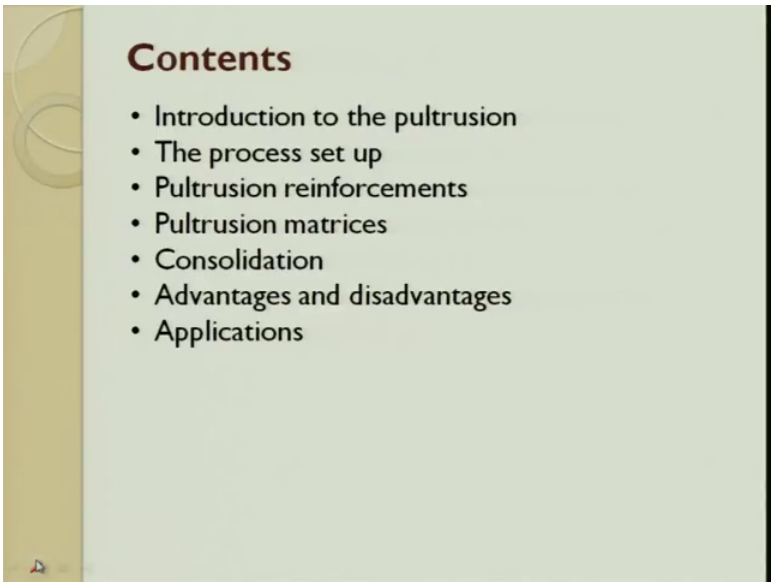
Manufacturing of Composites
Prof. J. Ramkumar
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur

Lecture - 11
Pultrusion

Good morning friends. So, we will move to the next lecture. The next lecture is on pultrusion. So, pultrusion is process if you see the name itself something might strike you pull. So, there has to be something like a pulling component and trusion. So, this trusion comes from extrusion. So, we are going to learn a process where in which we are trying to see pulling plus extrusion put together for making a composite, you are right. So, like in filament binding process there is a fiber which gets immersed inside a tank where there is a resin, it immerses and then it gets out of the tank with coating of resin on top of it. And then it is wound on a mandrill.

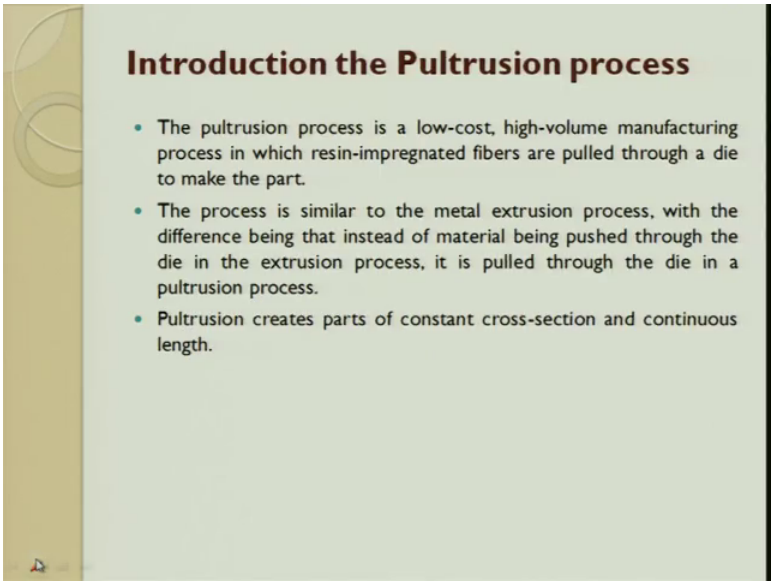
So, in the similar way here we have to make sure that the fiber or the reinforcement is uniformly wetted with resin. And then we try to extrude it through a die. So, the process name very clearly says it is pultrusion pulling plus extrusion. So that is; what is a process we will see today. So now, you quickly what comes and strikes to your mind what will be the can I make different shapes yes you can make different shapes, but it has to be in a restricted die. For example, you can make a cross section uniform cross section materials or products, you can make through pultrusion.

(Refer Slide Time: 01:58)



So, the content is first we will see the introduction of pultrusion, then the process set up. Then pultrusion what are the different kinds of reinforcement, then matrices. Here it is thermoset. So, what are the different matrices in thermoset? Then consolidation how does it happen advantage disadvantage? And few of the applications.

(Refer Slide Time: 02:17)



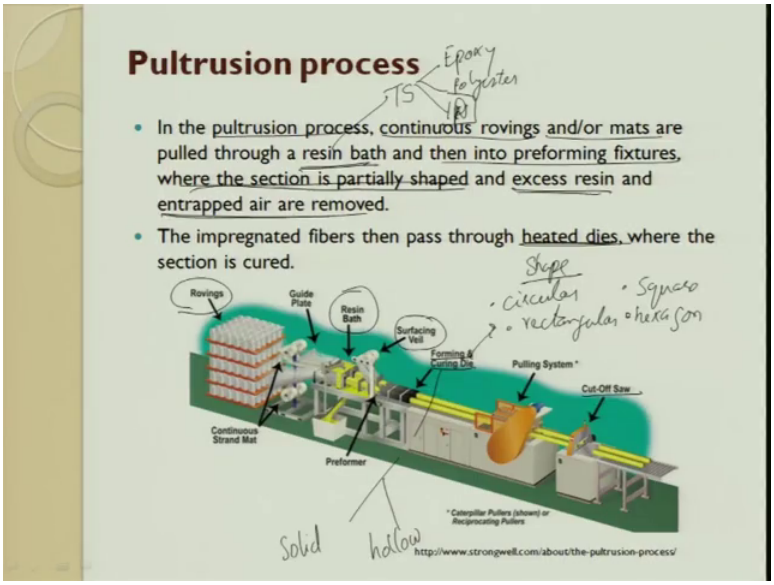
It is a low cost process by and large composites itself is used for batch production and small volume production as compared to that of polymers right. So, here whenever I talk about small volume production the cost comes into effect. So, it is a low cost process and

it is also used for high volume. High volume please do not compare the high volume with respect of a polymer or with respect to a metal forming operation sheet or a rod or shaft something like that. This high volume is comparatively in the spectrum of composites it is a high volume process, here the resin is impregnated on a fiber. And it is pulled through a die now it is very clear the die geometry is the part geometry.

So, if there is a die. So, it has to be predominantly access symmetry part. So, it is used for making access symmetry parts. So, it is like your extrusion process what we use in metal forming the metal is extruded through a die to give a shape. So, same way here the fiber along with the resin is extruded through a die which gives you the shape the process is very similar to that of your metal extrusion process. The only difference is instead of a metal here you will push through you will pull the fiber and the reinforcement through the die. So, it is pulled there it is push right.

So, this is what is a difference. So, the pultrusion creates a constant cross section and continuous length. So, this is the gist of the process. So, the gist of the process is you will pull the component out of a die. So, the cross section will be uniform and it has it can be a long lengthy parts. For example, if you want to make a cover a strip cover or a shaft, you want to make made out of thermoset resin with fiber reinforcement you can do it through this.

(Refer Slide Time: 04:22)



So, pultrusion process it is like this. So, here you have you see the rovings. So, you can have a combination of glass fiber, carbon fiber kevlar whatever combination you want you can start putting it here. And correspondingly all these things are continuous strand mats it is all here. So, then it gets guided then it gets into a resin bath. In this resin bath the glass fiber is wetted, and now it is further pass through.

After it is wetted then it is surfacing wheel happens, and then it tries to get into a die, which is where it tries to get in to a shape of forming and curing is happening as and when it passes through it. Moment it is it is getting it is getting a shape and it is slowly getting cured. So, here what happens? There has to be somebody to pull it out you can push it or you can pull it. So, pulling is easier. So, we try to pull the glass fiber along with the resin outside and then it is continuously allowed to cure you will have rollers continuously for long lengths and depending upon the length they cut it off.

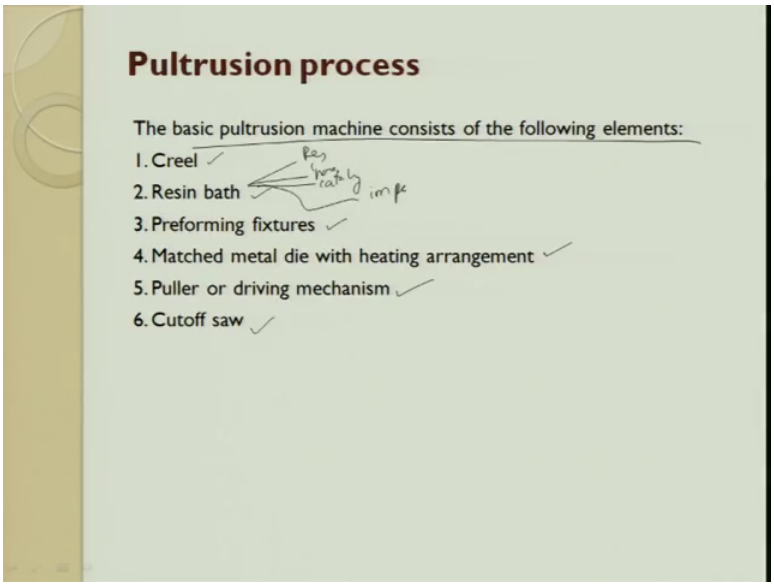
So, this is a cutoff saw which tries to cut to your required dimensions. So, here the die geometry can be circular, it can be rectangular, it can be square it can be hexagon, and all these things can be for this is shape classification. And then you can also have another classification whether to have a solid or a hollow tube that is also possible. So, you can have a pipe or a shaft of varying cross section area. So, here it is a pull a pultrusion process a continuous roving, again this roving I can be combination can be glass fiber can be kavlar fiber.

So, you can choose or it can be a mat it can be a roving or it can be a mat, which is pulled through the resin bath. So, this resin bath will try to have a thermoset, which can be as usual 3 which can be epoxy, which is easy to work you can have polyester to work or you can have some ester. Or you can also have nylon not nylon you can have polyester. And you can have some other polyester also. You can have (Refer Time: 06:50) epoxy also. So, if you see in this.

So, there are passes through a resin bath, and then it is it is pushed into a preformed fixture. And it is not that just it exits you take the preform to for a longer distance. So, where the cross section is partially shaped and the excess resin and air gaps is remove, and then you allow to cure. The impregnated fiber then passes through a heated die, where the cross section is cured is it cleared.

So, here the section is partially shaped. And the excess resin is removed. As and when it is removed the air is also the air which is trapped is also removed, and then you move to the next stage where the die is heated and then you get the require output.

(Refer Slide Time: 07:37)

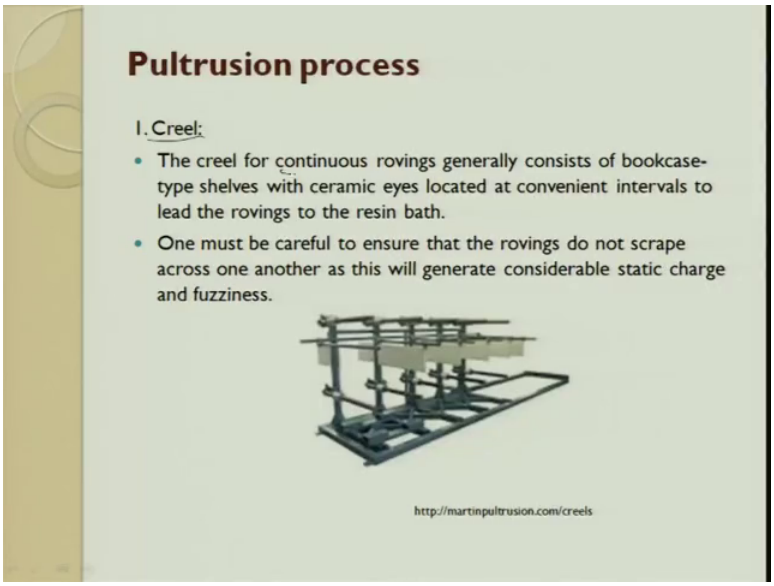


So, in pultrusion process basically consist of the following elements one is creel and the resin bath preforming fixtures matched metal die for the extrusion, then it is puller which tries to pull and then cutting saw. Cut off saw it measures a required distance and then it tries to make.

So, resin bath where you have the resin here when I talk about the resin, you will have a mixture resin hardener and you can have whatever it is. Catalyst you can also have other impregnations whatever you want to do you can also have for example, you can even or you can also have filler if you want impregnations or fillers you can add. So, preforming fixture this is what is the preforming fixture forming and curling. So this is; what is the preforming fixture matched metal die where there is a heating arrangement because as and when the fiber flows into the die and the forming fixture. So, there will be slightly heat applied because the resin should not set. So, the apply heat and the resin also they try to play little bit with the viscosity.

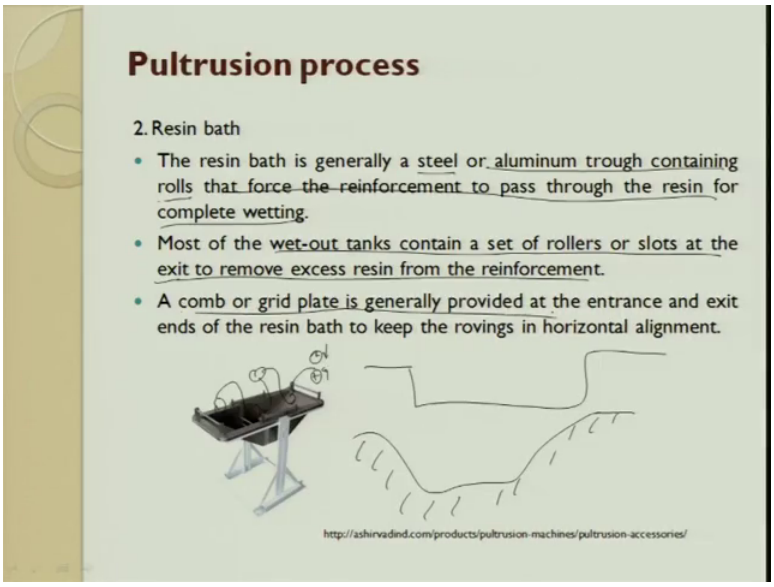
So, this is what it is. So, this is the creel a creel is a continuous roving consisting of a books casing typed shelves.

(Refer Slide Time: 08:53)



With ceramic eyes located at a convenient interval to lead the roving into the resin bath. Basically this is a place, where you stack the all the glass fibers, it can be fiber or it can be a mat roving or it can be a mat.

(Refer Slide Time: 09:11)

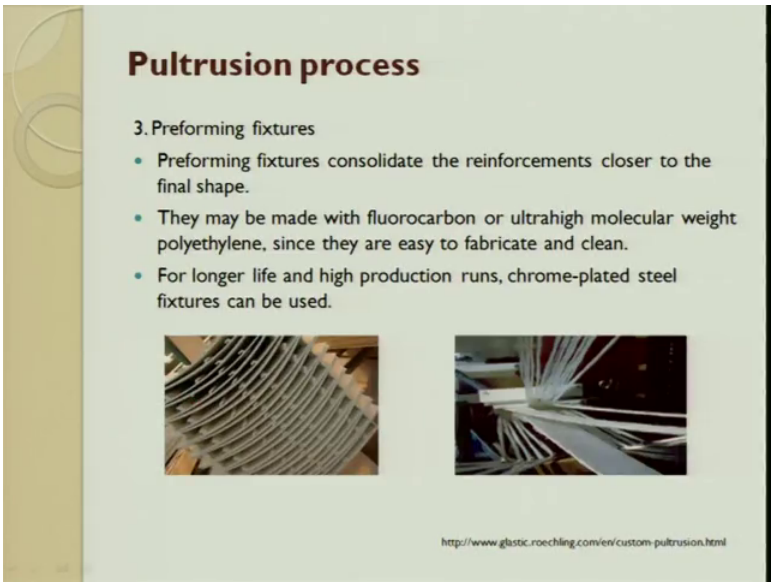


So, then this is the resin bath interesting resin bath. You look at it is never a deep trench like this. It is a gradual coming in and a gradual exit out. So, this is what is followed. So, this is what is given here also. The resin bath is generally made out of steel or aluminum trough containing rollers rolls the force of reinforcement to pass through the resin and

completely wet. So, the entire wetting process happens only in the resin bath. So, you can have multiple stage rollers going up and down and up and down. You can have such that you doubly make sure the stiffness is maintained the wettability completely happens. If one fiber in the roving is not getting wetted properly, then it might lead to a defect. Most of the wet out tanks contain a set of rollers or slots that exists to remove the excess resin from the reinforcement.

So, moment it comes out you will have 2 rollers, these 2 rollers will squeeze and try to remove the excess resin. Comb or a grid plate is provided at the entrance and exit of the reinforcement the grid plate is given here this is the comb or a grid plate. So, it makes yours that the glass fibers passes through this grid plate and then comes into the resin bath; this basically to maintain tension basically to avoid interlocking another things.

(Refer Slide Time: 10:33)

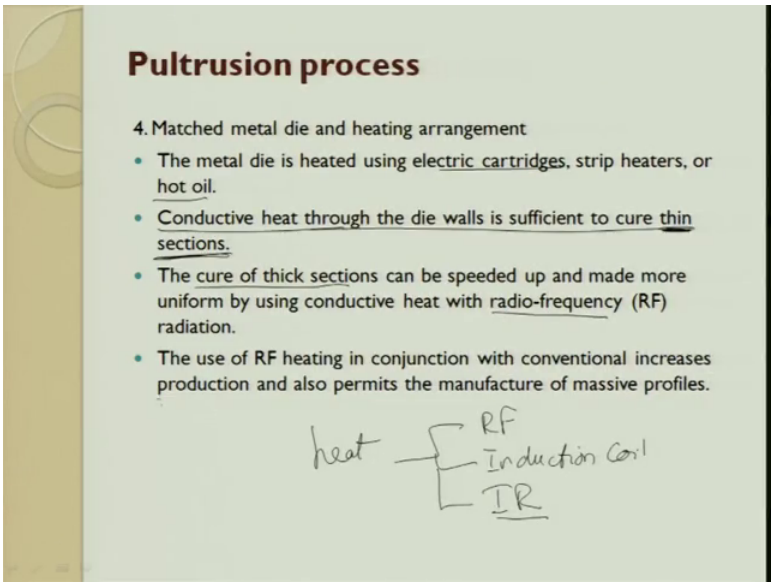


This is a preforming fixture, you can have a very close look of it tries in consolidating the reinforcement closer to the shape. You do not get the final shape in one shot. So, the preforming fixture tries to play an important role, try to consolidate what is a consolidation, consolidation between resin reinforcement between these fellows this, this does it and then you try to get a required shape. They may with fluorocarbon or ultra high molecular weight polyethylene.

So, this is the material which is used in this fixture. So, that it can be it can be it can help in cleaning and doing. So, for longer life and higher production chrome plated steels are

also used. So, this is how it is you can see here the fibers coming in, and the resin bath and then the fibers these are the fibers which goes out of it. So, you can have a chrome plated one or a polymer one.

(Refer Slide Time: 11:31)

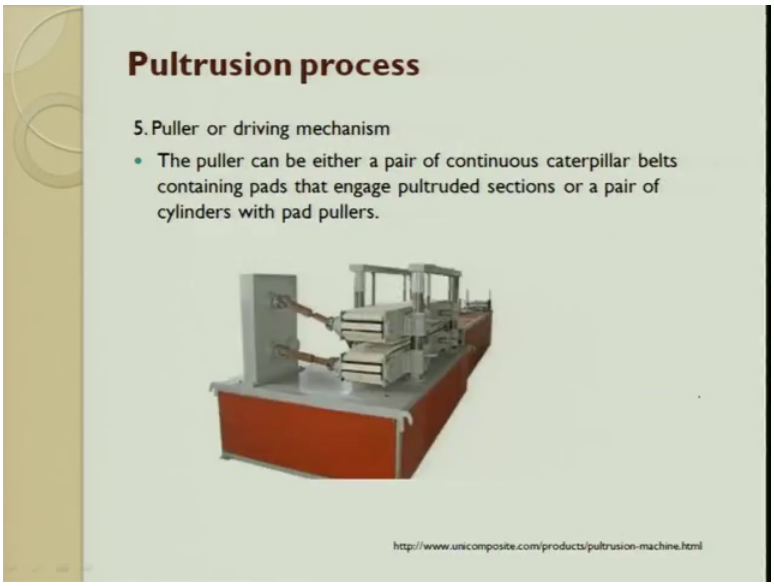


So, pultrusion process here the match, the matched metal die and the heating arrangement is given here. So, here we have to apply heat. So, heat is generally applied nowadays by RF you can apply heat by induction heating that is means to say you can put a coil. People are also using infrared heating people are trying to play with it so that you can get a better efficiency. So, the metal die is heated with electric cartridge at strips of heaters or it is oil heat oil hot oil is not is not thought of nowadays because nowadays the electric things are found to be much more efficient handling hot oil has it is own problems.

The conductivity of the conductive heat passes through the die walls and helps to a high level and make sures the curing happens. And here interestingly what is there is you are we are trying to work on thin sections also. So, in thin sections if the heat is not properly applied, it always tries to warp. So, that is one thing. So, curing of thick sections also needs to be done in a very quick fashion. So, we go for radio frequency or infrared.

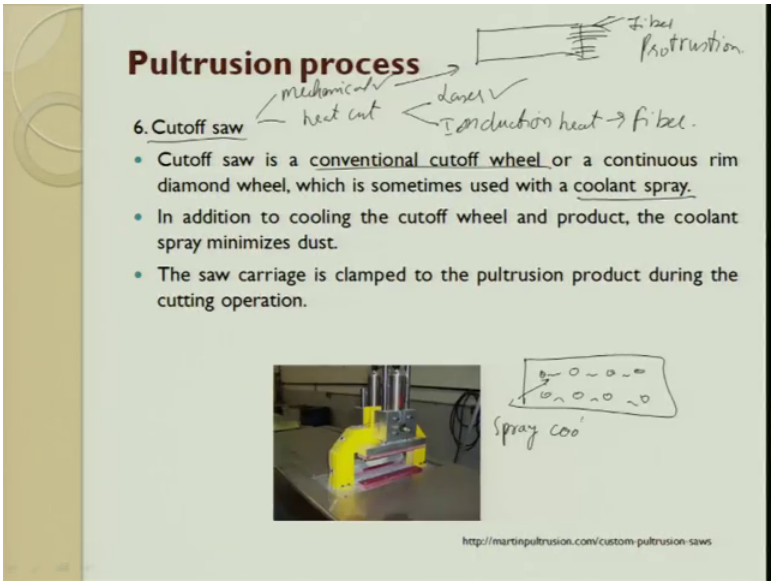
So, the use of is in conjunction with the convectional increase of productivity and permits for a massive profiling.

(Refer Slide Time: 12:55)



So, this is the pultrusion mechanism, you see here there is this is a roller. And here you it is not a roller it is a it something like. And endless belts which keeps rotating and here this tries to roll and it tries to pull, pull in. So, puller or a or a driving mechanism the puller can be either a pair of continuous caterpillar belts containing pads that engage in pultrusion or a pair of cylinders with pad pullers. So, these are pad pullers. So, what type assignment it rolls? There if the glass fiber is coming if the roving is coming through this direction it will try to maintain a tension and it will try to pull it and then go.

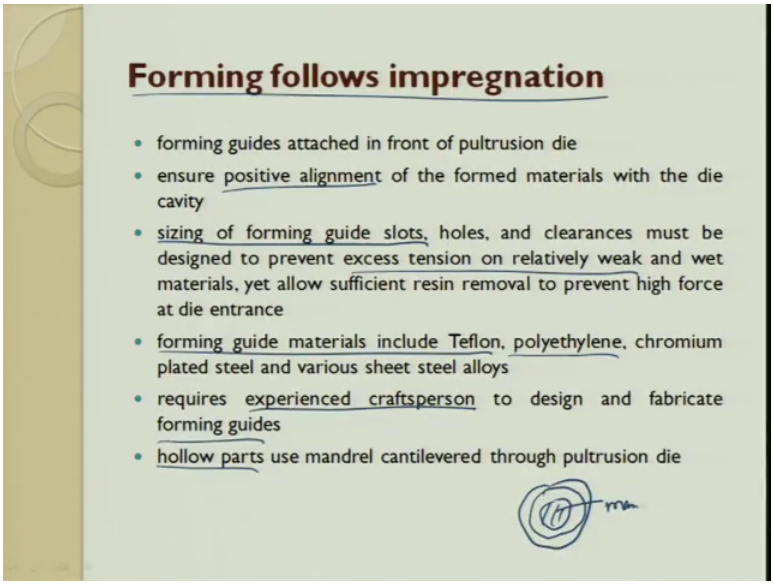
(Refer Slide Time: 13:39)



This is a saw. So, this saw can be 2 types it can be mechanical type you can have a saw to cut or you can use heat to cut. So, heat to cut again it can be laser you can use for cutting, or you can even apply induction heating, but induction heating induction heating the only one thing you should understand is cutting of fiber becomes a challenge. So, we always prefer this or we prefer this. In this also what happens is you if you if this is the object. So, either this will be the protrusion of fiber, these are fiber pultrusions protrusions. If we do not have a proper sharing mechanism, we will have these protrusions which are coming out which will (Refer Time: 14:26).

So, today laser is used exhaustively which can very easily go cutted. So, it is a conventional cuttings of wheels are used. So, we will be use coolant, but we should be we should keep in mind moment, we have matrix and we have fibers. These are fibers, and if there is any small amount of cracks or defects or delamination is there moment you spray water. Spray water, spray coolant which is water based then what happen there is a hydro hydroscopic effect.

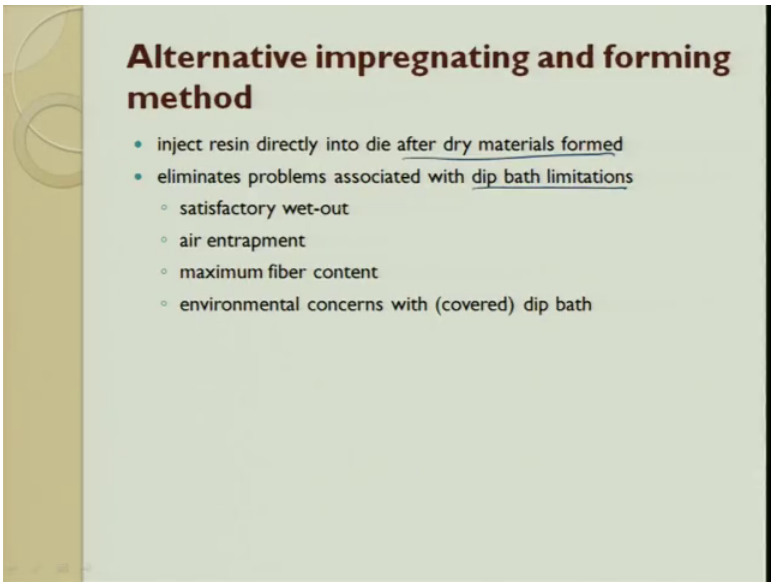
(Refer Slide Time: 15:06)



Then forming follows impregnation. So, here the forming guides attached in the front of the pultrusion die. The ensures positive alignment positive alignment is very important of the form material. The sizing of the forming guides slot guide slots holes clearance must be designed to prevent excess tension or a relative to weak points. Then forming guide materials includes teflon all these things. They requires experienced crafts men for

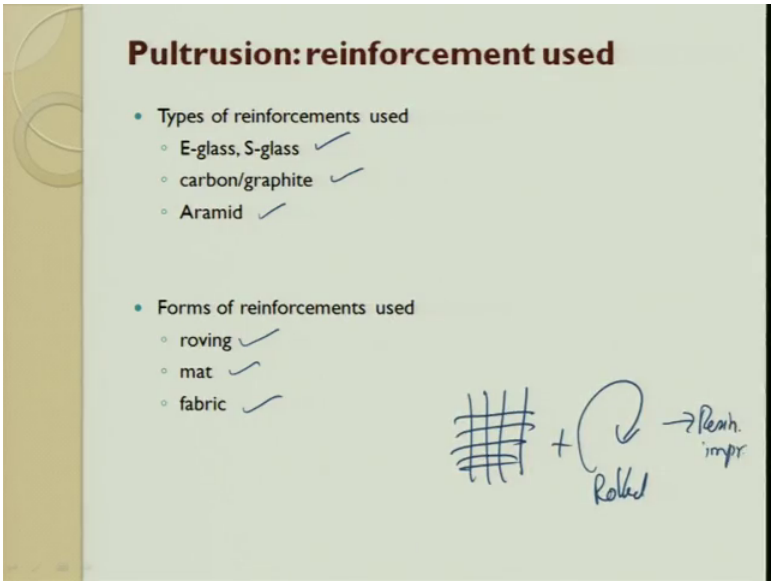
designing and fabrigation a forming guide, hollow parts uses mandrel in between. So that means, to say you will have a die you will have this will be the mandrel. This will be the mandrel, and the fiber flows through this out. So, this is a die outer surface.

(Refer Slide Time: 15:55)



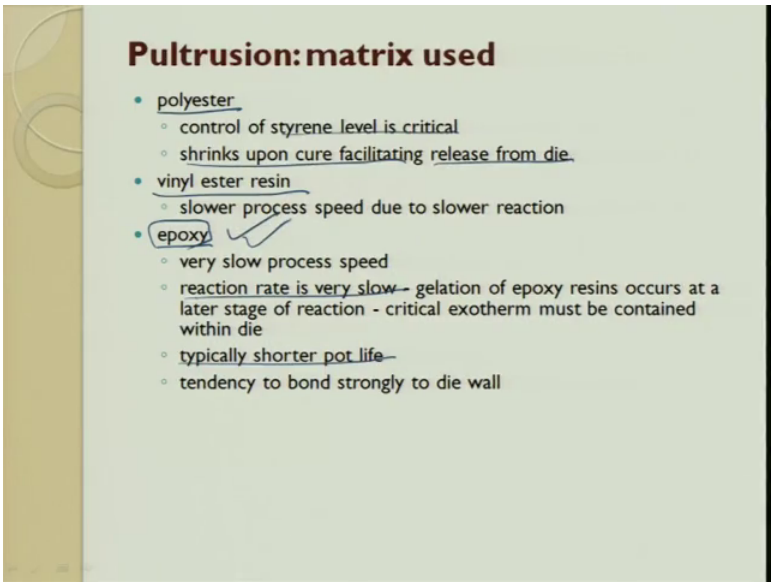
So, alternative methods for impregnating and forming method is inject resin directly into the die after dry material is formed, eliminate problem associate with dip bath the limitations it satisfactory wet out air entrapment is less and then maximum fiber content can be done. And environmental concern also can be taken care with the dip.

(Refer Slide Time: 16:19)



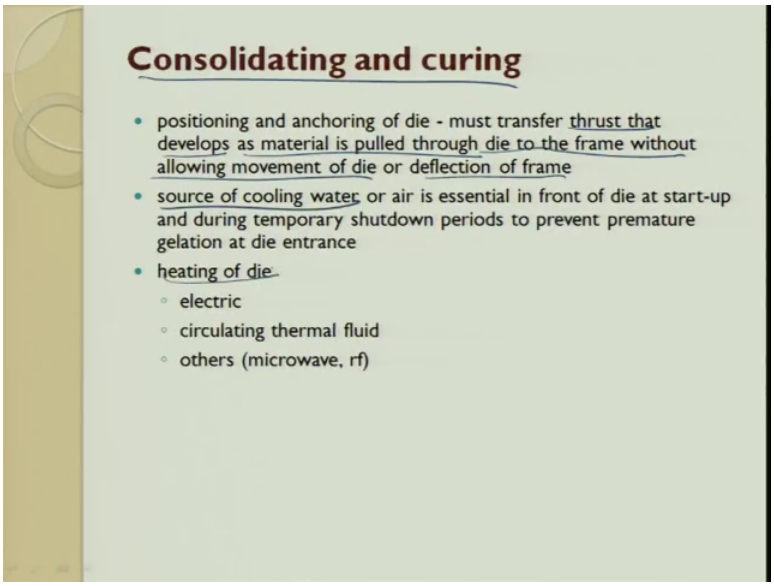
So, pultrusion reinforcement it can be a e glass fiber s glass fiber carbon fiber or kevlar fiber. The form of the resin can be roving can be a mat can be a fabric also. So, fabrics is a fabric whichever is there, it will be rolled it will be rolled. And then you will try to give the resin impregnation.

(Refer Slide Time: 16:47)



So, the matrix use polyester vinyl yester and epoxy these are the common resins used. But the most common among the lot is epoxy. Epoxy is a very slow very slow process, then the reaction rate is very slow. It is it has a shorter pot life, but since it is liquid starting form and there is a huge strength people always go for epoxy poly ester controls with a styrene level is critical shrinkage upon the curing facilitating release from the die is also there epoxy is the most commonly used matrix for making this pultruson process.

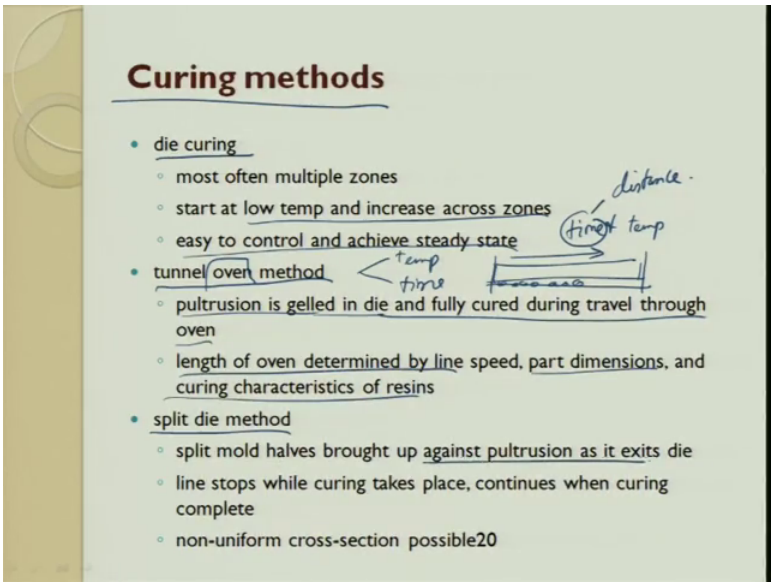
(Refer Slide Time: 17:26)



So, consolidation and curing the positioning and anchoring of the die: die is very, very important must transfer thrust that develops as material is pulled through the die to the frame without allowing movement of the die or deflection from the frame. So, this is very, very important. I repeat must transfer thrust that thrust that develops as material is pulled through die to the frame without allowing movement of die or deflection of the frame. Basically what we are trying to say is without making the die move even a few die to get to deflected we are trying to position and anchor the die.

So, the die has to be very, very tightly and very, very properly positioned. Then the source of cooling is also done and the source of heating the die is also done. This cooling and heating follow the same thing of your injection molding process.

(Refer Slide Time: 18:25)



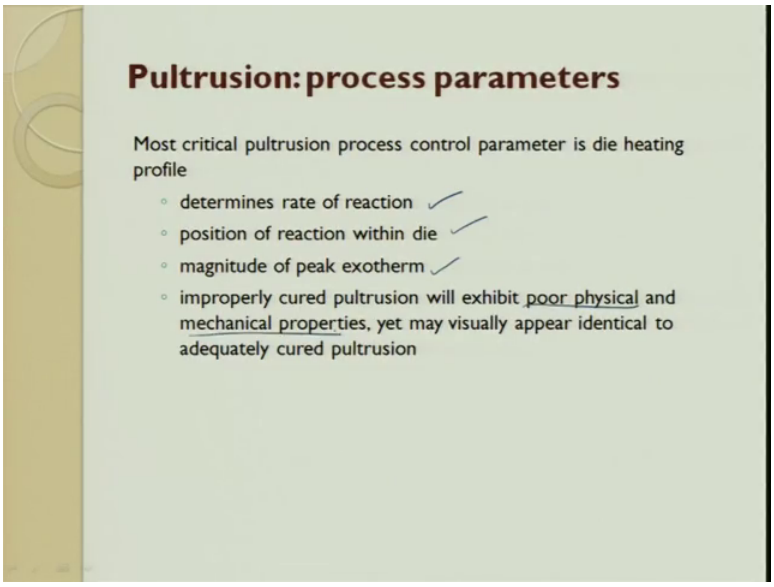
There are curing methods, if there can be a die curing that can be tunnel oven method there can be split die method. Die curing is at multiple zones in the dye itself we try to cure it. So, here starting at low temperature and the increases across the zones, and then we try to increase easy to control and we and achieve in a study state. When you talk about tunnel oven method the pultrusion is gelled in die and fully cured during the travel through the oven.

So, it is nothing but like a pizza whatever happens you pass through a heating pan. So, in the same way here pultrusion the tunneling oven; so the oven which is used for even in pizza; so we have a oven. So, in the same way what is that oven does oven has 2 things one is temperature another one is time. So, as and when it moves the component moves it takes certain time. So, you control the time period here and also you try to control the temperature. So, time and temperature is controlled a time in turn is control you by distance.

So, that is why you see in pizza you will always have a oven which is which runs along a length and it will be a endless conveyor belt which keeps rolling the same way we can do here. So, the pultrusion is gelled in die and fully cured during travel through the oven the length of the oven determined by line speed part dimensions and the curing characteristics of the resin. You can also have something called as a split die method, the split die mold halve brought up against the pultrusion as it exits the die.

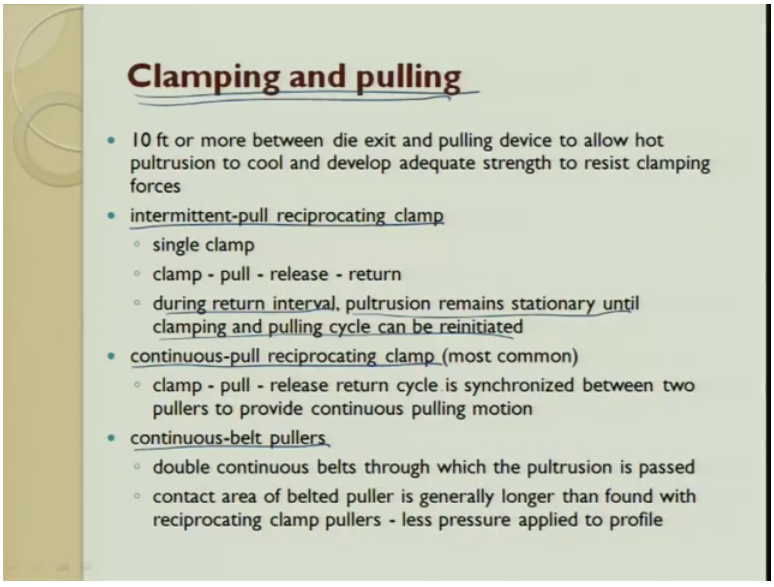
So, this is another thing which is also possible.

(Refer Slide Time: 20:08)



The process parameters which are involved the most critical parameters is the rate of determines the rate of reaction. The position of reaction within the die that is very important magnitude of the peak exotherm because as and when it is curing there will be a heat release improper cure pultrusion will exhibit poor physical and mechanical properties which visually might look, but when put on service condition might fail early. Clamping and pulling.

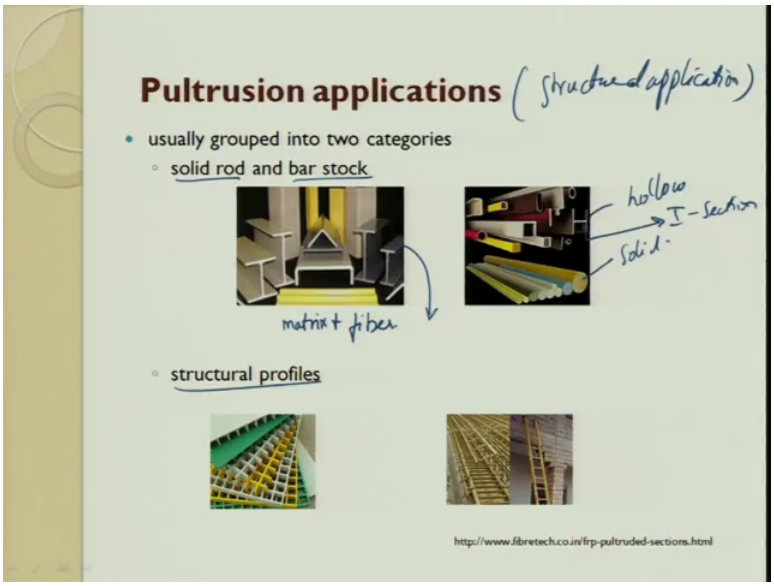
(Refer Slide Time: 20:37)



So, the clamping can be here the pulling can be intermediate pulling, which is reciprocating clamp continuous pulling reciprocating clamp continuous belt puller is also there. So, here there is a single clamp the clamp pulls through a pulls and get released enters, and then it also has intervals during the return interval pultrusion remains stationary until the clamping and pulling cycle can be reinitiated.

So, these are basically different types of pulling techniques which are used in the shaft floor to produce a good quality output. Continuous pull reciprocating clamp, here the release return cycle is synchronize between the pulling pullers to provide a continuous pulling. So, that is what we said if you go back and see here this diagram, here I said this is; what is the 2 things, which are getting pulled in a regal with the proper tension. And so, that you get a good output.

(Refer Slide Time: 21:44)

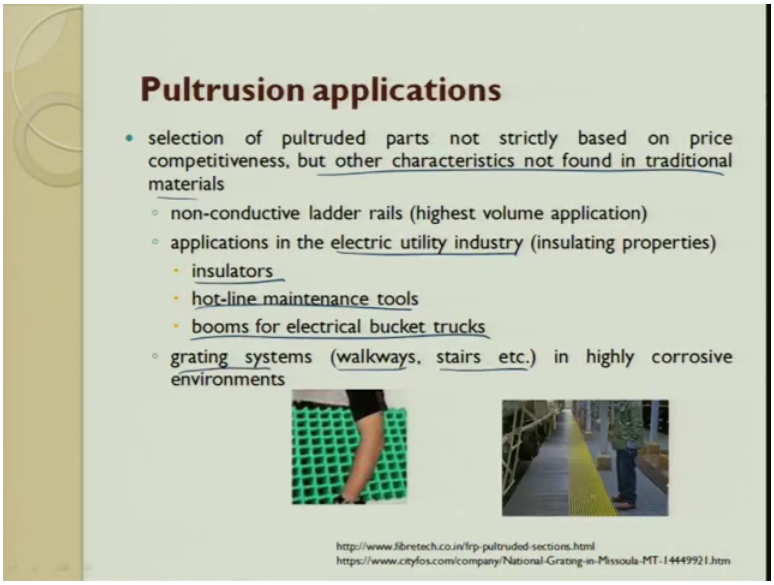


So, these are some of the components you can see. So, you can see here a solid, you can see here hollow, and interestingly you can also make eye sections. Through this pultruison process which is very wonderful. So, all these things are now a days used for structural applications. So, structural application means, this can be a load tag carrying member it can be a load carrying member structural applications can be done. So, usually there are grouped into 2 one is solid rods, solid rods and bar stocks. The thing other thing is you can also make structural profiles out of this.

So, you can make structural profiles. So, you can extrude whatever can be done by extrusion process can also be done, but the only difference between that is here you will have matrix and fiber. So, there it will be only matrix. So, here it will it can go for high strength, and it looks here what does that this things can be all on top of the polymer you can also give a metal touch. So, then it looks like as though it is a metal aluminum channel, but it is made out of composites pultrusion process and you get the output.

So, this can be made, this can be made, and these stocks can be made.

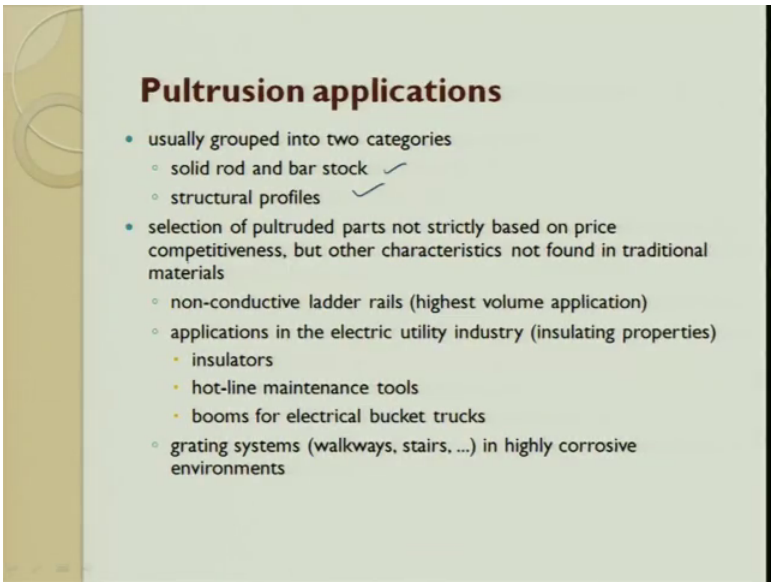
(Refer Slide Time: 23:10)



So, section of the pultrusion part not strictly based on the price competitiveness, but the, but the other characteristics not found in the traditional can be done. So, if you want to make a nonconductive ladder rail. So, it can done you can have an application in electrical utility industries. We can have insulators made out of it hotline maintenance tools can be made booms of for the electrical bucket trucks can be made gratings can be made like walk walkways stair case etcetera.

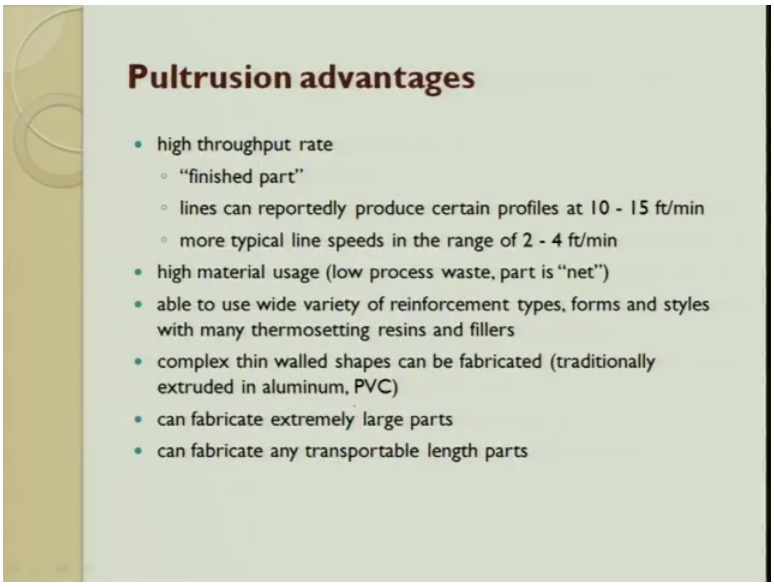
So, these are things are nowadays are nowadays made out of pultrusion process.

(Refer Slide Time: 23:49)



So we have already seen these examples. So, it can and all these things also we have seen; so where ever you would like to have continuous production process. So, there we would try to have this pultrusion process.

(Refer Slide Time: 24:03)

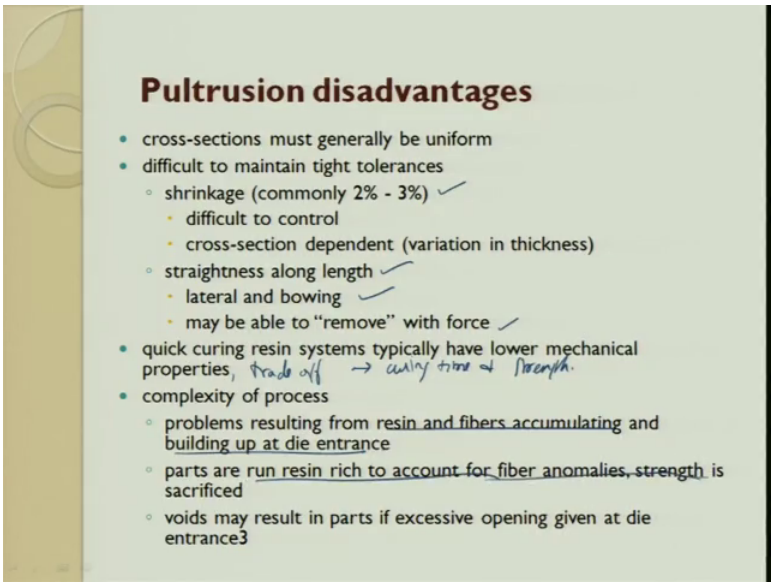


So, it is it advantage it has a very high through put, because if you initial set the process then if we have a constant die you keep on pulling. So, here the products can run to several meters, several meters. So, the lands are reporting certain profile to 10 to 15 feet

per minute for a typical line speed of 2 to 4 feet per minute. So, those of who do not have a feel for a feet is nothing but a 30 centimeter is one feet.

So, it has high material usage. So, there is low high material usage means; that means, to say we are there is less amount of scrap, which is getting produced. And whatever you produce here is final product there is no other secondary process done on it. So, you can do it on a variety of reinforcement type depending upon the forms style thermoset everything. Then commonly thing walled shapes can be fabricated can fabricate extremely large parts can fabricate any transportation length part also transposable length parts also can be made out of this pultrusion process.

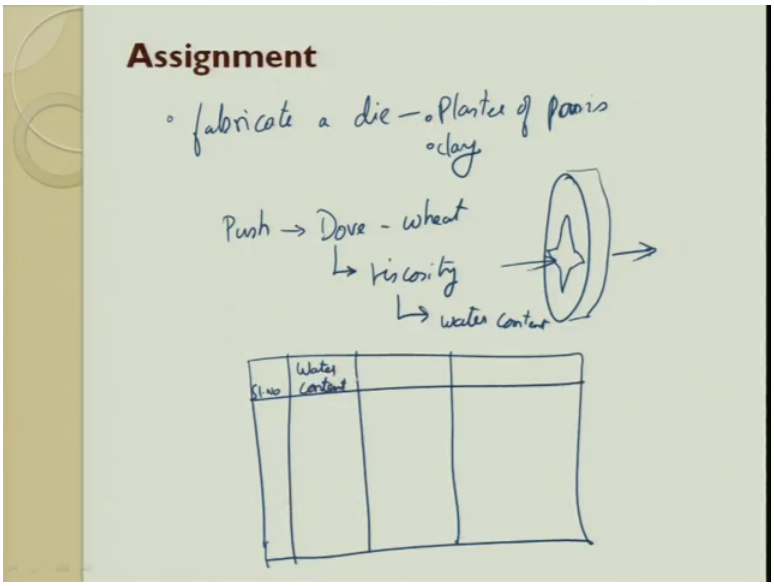
(Refer Slide Time: 25:04)



So, the shrinkages commonly is only 2 to 3 percent. The straightness along the length the lateral and bowing to a large extent can be controlled. Because of the reinforcement percent may be. So, this can be taken for heavy thing the quick cure resin system typically has a lower mechanical property. So, you have to have a tradeoff between the between here in time and strength.

So, the complexity of the process is resin fiber. So, we have to make sure the wettability comes, and the die entry point is one more thing and then the parts of their run resin rich account for the fiber. So, it is like agglomerations anomalies strength on this strength is done.

(Refer Slide Time: 25:55)



So here assignment part of pultrusion what I would like to do is try to try to fabricate a die, which can be made out of plaster of Paris, plaster of Paris. Or you can take clay you make a die. And through this die you try to push, you try to push say for example, you have this is a die. So, you have made some cross section whatever it is star or right. And then what you do is through this die you try to push a dove which is made out of wheat ok.

So, this dove what you do is you change the viscosity of the dove. How you keep changing the water content? And you keep pressing it right. After you do you get an exit out? So, whatever exit you get. So, then what you do is you try to make a table. So, what you do serial number one. So, what is the water content water content? And then what you do is you try to measure you try to have a strength feel, and you also try to see the shrinkage. So, one more column you can open with respect to time.

So, serial number one, water content whatever say for example, 10 percent. So, strength again you can take it in terms of qualitative, it you can say less or more whatever it is shrinkage align less or more you can see. And then time you can say after 10 minutes 20 minutes 30 minutes what happens to the same component. So, with this what will you try to have is you will try to have something an experience with respect to viscosity what will be the pressure applied. And with water content what happens to shrinkage. And

then you will try to see; what is the performance of the product in terms of understanding.

With this we will try to complete. So, in this lecture what we saw was pultrusion process pultrusion is nothing but pulling plus extrusion of a glass fiber which is immersed which passes through a resin and gets coated.

Thank you very much.