Manufacturing of Composites
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Lecture – 15
Thermoplastic Composites Manufacturing Processes: Tape Winding, Pultrusion and Thermoforming

So, welcome friends, this is lecture 15. So, till now in this course we were seeing basics of composites different types of a fabrication of composites as far as thermoset resin is concerned. For the next 2 to 3 lectures we will be seeing more details on thermoplastic manufacturing of composites. Though this is very challenging and it has not come up in a big way like thermosets. There are processes, but we will try to see some of these processes for our understanding. So, the lecture will flow like this the content will be there content is thermoplastic composite manufacturing processes.

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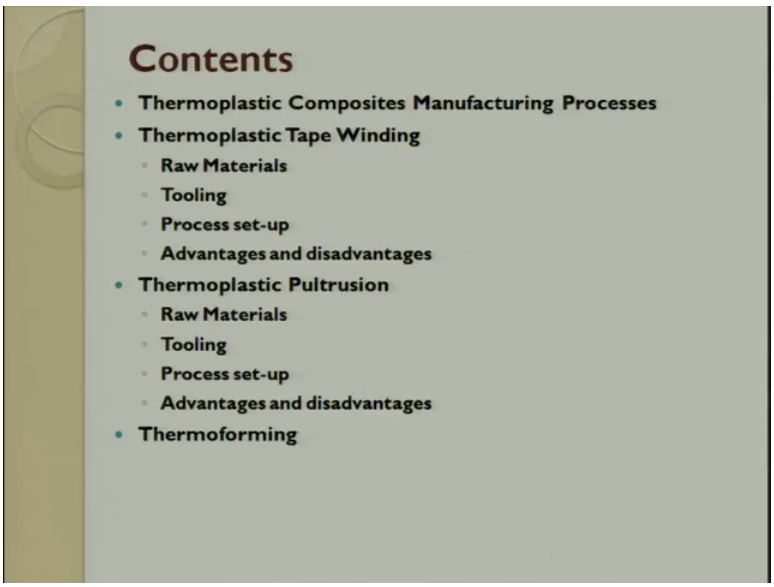

So, we have taken 3 processes in this lecture. Tape winding process, then we will see pultrusion process and the last one is going to be thermos forming process.

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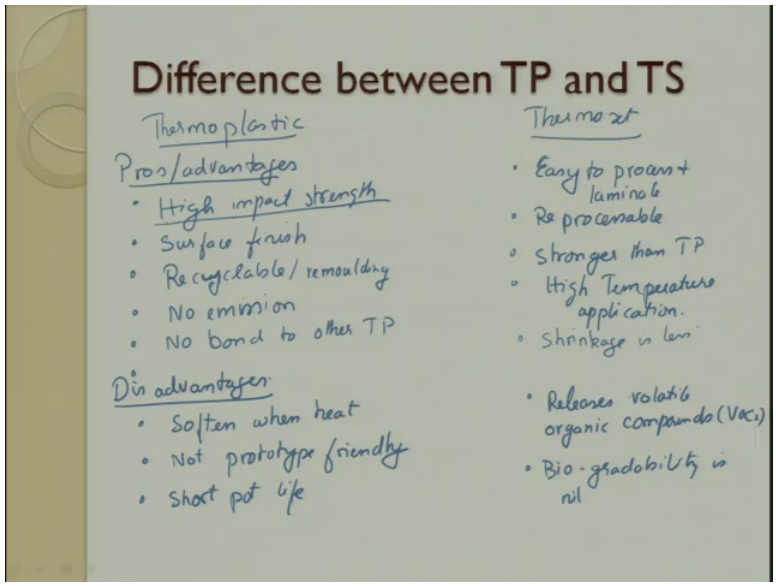

Before getting in to the manufacturing process we will quickly rebrush the difference between thermoplastic plastic as well as thermoset matrix is concerned. So, thermoplastic and thermoset, so some of the prose or if advantages and some of the disadvantages. So, we will see the advantages first and then we will see the disadvantages. So, thermoplastic it can with stand very high impact strength very high impact strength right. It can give very good surface finish. Then it is recyclable cyclable. It is recyclable then we have no emission while fabrication is concerned, it has it has no bound to other thermosplasts. And the last one is it recyclable. So, recyclable or I will put it as remoulding here itself remoulding or reprocessing whatever it is.

So, here as far as thermoset is concerned, it is easy to process this is a biggest advantage which is not there comparatively which is not there with thermoplastics, it is easy to process. And it can easily be made into several laminates right. The next thing is it is not reprocessable, it is not reprocessable. So, if it if you heat it once and try to get her a final shape and then the next time it is going to (Refer Time: 03:41)

The next thing is it is typically it is stronger than TP keep this in mind it is strength wise stronger than TP. But thermoplast has impact resistance more. So, it is then it is suitable for it is suitable for high temperature applications, high temperature applications it is suitable where in which thermoplasts are not so. And here you should understand there is

emission which there is no emission which comes out here in thermoset as and when it is getting cure, many a times it evolves gases which are toxic to operator and mankind.

So, what are the disadvantages? What are the disadvantages? The first disadvantages it will soften when it is heaten, it is soften when heated. This is one of the big disadvantage. So that means, to say this cannot be used in high temperature of applications. It is it is not prototype friendly not prototype friendly; that means, to say you should minimum have some basic die or something to make a product, because here we will work on high pressures and temperatures. So, we need to have some devices or aiding devices to make a product. So, it is no way prototype friendly and it has a very short pot life; that means, to say it cannot stay in a semi viscous state for a very long time. Whereas, here the disadvantages are it is it often releases it releases something called as volatile organic compounds, which we call it as VOCS which is very, very dangers, and it is no way bio friendly. So, it is bio degradable degradability is nil, is nil.

So, these are the advantages and disadvantages of thermoplastic and thermoset composites right. So, this you should keep this in mind, because when you keep this in mind only you can start seeing which process to choose and how do we want to go about. And the most important thing is it has very high impact strength that is why you see majority of the covers or the closures are made out of thermoplasts, thermoplasts has very high impacts strength it can withstand. For example, your baggage your luggage bag. So, it is all made out of you know thermoplastics say we use ABS to make. But here in this thing you have we have missed out one more point here the shrinkage is less as compared to that of thermoplast. So, thermoset shrinkage is less and it is easy for making small prototypes.

So, you should keep this in mind. So, next let me list down some of the some of the, some of the different types of thermoplast and thermoset materials.

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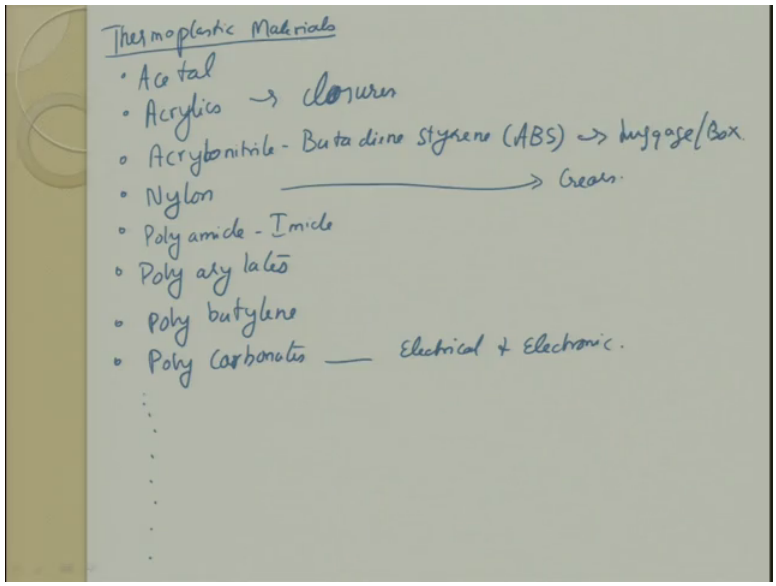

So, the thermoplastic materials. Let me just list down all the names so that you can you can feel little comfortable. So, thermoplastic we can have acetal you can have acrylic, you can have acrylics, you can have acryo nitrile buta diene styrene, so this nothing but ABS. You can have nylon. So, if you see you can see nylon, first let us me list it down nylon. For example, you can have poly amides poly imides. So, you can also have citrane, and then you can have poly butadylene you can have, and then you can also have polycarbonates. These are so, you can have many more to go. So, for example, nylon you can think of making gears right. And poly carbonates you can think of having electrical and electronic electrical and electronics applications you can try to have based on these materials.

So, like this you can have so many so many materials which are for thermoplastic. Thermosets we have already discussed. So, I do not want to get into more details. So, these are some of the few acetal, then acrylic. Acrylic is used for making closures and then ABS for luggage box or boxes for transportation and other things. So, these are some of the examples of thermoplastic materials.

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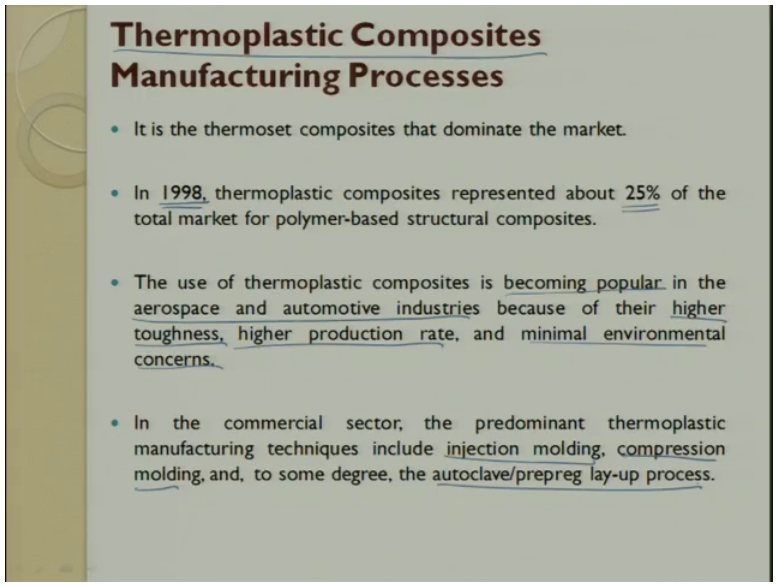

So, thermoplastic composites came into market somewhere close to 1990's only. So, around about 1990's they were having only 25 percent of the market requirement, was taken by thermoplastic composites. Why because, thermosets where doing fiber people were we were happy with the usage of it people were happy with the benefits which they got from thermoset composites. But after 2000, when the when the environmental norms became stringer and stringer and stringer, now there is a huge requirement to move towards thermoplastic composites. All the automobile big giants aerospace big giants are moving towards thermoplastic composites. Today the entire bumper of a car which was earlier made out of thermoplast, now they are made out of thermoplastic composite materials.

So, slowly it is getting more and more important, and people feel the need of it. And there is also an environmental push for going toward thermoplastic because of it is re process ability. The thermoplastic composite is becoming popular in aerospace and automobile engineering because of it is higher toughness, then higher production rate and minimal environmental concerns. These are the things 3 things which are pushing very hard to get into thermoplastic composites. So, aerospace and automobile are a big giant industry they slowly push and then rest of the market follows. Then in the commercial segment, the predominant thermoplastic composites include injection moulding compression moulding and autoclave and prepreg layup is also there.

So, prepregs is also there with thermoplastic prepregs are coming into the market today.

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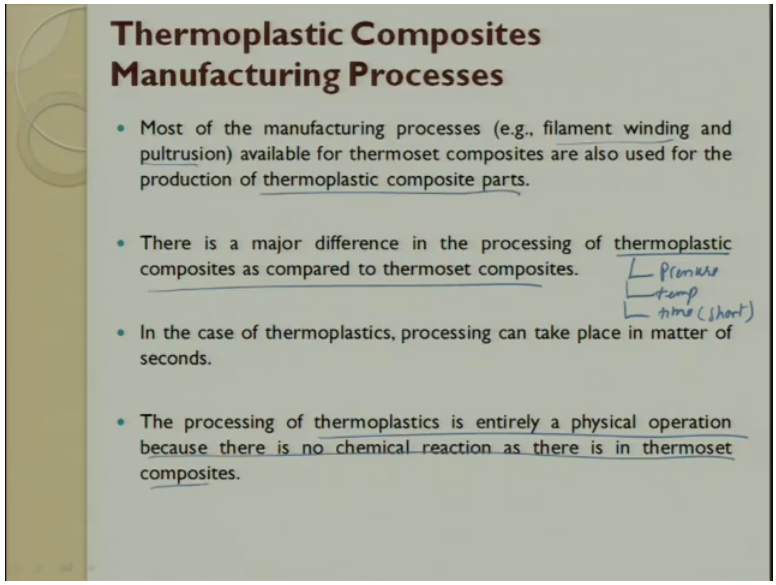

So, most of the manufacturing process filament winding and pultrusion available for thermoset. Composites are now thought of slowly getting tweet to meet out the requirements of making it into thermoplastic composite materials. There is a major difference in the processing of thermoplastic composite as compared to thermoset. So, we have pressure, we have temperature an then we have time. So, all the 3 parameters has to be properly controlled such that you get to the final requirement. In thermoset majority of them are liquid in states. So, you can try to play with it the pressures need not be high the temperatures, also here you can play little bit up and down and then get it. In thermoplastic time what I am talking about is too short so that means, to say they will try to get the entire output the finished product within couple of seconds or within a minute something like that. So, this makes a huge difference in the process.

So, thermoplastic is entirely a physical operation because there is no chemical reaction as compared to that of thermoset. That is why I said vocs are not there in thermoplastic composites.

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So, some of the major processes which are gaining importance today. Still lot of learning is going on the process have not still optimized. So, the thermoplastic tape winding process is one thermoplastic pultrusion process, hot press technique, autoclave processing, diaphragm processing, forming process and injection moulding are some of the processes which are gaining importance. It is still in research there are few industries which are doing of tap winding process there are few industries which are come where in which they make huge products.

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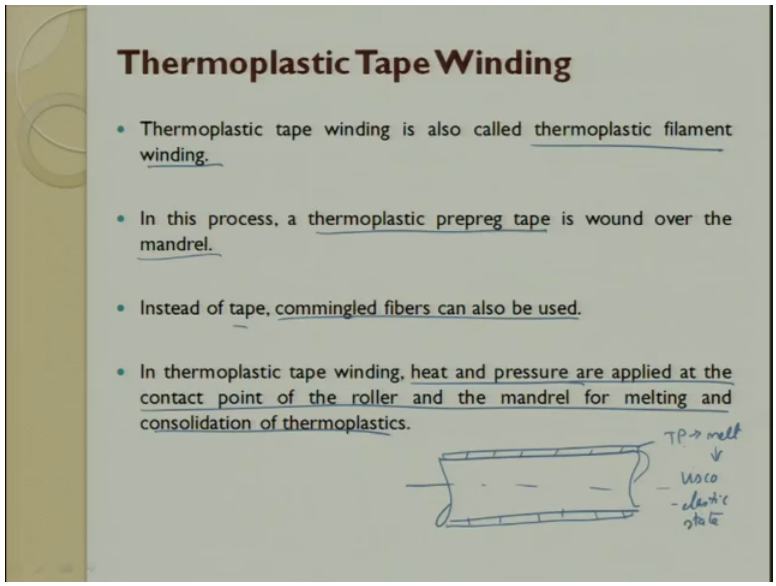

So, tape winding process. In thermoplastic tape winding process is also called as thermoplastic filament winding process. The names people are trying to use it as thermoplastic filament winding process. In this process the thermoplastic prepreg tape what is prepreg where in which the resin is infused in the reinforcement and it is available to use is bound around a mandrill. Just like you have got hurt and you put a tape gauss around your wound. So, it is something like that they put a mandrill and top of the mandrill they try to wrap it with prepreg tape so that they can meet out the requirements.

So, instead of tape here fibers can also be a complement fibers can also be used to get the required output. The tape after the winding is heated and pressurized and pressures are applied at the contact points of the roller, and the mandrill for melting to happen and the consolidation of thermoplastic happens. So, you have a mandrill to be done. So, this is a mandrill and on top of the mandrill you try to wind tapes and this tapes can be bound again with any direction you want. And after you wind so, this is a prepreg. So, it has thermoplastic resin. So, this resin has to melt. So, here it is not melt means it is not go to liquid state it goes to viscoelastic state visco, elastic state it goes to a viscoelastic state so that it goes to so that it gets the required viscous nature and then it tries to join very well with the fibers.

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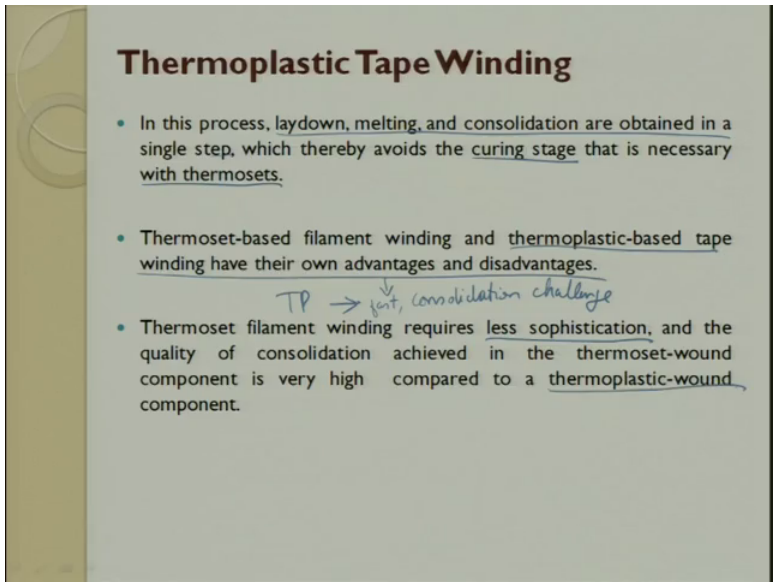

So, in this process a lay down a laydown melting and the consolidation are obtained in a single step. So, this avoids curing stages like a thermosetting process, so that is what I said. Thermoplastic processes majority of the processes are one shot process quick processes you get the required output. The thermoset filament winding process and thermoplastic based tape winding process have their down advantage and disadvantages. So, here it is fast thermoplastic is fast, but consolidation is a challenge consolidation is a challenge is a huge challenge consolidation as far as thermoplastic composite is concerned. So, the thermoset filament winding process is less sophisticated. So, we can get it done much faster even a ordinary late machine you can start using it. If you start pushing the or if you starting weighting the fiber and then pass it through a tool post on the mandrill you get a output, but as far as thermoplastic is concerned it needs slightly higher sophistication.

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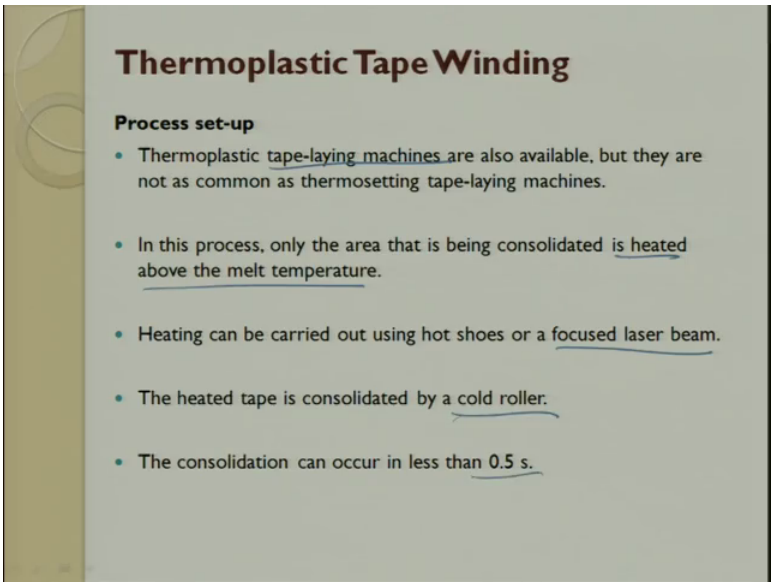

So, what are the process setup? So, the lay up the tape laying machine are available today you have 5 axis tape laying machines today available. So, the tape keeps doing. So, if you want to do a very large surface area you can still go head a tape laying machine keeps laying it on the mandrill or on the die so that you get the required output. Then the heat is applied for consolidation, then you try to you can heat it by 2 sources you can heat either by focused laser can be done; that means, to say at selective areas you want to heat you can heat it or you can heat the entire thing. And then it is also finally, it is consolidated and then you get the output at point 5 seconds you get the consolidation and then you get the required output.

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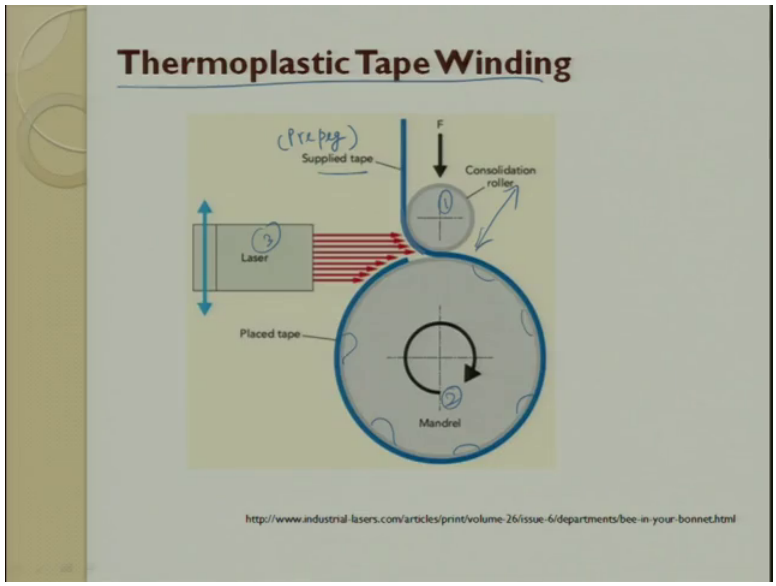

So, this is how it is. So, you have the tape which is coming. So, this is the tape this tape is prepreg. So, it is a prepreg where in which it has a thermoplast matrix, and you have glass fiber reinforcement. So, this done and then a roller is used to consolidate this is the mandrill which I am trying to talk about, this mandrill it can you can have cylindrical you can also have some grooves whatever it is on your on your mandrill, and still you can get the required output. But you have to play little safer so that you get the required output. So, mandrill is there. So, here it is placed the placed tape keeps going and then you keep.

So, if you can move this in this direction, if it is a small roller you keep moving it in this direction so that you get the required output. At this stage exactly there is a laser which is heated. So, this laser tries to change the viscoelastic change the behavior from solid to semisolid; that means, to say a viscoelastic state and this viscoelastic state there is a tension maintain and then you start wrapping it around. So, this process is called as thermos plastic tape winding process. It is very similar to that of thermoset filament winding process, but the only difference here is matrix. So, this matrix play a very, very important role.

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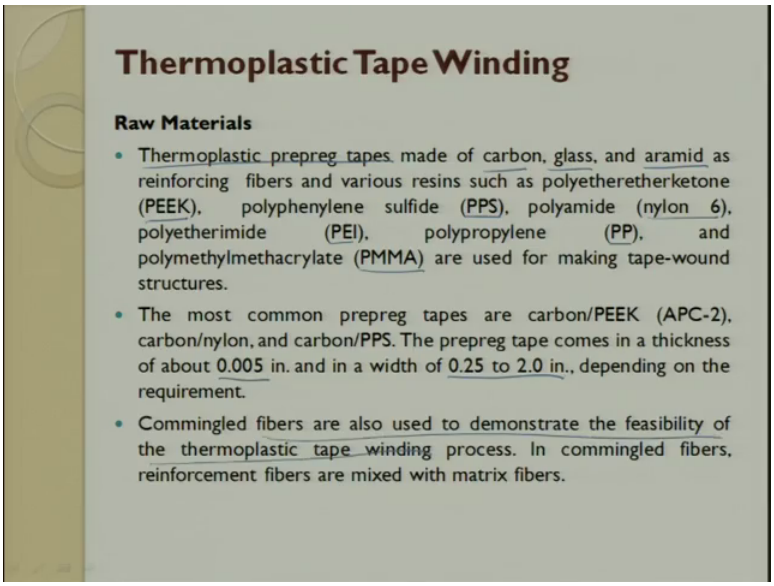

So, what are the possible prepregs in thermoplastic tapes which are available? So, you can have a carbon fiber you can have glass fiber, you can aramid or kevlar fiber and the varying reinforcements war peak can be one depending upon your temperature depending upon your strength, depending upon your fiber. We use we can choose peak, we can choose PPS, that is poly propelenes sulphide. And then you can use polyamide which is nothing but nylon can be used. You can use poly ether amide PEI, you can also use PP poly propelene, and you can also use PMMA.

All these tapes are available today. So, the tapes are available at a thickness of 0.5005 inch and the width is this. So, you if you want to play with the width you can also keep going around so that you get the required output. So, the fibers are also demonstrated the feasibility of thermoplastic tape winding process. So, there are lot of things which are coming up so that you get the required output. Tooling, so if you go back to the figure you see the tooling what is tooling is you need a roller. So, you can also have serrated rollers to maintain attention or you can have a flat roller. So, there will be lot of friction. So, you balanced it around and then try to choose it. So, this is one. So, this is one tool, this is second tool and the third one is heat. So, you can also use a you can also use an induction coil, you can also use infrared you can play with the heat source. But laser gives a better control it is coherence. So, you get a better control to get the required output.

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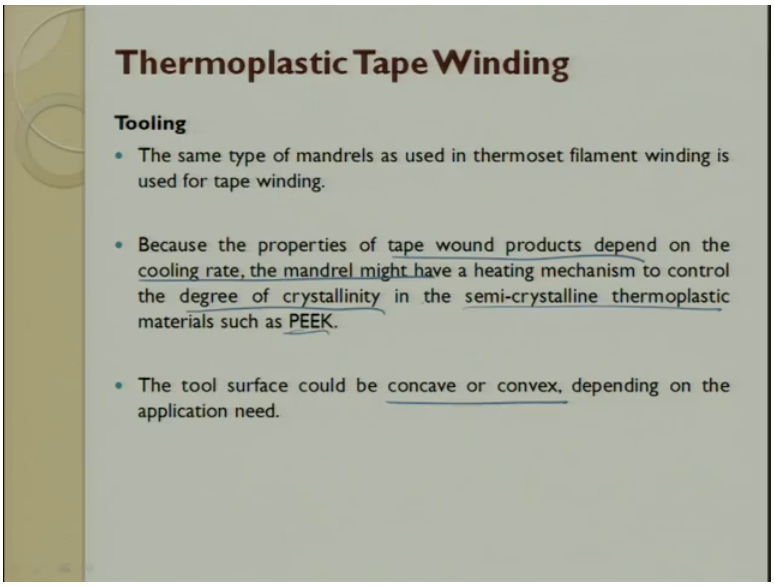

So, the same type of mandrill can be used whatever it is. Then the properties of the tape wound around depends upon the cooling rate of the mandrill right. Because heating and cooling is very, very important because if you change the heating property and the cooling property, we can change the degree of crystallinity. So, if you can change the degree of crystallinity, then the property changes so that is what we have written. Here because of the property of the tape wound products depending upon the cooling rate the mandrill might be heat might have a heating mechanism to control the degree of crystallinity. In the semi crystalline thermo plastic such as peek.

The tool surface can be concave or convex depending upon the requirement. So, here heating of the mandrill is very, very important. If you want to have a property. So, for peek we have this.

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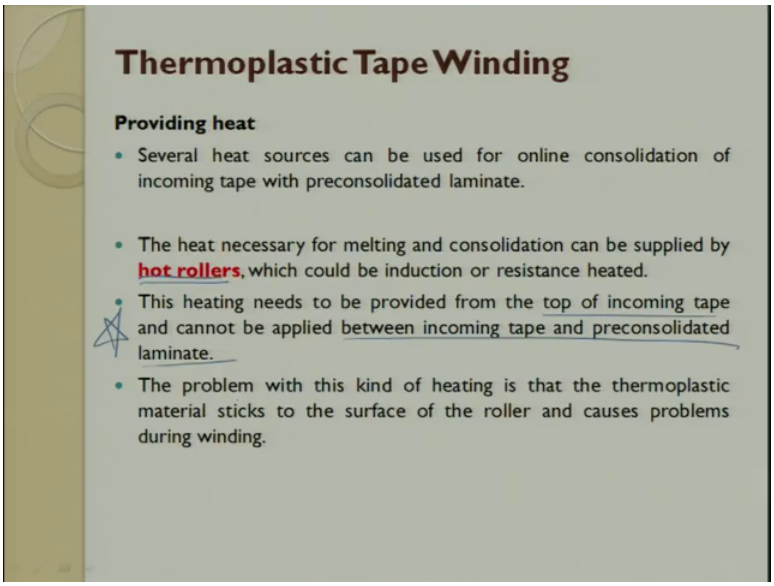

So, then providing heat as I told you it can be through it can be through whatever it is. Then you can also use a hot roller for doing it. This heat needs to provide on the top of the incoming tape and cannot be applied between the incoming tape and the pre consolidated laminate. So, keep this point in mind. The heat needs to be provided from the top of the incoming tape and cannot be applied between the incoming tape and the pre consolidated laminate. So, this is very, very important ok.

So, we use hot rollers. So, here I have written the problem with the kind of heat is that a thermoplastic material sticks to the surface of the roller.

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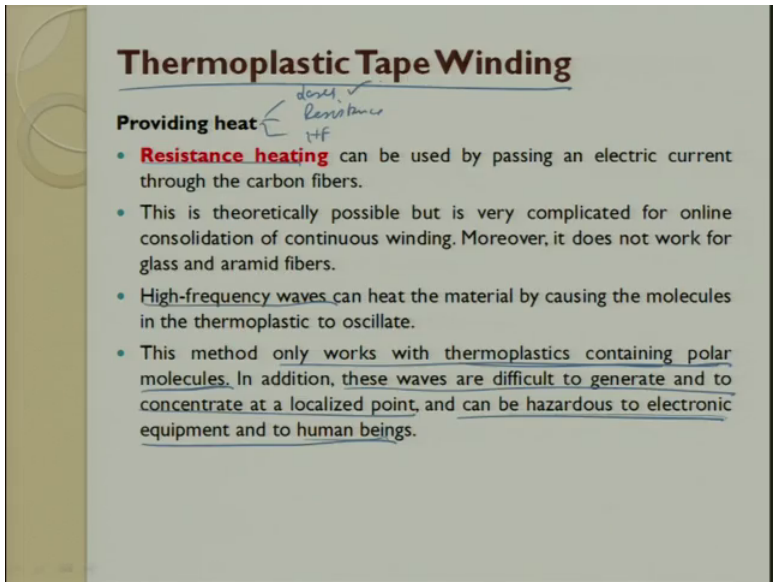

So, you have to be little careful because of that. Heating as I told you laser you can use resistive heating, you can also use high frequency wave heating. And then this can be used for consolidating the laminate. So, this tape winding process method only works with thermoplastic containing polar molecules. So, if the polar molecules are not up percent then this thermoplastic composites will not or this technique will not work. In addition these waves are difficult to generate and to concentrate at a local point. So, and electronics equipment can be hazardous to the electronic equipments of the human beings.

So, this point, so thermoplastic containing polar molecules this is very important. So, if you have polar molecules only, if you have polar molecules then only high frequency will work. So, it is something like your microwave polar molecules that is what we are trying to say. So, the only thing what I want to say is heating can be done by laser it can be done by resistive, it can resistance, it can also be done by high frequency. So, we always go for laser if you want to do you can also try other waves other ways of doing it also. You can also use open flame but it is not focused at a point.

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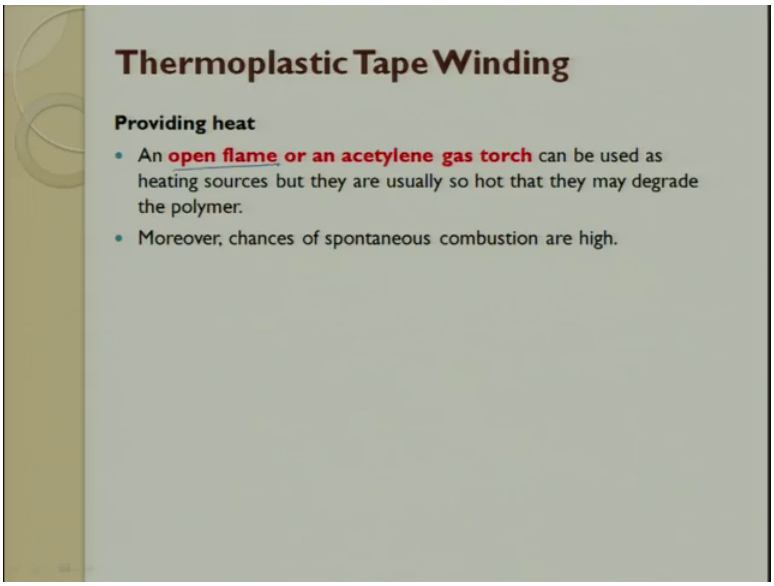

So, you cannot have better consolidation. Hot air can also be used or nitrogen gas can be also used.

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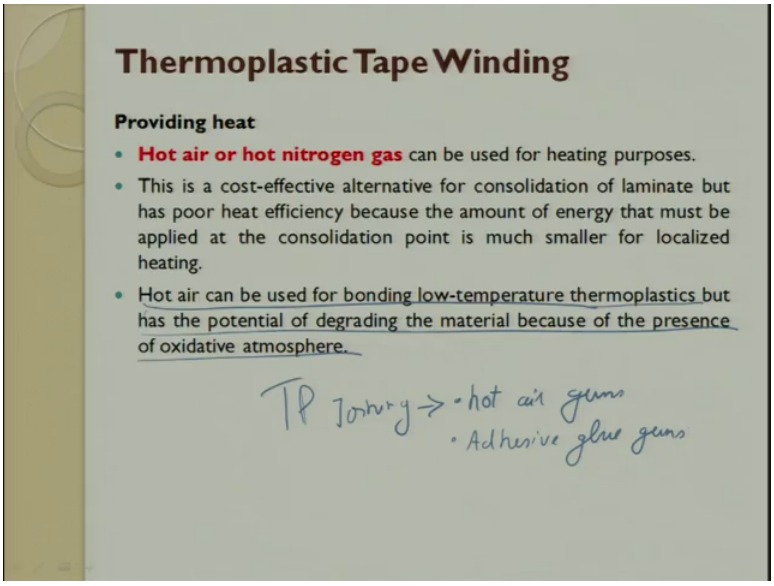

Instead of you can use a hot gun In fact, hot gun is used for joining 2 thermoplastic if you want to do joining you always use a hot gun.

So, hot gun or hot nitrogen gas also can be used for bounding. So that is what I have said the hot air can be used for bounding low temperature thermoplastics, but has a potential of degrading the metal because of the presence of the oxide oxidative atmosphere. So, keep this in mind. So, hot air and hot nitrogen gas also can be used, but the only problem is this will try to degrade your thermoplastic. So, as far as thermoplastic joining technique joining if you talk, so they always talk about hot air gun. There will be a hot air gun which is they used and this will be help trying to help you to consolidated or you can also have some adhesive glue guns, they are also used and they are used for also joining.

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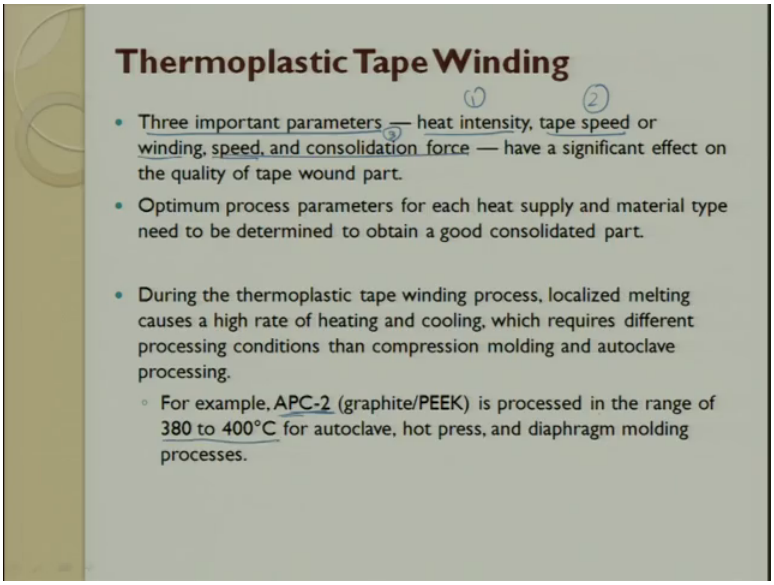

Laser we have discussed many laser has a focused source. So, we do not have to go more into laser. So, the other 3 important parameters are heat intensity tape speed or the winding and speed and consolidation force these are the things. So, 1 2 and 3 these are the 3 important parameters. Heat intensity, tape speed and consolidation force. These 3 parameters have to be optimized such that you get the best out of this process. So, for example, APC 2 which is a graphite peak is processed in the range of 380 degrees to 400 degrees for autoclave hot press and diaphragm moulding process ok.

So, this is very important. So, heat intensity tape speed and consolidation force are very important as far as the process is concerned. So, a proper choice might help in getting a good quality output.

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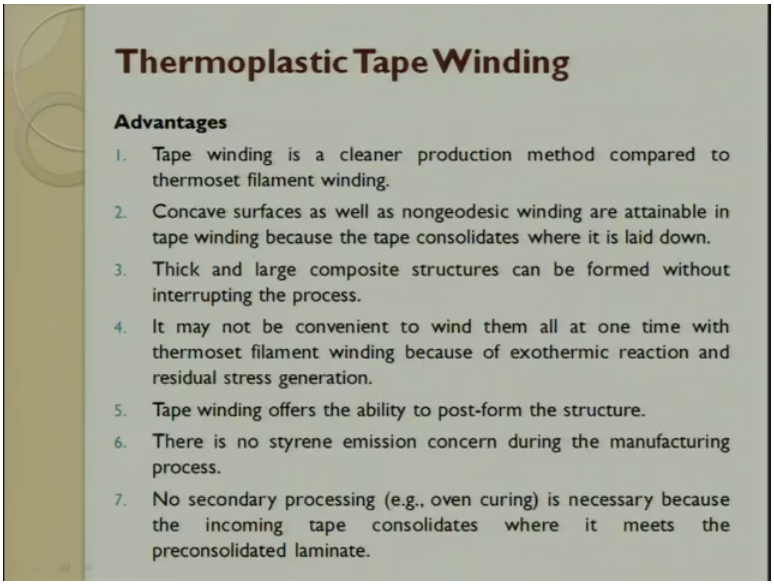

So, this is the cycle which is used for consolidation. So, this is otherwise called as consolidation cycle for thermoplastic composite. Here the temperature time and pressure might vary depending upon the fiber and depending upon the matrix. So, the magnitude might change the magnitude. This is this is temperature and a pressure. This magnitude changes with depending upon the combinations.

So, first cycle is heating cycle, in heating cycle you can see the temperature will start raising from somewhere very close to glass transition temperature or slightly above or below depending upon your requirements. So, what happens is you change it from a solid state it goes to a viscoelastic state. In the viscoelastic state there is a consolidation happening. What do you mean by consolidation? Consolidation means suppose you have 2 different layers. Now these 2 layers are pressed such that the gap is collapsed, this is collapsed. So, you get 2 laminate together. So, you get the required output. So, if you have multiple layers. So, it is always good to have consolidation. And this consolidation what you do is you try to maintain pressure and temperature, in the first state when it was heating I was least bothered about the pressure.

So, pressure at the first stage will be less than the pressure consolidation will be very high. So, the heating whatever happens can be given externally it can be done externally or it can also be one mandrill heating. Any way which ever you want to choose you can choose. And here after this consolidation after a certain time of temperature this temperature is risen then what do we do is we try to increase the pressure at this zone. So, moment the pressure is increased then what you do is we try to maintain the pressure for a longer period. And look at it pretty interesting the consolidation is over, but then why do we have to maintain pressure for a longer time? This question is answered like this, like what happens is after you finish your consolidation and if you quickly remove it out then there is a possibility that the material might trace back their original state; that means, to say what shape they had or there will be a distortion in your product dimension and geometry. In order to avoid that after the consolidation is over, they try to maintain some more time at that pressure itself and during that period they try to keep reducing the temperature.

So, if you see here they will go very up they go above the melting point here. So, this is the melting point they go above. So, it is not like liquid state completely liquid state they go slightly above, and then what they do is here there is a T g. So, what they do is till it reaches T g, the pressures what they do is they keep maintaining it and then moment it reached T g then it starts falling down. The consolidation the pressure is removed. And then finally, the pressures are 0, but slowly it is allowed to cure either in the die or in the open atmosphere whatever it is slowly it is allowed to cure down so that it gets properly consolidated.

So, parameters which are important are temperature pressure and time. So, initially the temperature increases above melting point. And this above melting point is all please do not go by scales it is all not according to scale slightly above melting point, and then you try to do consolidation. Consolidation pressure is increased it is maintained. It is maintained to some extent in the cooling cycle itself. So, what happens in the cooling cycle? The pressure is maintained to some extent and the temperature is allowed to fall down. The pressure continuous to be on hold till the temperature curve meets the T g, moment after T g you are pretty sure the shape and the shape and the dimensions does not change. So, we try to release it and get the required output.

So, this is a very, very important consolidation cycle chart. You should know all the 3 stages, you should know the influence of pressure and temperature.

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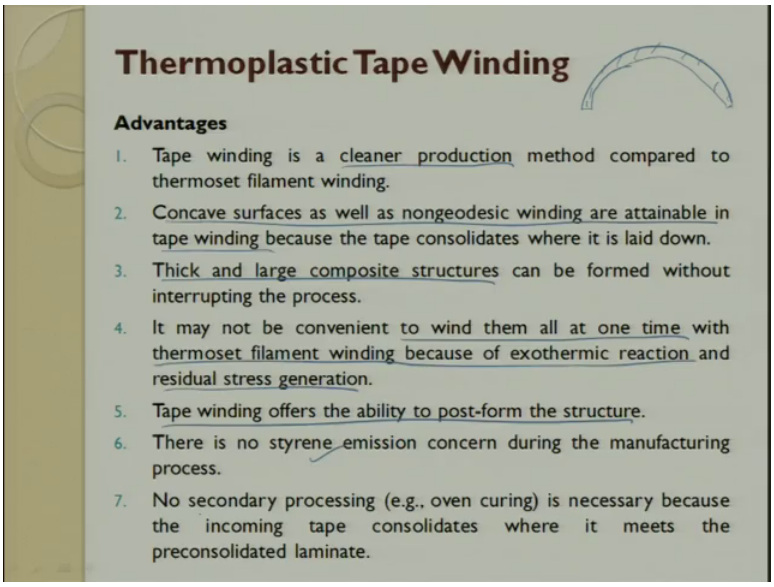

So, what is the advantages of this process? It is a clean process, there is no gas. And second thing is whatever you the input there is nothing called wastes. So, you get the required output. The concave surfaces as well as nongeodesic winding are attained in this tape winding process. For example, geo discs a disc like this you can always get concave shape or a convex shape whatever it is. So, you can use this as a mandrill and on this mandrill you lied a tape and you get the required output.

Thick and large composite structures can be made even a meter long components are been made 10 meter long pipes have been made. People have demonstrated it and very complex free form surfaces also people have demonstrated, but it really needs skill. It may not be convenient to wind them all at one time. So, they do piece meal. So, and then they try to make with thermoset winding process. So, see here what happens is in thermoset winding process it is exothermic in nature. So, it releases heat. So, this release of heat always try to distort the nearby area. So, as far as thermoplastic composite this type of problem is not there.

So, thermos the tape winding process gives you the ability of post forming; that means, to say you make a preform and then you consolidate get a post form, this point we have

already discussed. And here you do not need any secondary curing process, like which we use in thermoset. Thermoset what happens the basic shape is made, and we know it is 80 percent consolidated. Then what we do we just put it inside a furnace maintenance for some time so that we get 95, 98 percent cure or 99 percent cured thermoset. As far as this processes is concerned it is a one shot process, you get the required output.

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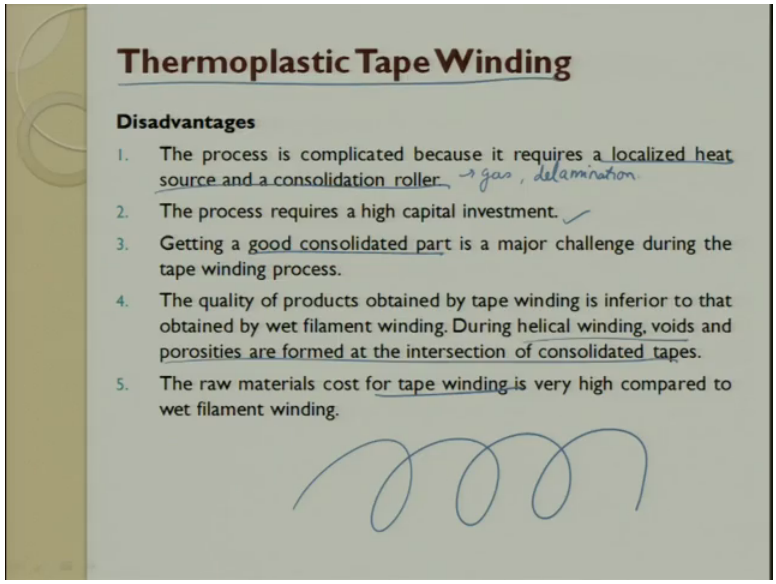

What is a disadvantage? The disadvantage is it is locally heated. So many a times there can be problem of gas getting trapped or a delamination coming into existence. A defect which is coming into existence, it is a capital intensive investment all thermoplastic processes needs heavy investment. Keep that in mind getting good consolidation as compared to that of the filament winding here it is slightly tougher the raw material for making this tape winding process is costly. And on top of it the helical winding voids and pores are easily getting formed. See as far as simple laying is concerned it is moment, you have a helical which is getting made on your mandrill. So, then this becomes a problem we have lot of other defects which get into existence.

So, with this we will try to come to an end for the process of thermoplastic tape winding process. So, we saw the advantage we saw disadvantage we saw the consolidating cycle heating cycle which is very, very important. So, the next process of discussion is going to be thermoplastic pultrusion process.

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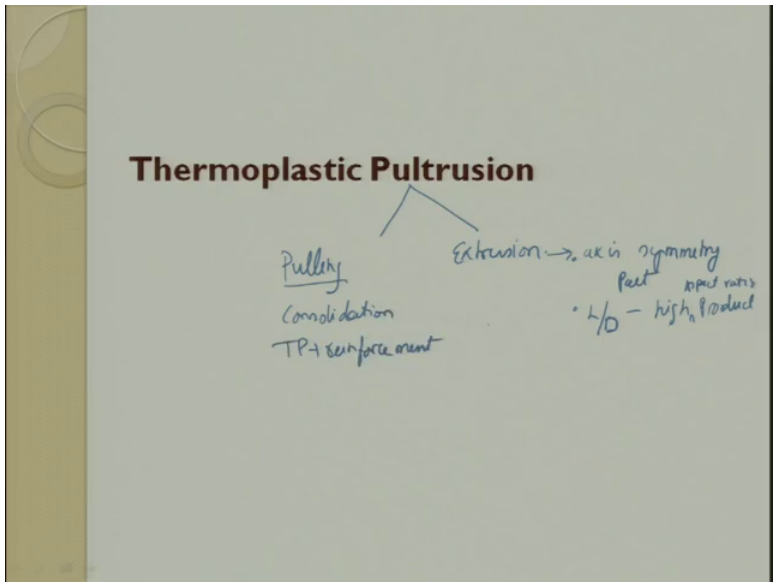

Pultrusion, pultrusion itself very clearly says it is a combination of 2 process one is called as pulling, the other one is called as extrusion. Extrusion process it clearly says that I will have a axis symmetry part manufactured. And second thing I can have length to diameter aspect ratio very high; that means, to say I can have a meter 10 meter long pipe, which can be made which can be reinforced with fibers and then it can be done.

So, very long pipes can be shafts can be made. So, high aspect ratio products can be made high aspect ratio products high products no. It has to be high aspect ratio products ratio products. And it has to be axis symmetry predominantly. Today there are techniques which has come where in which you have you can also make non axis symmetry parts, so that is on the higher level which we will not be discussing. So, this pulling is also there. So, pulling why because to have a proper consolidation of TP and reinforcement. So, because of that we try to have these 2 so, you can balance it out.

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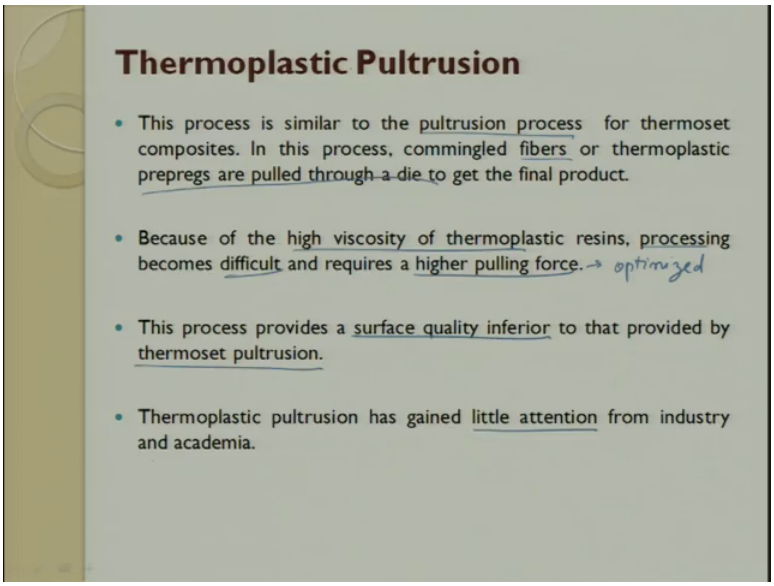

So, this process is very similar to that of pultrusion, which we studied in thermo thermoset process. The fibers or the thermoplastic prepregs are pulled through a die to get the final product. Because of the high viscosity as compared to thermoplast, thermosets thermoplast has very high viscosity because of it is high viscosity there is always a processing difficulty we have. So, what is a processing difficulty? We have to apply very high pulling force, and this has to be optimized. If you do it in a random manner the fibers might be there the matrix material will not move along with them. So, there can be a possibility of discontinuity in that.

So, the process provides surface quality inferior to that of your thermosets pultrusion process keep that in mind. So, thermoplastic pultrusion the surface quality is inferior to that of your thermoset resin. Today it is gaining lot of importance and people are trying to beat this surface quality inferiority in thermo plastic it can be done.

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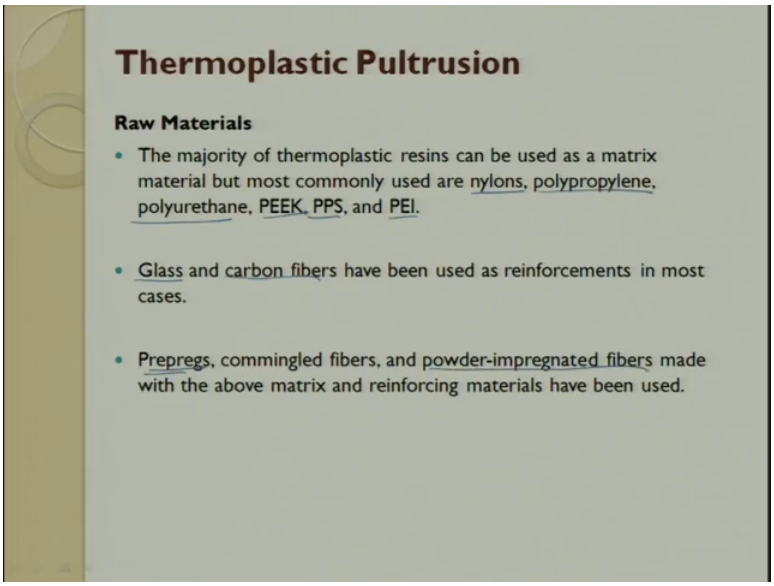

So, the raw materials as I have told earlier it can be nylon, it can be PP, peak poly urithane, PPS and PEI the glass fibers P. So, here you will not use a mat. So, you will use long lengthy fibers. So, glass fibers and carbon fibers are used to a large extent. The prepregs are also available today, and there are powder impregnated fibers are also today for certain applications. So, raw materials along with the reinforcement prepregs.

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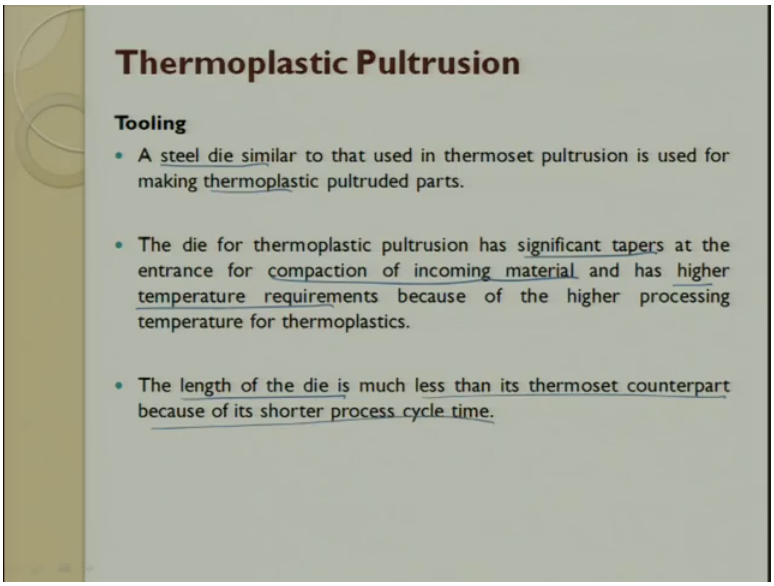

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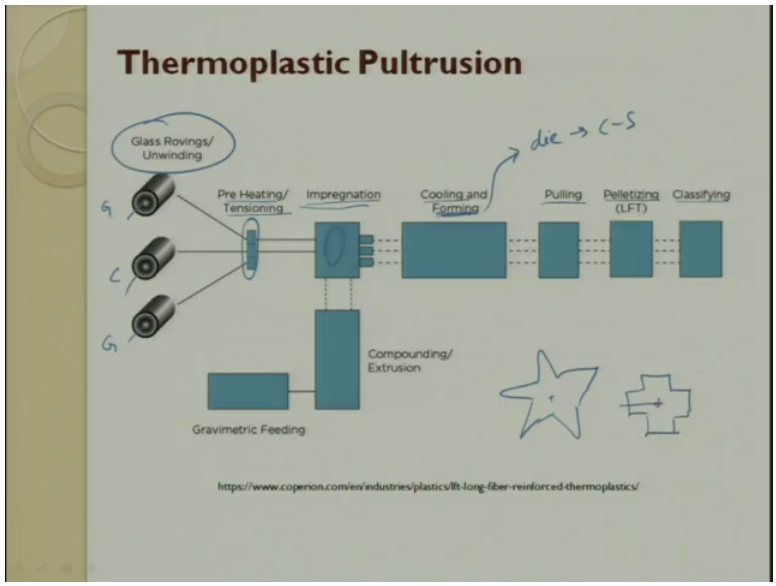

So, what are the toolings? Before getting into toolings let us look into the process and then get back into toolings. So, you will have glass rovings which are coming out of the which are which are in reels or in spools they are there. So, they will be asked to move over a preheated tension where in which it is maintained here. In at this stage they used to maintain a proper tension so that you get a regular infeed from this mandrills. So, it can be glass fiber, it can be carbon fiber, it can kevlar fiber, it can be a combination of glass fiber glass carbon glass it can be there. So, you can also have mix and match made here. So, form the reel it goes and here by the way friends it is 2 axis in real time what happens you will have multiple reels feeding in, so multiple reels feeding in. So, this has to be done to the first stage where in which we do, small amount of preheating and we also try to maintain some amount of tensioning. So, then after this what happens through a the feeding unit we try to we try to give the compound whatever it is which is extruded and it is getting impregnated in this facility.

So, here it is getting impregnated. So, the fiber and the matrix gets bland at the impregnation station. After the impregnation station is there, then what we do is we try to cool and give a basic shape to the fiber and the matrix which is mixed. So, here the resistance is very high. So, instead of pushing pulling is a better thing where in which you get a consolidated output. So, we try to pull the fibers along with the consolidated whatever matrix is filled upon it we try to pull it. Then what we do is, we try to do this

pelletizing and then we try to do classifying. So, what are the toolings? The steel die which is the very similar to that of thermoset pultrusion is used here in thermoplastic. The die of the thermoplastic extrusion has a significant taper, because you have to consolidate and then you have to get the output. So, we always have a taper and the taper at the entrance and the for compaction of the incoming material, it and when you have a taper you just by room temperature you cannot get consolidation, we always apply high temperature which is required for consolidation.

So, what we get here is these dies whatever we saw here, these steel dies are heated and then they are they are taper so that you try to get the required thing. The length of the die depends upon the thermoplast whatever you choose, is much less than thermoset counterpart because the shorter life. So, the length of the die, so in the examination you can have a question if I ask you to compare thermoplastic pultrusion process and thermoset pultrusion process, what should come to your mind is the length of the die the taper of the die. The length of the die for thermoset is always less, because thermoplast is always less because here it is a processing time is much lesser.

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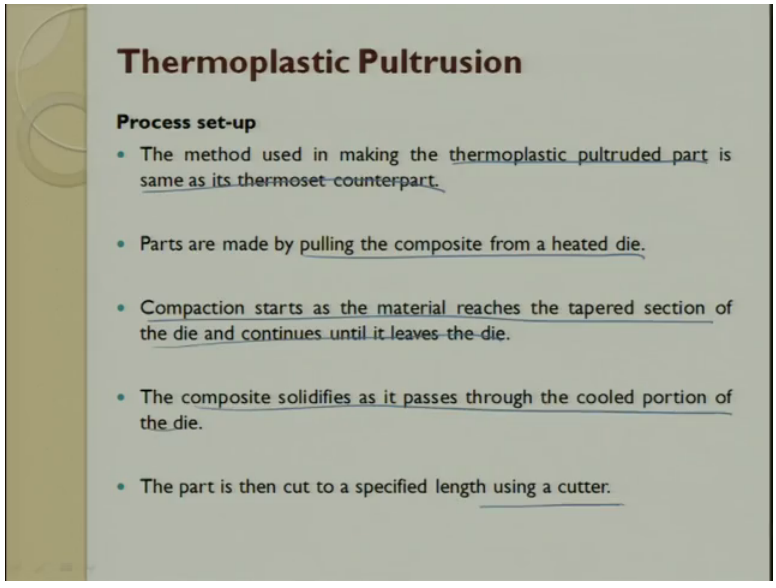

So, the process setup the thermoplastic pultruded part is the same as the thermoset in the counterpart. The pulling of the composite is through a heated die the compaction starts as a material reaches the taper cross section of the die, and continues till it leaves the die

right. The composites solidification is done in the cooling state and then finally, you cut to the required length. So, here cooling stage, it is there and then what you do is we try to take it and then we try to pull it then we try to cut it to get the required dimensions.

So, why do we provide heat? The pressure for consolidation which is applied in the die is not sufficient enough. So, we always try to aid with heat such that the pressures can be reduced to some extent. The die is heated to a processing temperature usually 10 degrees Fahrenheit lower than the melting point.

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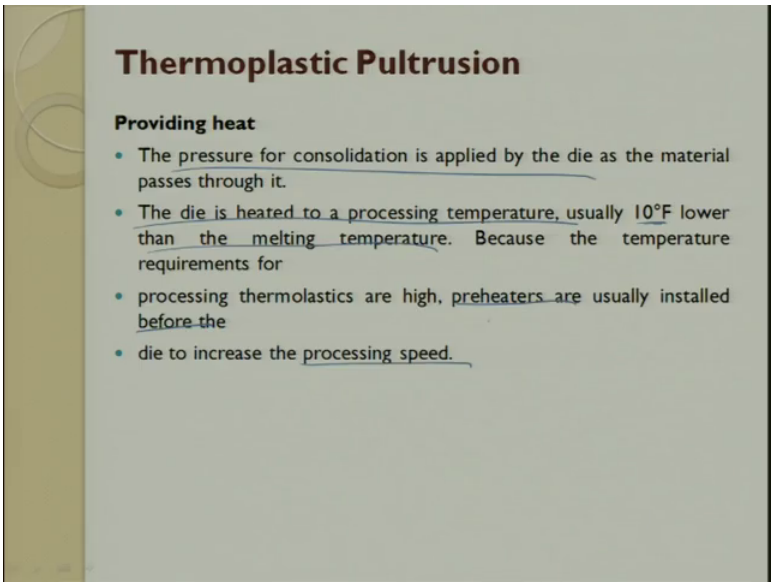

So, then the preheating is done initially so that you can increase the processing speed. So, this is very, very important. The processing speed has to be increased because you have to get quick outputs. And if you start heating right from room temperature to a very high temperature it is very, very difficult. So, what we do is we try to preheat?

So, preheat helps in consolidation to get the required output.

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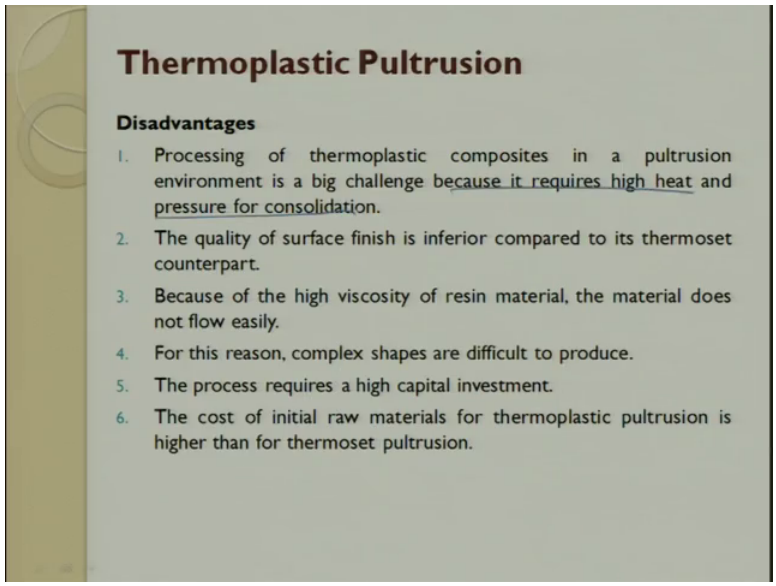

So, what are the advantages? Advantages are it is it is reformability and reparability is possible, as far as thermoplastic pultrusion is concerned and the parts can be recycled. What are the disadvantages? The big challenge is it requires high heating and pressure consolidation, which puts lot of restriction. So, here though it is said and here I have missed out a point. So, here what we do is we try to give the forming whatever I said here, here is where we keep a die and we try to maintain the cross section.

So, cooling is done and the cross section is also done, so that you try to get the square rectangle channel, square channel rectangular box channel, shaft circular shaft gear. So, in fact, interestingly you can also get pultruded star for some application like this. You can also get the same because here it is axis symmetry. So, you can get an axis symmetry part you can also get gears or maybe you can also get square for some application which is an axis symmetry part. So, you can always get so that die is kept in the forming process.

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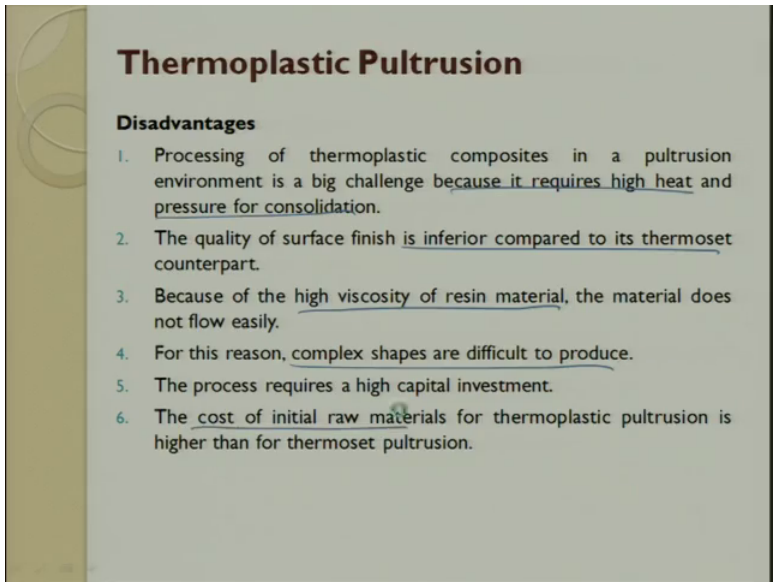

So, here it needs very high temperature and pressure so that it can consolidate and get pulled. The quality of the surface finish is inferior so that is what lot of research is going on and since it is recyclable today we make lot of reinforcing structures in automobile and aerospace industry, where we used metal alloys are now replaced by thermoplastic pultruded shafts where in which the fiber takes the load, and this gives a huge breakthrough in their weight. So, this process is picking up and, but the only problem is it has very poor surface finish which is what lot of research is going on. Because of the high viscosity the material cannot flow easily so that is why we try to maintain and play with the temperature. Maintain and play with the temperature gives you the viscosity flow. So, complex shapes are difficult to make like what we studied in tape casting you can make domes. Here it has to be only a axis symmetry part so that you get the required output.

So, the initial cost is high and the tooling cost is also very high. There are there is this process is slowly picking up and here the thermoplastic pultrusion process the long lengthy shafts which is reinforced this is the only process which you can make and if you think of something like a square cross section square cross section with the hollow inside. So, the reinforcement and the fiber reinforcement of the fiber along with the matrix this is the only process which can make such long high aspect ratio parts.

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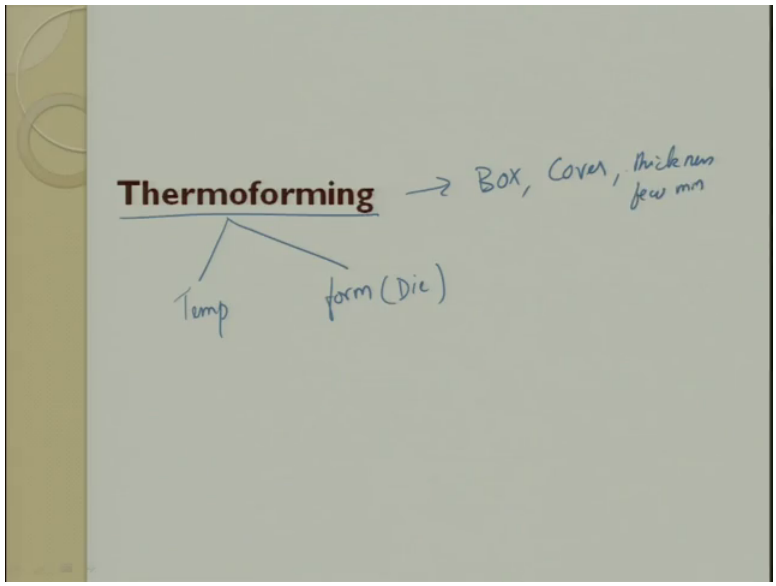

The next process for discussion is going to be thermoforming.

So, it is very clear it is thermo. So, I am applying temperature and the next thing is I am going to give a form. Form is basically I will have a die and I will try to give a shape to it. So, thermoforming is the next process which we are going to discuss. So, here the thermoforming process for applications like box, a cover with a thickness of few millimeter. Can be made out of this thermoform process. Those of who just for visualization if you want to make a post box out of polymer thermoforming is the only process. You can make and if you want to reinforce it thermoforming is the process which you can make.

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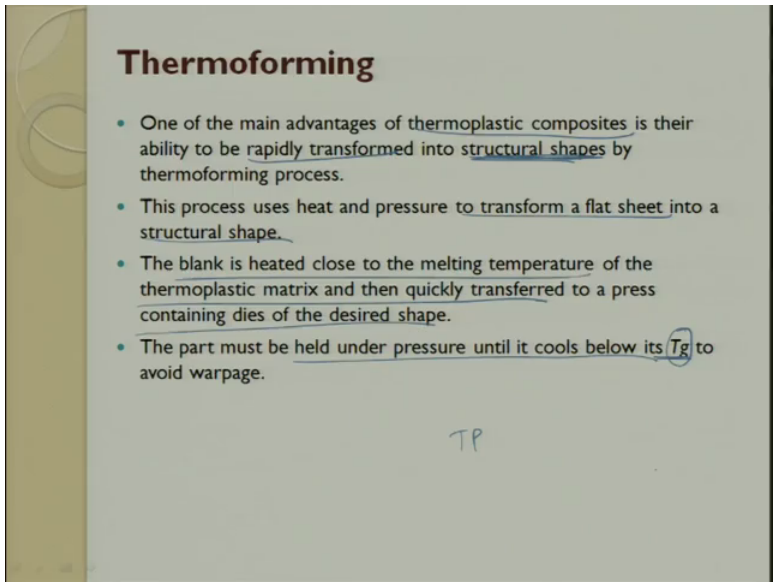

So, thermoforming process it is the one of the main advantage of thermoplastic composite is that rapid transforming into structural shapes. So, for structural shapes thermoforming process is used. So, here a flat sheet is converted into a structural shape. So, flat sheet means a prepreg where in which you have a thermoplastic resin matrix, where in which it has a carbon fiber or a glass fiber inside it. And you have a prepreg available which is in a flat sheet. So, you take the flat sheet take a mandrill or give a pattern, whatever it is wrap it on top of it heat it consolidate it you get the required output.

So, the blank is heated the close to the melting point, and the thermoplastic matrix quickly transfers into the transfers to a press containing the die and you get a required shape. The part is held under pressure until it cools below T g, if you go back and see this is what I was trying to explain to you when I was discussing about the tape process. The thermoplastic tape process tape winding process, where in which I was trying to explain to you about the consolidating consolidation cycle. Just below the T g you will try to maintain and then only release the pressure. Almost the cycle heating cycle whatever we use will more or less be the same.

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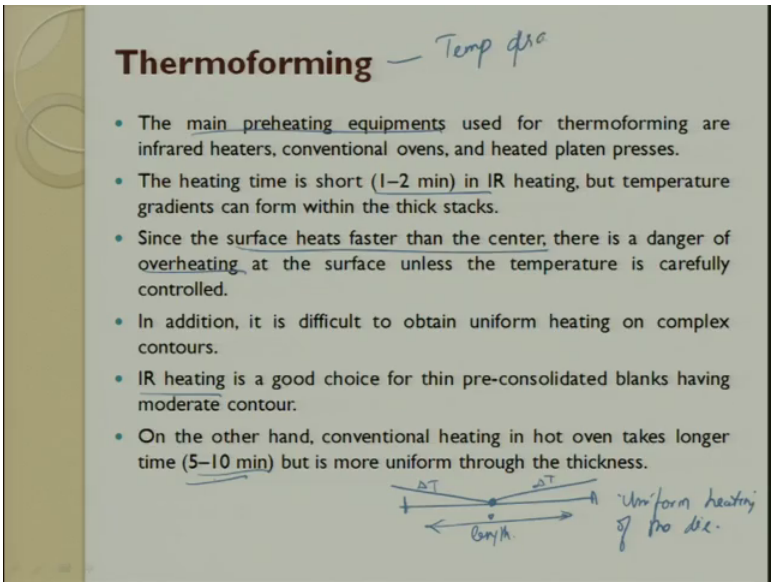

So, here the heat the equipment is preheated and then the heating cycle is for 1 or 2 minutes. It can be done through any source of heating right. If the surface right if the surface heats faster than the center then there will be a overheating, because of this overheating there will be a temperature mismatch. So, what I am trying to talk about is surface heating. So, this is the center heating or you can say center heating this is the surface, you can say if there is a thermal gradient between these 2 this is for example, this is thermal gradient delta t and delta t variation, which this is the length of the die. So, then there will be a problem. So, you should be very careful about it.

So, in order to have a uniform the uniform distribution. So, there will be an complex heater main; that means, to say the shape of the heater will have a contour shape so that they make a uniform heating of the die, uniform heating of the die. So that is there. So, IR is heated and then it is used for consolidation it is done on a heat oven for 5 to 10 minutes or you can use any other heating technique to do. But the most important point here is temperature gradients on the die has to be made sure that it is uniform.

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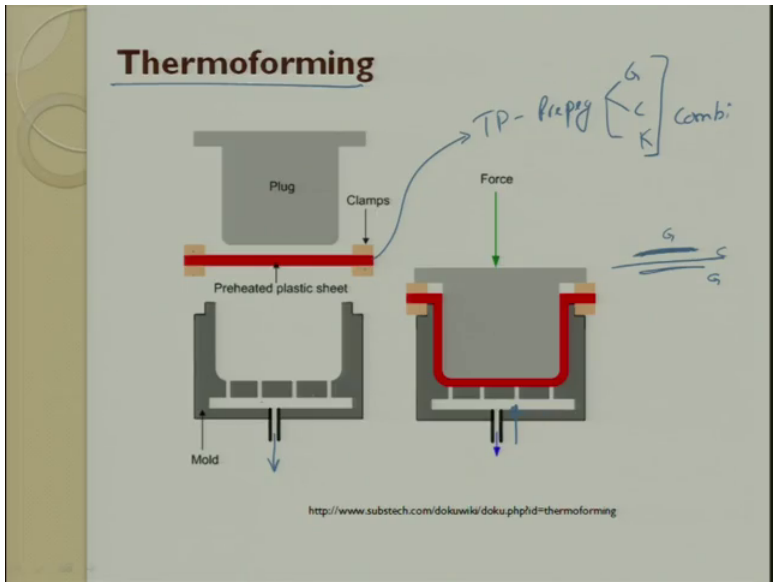

So, here this is it. So, here you can see a preheated plastic sheet is there. So, this sheet is clamped. So, this is a thermoplastic prepreg made out of glass, carbon, kevlar or a combination. If you want you can do; that means, to say you can put glass fiber here and then you can have this is glass this is carbon. You can also have one more glass and then you can get the required output. So, there is a plug there is a clamp and this is a plastic sheet whichever is done. And then what we do is we try to keep it on a die and then this die has mould this die it is called as mould. So, you have vacuum which is there, which is used to you place it you heat it and you suck the vacuum. So, it tries to take the shape and then on top of it if you want to have both sides finishing we use a plug force it in to and get the pre shape.

So, this process is called as thermoforming process. So, here axis symmetry non axis symmetry part can be made very large parts can be made depending upon your die, and then the vacuum plays a very important role in order to have a proper vacuum you can also have vacuum first we try to suck through this and once the consolidation properly happens. You can also have a push through this so that this is released. So, a same vent can be used for sucking as well as pressurizing to release the component, because here you do not have something called as a ejecting pin. And if you have a very large component ejecting pins might damage the surface. So, this is what is a process for thermoforming.

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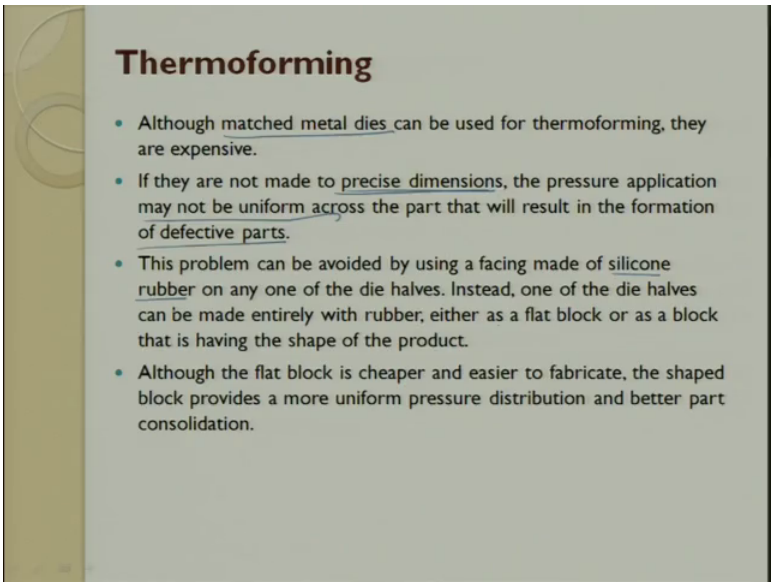

So, I have put matched metal die can be used if you want to make a composite die. You can use you can also use a wooden die for making the required output. Because here is not much of loads are there, but really if a proper consolidation should happen when we always go for a metal die. So, it is not made very precision the pressure application is not uniform. It can lead to defect. If the pressure distribution is not uniform then you can have defective parts.

So, the rubber; and so, this though in order to have a proper consolidation we would try to have silicon rubber consolidation to have on top of the on top of this metal. So, if you want to have a proper consolidation, rather than this you can always have a silicon rubber pad, which is kept on top of it. So, you can try to have a better control on top and bottom. So, if you have only bottom die the process is going to be economical if you do for a top die it is going to be 2 dies 2 parts it is going to be expensive.

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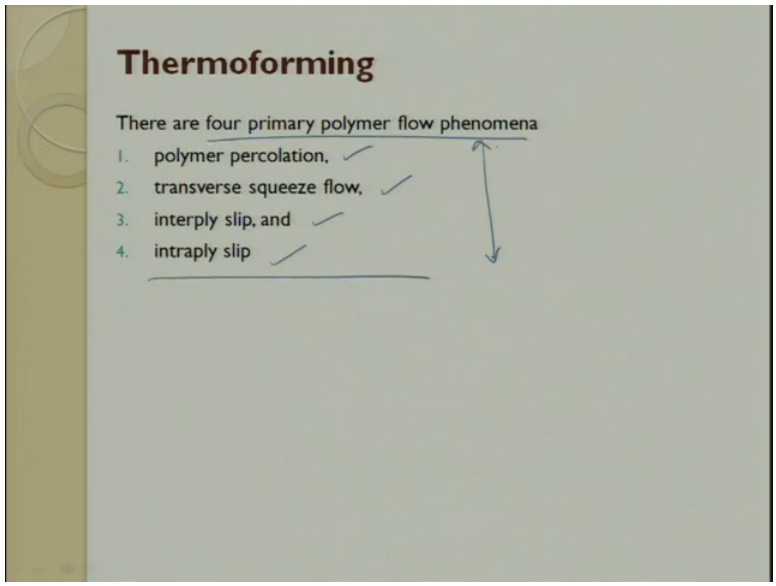

So, the polymer 4 primary polymer flow phenomenas are polymer percolation happens, then transfer of a squeeze flow happens. Then interplay slipping happens, then intraply slipping happens. So, here I said I would. So, if this is interply and intraply can happen at this portion. So, these are the 4 phenomenas which can happen in thermoforming, such that you have to balance this phenomenas to get a sound product.

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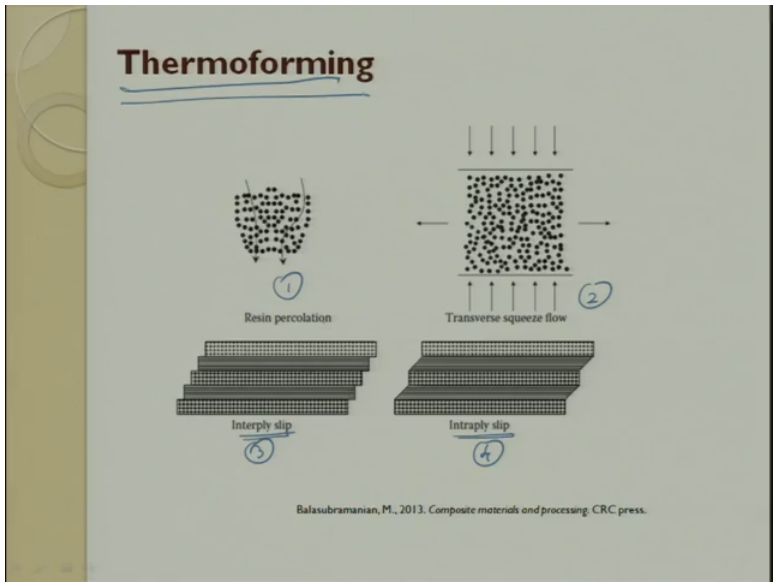

So, this is thermoforming process. So, where in which you have resin percolation can happen this is what is a resin. So, you have interplay and then you have intraply you have interply, interplay means between 2. Intraply means within one interply slipping can happen intraply slipping can happen and then transverse squeeze flow can happen.

So, these are the mechanisms resin percolation transverse squeeze flow interply and intraply slipping. So, all the 4 can be used are the 4 phenomenas which generally happens in the thermoplastic forming process. If this process has to be done by thermoset it is slightly easier. Since it here the matrix has to be taken to a viscoelastic state it is requiring lot of care to be done.

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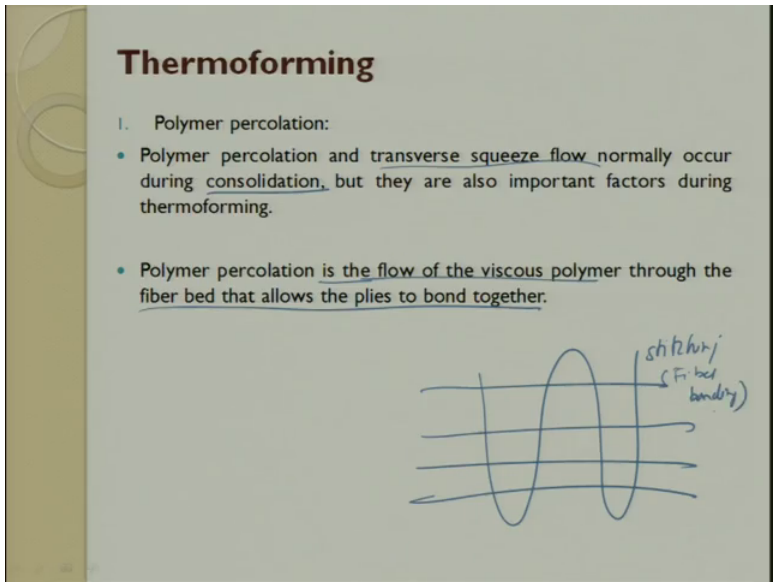

So, what happens in this percolation? Percolation and transverse squeeze flow normally occurs during consolidation process. In this flow the in this percolation polymer percolation, the flow of the viscoelastic polymer or a viscous polymer through the fiber bed that allows the ply to bond between each other happens in the polymer percolation. Basically you have several fibers, these fibers have to be stitched. So, stitching is nothing but this is stitching.

So, instead of stitching, here what we do is we do adhesion joining that is all so that is what through the flow of the viscous polymer through the fiber bed that allows the plies to bond together. So, this is replaced by fiber bonding clear.

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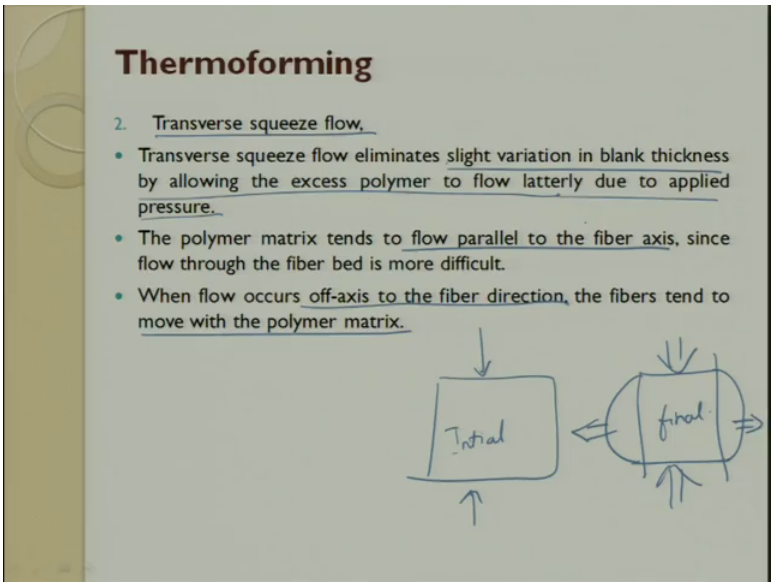

So, what is transverse squeeze flowing? In this traverse squeeze flowing the flow eliminates the slight variation in blank thickness by allowing the excess polymer to flow laterally due to rapid pressure; that means, to say I have a box I apply pressure. So, what happens is it gets something like this compression force it gets consolidate like this. So, what gets out through this is what we talk about in transverse squeeze flow.

So, there is load applied here, there is load applied here. So, this is initial and this is final. So, the transfers squeeze flow eliminates the slight variation in the thickness by allowing the excess polymer because we do not want to have resin rich polymer regions. So, for this we will try to use this. So, the polymer matrix tends to flow parallel to the fiber axis. Since the flow through the fiber bed is more difficult. So, it moves in the fiber axis flows through the. So, consolidation the transverse squeeze flow is very important the flow parallel to the fiber axis happens and then get down, when the flow occurs of axis to the fiber direction the fiber tends to move the polymer move along with the polymer matrix.

So, there is a small displacement which is happening. So, this phenomena is very, very important. So, please note it down transfers squeeze flow, transfers squeeze flow is to make sure that the excess resin flows out through a laterally such that in the transfers direction so, by applying pressure.

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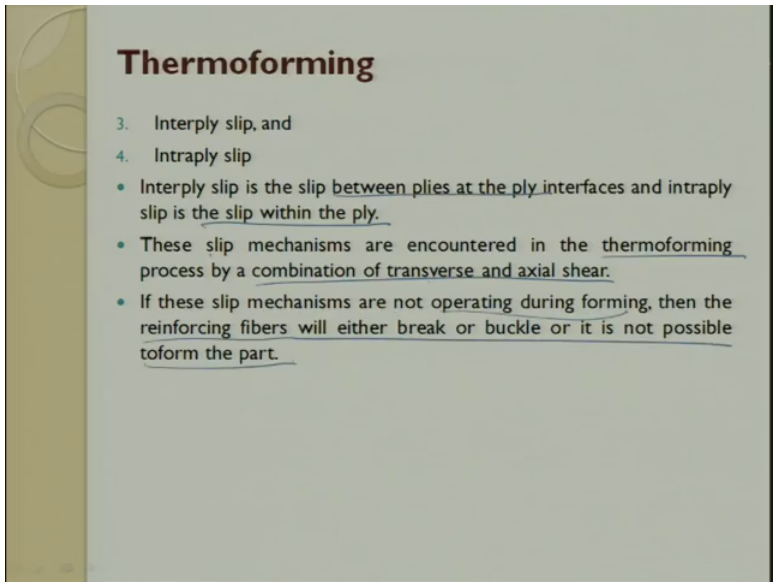

Next interply and intraply slip. Interplay slip is a slip between the plies between plies and intraplys within a ply. So, these 2 are the other mechanisms which are very, very important. Then the slip mechanism are encountered in thermoforming process is a combination of transverse as well as axis shear, transverse and axis shear.

So, these slip mechanisms are not operating during forming then the reinforcing fiber will either break or buckle or lead to a poor quality output. So, all the 4 mechanisms what we discuss still now is pretty important and you should understand all the 4. If it is going to be only thermoplastic sheet this process is very easily doable, but moment you put a next second factor which is a reinforcing factor as an ingredient, then the mechanics changes the phenomena changes. So, we have to very clearly understand polymer percolation phenomena, transverse squeeze phenomena inter slip phenomena and intraply phenomena has to be understood in order to have a uniform consolidation people have tried several tricks. So, one of the trick is using hydro forming what is hydro forming you apply ice you apply water at a very high pressure so that you consolidate to get the required output.

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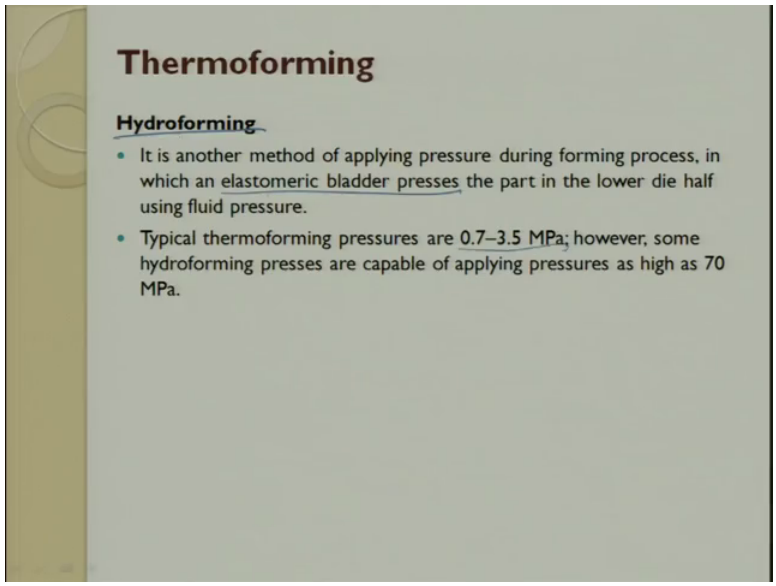

So, when you push water you have to put it inside a elastomeric bladder. So, the pressure is applied rather than putting a metal here the pressure is applied through hydro forming where in which we fill a we take a elastomer fill it with water, with very with water or any fluid with high pressure and then try to get a consolidation. So, here what is the big advantage you get a much better sound quality output, but you should be very careful about the hydro forming maintaining the pressures. So, the pressures typically are up to 3.5 mega Pascal and it can go up to 70 mega Pascal for various applications. We can also use diaphragm waste forming.

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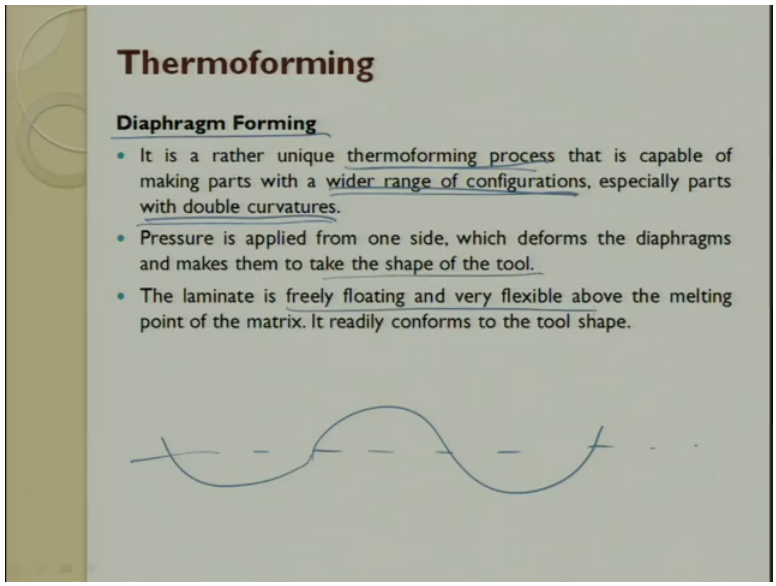

In diaphragm waste forming it is it unique thermoforming process which is capable of making a wide range of configurations especially for double curvature past we use diaphragm forming double curvature.

So, if you want to do a double curvature. It is very difficult such curvature figures if you want to do it, if you want to do it is very, very difficult. So, what we use is we use diaphragm forming process. It is a unique thermoforming process which is capable of making wide range of configurations, using especially double curvature can be made a through this process. So, here the pressure is applied from one side which deforms a diaphragm, and makes them to take the shape of the tool. So, here the laminate is freely floating and very flexible above the melting point of the matrix, so here and tries to confirm to the tool.

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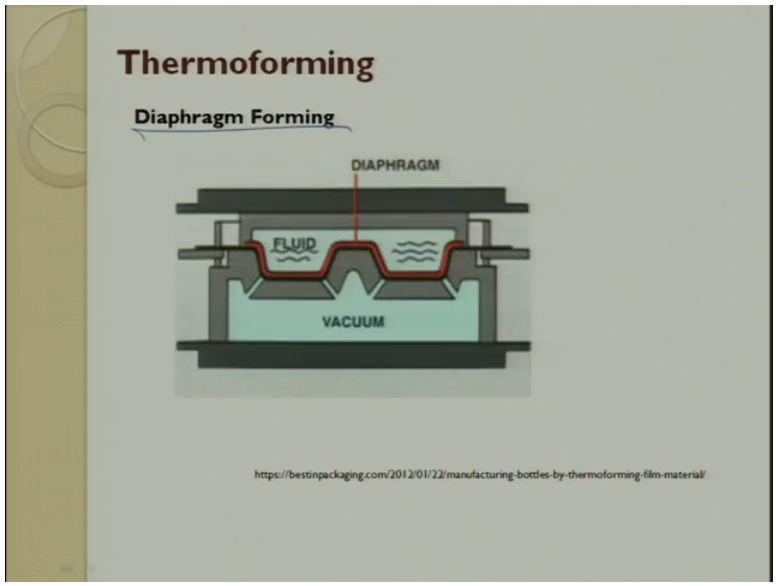

So, look at it so, here what has happened is you have made a tool, and here is the fluid which is present and here is the diaphragm. So, here what this is the diaphragm on the top. So, what you do is you try to get the required output whatever you have and the vacuum is applied at the bottom. So, here this diaphragm forming is used for making double curvatured surfaces which is very difficult to make through any other process, and here please keep it in mind it is a thermoplastic process. Thermoset is a different story thermoplastic process. So, here this is used for making any complicated shapes.

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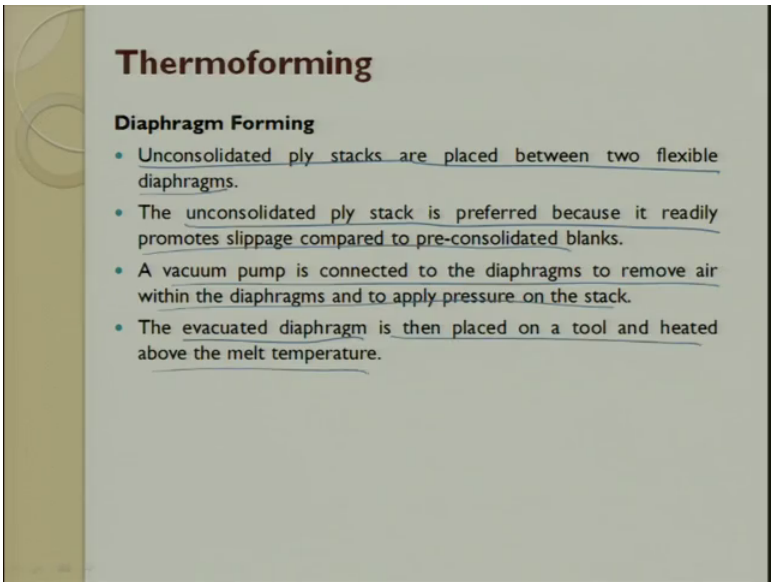

So, unconsolidated ply stacks are placed between 2 flexible diaphragms. The unconsolidated ply stack is preferred because it readily promotes slipping to pre consolidation blank. The vacuum pump is connected to the diaphragm to remove the air within the diaphragm to apply the pressure on the stack the excavated diaphragm is then placed on the tool, and heated above the melting temperature. So, this is the process of sequence which we follow so that we get the required output. So, unconsolidated ply stacks are placed between 2 flexible diaphragms. So, you can see the diaphragm here the consolidated ply stack is preferred usually it is it readily promotes slippage compared to that of pre consolidation blanks. So, this is very important so that you get a sound quality output.

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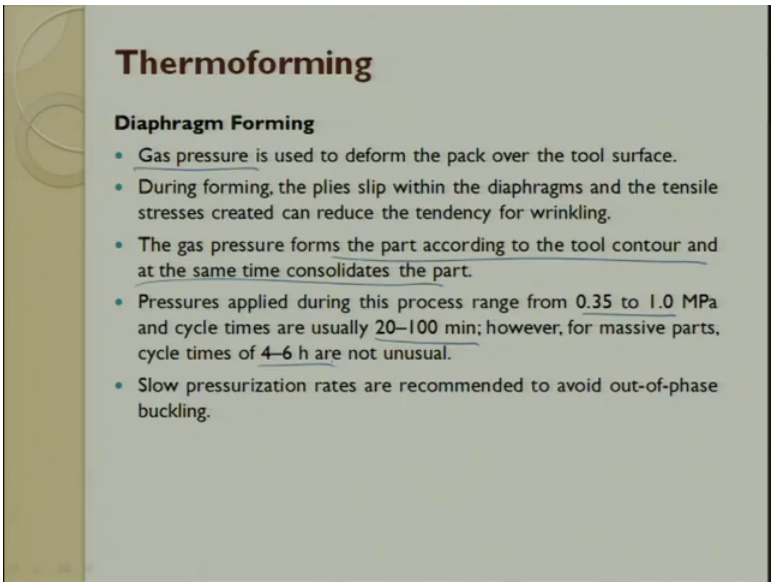

So, the gas pressures are used to get the forming, and then here the gas pressures form the part according to the tool contour and also gets unconsolidated at the same time. So, the pressures what we operate is 0.35 to 1 mega Pascal the cycle time can go up to 100 minutes. If you want to have a massive part it can also go for 4 hours. Slow pressurization is very important so that you try to avoid defects.

So, with this we try to come to end to thermoplastic composite thermoforming processes. So, in this lecture what we studied was we studied thermoplastic, thermoset, differences. And then we were walking through thermoplastic, tape winding process, then we went in to pultrusion process. Then last we went into thermoforming process, where in which we saw using through metal using through diaphragm, forming process to make sound quality outputs.

Thank you.