in cost saving. So, as we have already seen that the filament winding process can be used for high volume production. It can be use for low volume production also, but, for high volume, if we have a fully automatic process, it would lead to cost cutting or cost saving.

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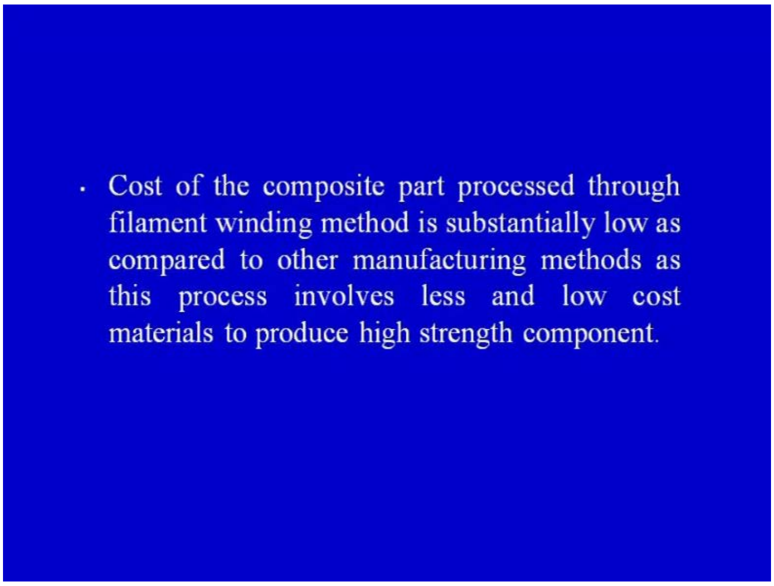

Cost of the composite part processed through filament winding method is substantially low as compared to other manufacturing method, as this process involves less and low cost materials to produce high strength component. So, the strength comes by the fibers and we have already seen that it in case of filament winding process the fiber volume fraction that can be achieved is considerably higher. So, when we have higher volume fraction we will defiantly get higher strength.

So, the type of materials that we are using can be slightly, we can say on the inexpensive side. So, in instead of using very expansive materials to get a certain degree of strength even if you are using slightly inexpensive material but, because of a very high fiber volume fraction which is achievable by this process we can think of using certain materials which would reduce the cost of the composite product.

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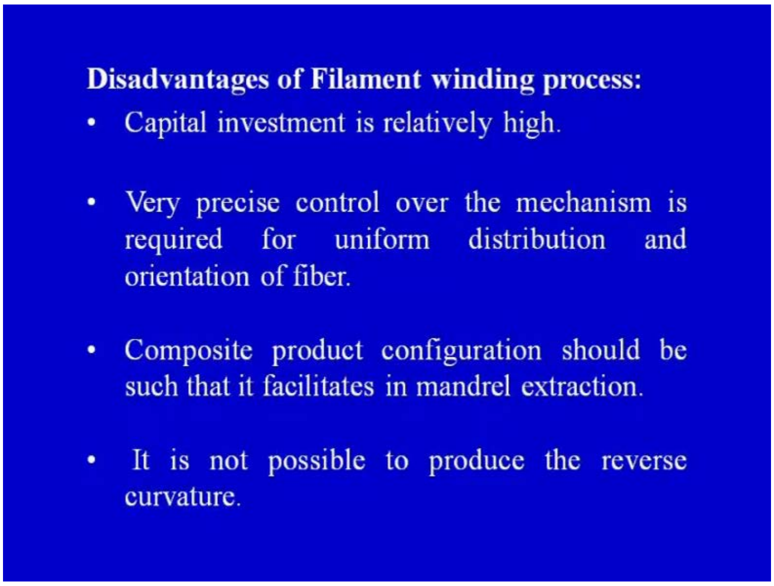

Now, what are the disadvantages of the filament winding process capital investment is relatively high, because we have to procure of filament winding machine. So, the capital investment is there. Therefore, relatively high very precise control over the mechanism is required for uniform distribution and orientation of fiber. So, this is one of the advantages that we can have a control, but, in or in order to exercise this control sometimes it may become difficult, because it will depend upon the viscosity of the resin that we are using it will depend upon the fiber tension. It will depend upon a number of other parameter. So, the precise control of the process is also equally important.

So, if we are not able to precisely control the process then, it will become one of the disadvantages of the filament winding process composite product configuration should be such that, it facilitates in mandrel extraction. So, if it is a very complex geometry we (( )) may not be able to process it using the filament winding, because the final mandrel extraction is one of the limitation. So, if it is a complex geometry we are not able to extract the mandrel out of the filament wound product then, it because the one of its limitations, it is not possible to produce the reverse curvature s, outside curvature can be made but, if the reverse curvature has to be made. It is sometime difficult to achieve by the filament winding process.

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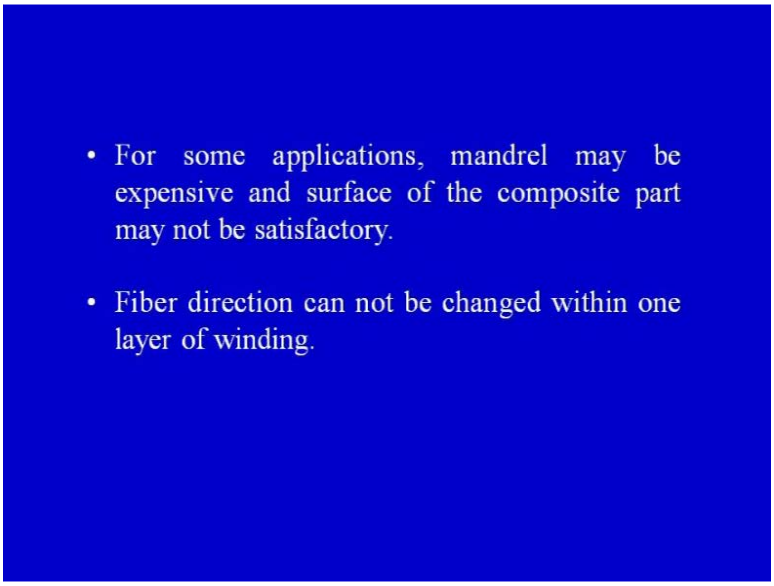

For some applications mandrel may be expensive and surface of the composite part may not be satisfactory. So, we can control the inner surface finish, because that would depend upon the surface finish of the mandrel, but, sometimes it becomes difficult to control outer surface of finish of the filament wound product and we cannot do any finishing operation on that suppose, somebody may suggest that we can do the turning of the filament wound pipes. It is difficult, because when we start the turning the fibers come out of the matrix and the fiber pull out takes place and the surface instead of getting improved it further deteriorates. So, surface finish is difficult to achieve and sometimes the outer surface is difficult to control incase of the filament winding process. Fiber direction cannot be changed within one layer of the winding. So, we have different layers of winding and in one particular layer of winding the fiber direction would be uniform or it would be same. So, in one particular layer we cannot change the direction of winding. So, fiber direction cannot be changed with in one layer of winding. So, fiber direction cannot be changed within one, it means that it will remain constant. So, fiber direction cannot be changed within one layer means, the fiber direction will remain constant in one layer of the winding.

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So, finally, we come to the applications. So, the 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 commonly developed with this method. So, on your screen you can see a wide verity of products which are mostly axis symmetric in nature and these can be processed by the filament winding process.

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. So, initially the application of filament winding process was only restricted to or limited to the axis symmetric components only, but, with the development of new and new filament winding machines and with more degrees of freedom possible and with more sophisticated software's, that have come into place. Now, it has become possible to make different shapes of the products made by the filament winding process. So, the application spectrum of filament winding process has increased or the last few years.

So, there are large number of applications, which you can see one your screen. So, in today's lecture, we have seen the basic process of filament winding with the help of the diagram, we have try to understand that, how the filament winding process takes place. We have tried to highlight the critical factors, which should be taken into account while operating the filament winding process, we have seen what are the advantages of the filament winding process, what are the limitations of the filament winding process and finally, on this particular slide, we have seen that what are the application areas of the filament winding process.

In the subsequent lectures in this module on processing of polymer matrix composites, we would be focusing our tension on some other processes such as, resin transfer molding for the processing of polymer matrix composites.

Thank you.