Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 22
Manufacturing of FRP Composites

Hello friends, welcome to the NPTEL online certification course retrofitting and rehabilitation of civil infrastructure. Today we will discuss module D. The topic for Module D is fiber reinforced polymer composites and its characteristics.

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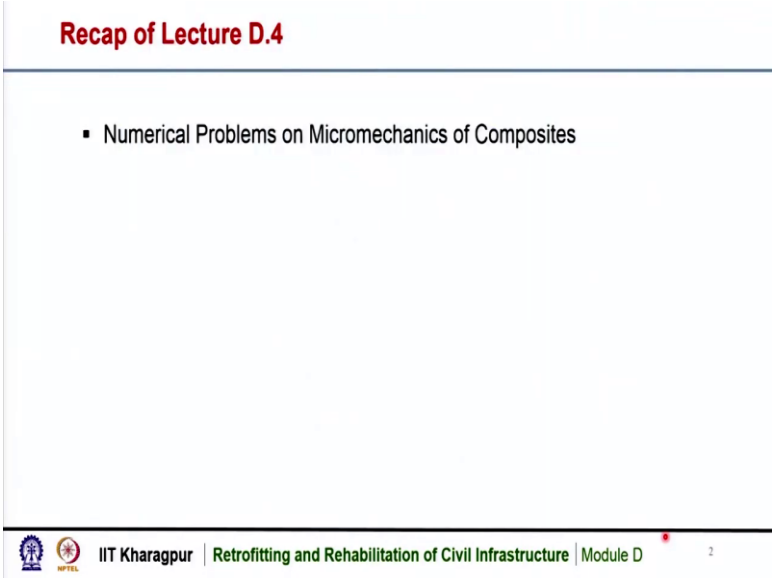

In the previous lecture, we have discussed micro mechanics of composites, and we have solved several numerical problems in the previous lecture. Today we will discuss the different methods of FRP manufacturing. The fiber reinforced polymer composite is comparatively a new material and its manufacturing or production is not similar to the conventional materials like concrete or steel.

There are different ways by which we can manufacture this type of material and there are different methods of processing of the FRP composites. In today's lecture, we will discuss the different methods of FRP manufacturing.

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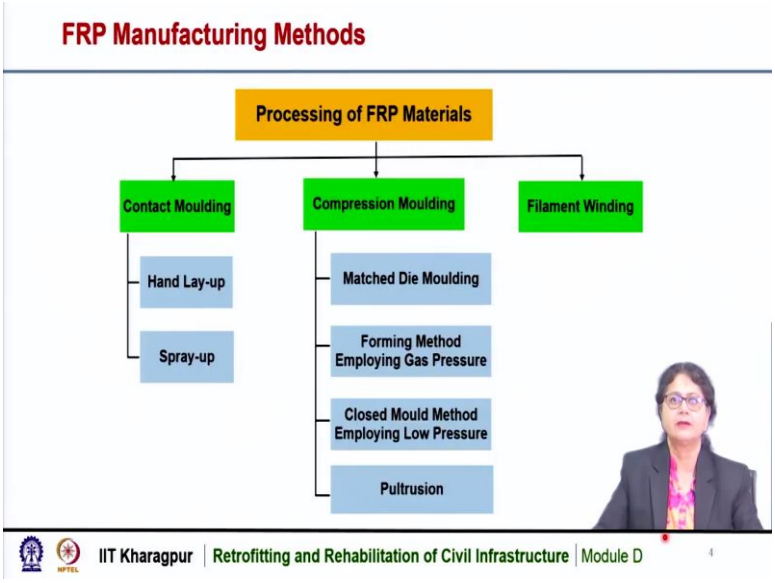

Fiber reinforced polymer composites are processed in several ways we can use contact moulding, compression moulding or filament winding. There are 3 broad types by which we can manufacture the FRP materials, which are contact moulding, compression moulding and filament winding. Contact moulding may be of 2 types, one is hand lay-up, and another is spray-up.

Compression moulding is also of different types, matched dye moulding, forming method employing gas pressure, closed mould method employing low pressure and pultrusion and there is filament winding. So, depending on the type of material and their usage, we can select any processing technique and by using contact moulding or compression moulding or filament winding we can manufacture the FRP composites.

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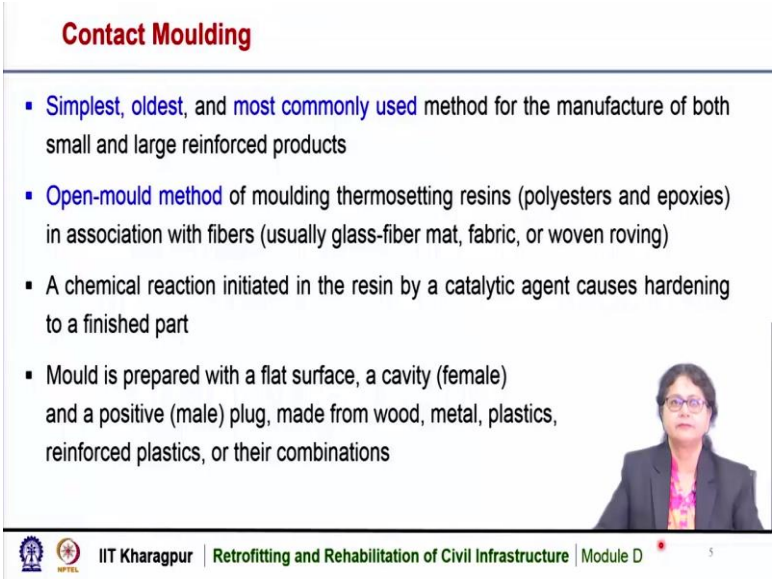

Contract moulding is the simplest, oldest and most commonly used method for the manufacture of both small and large sized products. So, it is a very simple product and we do not require any high-end equipment for contract moulding and it is also the most commonly used method for manufacturing of FRP products. And we can use different sizes also for contract moulding.

It is an open moulded method of moulding thermosetting resins and fibers. The resins may be polyester resin or epoxy resin and the fibers usually glass-fiber mat, fabric or woven roving. In this method, there is a chemical reaction that is initiated in the resin by a catalytic agent that causes hardening to the finish part.

A mould is prepared in contact moulding, we need to prepare a mould and that mould should have a flat surface a cavity and a plaque that mould may be of wood, metal, plastics or reinforced plastics or their combinations. So, in case of contact moulding, we need to prepare a mould, a mould maybe of wood, metal or plastics and using this mould we can prepare the FRP products.

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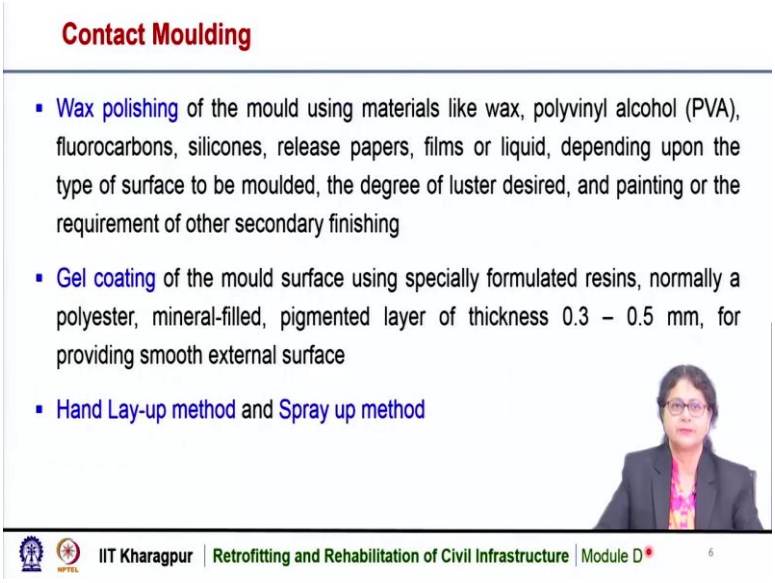

Now, after preparing the mould, the mould need to be wax polished and that can be done like materials, wax or polyvinyl alcohol, fluorocarbon, silicones, etc. And that wax polishing is required to get a uniform finish to the surface. Depending upon the type of surface to be moulded we can select the wax material and also depending on the degree of luster desired and the painting we can use the wax polishing material.

After wax polishing of the mould, a gel coating is to be done and gel coating of the mould is required to get smooth external surface. And that is done by specially formulated resins normally a polyester or mineral field and it will also contain some pigments and the thickness of the gel coating is very small maybe in the range of 0.3 to 0.5 millimeter and that gives a smooth surface to the mould.

So, we need to prepare a mould for this technique for contract moulding and that mould to be wax polished and then gel coated for the preparation of the FRP products. There are 2 types of contact moulding, one is hand lay-up method and the other is spray-up method.

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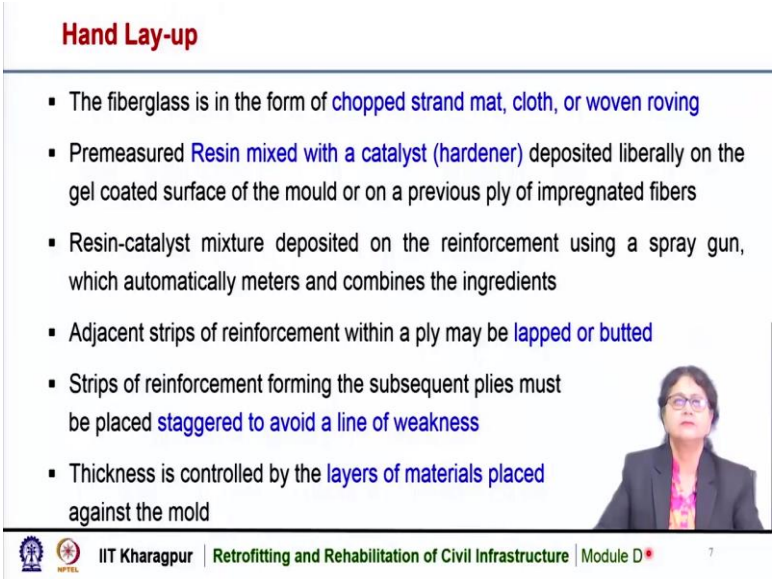

In hand lay-up method, the fiberglass that is used is in the form of chopped strand mat, cloth or woven roving, the resin is used and it has to be pre measured mixed with a catalyst or hardener that is to be deposited on the mould and which is gel coated and wax finished and on a previous ply of impregnated fibers. Initially it has to be on the mould and then some fibers may be there and we can put the resin onto it.

The resin catalyst mixture is deposited on the reinforcement that is the fiber using a spray gun which automatically meters and combines the ingredients. So, we can measure that resin and using a spray gun we can apply the resin material. Adjacent strips of reinforcement within a ply maybe lapped or butted. Here in this hand lay-up method, we can use moulds that may be of different sizes and shapes and that is the advantage of hand lay-up process.

So, if it is too long, we can use lapping on the fibers or it can be butted and that can be done in a staggered way. So, the strips of reinforcement forming the subsequent plies must be placed staggered to avoid a line of weakness. So, if we need to apply some lapping and that has to be done in a staggered way otherwise, on the lapping region there may be a line of weakness. So, to avoid that type of line of weakness, the plies can be lapped or buttered and the reinforcement can be placed accordingly.

The thickness of the composite is controlled by the layers of material placed against the mould. So, we have to apply the resin onto the reinforcement of the fibers and the thickness is controlled by the layers of the materials placed on the mould.

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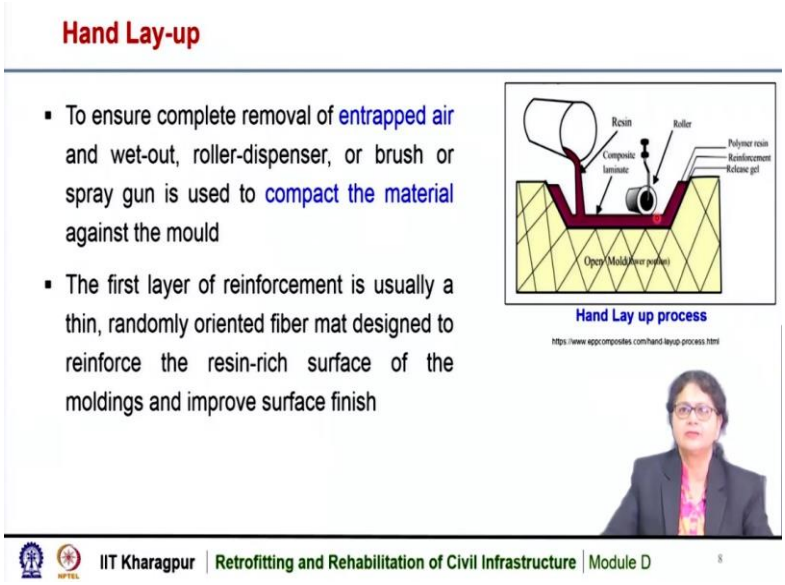

To ensure complete removal of entrapped air and wait out a roller dispenser or brush or spray gun is used to compact the material against the bolt. This is a manual process and we are applying the resin on to the mould. So, it is important that there should not be any entrapped air into the material. So, to remove the entrapped air, we can use a roller or a brush. So, that the material is compacted properly and there is no air or void within the material.

The first layer of reinforcement is usually a thin randomly oriented fiber mat, designed to reinforce the resin rich surface of the moulding and improve the surface finish. So, here is one schematic diagram of the hand lay-up process, we can see here this is the mould, this is the mould and this is the shape of the composite that is to be prepared. So, we have to place the reinforcement here as we can see here and the resin is to be deposited on it.

And this is the roller that is used for proper compaction of the resin onto it so that there is no entrapped air into the material. So, this is a schematic diagram of the hand lay-up process, by which we can apply the resin on to the reinforcement and then it is rolled so that there is no entrapped air into it.

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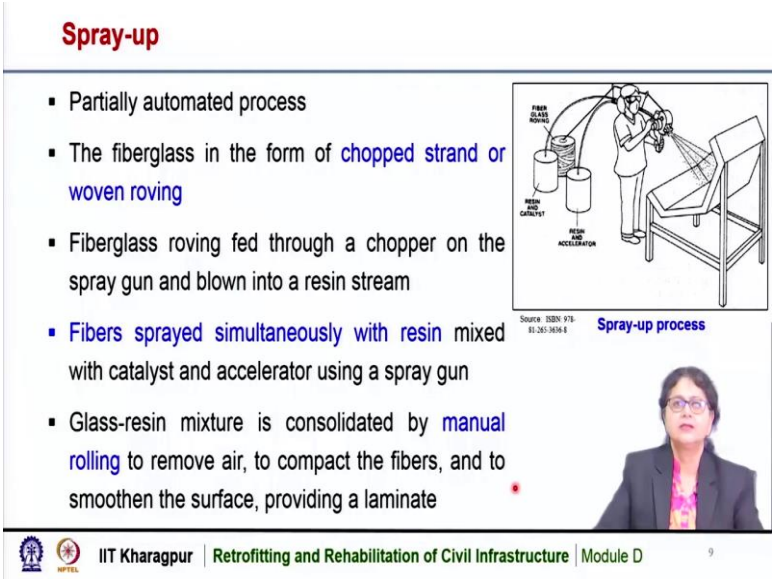

And spray-up method is a partially automated process. The hand lay-up is fully manual and in case of spray-up it is partially automated. The fiberglass is in the form of chopped strand or woven roving. The fiberglass roving fed through a chopper on the spray gun and blown into a resin stream. So, here the fiberglass that is used as the reinforcement is a chopped strand or woven ring and it is fed through a chopper on the spray gun and blown into a resin stream.

The fibers are sprayed simultaneously with the resin, mixed with catalyst or hardener and accelerator if it is required using a spray gun. The glass resin mixture is consolidated by manual rolling to move air as is done in the hand lay-up to compact the fibers and to smoothen the surface providing a laminate.

So, here is a schematic diagram of the spray-up process, as we can see that this is the fibers and this is the resin and the catalyst and this is the resin and the accelerator and it is applied through the spray gun and then this is the mould. So, it is applied with the spray gun onto the mould and then it is compacted by rolling.

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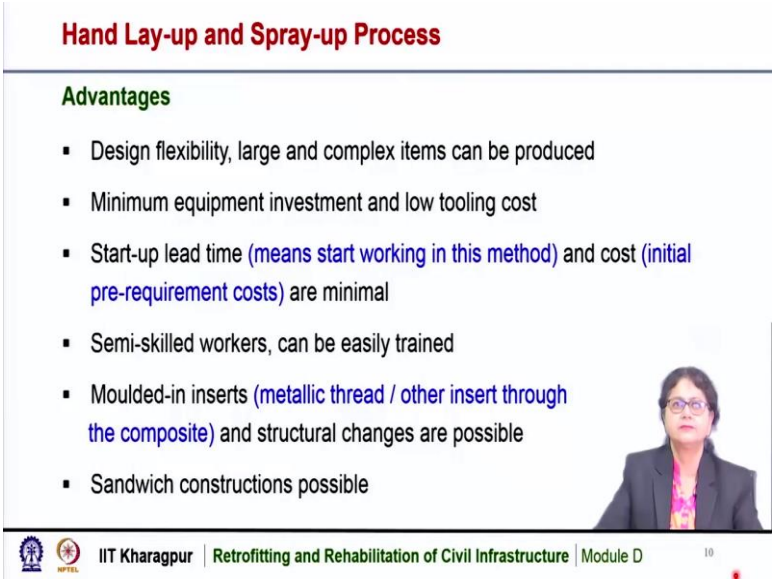

Hand lay-up or spray lay-up process have several advantages as well as some limitations. It is the most common method used the main advantage is the design flexibility. We can prepare large and complex items through this hand lay-up or spray-up process. We can prepare the mould as per our requirement with different shapes and sizes.

So, the design flexibility is there and the FRP can be manufactured from small to large sizes. The minimum equipment investment and low tooling cost, there is hardly any sophisticated equipment required, but we have to prepare the mould and that is it. So, minimum equipment investment is required and also the cost.

The startup lead time and costs are minimal. That means the time for carrying out this technique or this hand lay-up or spray-up process or the prerequisite time and cost are also minimal. It does not require any skilled personnel to prepare the FRP materials. Semi-skilled workers are sufficient and if some training is required that also can be done.

Moulded in insert that is metallic thread or other type of inserts, if it is required to the composite that also can be placed and the structural changes are also possible in this hand lay-up or spray-up process and sandwich constructions is also possible. So, in this hand lay-up or spray-up process, they are very simple.

And we do not require any sophisticated equipment for this process. We can make large and complex items through this hand lay-up and spray-up process. And it does not require any high cost or high skilled labors as well for preparation of the FRP composites.

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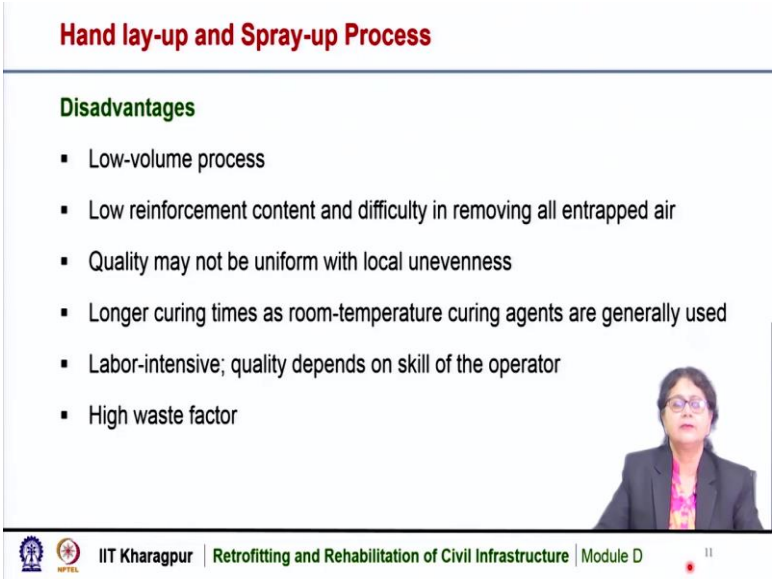

However, there are some limitations; the main disadvantage is that it is a low volume process. If we want to prepare a large number of FRP materials, this hand lay-up or spray-up process is not very suitable, because it is a manual process. So, a lot of time will be required for that. So, this is not very suitable when we require large number of products to be prepared.

Low reinforcement content and difficulty in removing all entrapped air, sometimes it is quite difficult to remove all the entrapped air within it because it is manually applied and that is why the quality may not be uniform throughout with local unevenness. So, local unevenness maybe they are because of some entrapped air and in many cases, it has been seen that quality also is not uniform throughout the material, if it is of longer length.

Longer curing time as room temperature curing agents are generally used, because we are using the curing agents which works at the room temperature. So, it takes longer time for curing. Labor-intensive because we require laborers or workers for carrying out this process. So, the quality depends on the skill of the operator and there is high waste factor.

So, that is also there, the wastage may be significant in case of hand lay-up or spray-up process. So, though they are very simple and use significantly, they have few limitations. Because if we want to prepare a large number of products, this hand lay-up or spray-up process is not very good.

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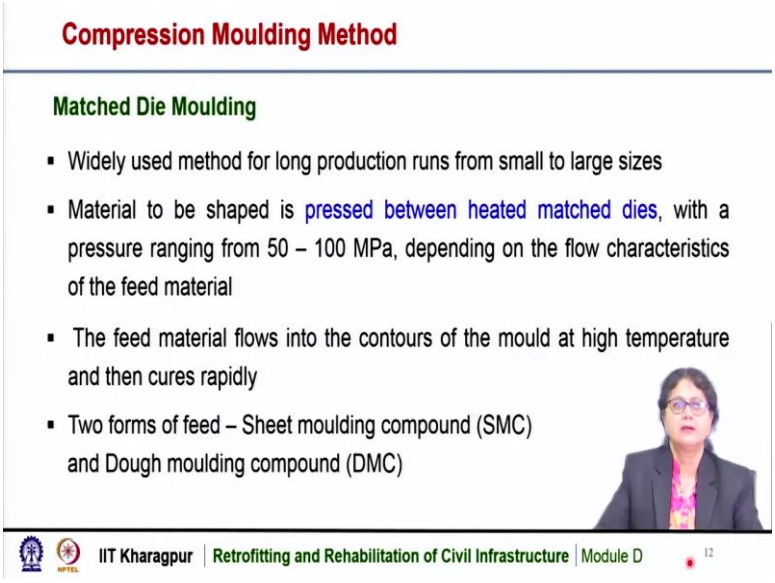

So, after contract moulding, there is one method that is compression moulding method. In compression moulding, we have several techniques for compression moulding, one is matched die moulding. Matched die moulding is also widely used method for long production plants from small to large sizes.

So, here if we want to have large number of products, matched die moulding is better method as compared to contact moulding. The material to be shaped is pressed between heated match dies with the pressure ranging from 50 to 100 MPa depending on the flow characteristics of the feed material.

Now, here in case of matched dye moulding, the material to be feeded is to be pressed against the heated match dies and that pressure is quite high and it depends on the flow characteristics of the feed material. The feed material flows into the contours of the mould at high temperature and then cures rapidly.

So, here pressing is done at high temperature. So, it is comparatively faster. There are 2 forms of field, one is sheet moulding compound or SMC and another is Dough moulding compound or DMC.

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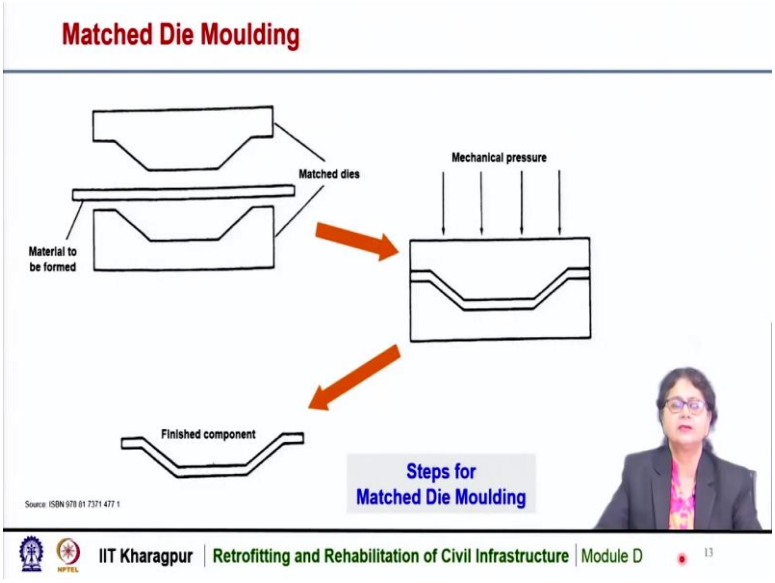

This is the schematic diagram of matched dye moulding process; we can see here. These are the 2 matched dyes. So, this is the mould which is called matched dies and this is the material that is to be formed.

This is the material and it is to be placed in between the 2 dies, then a pressure is applied putting this material in between and with this applied pressure the material takes the shape of this mould. We can see here the material takes this shape, and we can get the finished component like this.

So, this is the finished component and using the method match dye moulding we can get the composite of this shape or any other shape as per the requirement. So, this is the schematic diagram of matched dye moulding.

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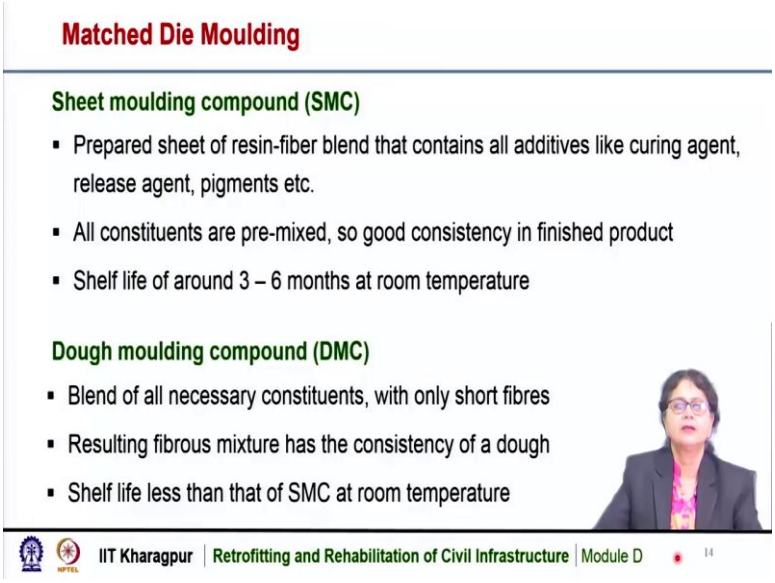

So, the feed material may be sheet moulding compound or Dough moulding compound. In sheet moulding compound, the prepared sheet of resin fiber blend contains all our additives like curing agent, release agent, pigments etc. All the constituents are pre-mixed, so, we can get a good consistency in the finished product and the shelf life is also high in about 3 to 6 months at room temperature.

In case of dough moulding compounds, here also it is the blend of all the necessary constituents like your curing agent, release agent, etc. But the fibers used here is short fibers. So, in case of Dough moulding compound the fibers are generally short fibers and the resulting mix has the consistency of a Dough. The shelf life is less than that of the SMC or the sheet moulding compound at room temperature.

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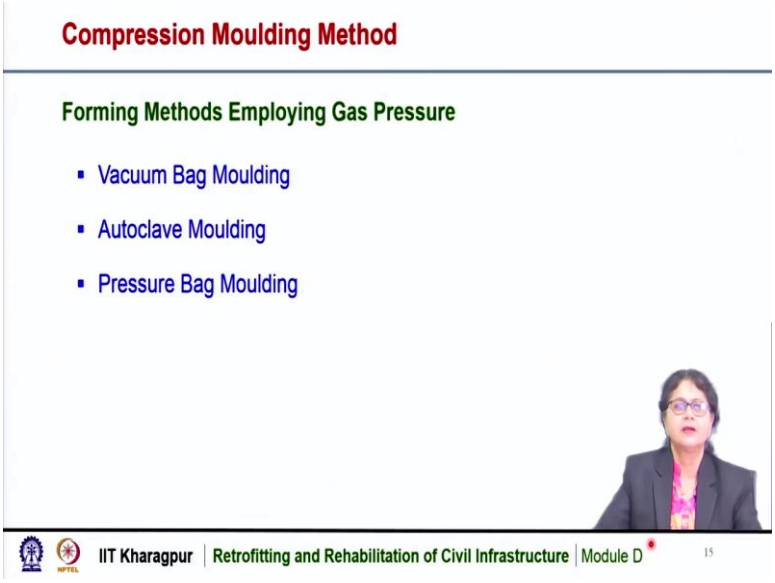

Now, we will discuss another method of compression moulding method it is called forming method employing gas pressure. So, this is a method of compression moulding. And this method is of 3 types, one is vacuum bag moulding, autoclave moulding and pressure bag moulding.

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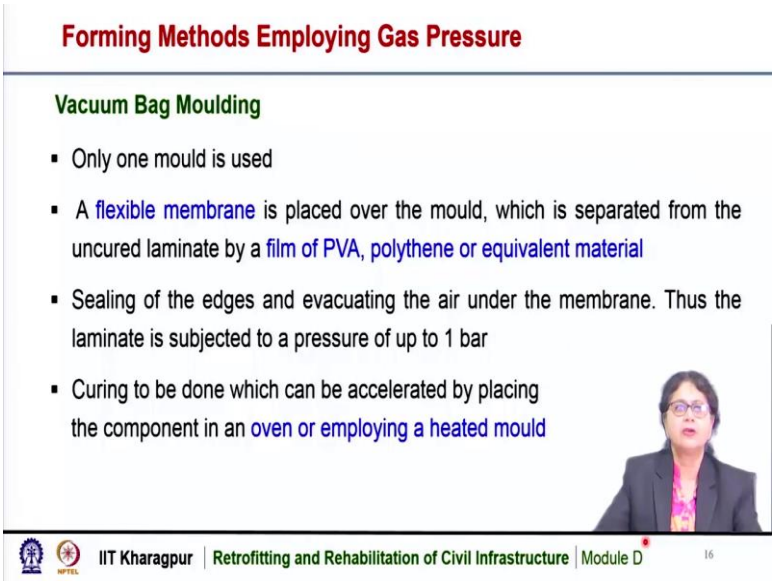

In vacuum bag moulding, only one mould is used. So, unlike the match dye moulding, here only one mould is used. A flexible membrane is placed over the mould, which is separated from the uncured laminate by a film of PVA, polythene or any equivalent material. So, here one mould is used and we are using a flexible membrane placed over the mould.

Now, the edges are sealed and the air is evacuated under the membrane. Thus, the laminate is subjected to a pressure of up to one bar. So, here we are putting this flexible membrane on the mould and then we seal the edges and then evacuate the air under the membrane. Thus, the laminate is subjected to some pressure up to one bar. Now curing is done, which can be accelerated by placing the component in an oven or employing a heated mould.

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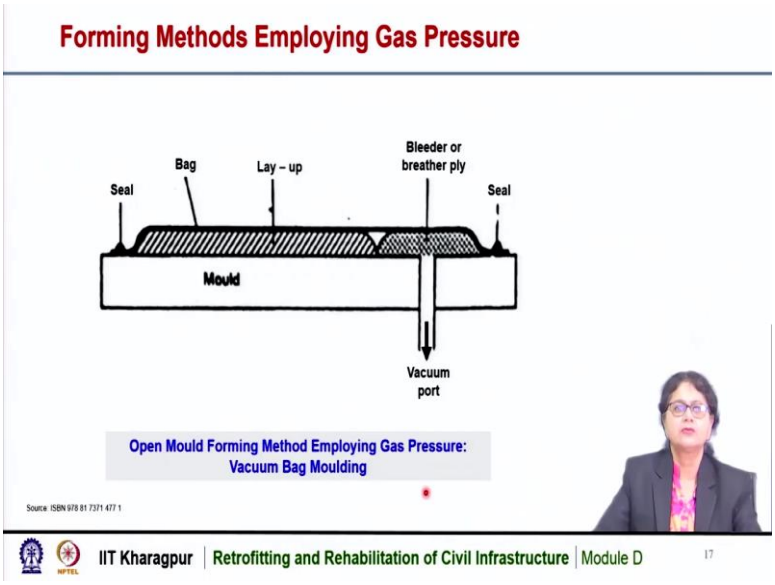

So, here is the schematic diagram of the open mould forming method employing gas pressure that is the vacuum bag moulding. So, here this is the mould, this is the one mould that is used and this is the membrane and the edges are filled, the material is placed here, the edges are filled and the air is evacuated through this vacuum port and with this there is compaction of the material and we can get the FRP product.

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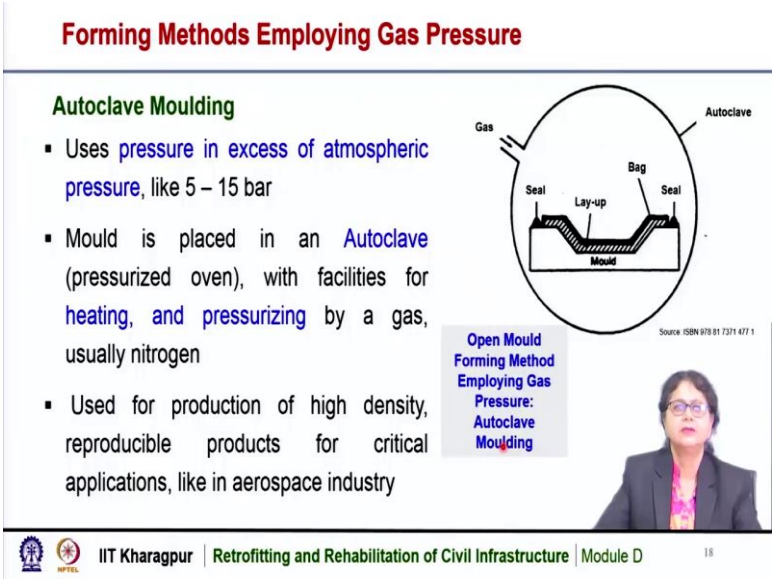

Another one of forming method is autoclave moulding. Here the method uses pressure in excess of atmospheric pressure. The pressure is in the range of 5 to 15 bar. So, higher pressure is used in case of autoclave moulding. The mould is placed in an autoclave which is a pressurized oven with facilities for heating and pressurizing by a gas and that gas is generally nitrogen gas.

So, here in autoclave moulding, we use high temperature and also high pressure, used for production of high-density reproducible products for critical applications. The autoclave moulding is used for specialized products and because of this autoclave moulding the product quality is also good. So, for critical applications or for critical structures, we can use autoclave moulding, like in aerospace industry.

Here is a schematic diagram of the autoclave moulding, this is the mould this is the only mould that is used here and this is the membrane or back and the material is placed here it is sealed and the pressure is applied in this autoclave chamber with high temperature, so this is the gas and with this the pressure is applied.

So, this is the schematic diagram of open mould forming method employing gas pressure and this is by autoclave moulding. So, after proper curing and that curing is also rapid because we are using high temperature, so we can get the product at a much faster time.

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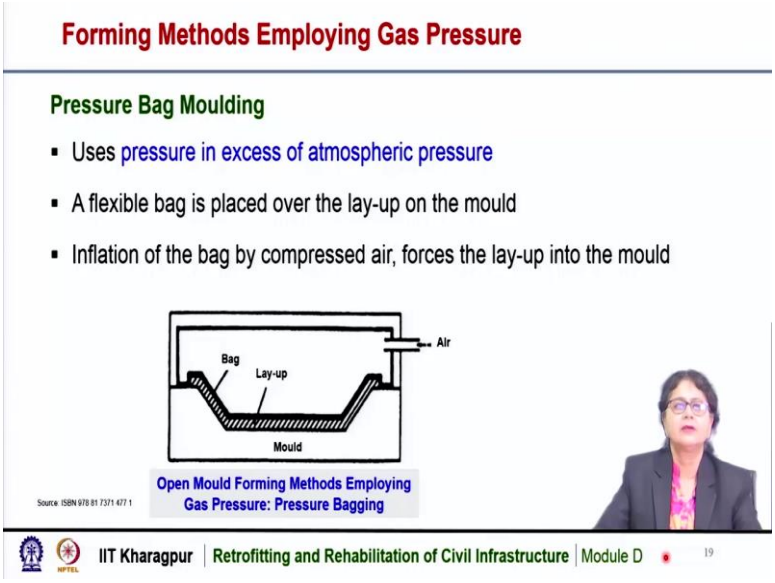

Another one is pressure bag moulding. In this method we are using pressure in excess of atmospheric pressure. Here also a flexible bag is placed over the lay-up on the mould, this is the mould we can see here on the schematic diagram, this is the mould and a flexible bag is placed over the lay-up on the mould. Inflation of the bag is done by compressed air forcing the lay-up into the mould.

So, we are applying the pressure by this vent, you can see here this is the compressed air and that forces the lay-up here into the mould. So, we can get the material after proper curing. So, this is pressure bag moulding. In all these 3 methods we are applying high pressure and from that we can prepare the FRP composite.

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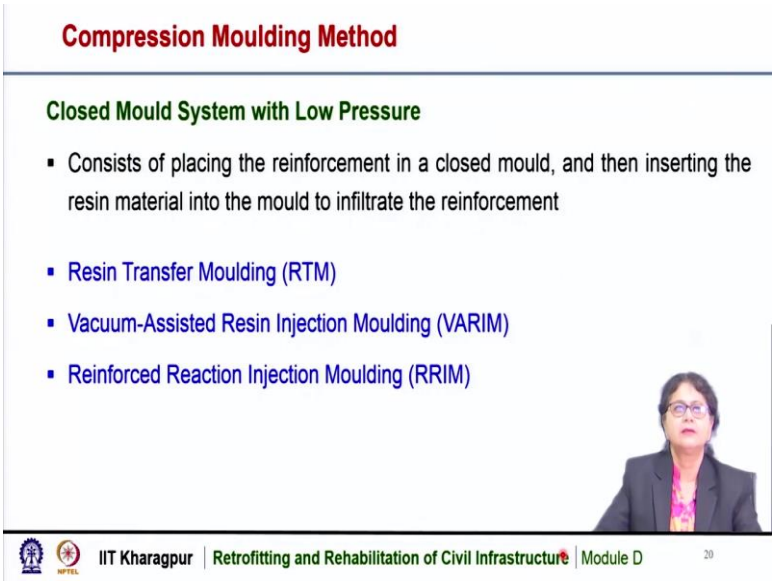

Another method of compression moulding is by using low pressure. So, here it is the closed mould system with low pressure that consists of placing the reinforcement in a closed mould and then inserting the resin material into the mould to infiltrate the reinforcement. So, here we are using a mould and that is a closed chamber. So, that is called closed mould and then the inserting the resin material into the mould to infiltrate the reinforcement that is the fibers.

The closed mould system also is of 3 types, one is resin transfer moulding or RTM, vacuum assisted resin injection moulding or VARIM and reinforced reaction injection moulding or RRIM. So, these are the 3 methods that uses low pressure for compression moulding.

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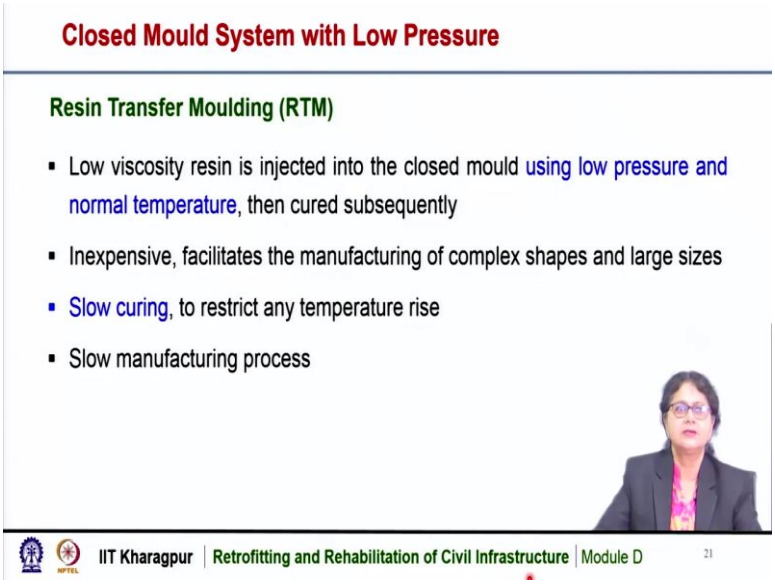

And resin transfer moulding, here we are using low viscosity resin and that resin is injected into the closed mould using low pressure and normal temperature and then it is cured subsequently and slowly. The method is inexpensive, it facilitates the manufacturing of complex shapes and large sizes. The process involves slow curing because it is at the normal temperature and at low pressure.

So, it is a slow curing method. And since the material is also of such kind that it restricts any temperature rise, because the material is not capable of resisting high temperature. So, slow curing is done to restrict any temperature rise and because of the slow curing, it is also a slow manufacturing process. So, resin transfer moulding involves a low pressure as well as normal temperature curing. So, it is a slow manufacturing process.

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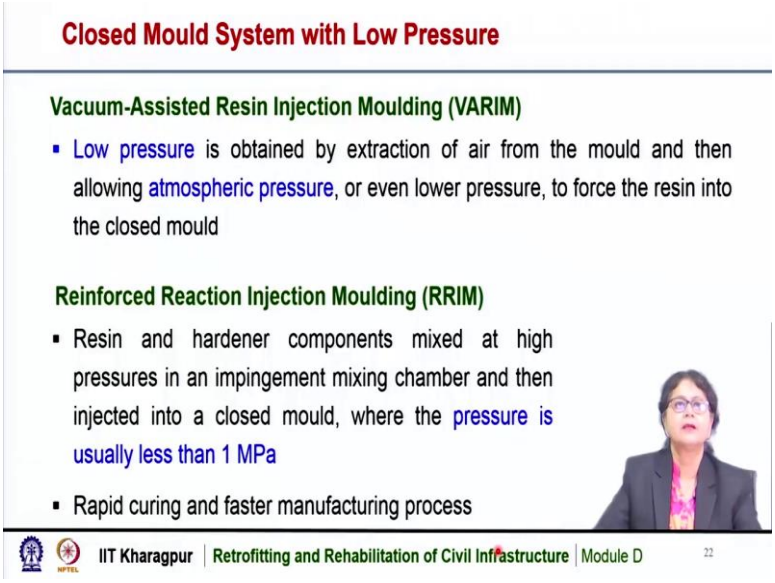

In vacuum assisted resin injection moulding or VARIM that also uses low pressure and this low pressure is obtained by extraction of air from the mould and then allowing the atmospheric pressure or even a lower pressure to force the resin into the closed mould.

So, in case of vacuum assisted resin injection moulding, we are applying low pressure and that low pressure is obtained by extraction of air from the mould and then atmospheric pressure is allowed or even a lower pressure is allowed at that forces the resin into the closed mould to take the shape of the composite.

In case of reinforced reaction injection moulding or RRIM, resin and hardener components are mixed at high pressure in an impingement mixing chamber and then they are injected into a closed mould where the pressure is low and the pressure is in the range of 1 MPa.

So, here in case of reinforced reaction injection moulding, we are using the resin and the hardener and that are mixed at high pressure in a mixing chamber and then they are injected into the closed mould where the pressure is low. So, here in this method the curing is rapid. So, the manufacturing process is also faster.

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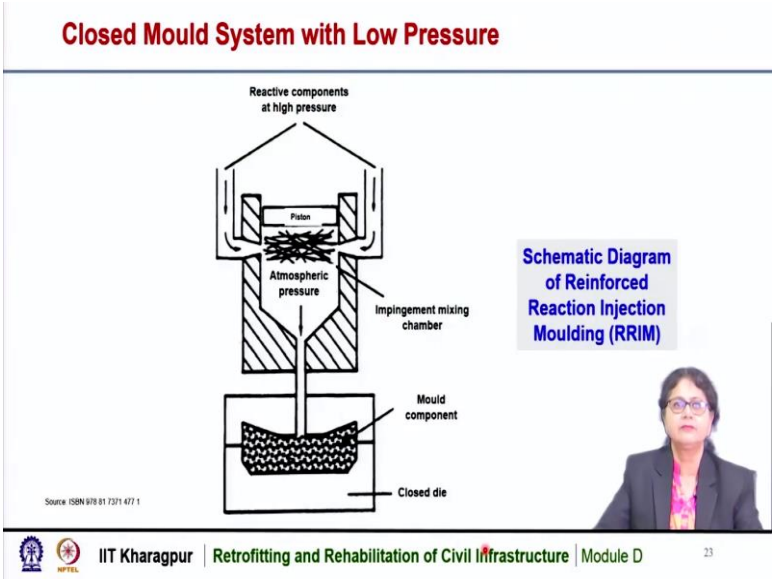

This is the schematic diagram of reinforced reaction injection moulding. We can see here this is the reactive components that is the resin is mixed here and at that is at high pressure and then the atmospheric, then it is placed into this closed mould and there the pressure is atmospheric pressure or even lower. So, here the actual moulding is taking place and we can get the composite material. So, this is the schematic diagram of the reinforced reaction injection moulding of closed mould system with low pressure.

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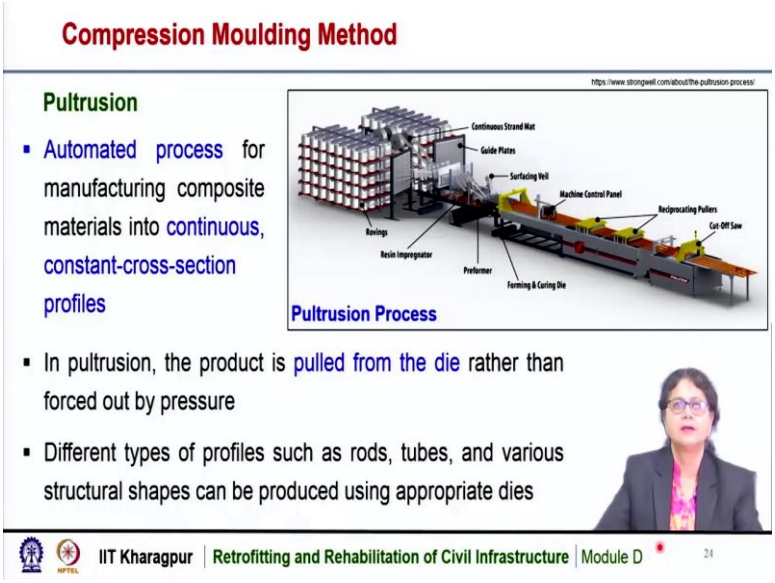

Now, another compression moulding technique is pultrusion. This is an automated process, where the manufacturing composite materials are continuous or constant cross section profiles. So, in case of pultrusion this is much advanced process of manufacturing of the FRP

products automated process and we can get a continuous constant cross section profile composite material through this pultrusion process.

In pultrusion, the product is pulled from the die rather than forced out by pressure. In case of contract moulding or compression moulding, the product that is prepared is by applying some pressure. Whereas, in case of pultrusion the product is pulled from the die and that is why it is called pultrusion method. Different types of profiles can be obtained through this pultrusion technique, we can get rods, FRP rods, FRP tubes or various other structural shapes like I-section or channels etcetera from this pultrusion process using appropriate dies.

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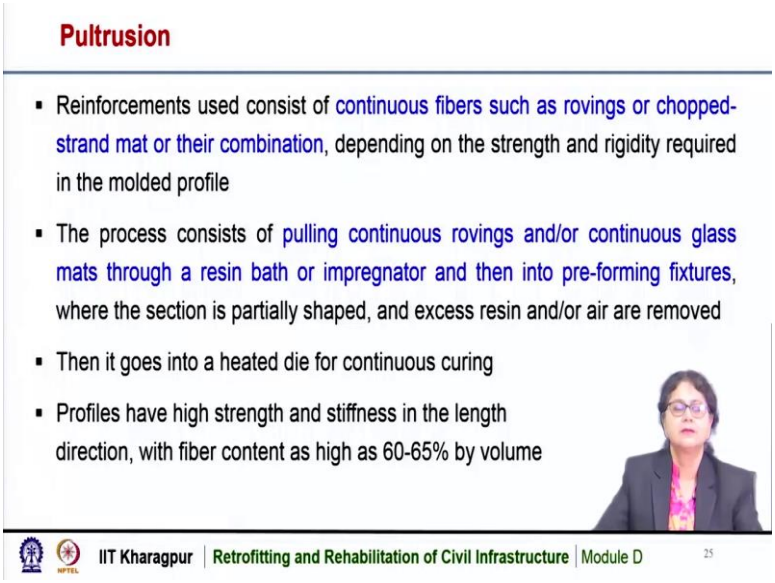

In pultrusion, the reinforcement that are used consists of continuous fibers such as rovings or chopped strand mat or they are combination depending on the strength and rigidity required in the moulded profile. So, different types of fibers can be used or rovings or chopped strand mat or their combination as per the requirement or as per the strength and rigidity of the FRP product. The process consists of pulling continuous rovings or continuous glass mats through a resin bath or impregnator.

And then into pre-forming fixtures, where the section is partially shaped and then excess resin or air is removed. Then the product is to be transferred into a heated die for continuous curing and we get the FRP products with profiles having high strength and stiffness in the length direction that is along the length of the fiber and the fiber content may be as high as 60 to 65 percent by volume.

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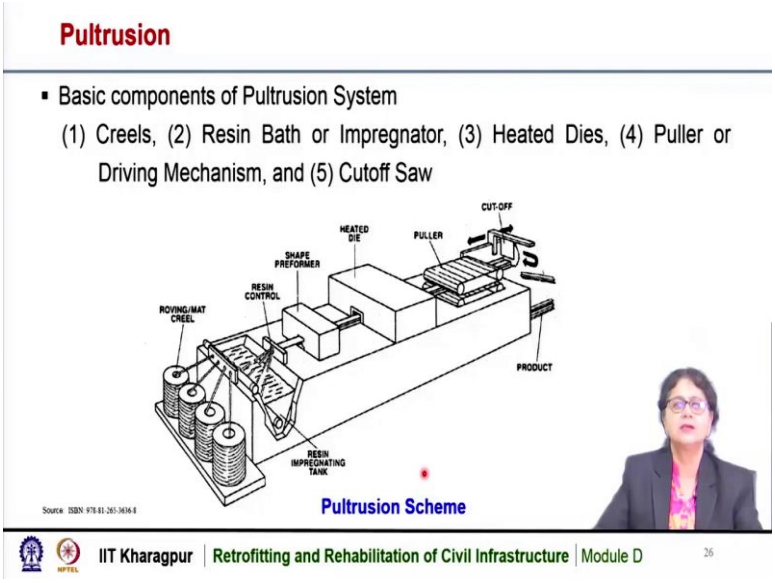

So, this is the schematic diagram of the pultrusion process. We can see here this is a fully automated process. The basic components of the pultrusion system consist of creels, resin bath or impregnator, heated dies, Puller or driving mechanism and cutoff saw. So, this is the creel, where we have the fibers or the roving or mat. The fibers here are placed and this is then is connected to this resin impregnated bath or tank.

So, this is the resin bath or impregnator where the fibers are going through and then is the shape reformer, we can see here where the desired shape is obtained and then it is heated. So, this is the heated dyes, where it is cured and this is the cooler from where the material is pulled out. Finally, we can get the desired product of the required length.

So, we can get the long material and then as per the requirement using this cutoff saw, we can get the product of the desired length. So, this is the schematic diagram of the pultrusion process.

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Here are some photographs of pultrusion process, this is the reinforcing fibers we can see here these are the reinforcing fibers mechanically pulled into a resin bag, where the fibers are saturated thoroughly and then impregnated with polymer resin. Next step is the saturated fibers that are saturated with raisins, they are pulled through a machine precision die with entry portal and internal cavity in the shape of the final product.

So, in the die, we have the final shape of the product, the composite is formed and then it is cured within the heated steel die. So, normally steam is used as a heated die material. So, the composite is formed and cured within this heated die. Upon exit from the die, the thermoset composite is cut to desired length using that socket technique. So, this is the finished product and then it is to be cut at desired length. So, these are the steps for pultrusion technique to get the FRP products.

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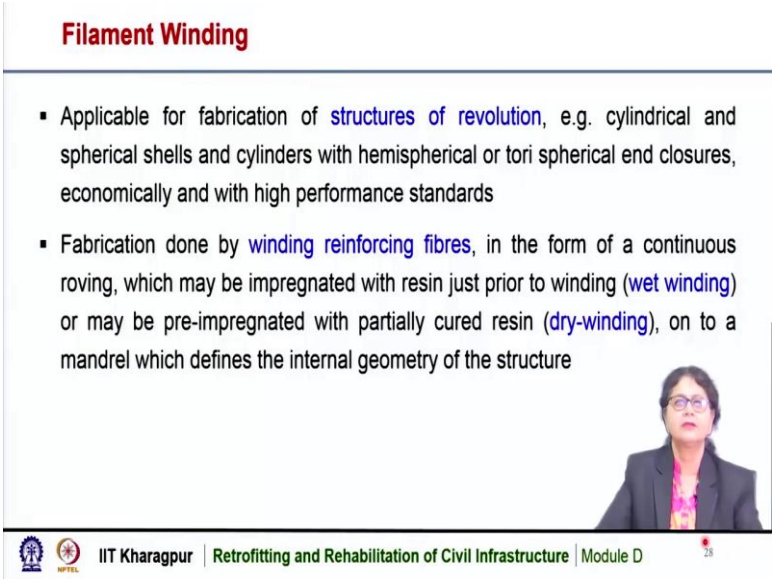

Another technique of FRP manufacturing is filament winding. Filament winding is applicable for the fabrication of structures of revolution like the cylindrical members or spherical members or spherical shell or cylinders with hemispherical, or tori spherical enclosures etc. So, filament winding is a high-performance method and we can get material of FRP with high quality and thus it is economical as well, because we are getting a good quality FRP material from this filament winding method.

The fabrication is done by winding reinforcing fibers in the form of a continuous roving which may be impregnated with resin just prior to winding, that is wet winding or it may be pre-impregnated with partially cured resin that is dry winding on to a mandrel which defines the internal geometry of the structure. So, the fabrication is done by winding reinforcing fibers either wet winding or dry winding using a mandrel and that mandrel defines the internal geometry of the FRP structure.

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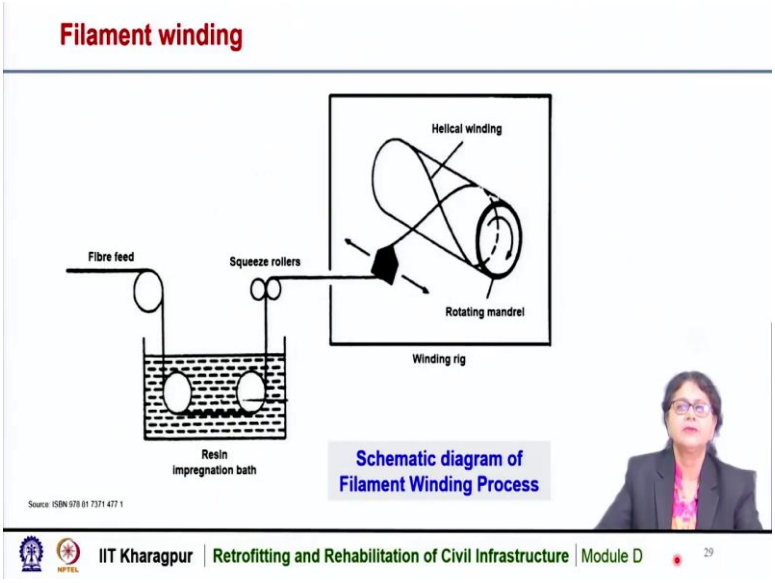

Here is the schematic diagram of filament winding process. This is the fiber to be fed, the fiber is going through this resin impregnation bath. So, it is saturated with resin and then it is squeezed and then it is coming to the winding rig and this is the mandrel. This is the mandrel which is rotating and the fibers are placed onto the mandrel and the winding is helical in nature. And by the rotation of this mandrel, we can have the fibers on it and we can get the product.

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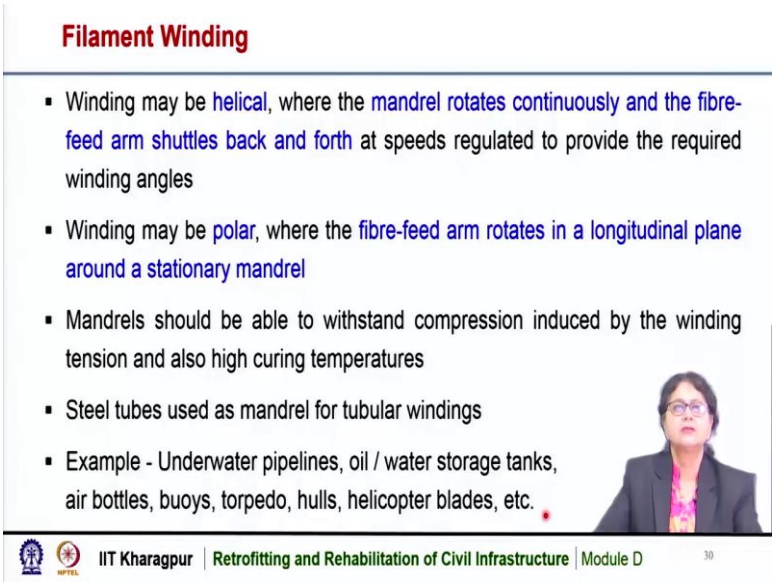

So, winding maybe helical, where the mandrel rotates continuously and the fiber-feed arm shuttles back and forth at speeds regulated to provide the required winding ankles. So, here in this case, the mandrel is rotating and the fiber feed arm that moves back and forth and with

that we can get the material. So, here the mandrel is rotating and in some cases the winding may be polar, where the mandrel is stationary and the fiber feed arm rotates in a longitudinal plane around the stationary mandrel.

So, we can do the filament winding in 2 ways either the mandrel is rotating or the mandrel is stationary and the fiber feed arm is rotating in a longitudinal plane. So, the mandrel should be able to withstand compression induced by the winding tension and also high curing temperature. So, mandrel should be capable of resisting the compression and the temperature.

The steel tubes are generally used as mandrel for tubular windings and this type of technique, this filament winding gives FRP products that is of good quality and so, the it is used for special structures like underwater pipelines, most of the cases the structure is having some circular in shape or cylindrical or spherical.

So, for underwater pipelines or oil or water storage tanks, air bottles, torpedo hulls or helicopter blades where we have this type of structures, we can use filament winding and that gives us a product which is of good quality and of uniform strength and stiffness.

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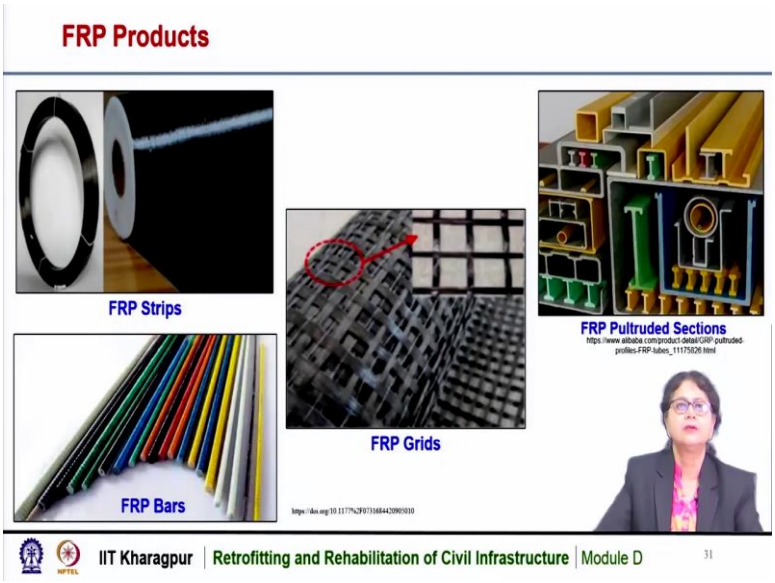

So, these are some of the FRP products that are manufactured using the techniques we have discussed. This is FRP strip, these are FRP bars, these are FRP grids as we can see these are FRP grids and these are FRP pultruded sections. So, we can have different types of shapes, we can see here maybe an eye section or some angles channels or boxes or FRP bars that can be obtained from this type of pultrusion.

So, these are some of the pultruded sections, these are FRP grids, FRP strips etc. And these can be manufactured using the techniques what we have discussed.

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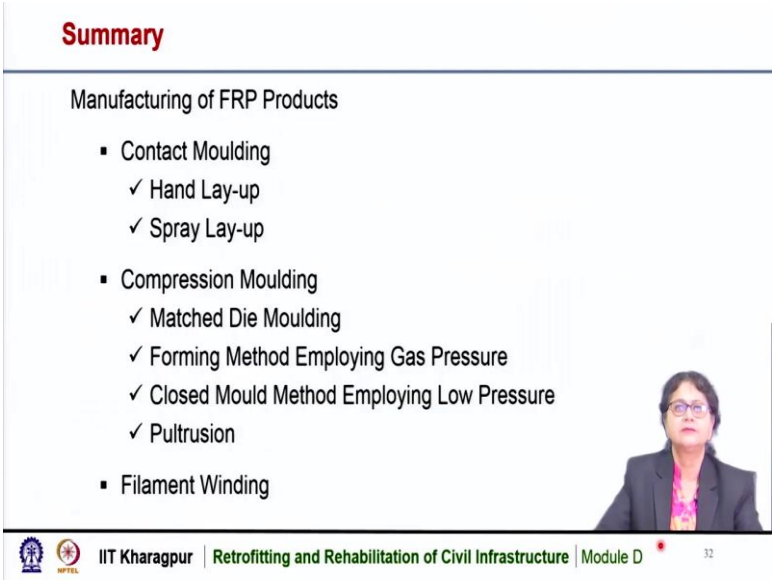

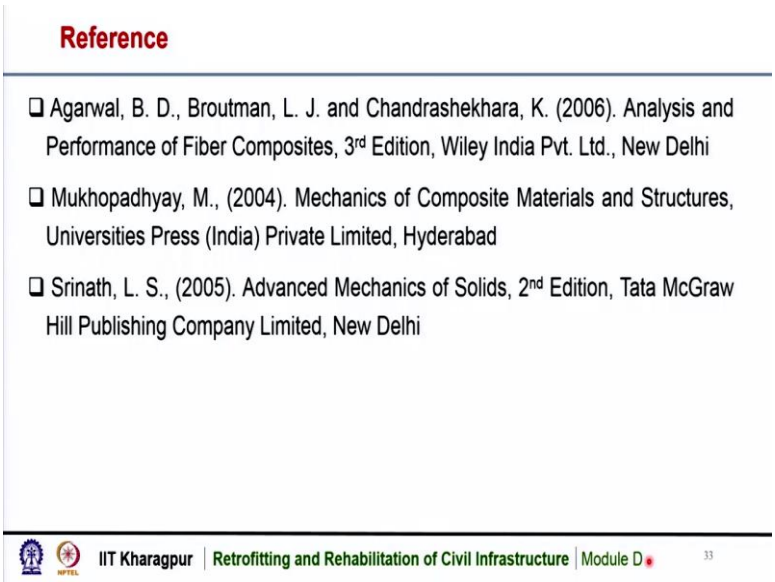

So, to summarize we have discussed several manufacturing techniques for FRP products. We have discussed contact moulding, compression moulding and filament winding. Contact moulding is the most common and simple method and it is mostly manual method, we have 2 types of contract moulding, one is hand lay-up and the other is spray lay-up.

The compression moulding is of 4 types, one is matched dye moulding, forming method employing gas pressure, another one is closed mould method employing low pressure and the other one is pultrusion method which is a completely automated process. The other method is

filament winding. So, these are the different types of a manufacturing techniques which are used for processing of the FRP products. These are the references for Module D. Thank you.