Manufacturing of Composites
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Lecture – 10
Resin Transfer Moulding

Good morning friends. So, today we will be moving to lecture 10. So, quickly to recap whatever we have done. First, we started looking about basics, then we understood, suppose if there is strength required in some direction, how do we reinforce along the transverse direction and longitudinal direction, what was it. Then, we saw different matrices, fibers, fiber forms then we entered into thermoset polymer, different manufacturing processes for composites.

So, first one we saw, hand layup, in the last class we saw filament winding process. I am sure, you would have looked, you would have solved the assignments, the assignments which I give and yesterdays assignment lecture number 9, how do we solve it, if there is a pressure leak along a crack of a pipe, the quick thing to do is, try to take a rope or try to take a thread or a kerchief or something quickly wind up at that portion where it is leaking.

So, this gas can quickly go through the small orifice through the, which is there, small space which is between the winding, or if you put a kerchief with that small space between the weaving there this gas can escape. So, quickly what do we do is, on top of it we try to put a tight polymer cover and then seal it. So, if you look at it this is nothing but, a filament winding process alone, wherein which first the reinforcement was wound and the reinforcement had resin in it and we allowed it to dry. Today, there is like the tapes what we put on top of the wounds. Today, we also get patches, prepreg patches of varying orientation available in the market.

So, whenever you want to wind on such cracks for a small intermediate thing, immediately, what we do is we try to peel that prepreg, try to wrap the prepreg on the crack and that is how we arrest the leak. I thought this will be an interesting application for you; I wanted to share it with you.

Today, what we do is, we will move on to the next process. The next process is resin transfer molding, which is otherwise called as RTM. Why do you need this process? This process gives the best sound quality product and this process can be automated. When you are looking at large parts or a very high strength part, we always use resin transfer molding process. From the process title itself is very clear, there is a transfer of resin happening in to the mold, resin transfer molding process.

So, what is there inside a mold; as I told earlier, you have a glass fiber mat which is placed, of varying orientation such that it needs the customer requirement. So, there is a transfer of resin into the mold, where there is already preplaced glass fiber reinforcement. So, that is what we are going to see in this process. When I say resin, the resin can be nascent or the resin can be mixed with the hardener, and you all know once you add a hardener to it, the viscosity keeps changing and after the period of time the resins sets. So, then you cannot use it for transferring.

So, now it is very clear; if you try to add hardener to the resin, you have a fixed time period; you play with the fixed time period and trying to transfer within that time period in to the mold. So, let us get into the process.

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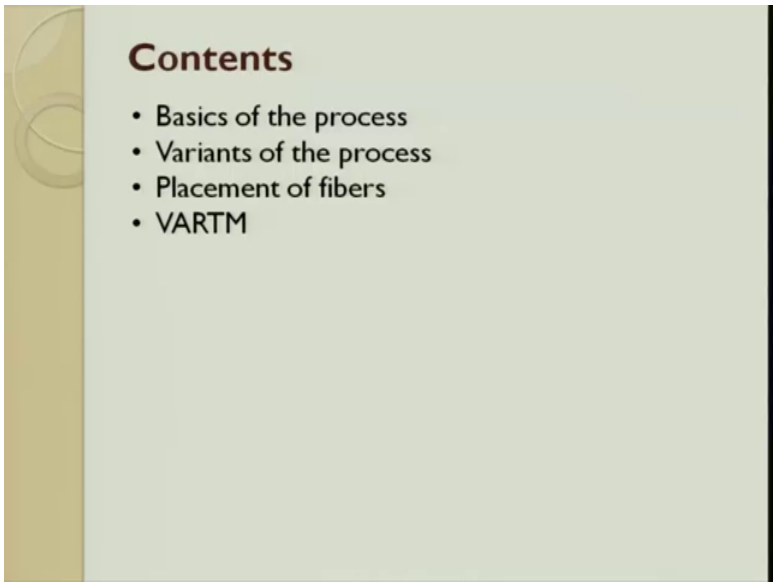

So, what is the content we cover today basics or introduction to the process, there are lot of variants. In manufacturing, you should understand there is a process which we develop and we add lot of attachments to it and we call it as variant processes. The

variant processes are coming into existence today, because wherever there is a manufacturing challenge, these variants try to help in getting a good sound product. Next one is placement of fiber and the last one is going to be Vacuum Assisted Resin Transform Molding.

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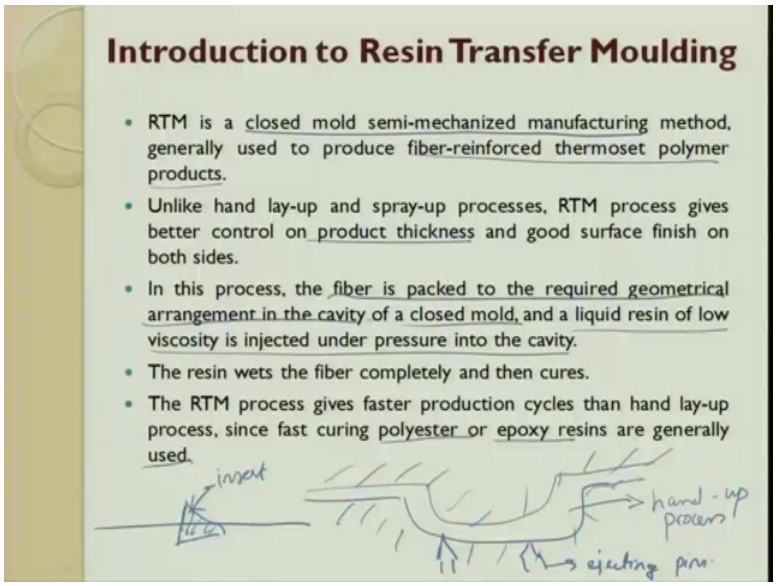

So, in this process this process, RTM is a closed mold semi mechanical manufacturing process. In manufacturing, if I could automate a process, I am pretty sure I will get sound quality product. So, this process is a closed mold; that means to say, open mold means you have only one part of the mold which is predominantly used for hand lay-up process. By looking at the design whatever I have drawn, you will quickly understand that, suppose you want to make something like a boat, you can make it. It is a open mold process. In resin transfer molding, we will have one more counterpart and we have it, this is called as closed molding. So, what is the advantage in closed molding process? Both the surface, the bottom surface and the top surface, will get what are the textures, what are the smoothness, on the die surface can be transferred to the mold surface.

So, I will get the inner surface as well as the outer surface, smooth and whatever is required for my texturing another things. The filament winding process what we studied yesterday in the last class, we saw that the internals of, the inside of the pipe, will have very good smooth surface or will have mandrid texturing, but the outside will be rough and you have to do a finishing process to make it smooth, when you go to resin transfer

molding you this process is a closed mold semi mechanized process. Generally, used to produce fiber reinforce thermoset resin; I have said thermoset liquid form, so, liquid can easily flow inside the mold. So, that is what it is.

Unlike hand lay-up and spray type; what is spray type, we chopped the fiber and we mixed the fiber along with the resin and we used something like a gun to spray on the open mold process. The RTM process gives a better control of product thickness and good surface finish; product thickness, plays very important role, because product thickness, if you have variation in the product thickness, the performance of the composite goes down. If you have variation; that means, to say you can have rich resin rich zone and ah fiber rich zone.

So, it is not uniform, and the failures can easily start from those places. And the next thing is, if there is variation in thickness, it is also said that the product weight is not uniformly balanced and this leads to when it put on service condition leads to early failure, because product thickness, if you have variation in the product thickness, the performance of the composite goes down. If you have variation; that means, to say you can have rich resin rich zone and the fiber rich zone.

So, it is not uniform. So, and the failures can easily start from those places and the next thing is if there is variation in thickness it is also said that the product is not the product weight is not uniformly balanced and this leads to when it put on service condition leads to early failure. So, product thickness is also very important, uniform product thickness you get in this process. The fiber is packed to the required geometrical arrangement in the cavity, so, you decide the arrangement, whether you what to keep all in one direction; that means, to say in zero direction or you want to keep in 90 degrees offset and keep it at 90 degrees or with varying orientation. The other interesting thing is, in between this fiber, if you want to keep an insert; that means, to say you want to keep a metal insert there, that also you can place for.

So, fiber will be there and you will have a metal insert. So, it will be like fiber and let us assume you have a nipple which is made out of metal, this is an insert, you want to keep, that also you will place it in the fiber arrangement and then the liquid resin is allowed to flow through the cavity. So, when I said flow through the cavity, the flow, you can keep changing the flow; that means, to say increasing or decreasing the pressure. You can

allow it to happen of it is own or what you can do is you can pressurize; that means, to say is you can inject liquid resin, inject you can do.

Injection can be done from the nozzle side or you can do it on the other side where in which you apply a vacuum and suck it. So, when you suck it, what happens, the pressure flow happens and the other advantage when you do vacuum, what happens is, uniformly it spreads. So, that is what it is. Depending upon your requirements, suppose it is a very large area, we always try to pressurize and inject the liquid inside. So, the resin wets the fiber completely and then cures and after you injected, you leave it for some time; may be for 3 hours, 6 hours depending upon the choice of their resin hardener you took and then allow it cure inside the mold itself. Once it is cured, then what you do is, along the mold you will have some ejecting pins.

So, these pins are called as ejecting pins, these pins will try to slowly eject the component without damaging the component out. The component prop ups out of the die and then you get you can take it for further operations like trimming and other things. So, the resin transfer gives faster production cycle then hand layup and a sound quality, since, fast curing of epoxy are generally used. You can choose, you want to use polyester, fine, if you want to use epoxy, fine. Epoxy gives high strength compared to that of polyester.

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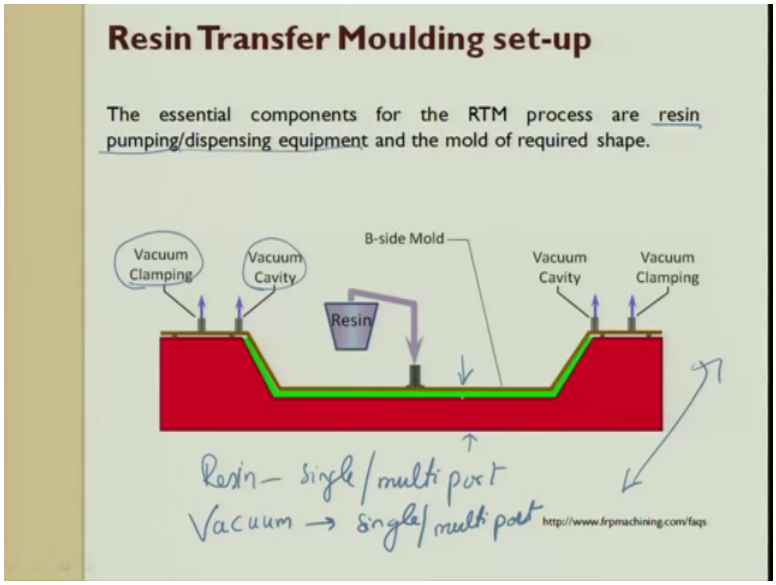

So, this is what is a process, which we talked about. So, this is the die, red color is the die and then you see there is a brown color which is there on top of it, that is the upper mold, the red is the bottom mold and what you have done is green one is whatever is there, is the fiber which is placed depending upon your requirements, strength whatever it is and then what do we do is, we try to have a port, this is a port on the front one, we have a port and through this port the resin is pushed inside. In order to have a uniform spread in both direction, if the component is large, what we do is we try to also attach a vacuum pump to it. So, basically what does a vacuum pump do, it sucks the air all along, when it sucks the air out parallely it or during the same time it also tries to suck the resin.

So, the sucking of the resin happens in multiple directions wherever you want to put, you keep putting in multiple directions and then you can start. The resin is poured inside, the resin wets the fiber and you allow it to cure and you get a required output. So, now, I am introducing a term called as vacuum. First what you do is, vacuum clamp is initially, you put the top die whatever it is and then you suck. Put the glass fiber, you suck, when you suck what happens, it all the air is initially removed, then you close it. Then what you do is, you try to put the vacuum pump there and then start sucking as and when the resin is poured inside. So, it is uniformly flown and you get a proper sound component. The brown one on the top, with the top die what will happen is, inside the die you will try to give provision for all these things.

So, the essential component of RTM are resin pumping; the resin can be poured or it can be pumped, then dispersing equipment and then you will have on the mold vacuum. Now you can make large components like, if you want make a boat also you can make it through this, but the only thing is you will have multiple ports. So, resin also can come through single port or it can be through multiple ports. See, this whatever, we are seeing is only a cross section; suppose, let us assume in the z direction, you have thickness very long running for a meter, then you will have resin is also pumped in single or multiple ports.

Vacuum can also be single or multiple. So, you will have 2 things; you will have single and multiple port. If you have multiple injection port and again the injections port can be on both directions; can be from the top direction, it also can be the from the bottom direction depending upon over. But, moment you put on the bottom direction, what will happen is, the bottom surface, you should make sure it does not have any projection in

the surface or if at all it comes you have to do a secondary operation to remove those projections.

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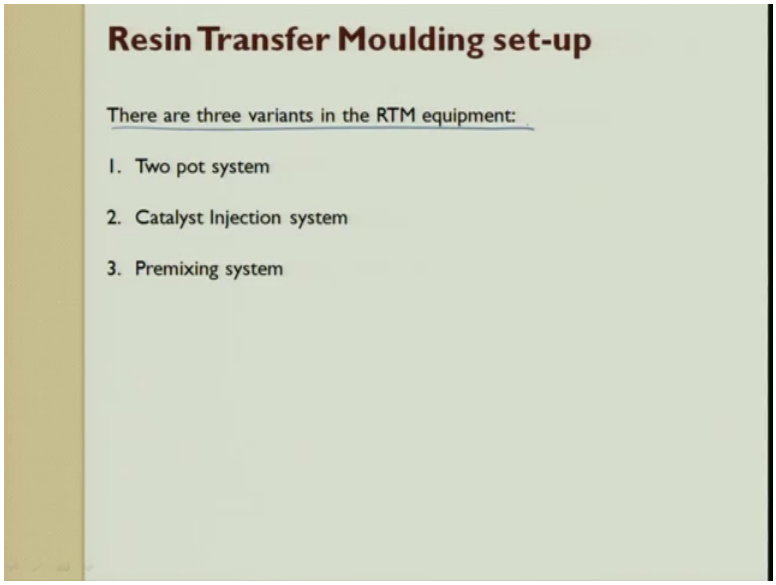

So, what are the variants; now, in this if you go back and see what are all the process parameters, the placement of resin fiber, the reinforcement, then number of ports of resin which is getting pumped in, vacuum, vacuum pressure and other things.

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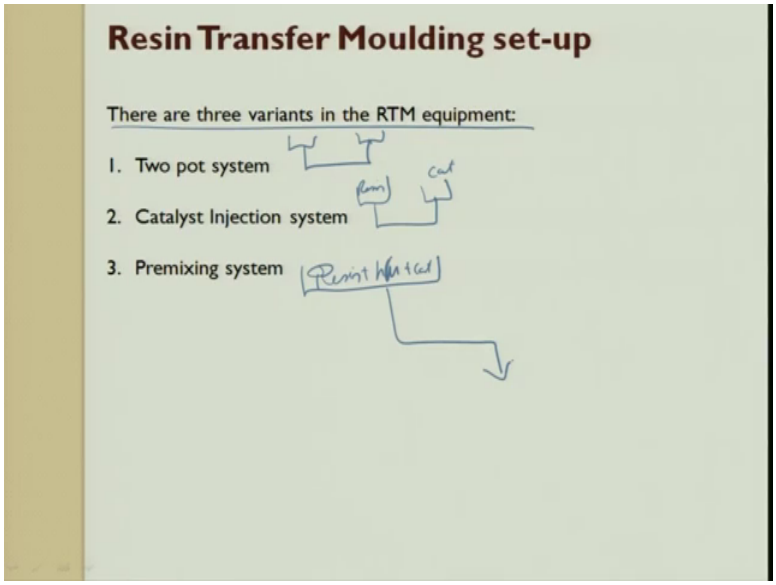

Now we will see variants. There are 3 variants in the RTM process: one is called as two port system, the other one is called as catalyst injection system and third one is premixing system. We will see all the 3.

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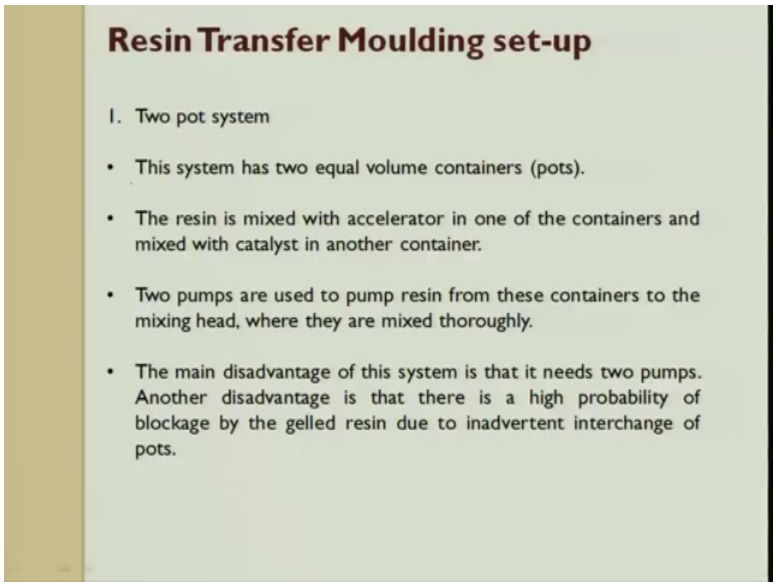

When you talk about two port system, two pot system; this system has 2 equal volume containers, that is a pot. The pot comes from that 2 value container. The resin is mixed with accelerator in one of the container and the mixed with catalyst in the other one; 2 parts, the resin is mixed with the accelerator in one of the containers and mixed with the catalyst in the another one.

2 pumps are used to pump the resin from these containers. So, what do you do is, they both are 2 things which are been, which they move from each other and then there is a pump which runs which tries to suck and then there is a mixing which is thoroughly happening and then it is injected inside. The main disadvantage of the system is that it needs 2 pumps. This is the main disadvantage, 2 pumps. In manufacturing, as far as possible, if you can reduce the number of components while manufacturing also, it is good, why because, each part you add and there is a process variable then that always dictates the quality of the product.

As far as possible try to reduce the number of steps, number of equipments used in the process. So, the main disadvantage is, it has 2 pumps and there is a high probability of blockage, why because, when we try to mix catalyst with, we try to mix the hardener,

accelerator all those things, immediately the reaction starts the gelation of the resin starts and it might try to block. The moment it blocks, then you have to clean the complete pipe.

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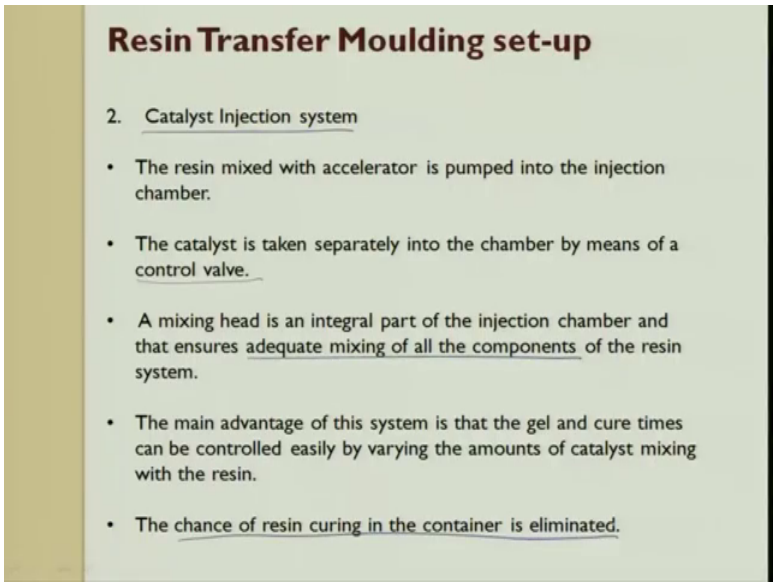

The other one process is the catalyst injection system. The resin is mixed with an accelerator is pumped into the injection chamber, then the catalyst is pumped separately into the injection inside the injection chamber. So, then in this the mixing happens and then the mixed one is now pumped inside a resin. What is the advantage; until and unless you mix this catalyst or hardener, what happens is, the reaction does not happen. To a large extent, what happens is, you will try to control the curing cycle.

The catalyst is taken separately into the chamber by means of a control valve. The mixing head is an integral part of the injection chamber and ensures adequate mixing of the components. So, this is the other one, catalyst is injected separately. In the previous one, what happens is, the resin is mixed with an accelerator in one container and the mixed with catalyst in another container. So, it was separate containers were using, here we are only trying to take the catalyst and that catalyst is kept separately and then injected. This process is giving more time and it is also better than the previous process. The chance of resin curing in the container is, to a large extent eliminated.

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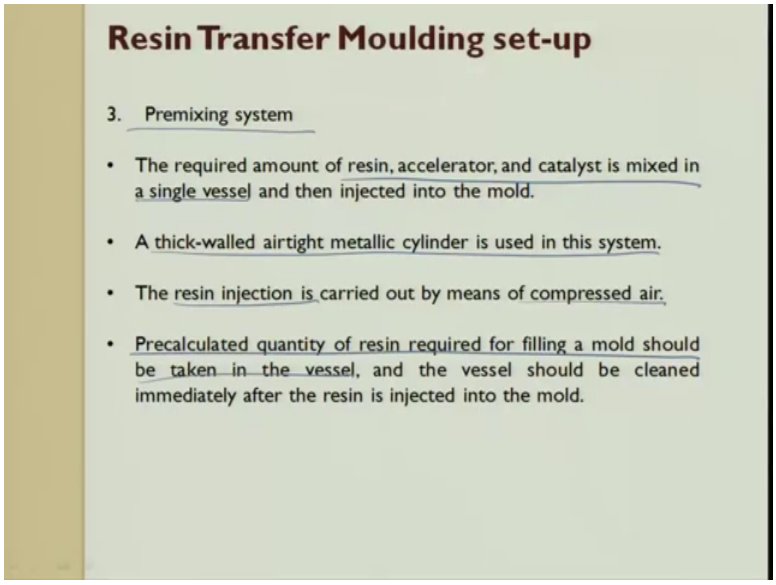

Premixing system: the required amount of resin, accelerator and catalyst is mixed in a single vessel and then injected. So, I mix everything keep it in a pot ready and then directly inject it.

The thick-walled airtight metallic cylinders are generally used. The resin is generally injected and it is into the die, so that, you get the output. The resin injection is carried out by means of a compressed air and then you try to do it. So, a pre calculated resin quantity fills in the mold and it tries to take the shape of the vessel whatever it is.

So, 3 processes we saw, one is 2 pot process, 2 pot is something like this and the other one, you have one pot here, one pot here, then what will happen is, this is catalyst directly injected, rest of the resin is mixed here. So, here everything is premixed; resin plus hardener plus catalyst everything is mixed and then it is injected.

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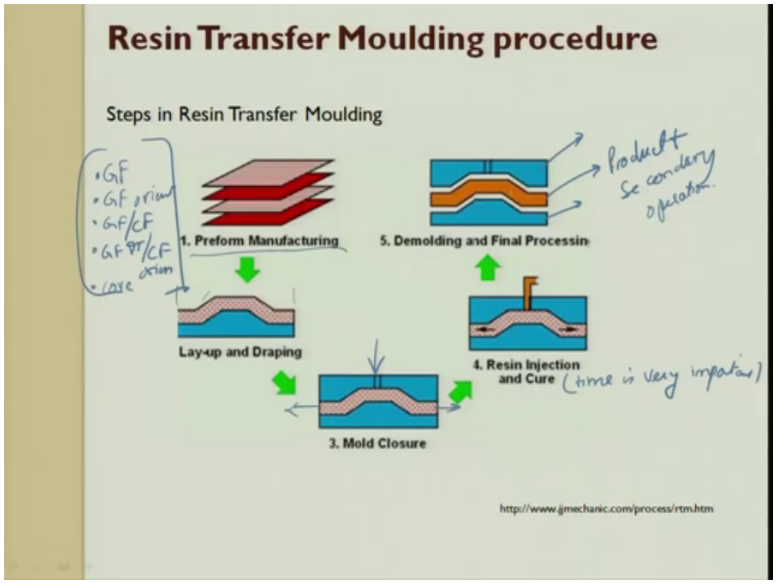

So, in the resin transfer mold steps, you can see that, first step you take the preform manufacturing, whatever it is, so that, is nothing but, the reinforcement varying orientation, say here see the options can be for you is, take G glass fiber and then this glass fiber this is one variant, their orientation you can change. Then you can take glass fiber and carbon fiber, now I have multiple things; glass fiber orientation then C of orientation. Depending upon the requirements, if you see, I can do so many variations in placing the preform. You can also add core if you want, wherein which it is like a sandwich structure, reduced weight, but still does a function of a composite light weight high strength material.

So, you can do this and this is how you make a preform. This is placed inside the die, then what you do is, the lay-up is done and then you do a drap. What is drap, drap is nothing, but you have a die, you place the fiber and then on top of it, you try to close the mold on top, this is the mold on top, you can try to close, and you try to give a shape to the fiber. So, that is what is drap. The mold is closed, once the mold is closed, I said here is vacuum, here is resin transfer. So, this resin transfer can be done by the 3 variants; like you can do it by a pot system, you can do by catalyst injection, you can do by premixing. You can do by any of those things and you try to get this thing. So, the resin is injected and it is allowed to cure; cure takes time. Time also plays a role, time is very important.

So; that means to say, you suck, you pump resin, you suck vacuum and allow it to be there for few hours, so that, you get a sound product. And once you finish the sound product, as I told you earlier, this part is removed, this part is removed, you get the

product. So, this product you take out and then you do secondary operations, like I told you earlier; you want to trim it, you trim it here and then you take a product out.

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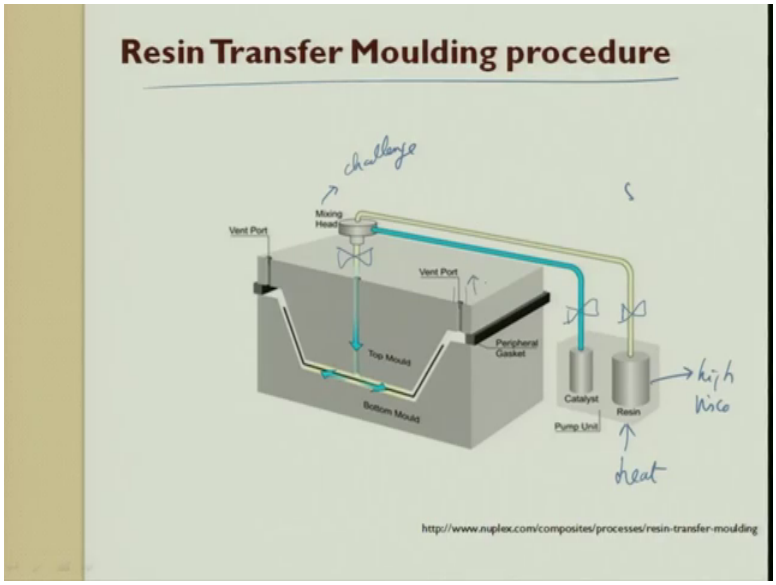

So, this is a 3Dimensional way I told you. You have catalyst separately, resin separately, they have pumps, so, this gets pumped inside. Here you will have a valve to control, so the flow rate is very important, it is all come here and this is a mixing chamber. This is a challenge, because resin is high viscous, if it is light like or if it is comparable with water then mixing becomes easy.

So, then what you have to do is, you have to may be sometimes apply heat to the resin to change the viscosity, so that, when it goes here and when the catalyst is added it can be uniformly mixed. Now everything is ready in a mixing chamber, you pump it inside, again here you have a valve and then here you have vacuum ports, first you do vacuum sealing. So, this is vacuum sealing and then you do a vacuum port, start sucking outside and then you try to get the sound product.

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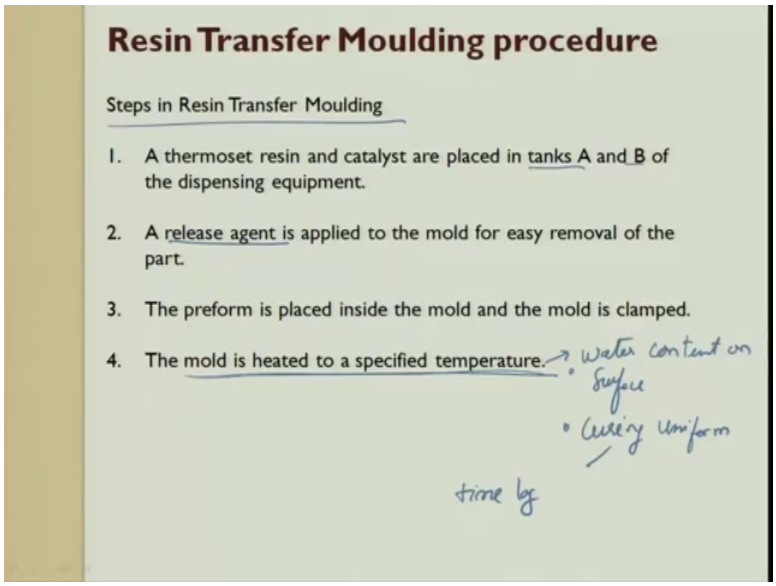

So, we have discussed, to quickly go through; you will have tank A and tank B, thermoset resin and catalyst is done, it is getting maintained at a certain temperature and the catalyst can be in a solid form or in a liquid form. You try to bring it to a liquid form, so that, you get a uniform dispersion. Then before even doing it, first thing what you have to do is, you have to apply the releasing agent, such that, the component can come out or what you do is, you have a ejecting pin, which can also be used.

So, ejecting pin to eject the component, releasing is to make sure that this smoothness is maintained. The preform is placed and if you want you can also heat the mold to a specific temperature, why, to remove the water content on the surface and to also help in curing uniform. Because, what happens is, there is going to be a time lag, when you inject the resin and when you apply vacuum. In order to further accelerate the flow of the resin, we always try to heat the mold.

So, this is one another variant you can try to do; heating the mold also can be tried. The resin can be heated, catalyst can be heated the mold can be heated. If you want, the preform also, generally what we do is, before placing the preform, we put it in a oven, so that, we remove all the water content and moisture, which is there to release it. Not to very high temperature, may be around about 80 degrees 70 degrees, we maintain it for an hour, so that, we make sure that there is no contaminations and moisture there, because these moistures will not allow to form a proper interface.

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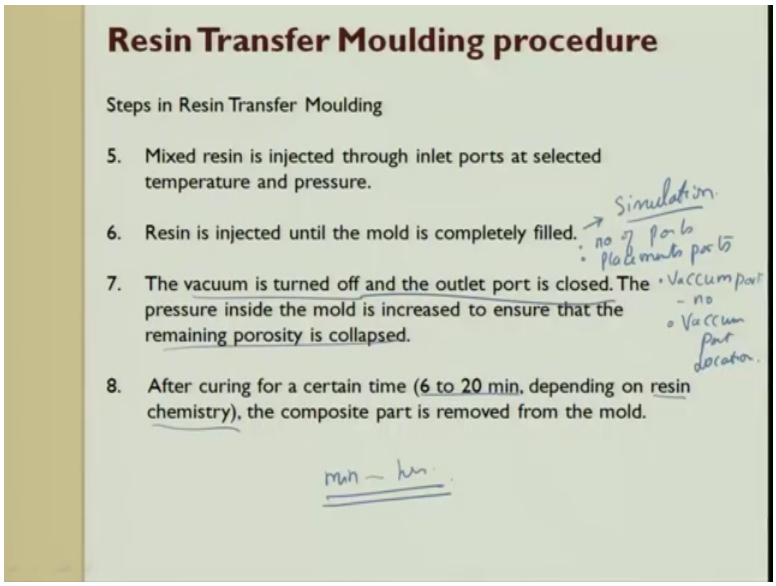

So, the resin is injected until the mold is filling is complete, this is a challenge. There is lot of simulation softwares, which are available today, to tell us the number of ports, placement of ports, all these things today there are softwares which are used. So, here placement, number and then we also see what is the vacuum you have to apply vacuum port; again number then vacuum port location. All these things, today, there is a software, wherein which, people try to use simulation, try to find out different locations and then only they try to do it, because it is a costly affair. Resin is expensive and the process, if you make a mistake, it is the complete part has to be scrapped and it is thermoset, it cannot be recycled also.

So, people are very careful. Today, the manufacturer motto is make the first part itself the best part. It is not that, I will do 10 parts, understand the trail and then do it. So, the vacuum is turned off and the outlet port is closed. The pressure inside the mold is increased then the remaining porosities, whatever is there is collapsed. The curing time can be from 6 to 20 minutes depending upon the resin chemistry, if it is a large product, it can also go to, this minutes, can go to hours also.

So, it is first is, injection. Injection time will be less, but curing time slowly it will happen and as I told earlier composites does not cure 100 percent in the given shot.

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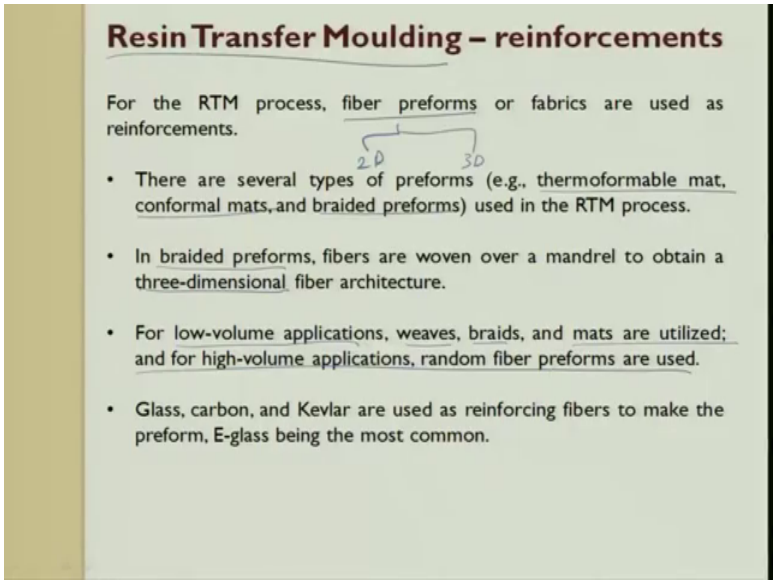

So, reinforcement as I told earlier, the fiber as preformed. You should now remember, you can use, 2D, 3D preforms, I said 3Dimensional viewing. 3D preforms also can be used. Fiber reinforcement can be 2D, which generates into 3D or directly 3D you can do it. A fabric can be used. There are several types of preforms: thermoformable mats; that means to say, the mat has glass fiber and it also sometimes has resin or the glass fiber, instead of glass fiber you use a polymer itself. Thermoformable, then mat, conformable mat, then you also had braided forms, all these things like 2D, 3D they are trying up, to talk about. Braided preforms are giving 3Dimensional which we saw. For low-volume application, weaves, braids and mats are used; for high volume random fiber orientation are used.

I told you an example of spray forming, using spraying process, there which is used in the amusement park dive boards, if you want to have a very good finish on both sides we also use RTM, and wherein which we try to use random fiber orientation. So, glass carbon, Kevlar or a combination of this can be used and E-glass fiber is the most common one.

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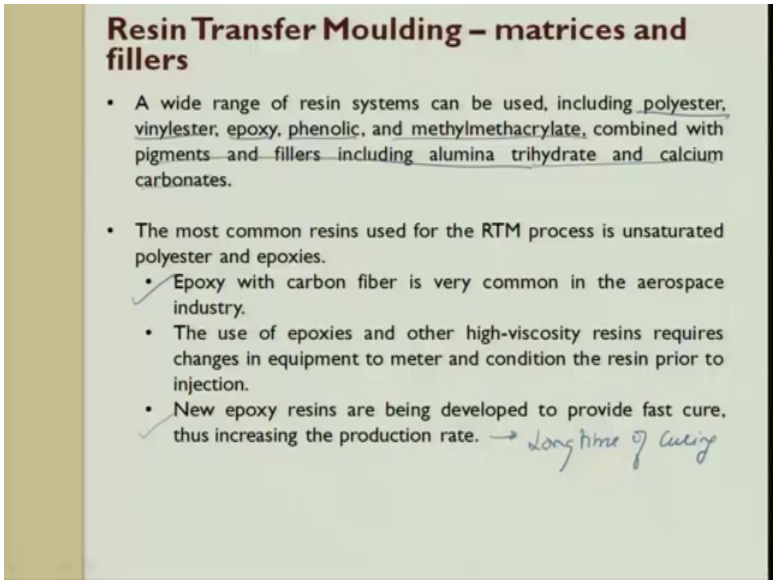

Matrix, I have discussed enough. So, we use epoxy or polyester, generally, thermoset and new epoxies are coming up, so that, you can have a long time of curing, so that, large products can be made, number of ports can be reduced and then you can try to get.

I have discussed enough, so, let me move through it. Polyester, vinyl ester, epoxy, phenolic or methylmethacrylate or a combination with pigments and fillers included with aluminum tri hydrate and calcium carbonate are mixed in the resin, so that, it tries to bring in the flavor, what you want for the product.

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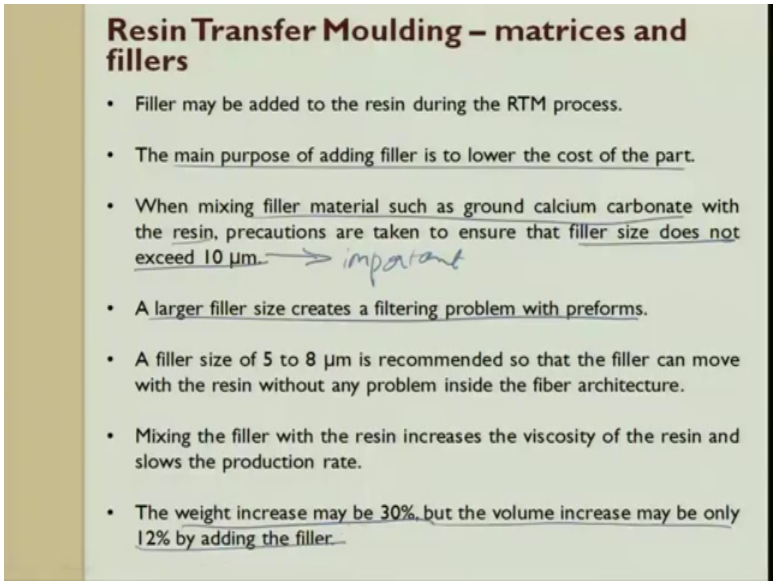

The fillers can be added. The main purpose of adding filler is to reduce the cost because, if you try to fill entirely by resin it might be, first heavy, second thing is, it is costly; resin is expensive. So, now, people have come out with adding fillers. These fillers can be used for casted action or it can also be used for adding new properties. For example, today, people are trying to disperse, carbon nano tubes, they are trying to disperse.

So, one, they say strength property enhances, two, they say on the surface I wanted to make some conducting things for several applications of placement of sensors all these things are talked about. The filler material such as calcium carbonate is added. Calcium carbonate is basically is to add thickness and give a shape or reduce the resin usage. The fillers size does not exceed 10 microns. So, it is just blundered and it dispersed or it can even try to slowly dissolve.

The large size fillers will create a problem, because it will try to restrict the flow. This is very important; the size, because this should not restrict the flow. The weight can be increased to 30 percent, but the volume increase will be only 12 percent when you add these fillers. This weight and volume, if you go back, we did some calculations for density; from there you can try to link. So, the weight increased by 30 percent, but the volume fraction increase will be only 12 percent.

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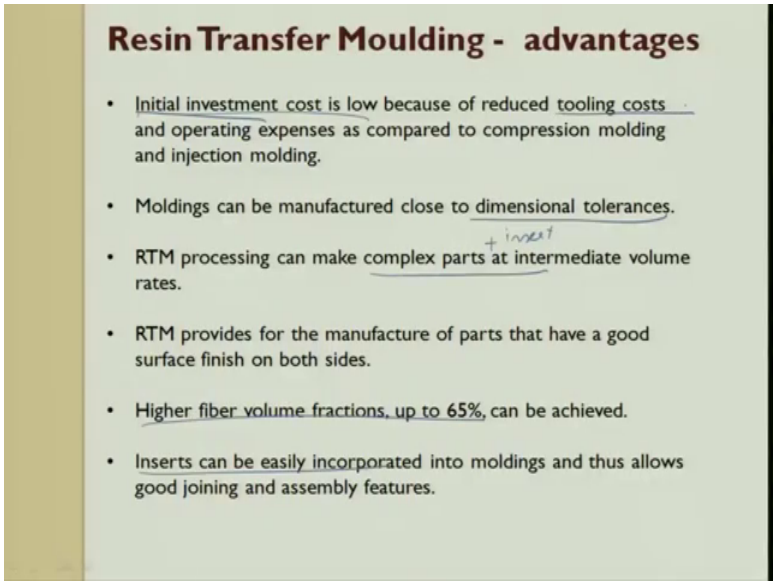

So, what are the big advantages; the advantages are going to be the cost, initial cost is low, because the tooling is also only one side and the other side is only a very small thing

and you can make the mold out of wood, because you are using it for large. So, wood or plaster of Paris, whatever you want, you can try to mold. Moment you go for injection molding, then you should always go for metals. The molds are manufactured to close tolerance. So, the object whatever you get is very good, complex parts can be done and then the other thing is complex parts with inserts; that means, to say complex parts and integrated parts can be made.

So, it gives good finish on both sides. The volume fraction can go up to 65 percent. Very high strength can be received and inserts can also be incorporated. So, the advantage is going to be cost is less, because tooling is less.

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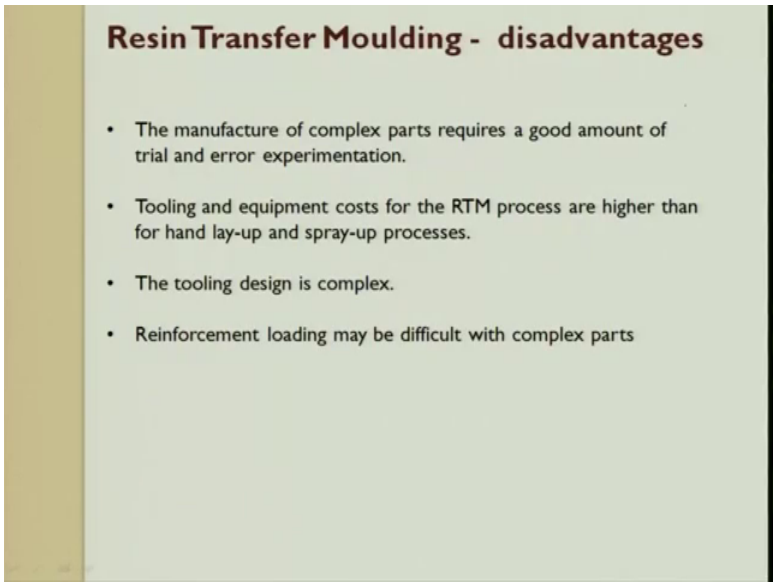

But what are the disadvantages; though they say simulation and all these things you have to do lot of trial and error to come to a very for deciding the location and pressure. Since, the tooling is expensive than handle lay-up, I can make the same whatever product to hand lay-up, but the quality will not be good. But, if you just wanted to make for secondary applications, then you can go for hand lay-up process, than going for resin transfer you can do it. So, the tooling design is also complex, because you have to understand the vacuum and the reinforcement loading may be difficult for complex parts.

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So, these are some of the parts which are made today, you have wing panel, truck panel, and then you have a aerospace parts, boat hull, wind turbine blades are made out of it and then you should understand wind turbine blades, complex geometry preforms are fixed and then you do. Helmets are used, light weight helmets which are used for racing people that is are used. Bathroom fixtures are made out of it and you also have car parts are made out of it.

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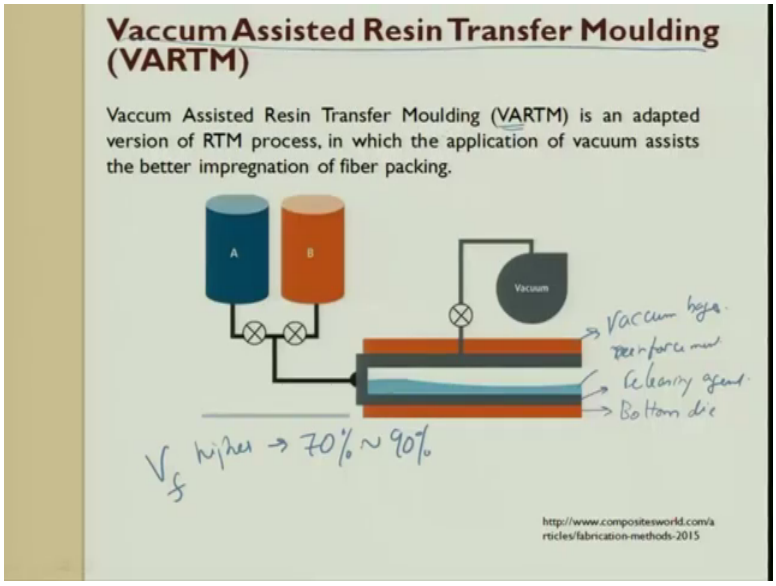

So, the last part of discussion is Vacuum Assisted Resin Transform Molding. In Vacuum Assisted Resin Transform Molding, what they have done is, the vacuum component is adapted. So, here we put something like a bag on top of the, you have a bottom die, you have and then you put a releasing agent whatever it is and then a reinforcement, instead of a die, I put a vacuum bag.

So, vacuum bag surface, vacuum bag is always made out of polymer, it can try to take the shape of the preform, because the preforms, in turn, try to take the bottom die and the plastic bag has a very smooth surface. So, it is just put on top of it and then you start sucking it. This is what is called as vacuum assisted or resin transfer molding. Today these process are coming up in a big way, wherever you want to do volume fraction higher; that means, to say 70 percent to 90 percent if you want to do, on a flat plate reinforcement, then this Vacuum Assisted Resin Transform Molding process, is exhaustively used, even for a small plate making. For research purpose, people always used to make the composite out of hand lay-up I would suggest you should now look for vacuum assisted, so that, you get a sound product for your output.

So, Vacuum Assisted Resin Transform Molding is an adaption version of resin transfer molding, in which the application of vacuum assisted for a better impregnation happens.

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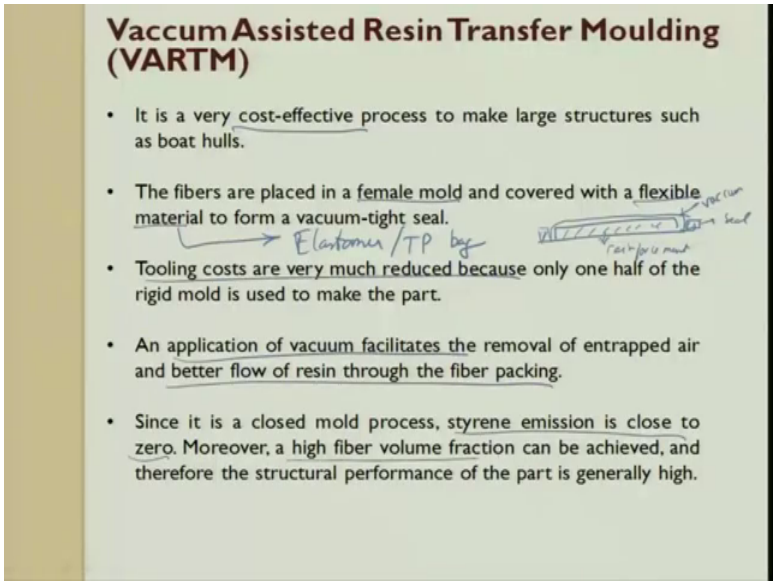

So, it is a low cost process; large things can be made. The fibers are placed in the female mold and it is covered by flexible material, that is what I said, a vacuum bag, this is

nothing, but elastomer or it can be a thermoplastic bag. So, what it does is, you try to place the preform and then what you do is, you try to place the bag, this is the reinforcement, this is the seal what you do and this is the vacuum bag.

So, now what happens is you put this bag and this is the air tight bag you put and this is a sealing. Sealing, is nothing but, a stopping you can put or a tape you can put whatever it is and then you start sucking vacuum. So, here the female is made and it is covered by a flexible material, it is nothing, but a vacuum bags. Vacuum bag is air tight polymer bag is to be put there, you put it and then you seal the both ends. The tooling cost is very much reduced, because you do not have another side of the mold, wherein the previous one resin transfer molding, we were trying to talk about male part, female part. So, only bottom side we had and the top side also we should have, here you do not have to need the top side.

Since, it is a vacuum bag, it is smooth, surface finish is also good, but the only difficult is, you might have some wrinkles which are formed, because you try to suck a polymer you form wrinkles, so that, has to be made sure that you avoid. The thickness of the bag plays a very important role. So, application of vacuum facilitates the removal of the air trapped and better flow of the resin through the fiber packing. Since it is a closed mold process styrene emission is closed to 0. Moreover, the higher volume fractions can be achieved by making this process. This can be used for structural applications.

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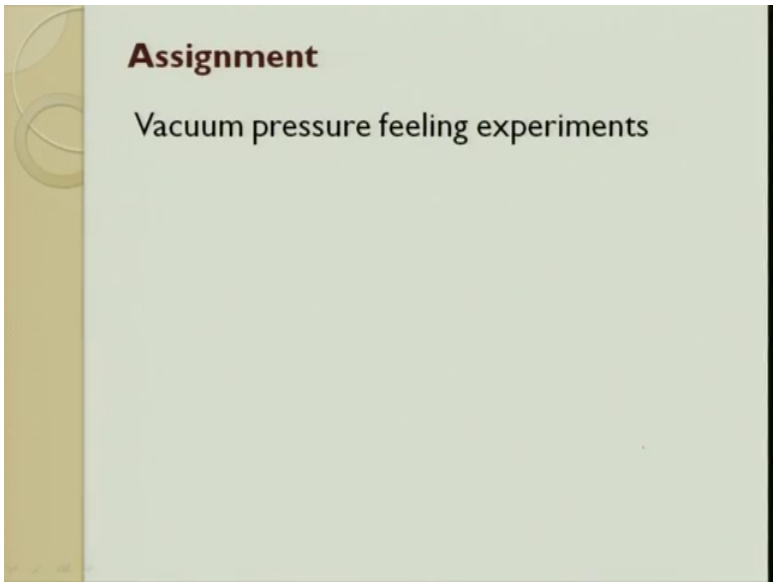

So, with this I try to finish, the vacuum the resin transfer molding process, the last process what we saw was Vacuum Assisted Resin Transform Molding. I would like to give a small experiment or a small exercise or an assignment which you will try to understand, what is the effect of vacuum we are talking about. Try to take plastic bag, any plastic bag, make a hole and then put a tube in it, you can take a very small tube; generally which is used for I V applications you can take it or you try to take a bag with the tube for urine track bags and all there is available, you take that and then what you do is, at the end of the tube you start sucking it and then try to make vacuum on the plastic bag. You will now see the amount of pressure which is required.

So, you suck is one mode. Like this you try to develop 2, 3 modes or means of sucking air from the bag through the tube, you try to do it and then qualitatively compare which process is good. This will try to give you a feel, what is the effect of vacuum on the process.

Thank you very much.