Manufacturing of Composites
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Lecture - 09
Filament Winding Processes

Good morning friends. So, we will move to the next lecture, lecture number 9 which we will discuss about filament winding processes. Last class what did we see was we were seeing that how do you make a flat surface or a profiled surface this profile surface can be double curvature depending upon the complexity. Filament winding process is typically used for applications where and which you have something like a cylinder this cylinder hands to be reinforced or a small bulb like structure where and which you would like to enforce.

So, here we do not use the reinforcing agent mat we use a thread glass fiber wire or a glass fiber we take and then we dip this glass fiber in polymer and then start making our winding around a mandrill or around a shape and get a geometry (Refer Time: 01:17). So, this is filament winding process filament winding process is predominantly for cylindrical surfaces and axis symmetry parts. So, the content we will look into the introduction of the process then we look into filament winding machines.

Today we have lot of filament winding machines available for doing various geometries, then winding patterns then we will see advanced machines which are available today, then how are the matrix getting reinforced, then how do you make a mandrel its quite challenging how do you make a mandrel for this. Then process parameters some of the problems associated with it and then finally, we will see the advantage and disadvantages of filament winding process.

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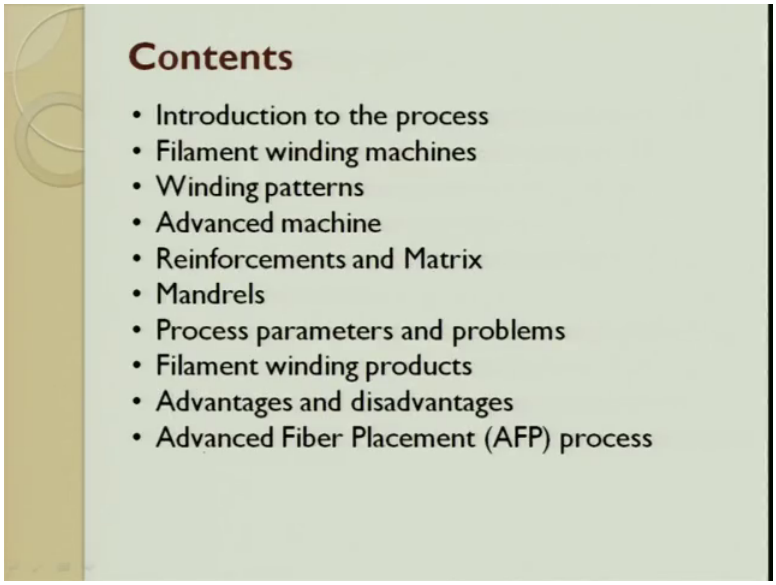

As I said filament winding process is one of the most important of important of composite manufacturing process. So, here we make lot of parts.

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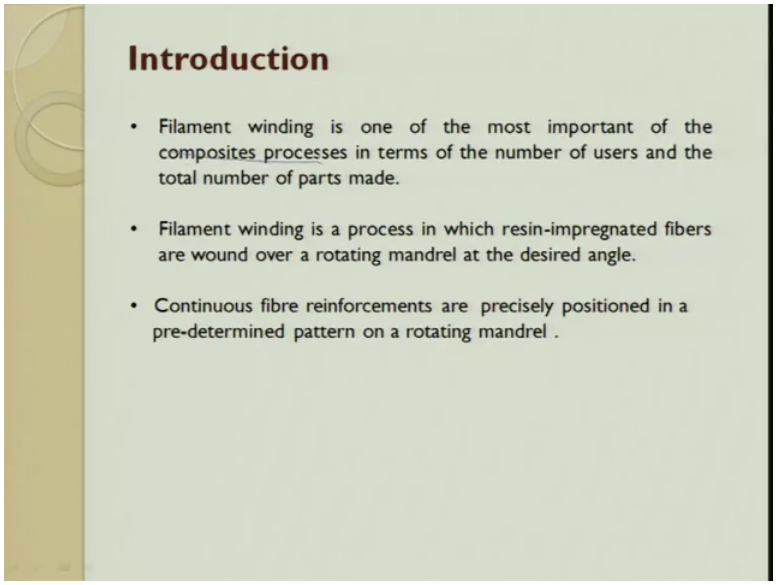

So, it is composite parts in terms of number of users and the total number of parts are made is a process where and which the resin is impregnated with a fiber and it is wound

over a rotating mandrel at the desired angle. So, how did you get the desired angle? Depending upon the properties you have for example, I need hoop strength I need along the circumference I need lot of strength, so here and for examples when you send space shuttle going outside the orbit. So, here the pressures are high they use solid propellant, they will use liquid propellants this has to be packed inside a container which has to withstand pressures, so what we do is we try to use many a times we try to use filament winding process. So, here a continuous fiber reinforcement are precisely positioned in a predetermined pattern on a rotating mandrel.

So, I have already talked about resin which is getting re impregnated in a fiber what is a fiber, fiber is nothing but a long thread in a very crude fashion long thread. So, this thread is impregnated with resin and then you tried and resin here what are the resin we are talking about predominantly this process is for polymers. And as I told earlier itself it is very easy for fabrication when using thermosets, so the form basic form is going to be a liquid. So, it is going to dip the fiber has going to dip through and then go. And keep it in mind the fiber which is getting coated with resin is already given a silane coating such that you enhance the wettability; that means, to say you have a very good interface between the glass fiber and the resin.

So, filament winding process are used for producing any product with a positive curved surface it can be a cylinder, a sphere, a cone, a geodesic shape. All these shapes can be made is it very clear now.

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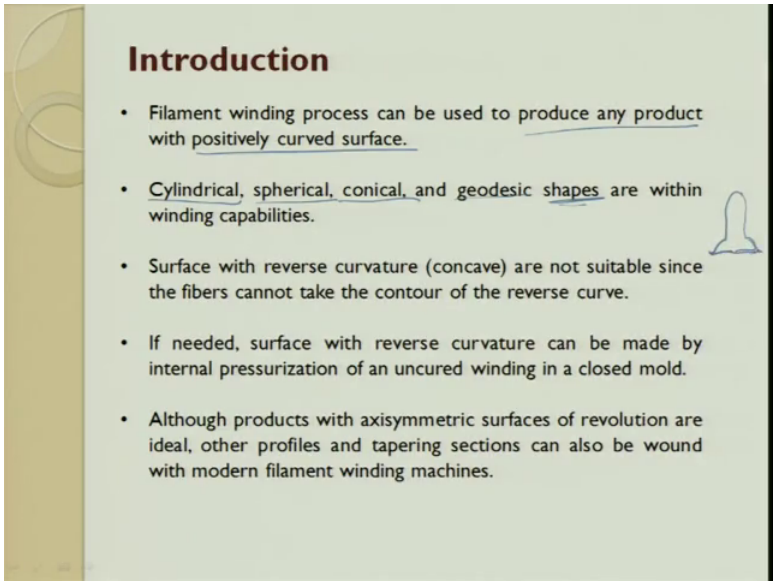

So, it can be used a geodesics something like which is used for space shuttle applications, conical a again in a space shuttle if you see the bottom most portion it is somewhere something like this they use homogeneous material they use alloys, but today what they do is they also do it with glass fiber reinforced plastic and here the matrix is predominantly carbon and the fiber which is used is also carbon fiber. So, it is very lightweight, it is used for and it can with stand very high pressure and very high temperature.

So, the surface with reverse curvature that is concave are not suitable since the fiber cannot take the contour of the reverse curvatures. So, please clarify this point and please think it is used for positive curvature and it is not used for reversed curvature, keep this in mind. Concave curvatures; that means, to say just along the surface if you want to do it cannot be done. You have a mandrel on top of a mandrel you can do but if you have a mandrel which is negative and then you want to do a positive this process cannot be thought. Of course, it can be thought of with lot of attachments in the setup it can be done, but predominantly it is better to avoid.

So, if needed the surface of the ca the reverse curvature can be made by internal pressurization of an uncured winding in a closed mold. As I said if you want to make s reverse curve, so then I said there has to be an attachment made. So, here what they did is

they have done an internal pressurization of an uncured winding is done on a closed molds. So, you can get it done. The axisymmetric surfaces on revolving are ideal for filament winding process. So, other profiles like tapper I said cone. So, tapper sections are also can be made easily.

So, let us see typical set up how does it look like. You see continuous roving this can be glass fiber, this can be carbon fiber, this can be Kevlar fiber or Kevlar which you have all these reels which are kept here and what they do is from these reels there are lot of wires which come here they pass through a separate combs and after passing through a separate comb.

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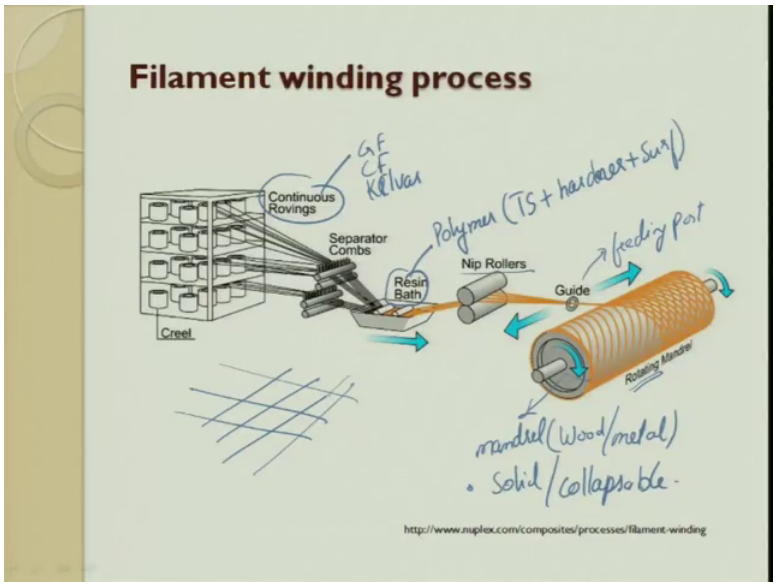

Now hear it all these things are brought in proper tension and the spacing is maintained and afterwards it is asked to pass through a resin bar. So, in this resin bar we have a polymer which is predominantly a thermoset and we also have other ingredients like hardener and then whatever it is other surfactant whatever you want to add. So, this can be added, so that surfactant can be added, so that you try to get the proper requirement.

And then the after it passes through the resin now you see there is a change in color of the glass fiber or carbon fiber. So, the black has become golden color this golden color means

that resin is getting coated all along the fiber. And now this is passed through nip rollers because you have to make sure excess resin should not be there and this excess resin is removed by passing through these rollers. So, that we doubly make sure that there is a uniform coating of polymer around the glass fiber and then it is moved to a small ring or this is called as a feeding post, feeding post. Now what you see that if this glass fiber whatever comes out individual fibers are now twinned they get into a shape and this the bundle of glass fibers are now wound over the mandrel. So, this is a mandrel. Why do you need this mandrel? This mandrel is made out of wood and then wood or metal whatever it is it can be it can be solid, it can be collapsible also. That means, to say this entire thing can be made out of a single piece or it can be made out of two halves depending upon your requirement. Now the single glass the roving which came are now bundled together and now this is allowed to wound over the mandrel, this mandrel is rotating.

So, now of what happens as and when you increase the glass fiber roving on top of this mandrel the thickness increases. Now here depending upon the feed rate, depending upon the rpm you can try to have varying hatch patterns, this hatch patterns can be process controlled to get whatever you want. Now slowly slowly this process gets repeated may be 1000 windings, 500 windings, 10 windings whatever it is you get and finally, what you get is a cylinder which is completely made out of polymer matrix composite which is reinforced with glass fiber and this angle of hatch pattern depends on your strength what you are the properties what you want from this composite. For example, the fluid can flow in this direction the pressures can be high in this direction. So, you try to balance the hatching and the winding angle to get the required composite.

And by the way if you pass through the bridges where and which these bridges have columns which are completely in the river itself riverbed itself; that means, to say all the time water is flowing of all the time a corrosive environment is there, so you have this columns on top of which were cars and other things go on. So, these columns are nowadays made out of composites. Two way (Refer Time: 10:39) exclusively composites they are made or what they have done is they have taken the cement concrete and then they had made a column and the column is protected by filament winding process using glass fiber to avoid corrosion and to enhance the strength property. The other thing is today they talk about self healing or they talk about how do we make sure the defects whatever happens on the concrete to be prevented further growth they use composite.

So, composites is also used for crack un healing. So, the filament winding process as I told you the winding machine is the biggest challenge.

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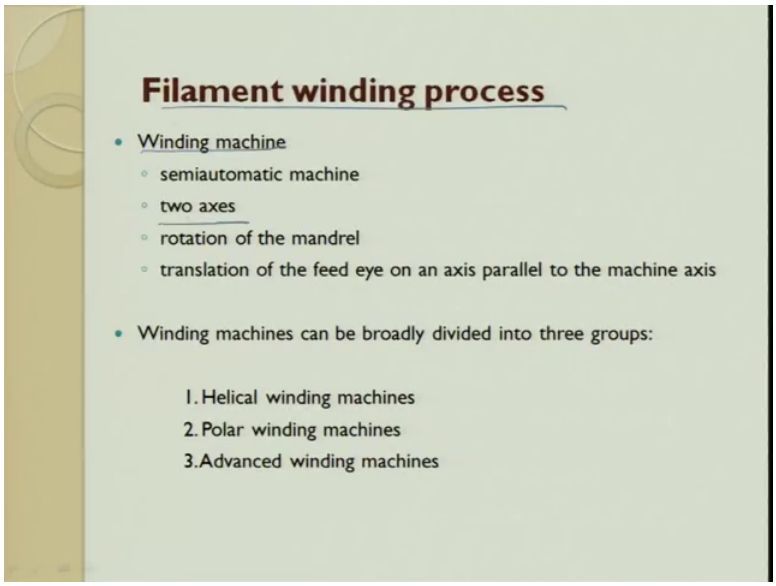

So, it can be semi automatic machine it can be two axis now you see I have slightly made it little more complex the earlier one was single axis you can also have two axis the rotation of the mandrel can be there. The translation of the feed eye on the axis parallel to the machine axis also can be there. So, the machine winding can be divided into helical, polar and advanced winding helical is criss cross pattern polar I will show you polar.

So, winding process, so in winding process what we have is the continuous reinforcement in the form of roving or yarns coated with matrix again here it can be polyester it can be epoxy it can be anything of your choice so, but maximum work is done on thermosets only. So, coat with matrix material are bound around using a pre designed machine.

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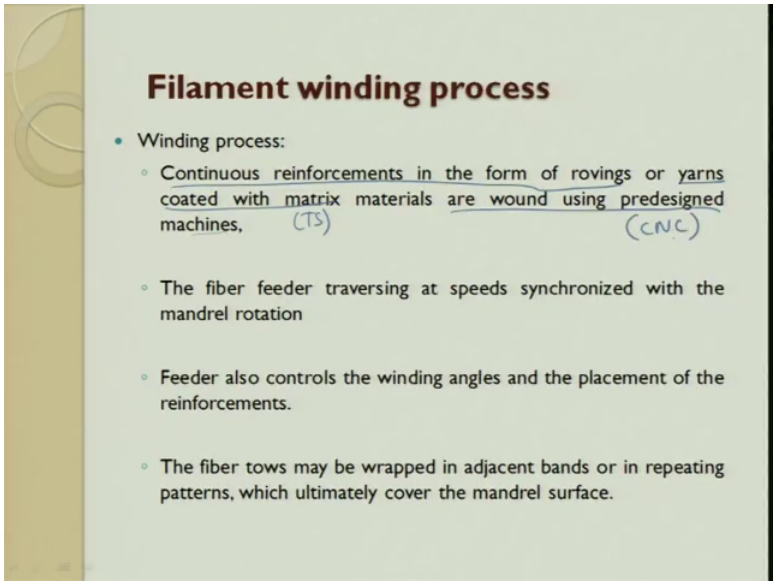

So, what is pre designed machine? It is something like a CNC machine. See if you go back and see I can hold this mandrel between centers in a lathe machine and then I can use this as a feed post I said now this can be also tool post of a lathe machine. So, as and when the tool keeps moving on the along the tool axis it can go in two directions one is perpendicular and along. So, depending upon this I can try to generate whatever profile you want. So, in a lathe machine between centers I hold with a mandrel I can do filament winding process.

So, this is what I said. So, it can be a ordinary machine it can be a CNC again here the rpm also plays an important the feed rate plays an important role the rpm with which it rotates that also plays an important role. The fiber feeder transfers speed has to synchronize with the mandrel rotation if there is a mismatch then what happens is this fiber does not wound properly or they lose tension. So, moment they lose tension either it becomes a fiber riched zone or a resin rich zone. So, there is a defect. So, the feeder are used to control the winding angle. So, what is the winding angle are we talking about, this angle theta. So, winding angle and the placement of the reinforcement is controlled by the feeder. So, what is a feeder? Feeder is the guide post. So, here feeder the fiber tow may be wrap may be wrapped in adjacent bands or in repeating patterns which ultimately covers the mandrel surface so that you get the required thickness. Otherwise what happens it will be only a glass fiber why just get bounding around the mandrel see for

example, if you buy a bobbin, if you buy a thread bundle.

So, what happens is it has a cylindrical mandrel and then on top of it they wind a thread same weight is there depending upon the winding you have the thickness number of turns are more the thickness is more, but here in the thread what happens there is no resin. So, it does not give a shape. So, here you can give a shape and this thing. So, winding process is nothing, but successive layers are bound at same angle or different angles so that means, to say throughout the thickness you can have a same angle or you can keep changing the angles. So, what does it mean it leads? So, it functionally graded this thing filament wind composites.

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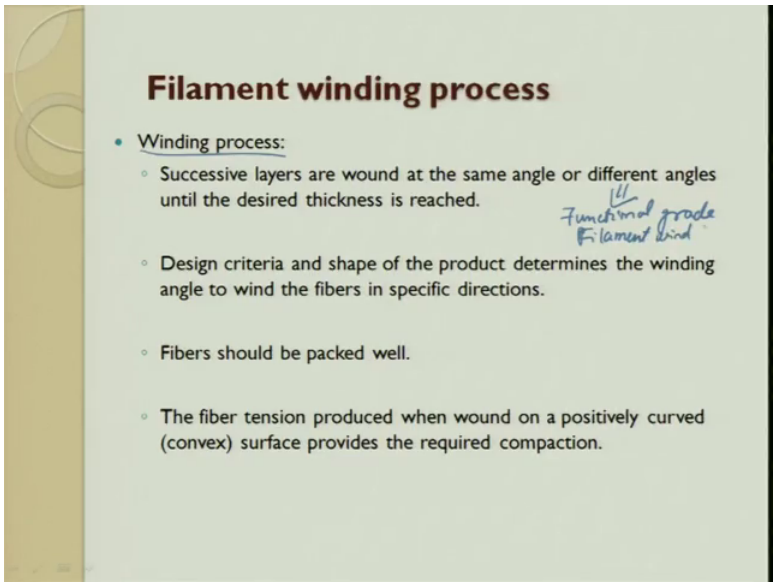

So; that means, to say the strength keeps changing, why is it very important because see some many a times what happens we do near net shape manufacturing through these components and after you make these composites you have to assemble these composites when you try to assemble these composites you have to drill, moment you have to drill then what happens the thrust force when it is acting on the component the thrust force has to be uniformly distributed. So, that distribution can be done if you use different angles. So, that is one way plus depending upon your mechanical requirements you can do. And people are smart what they have done is they have done filament winding and then they have put a core they have put a something like a sandwich structure they have made and

then they have put one more round of filament winding so that means, to say this is glass fiber this is glass fiber and here they have sandwiched core. So, this core will be light and this core can give can reduce the weight, so that is permanently light and then this can give the other properties what is required.

So, design criteria and shape of the products of the product determines the winding angle to the wind the fibers in a specific direction. I have already discussed this. So, the fibers should be packed very well if it is loose it becomes resin rich. So, when I say fiber has to be properly done there is something called as a tension which has to be maintained such that the fiber sinks inside the resin bath comes out and then gets wound. So, there has to be a proper tension maintained the fiber tension produced when wound on a positively curved at is convex shape provides a required compaction. So, this is more of very closely if you see resin impregnated.

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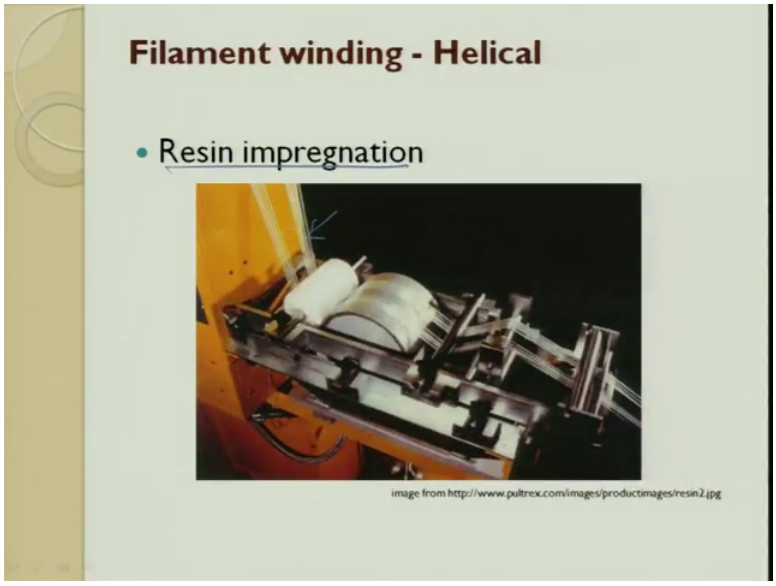

These are the wires, so these wires pass through two rollers and there is a bath so where and which the fiber goes through this and then it comes out of this and then it goes like this. So, this is where it goes.

So, if you see that it the fiber gets uniformly coated with the resin this is very very

important. Again here you can see different wind pattern this is helical like a helical helix of a spring it is helical.

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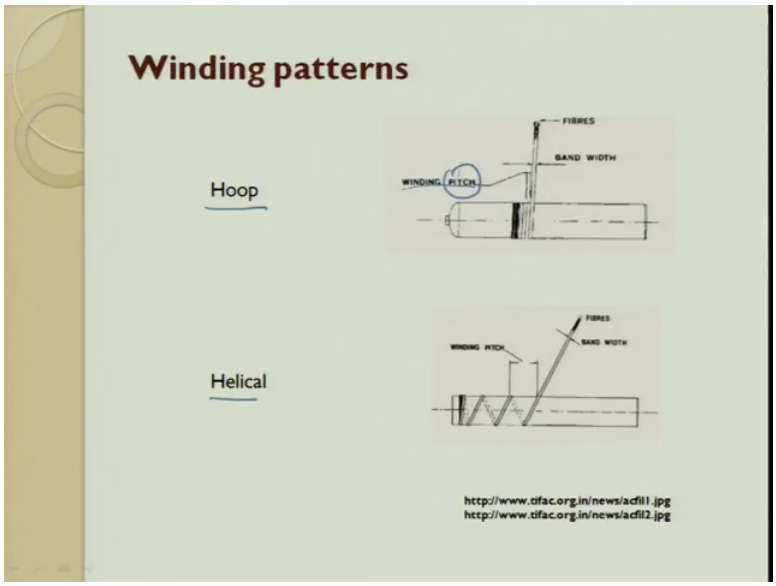

This is hoop, so you see there is a mandrel, there is a mandrel and you see a winding and again in winding an important parameter is the pitch. Pitch is the distance between two windings. Then it is about the bandwidth is also talked about. So, you see here bandwidth is at an angle. So, now, depending upon the application on the mandrel you keep playing with the feeding post you try to get different different angles. So, this is polar, polar you see it is very interesting it winds in this direction and it also rotates in this direction.

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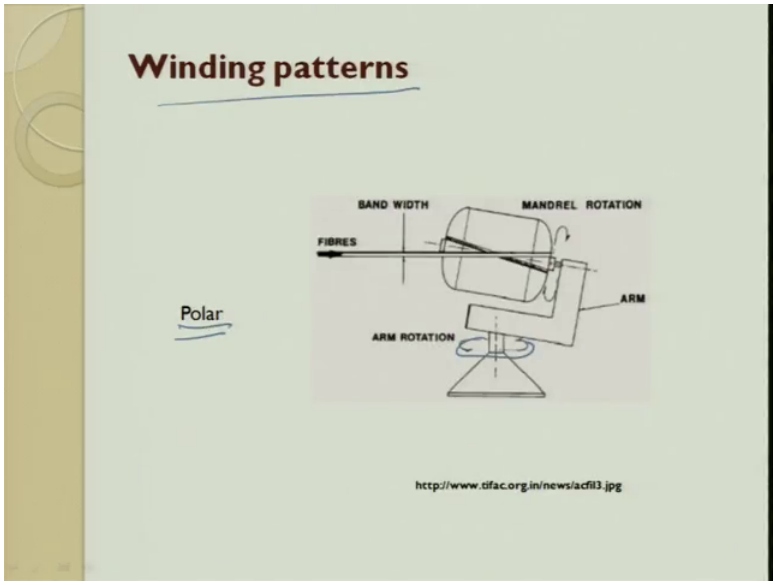

So, here is a fiber getting fed. So, this is what I was talking to you about a mandrel rotating or this is a called very crudely as a bottle where and which it is otherwise called as fuel bottle when and which you store solid propellant or liquid propellant or very high gas whatever it is and then use. Today for example, hydrogen, hydrogen is a very lightweight is a lightweight gas. So, if you want to store hydrogen we use filament wound composite bottles for this application. So, here if you see it is wound in two directions so around the bottom and then this direction. So, two directions it does. So, you get a angle. So, this is called as polar.

So, if your component is a small you can have a mandrill and then you do it. Now there must be a question which you might ask. So, what happens to this mandrel, how do I remove this mandrel you are right. So, as and when I do this winding finally what happens this mandrel is now an integral part of the winding. So, we always use collapsible mandrels. So, this collapsible mandrels means what happens is this mandrel is used for initial winding allow the resin to cure, moment it cures then there will not be a change in shape. Then what they do is they see they always use split mandrels something like this and center they might have the center core or something where at which it is a tapered. So, what they do is they release this taper hitting at one part then this fellow the distance is reduced and then they slowly remove it out. So, we always use collapsible mandrels these mandrels are not integral part of the product they are only used to give shapes.

For example when I gave you an ex for cement concrete it becomes an integral part, but generally if you want to make a pipe we do not do it. So, winding we have we have seen four different windings hoop winding, helical winding, polar winding and axial winding where ever you want to have good circumferential strength we always go for this. So, the angle is closed is closed and below 90 degrees we use it. Each complete rotation of the mandrel shifts the fiber band to lie along the side of the previous band.

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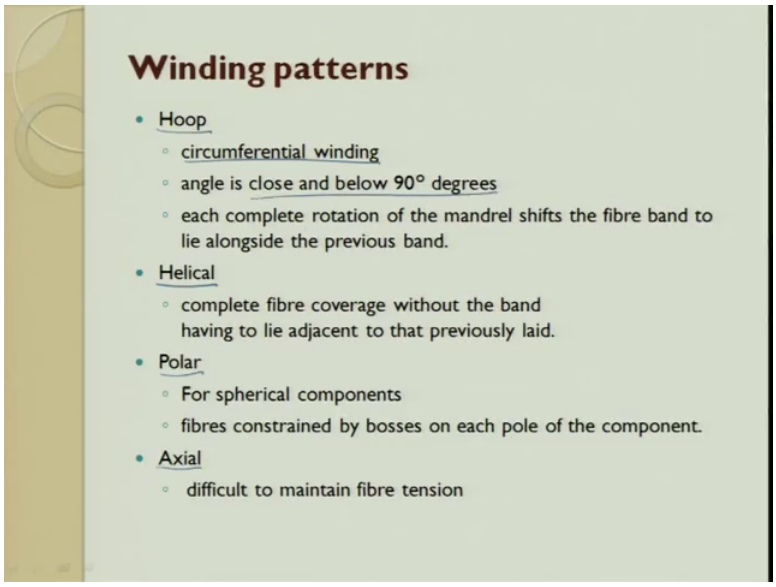

So, next is helical. So, if you want to look back please look at it this is hoop then next one is helical I told you a helical spring complete fiber coverage without the band having an adjacent to the previous slides. So, that is what I said this is at an angle. Polar for spherical components fiber constrained by bosses of each pole of the component, you can also have axial which is difficult to maintain fiber tension this is also there.

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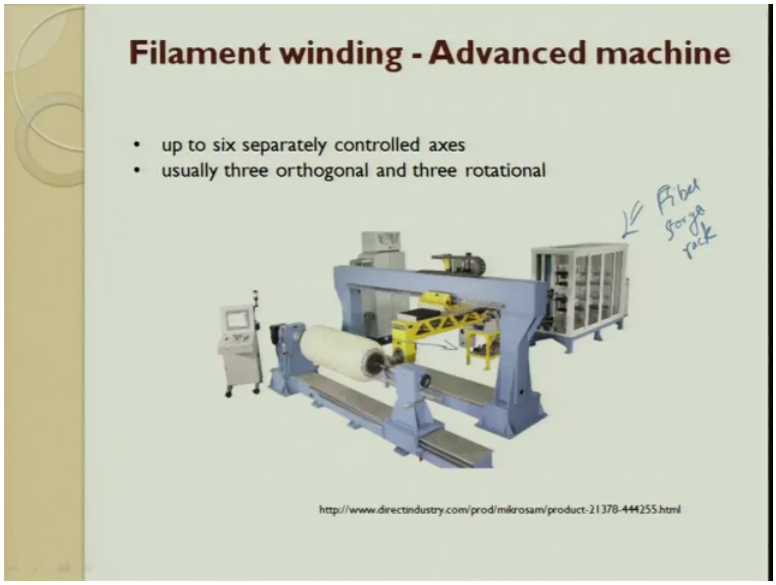

So, these are some of the advanced machines which are available today this is a fiber storage rack, where all these things are there. So, you see now this fellow can move up and down at an angle and this also rotates. So, up to 6 separately controlled axeses are available today usually 3 are orthogonal length 3 are rotational to make cylindrical pipes. Reinforcement predominantly what we use is for structural applications we always go for e glass fibers and when you think of using it for space applications we always go for much slighter we go for carbon fiber. And keep in mind whenever you use carbon fiber there is high pressure and high temperature also can withstand.

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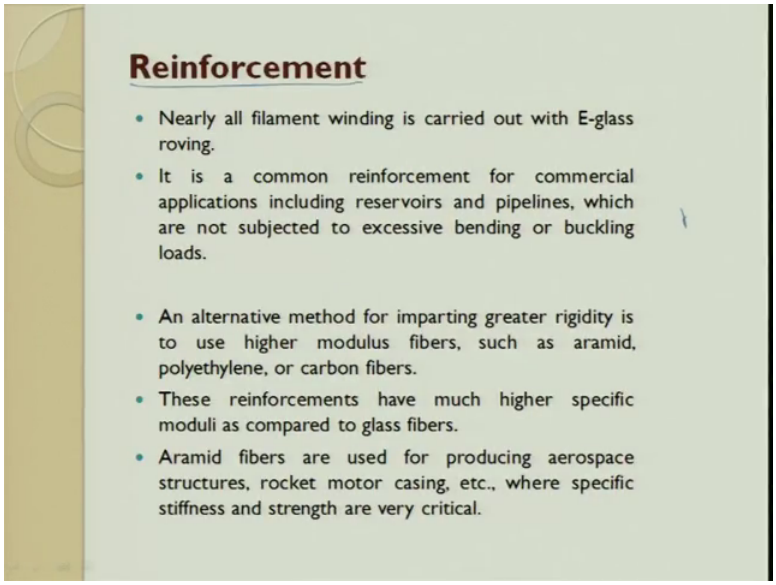

For example, if you are thinking of sewage pipe to be made where and which you have to have a economical factor as one of the major thing we always go with glass fiber which is freely available or it is economically available for commercial applications like reservoirs, pipelines and not subjected to excessive bending and buckling loads.

So, predominantly is used for non structural that means, to say something like a reservoir and pipelines and alternative impregnate with the higher modulus fiber like aramid fiber polyethylene or carbon fiber. So, here it has a very high specific modulus compared to glass fiber. So, I have told all these things. So, it is used for, so you see here rocket motor casing aero aerospace structures where and which specific stiffness and strength are very critical we always use carbons. So, here there are two ways one is glass fiber and other one is carbon fiber.

Matrix material I said it is easy to use matrix which is in the liquid form. So, thermoset has a thermoset. The other big advantage is it has very less strength very low shrinkage. it has very high strength.

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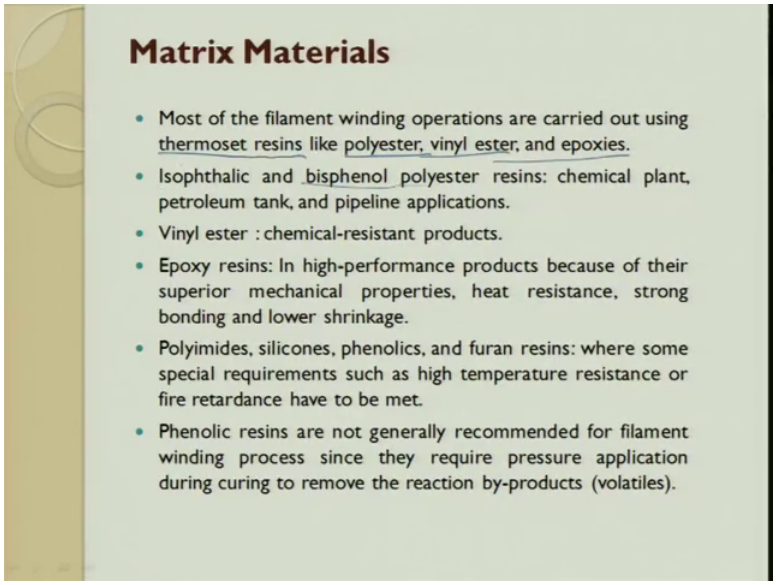

So, thermoset resins like polyester, vinyl ester, epoxy can be thought of. Isophthalic and bisphenol polyester resins can also be thought which is used in for chemical plant petroleum tanks and other applications we use. We use venyle esters for chemical resistance. So, generally we use epoxy then polyimides, silicon, phenolics and other resins also we use where and which we use for (Refer Time: 24:00). So, depending upon your requirements, depending upon your service condition service condition, what is service condition? So, here one is humid or water content next is corrosion next one is temperature the next one is pressure. For example, today wind mills the base stand or the stem is now made out of composites and they also trying to make this with filament winding process. So, mandrel, mandrel is a major follow which is on which the filament win filament is wound or the fiber is wound. So, mandrel is the tool around which the impregnated fiber is wound.

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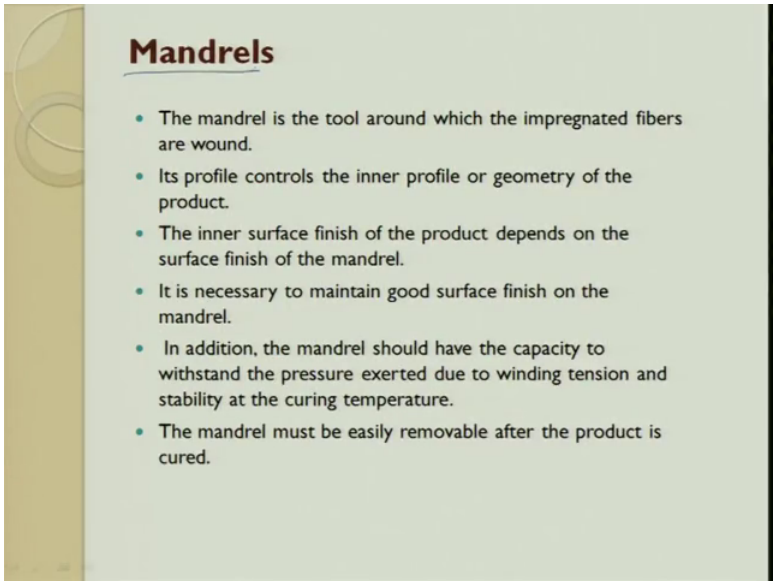

So, the shape of the mandrel the collapsing nature of the mandrel plays a very very important role and on top of it the material of the mandrel also plays a important role. For example, you can use a polymer material you can use wood you can use ceramic you can use concrete. So, depending upon those things your finish of the product depends second thing is curing depends. So, it its profile control the inner profile geometry I have told you all these point the inner smooth surface depends upon the mandrel it is necessary to maintain good surface finish inside the that means, to on top of the mandrel. So, that the inside of the component is maintained and we get. So, mandrel is very very important in terms of dimensions material and also they give texture to it to have better grip see the tension what I was talking to you about suppose if the tension is not properly maintained then the angles of winding cannot be maintained ok.

So, the mental pressure should the mandrel should be capable to withstand the pressure exerted by the winding tension because depending upon the thickness, if the thickness is very high there will be a lot of pressure on the wilding if the number of turns are more it is high and then what happens while curing it is exothermal; that means, say it releases heat. So, it has to be make sure that that also does not affect the mandrel geometry.

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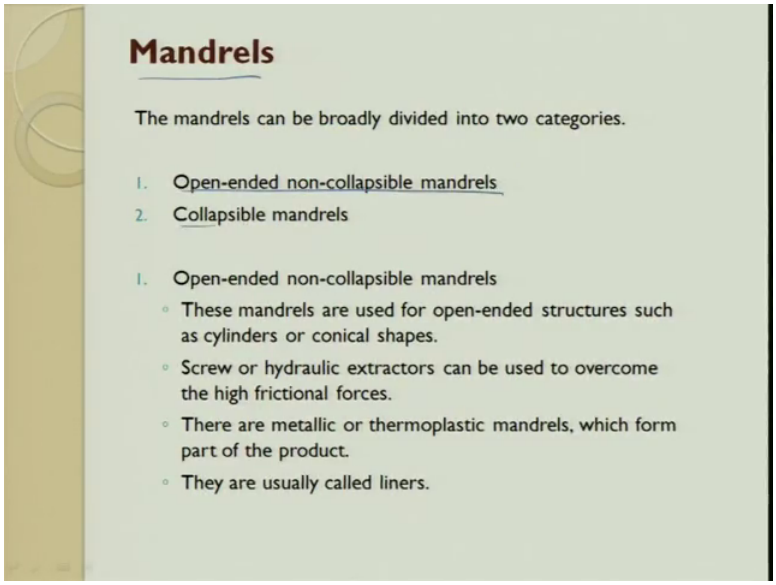

So, the mandrel can be of two types we have seen open ended non collapsible mandrel and collapsible mandrels. So, open ended non collapsible mandrels these mandrels are used for open ended structure such as cylinder or conical structure. So, after winding it is released out.

So, screw or hydraulic extractors can be used to remove to can be used to overcome the high friction force and this can be hit and removed like just tapping it and then removing it they can be thermo metallic thermoplastic mandrels which forms part of the product. So, these are usually called as liners. So, mandrels which are part of the product are called as liners. So, you can also be here collapsible mandrels plays a very important role these mandrels are made of different materials depending upon the size quantity quality of the product that means to say re-usability.

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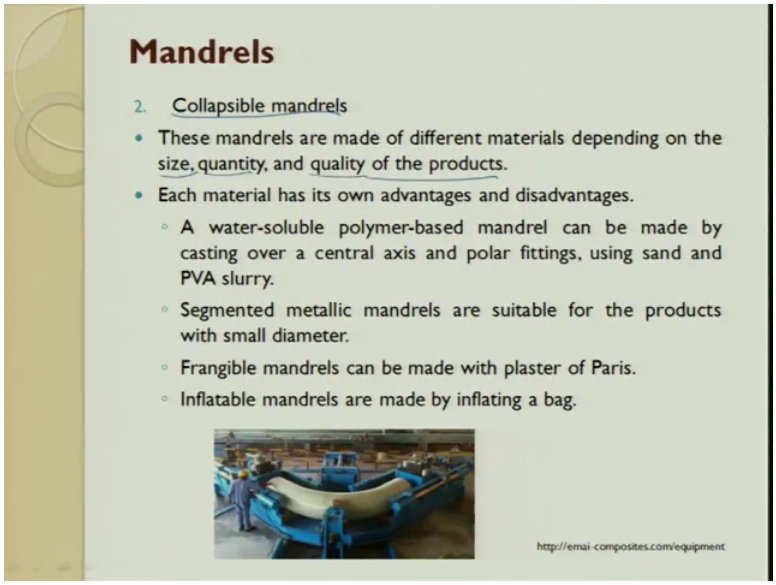

So, each material has its own advantage and disadvantage. A water soluble polymer based mandrel can be used by casting over a central axis and the polar fitting used sand and the PVA slurry its can be done. So, look at this, this is a filament winding process tube where and which it is bend. So, here these are some of the mandrels which are used for making all these structures and inside this mandrel, mandrel can be also made of thin tube filled with pressure can also be done, so that it brings in the stiffness. So, segmented metallic mandrels are also available today for making small fragile mandrels are also made which is made out of plaster of Paris.

So, plaster of Paris it is easy to make and good form can be done easily. Plaster of Paris is the same material what which is used to when you have a fracture the doctor wants to arrest the mobility of your arm or leg. So, then he puts a plaster of Paris which is stiff and on top of it if you want to u use that material as a mandrel yes you can and then do it. And then you also have inflatable mandrels where and which we use a bag where and which is the bag is blown with air or liquid. So, it tries to take a shape and then you try to wind filament on it. So, inflatable mandrels are very much used for space applications and wherever there is a complex geometry sharp edges are there. So, what are all that major parameters? Fiber tension is important.

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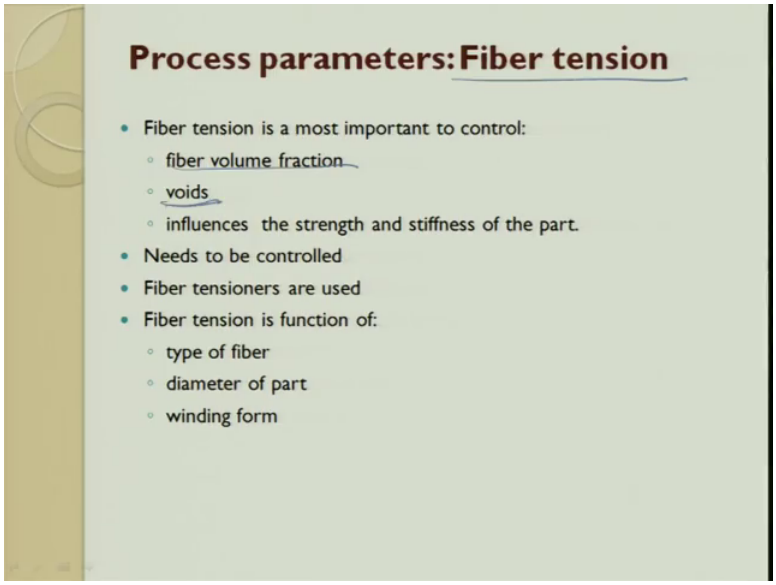

So, fiber tension is one of the important parameter, fiber volume fraction is important and voids. See what happens though it might be very easy to say that the filament winding process the glass fiber is laid at an angle and then does, but many a times what happens as and when you keep doing the thickness is very high the initial layers starts curing and when it cures there is a possibility of voids also coming in. So, this is important. So, the finer tension has a direct influence on the strength and stiffness. The fiber tension needs to be controlled there are tensioners which are used tensioners are free wheels through which the if on top of it the fiber goes or we try to increase the we try to pull them in some direction, so this tries to stiffen the fiber so we get it done.

So, fiber tension function is a function of type of fiber diameter of the part and winding form. So, fiber tension is one of the very important process parameter in this process. The general problems which we undergo is fuzzing, then you also have catenary formation, then wettability. Fuzzing is nothing but fiber breakage.

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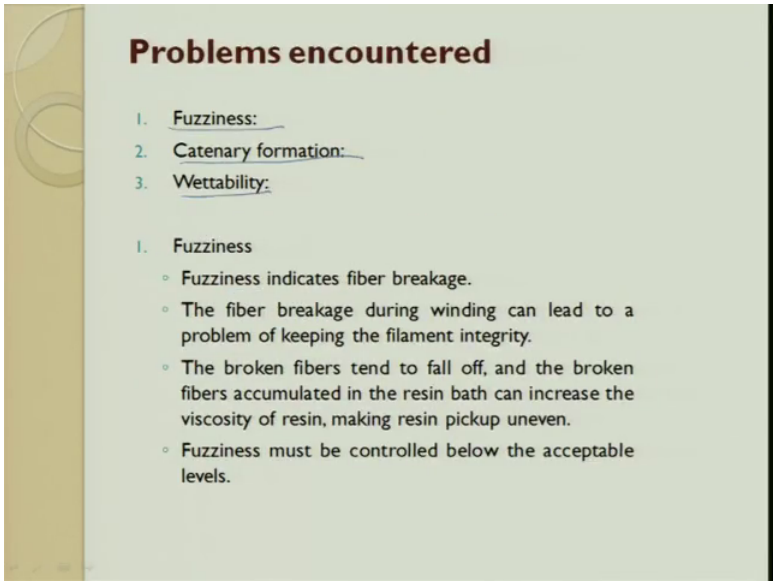

When you keep on winding the fiber many a times if six fibers are coming by one fiber if it fails then the number of fibers that gets on winding will be 5 at certain points. So, this is called as fiber breakage.

When it is very very, this process it looks automated today, but still there is lot of intervention manual intervention required to make sure the fiber is continuously fit. The fiber breakage during the winding can lead to filament integrity that means, to say there is a quality problem, which is directly proportional to the performance. So, it effects the performance. The broken fiber tends to fall off and the broken fiber accumulates in the resin bath and it can increase the viscosity of resin and which can lead to resin rich or resume poor layers. Can be controlled then below that acceptable it is very difficult to avoid fuzzing, but you can control it to a large extent.

Catenery formation this is basically used for this is used for unequal tension of the filament within a strand or a roving if it is there then we always try to have this canetery formation. The roving is a collection of strands which themselves are a collection of filaments. So, you should link to the previous thing we started saying that collection of rovings,

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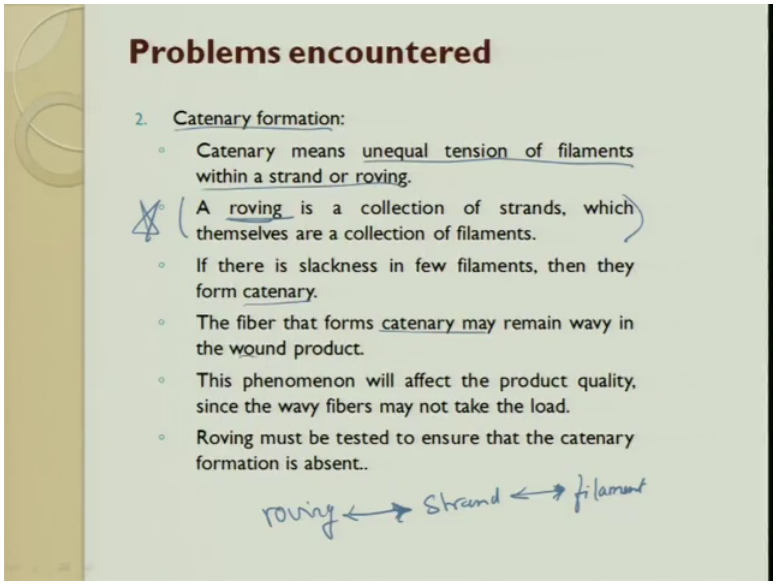

So, rovings collection of strand that is thinner wires and which themselves are a collection of is a filament, so filament strand roving, it goes like this I can erase. So, you can like this right filament leads to strand, strand leads to roving. So, this point is very very important this is have to go. If there is a slackness in the few filament then the formation of catenary happens. So, the fiber formation catenary may remain vavy and on the wounded product. So, it is leading to defects.

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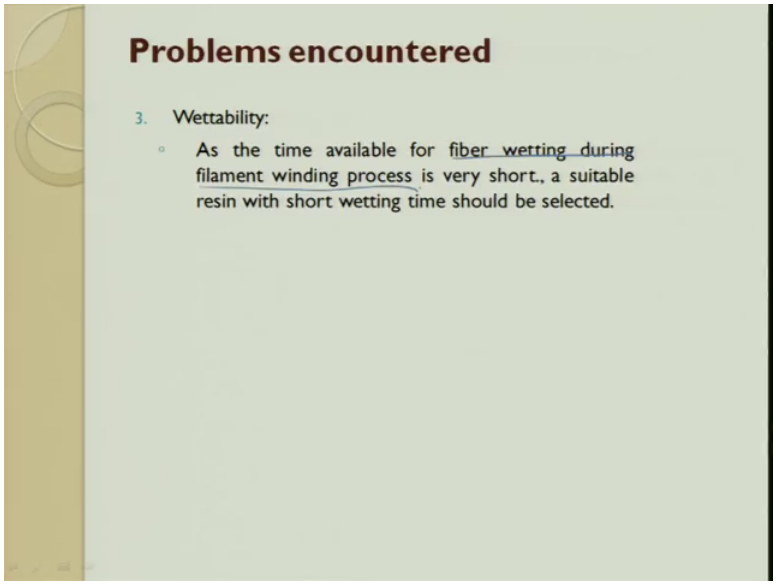

Next one is wettability, wettability is basically between the fiber and the resin if there is no wettability then it will always lead to delaminations and other defects.

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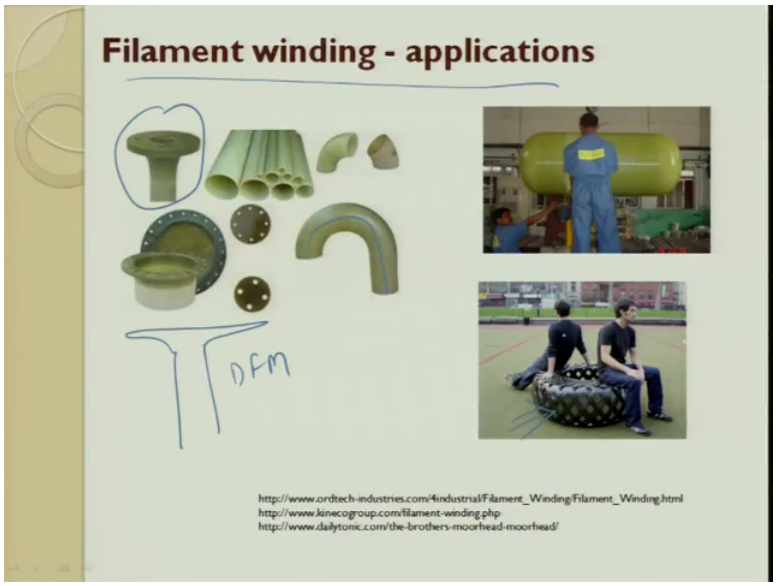

So, these are some of the examples you see there, these kind of pipes can be made. So, a structure like this can be made. So, these are with flants integrated. So, now, if you see design for manufacturing I said reduce the parts to as much as possible.

So, here the flants and the pipes is all integrated together and it is a single component. So, you can see varying diameters, you can see bends right and you can see here look at it a tire where and which it is used here it is used for a entertainment purpose, but this can be used for this can be used as a mandrel which is wound by filament binding for other further process. This is what sis the bottle I was talking to you for storage.

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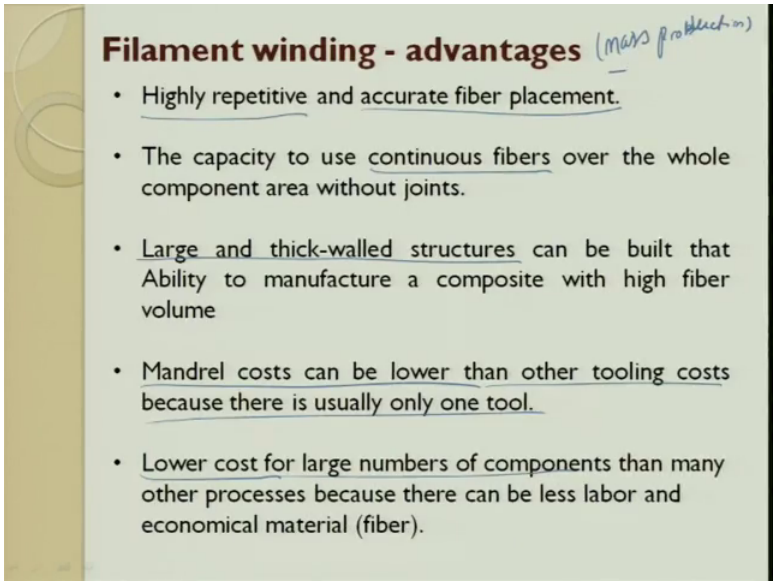

So, major advantage it is highly repetitive and accurate process it is a continuous fibers are used. So, the strength of the part is very good and the number of defects though we say three defects the number of defects can be reduced to a large extend. So, large and thick wall structures can be easily made depending upon your requirements. The mandrel cost can be lowered than the other tooling cost because there is usually only one mandrel is used this mandrel is repetitively used.

So, large cost for low cost for large number of parts; that means, for mass production this process can be thought of, this process mass production can be thought of and why because the mandrel can be reused.

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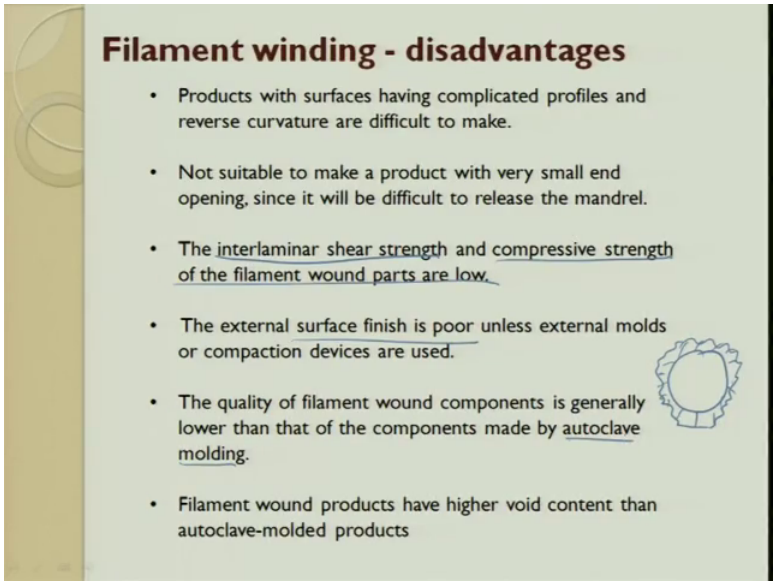

So, the disadvantage is that the product with surface with complicated profiles yes; that means, your concave convex difficult. Not suitable for a very small because it is a huge investment and inter laminar shear strength very important sir please make a note of it inter laminar shear strength and compressive strength of the filament wound products are lower. So, these between two layers inter laminar shear strength and the compressive strength of the filament wound parts are lower. So, external surface is generally poor should understand why because we have a mandrel we put the filament winding on top of it.

So, here you see the surface is undo later or you can finish by doing it, but the internal surface is very good external surface is not uniform. The quality of filament wound is generally lower than the component made by autoclave; definitely yes autoclave is a process which we will see in the near future. So, compared to that process this process the products soundness is less.

So, with this we come to an end for this lecture let us say number 9.

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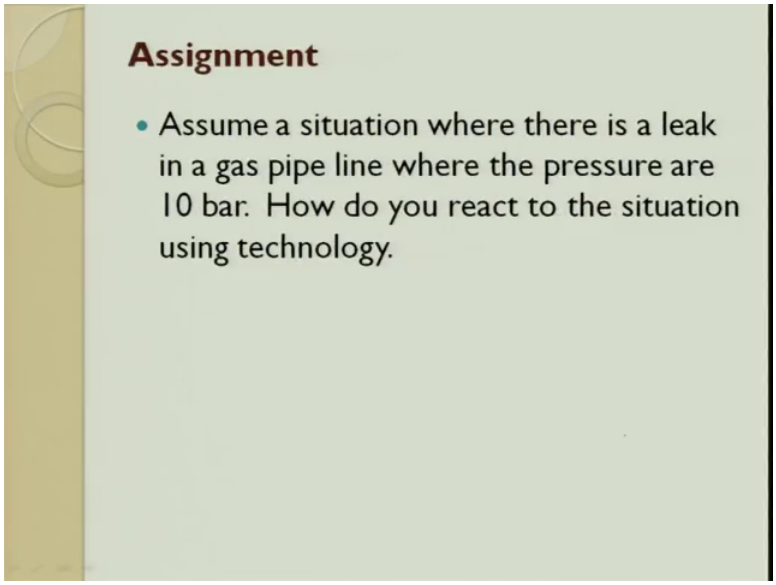

So, in this lecture number 9 we saw a process which is called as filament winding process which is used for making cylindrical components and we said reverse geometry if it is there it is very difficult to use. In this process you can try to have fibers at varying angles you can do varying windings like helical winding, polar winding, you can choose and you can try to give a strength depending upon the requirement you can keep playing with a winding pattern with the reinforcing richness of the reinforcing all this plays an important role to get the required output you can do.

So, an assignment which is home assignment, do not have to submit to me assume that you are in a situation where you see a gas pipeline leaking where the gas is passing by a pressure are about 10 bar there is a leak which is happening. So, what technological solutions you will do to make the situation more safe and when you think of this please keep in your mind filament winding process and try to give a solution.

I repeat the problem there is a gas there is a pipeline which goes and there is a crack which happened because of some product defect in the pipe there is a crack which happens and the gas leaks through it the pressure of the gas which is leaking is around about 10 bar. Now, you are walking by and now immediately you are supposed to give a solution to the problem so that the people around do not get panic and including, you do not get panic. So, how do we go about in giving a solution and when the hint for giving a solution is please think of a filament winding process how will you tweak the filament

winding process to that situation and solve the problem.

Thank you very much.