Processing of Polymers and Polymer Composites

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Lecture - 27

Pre-pregging and Challenges in Primary Processing of Composites

[FL] friends welcome to session 27 in our course on processing of polymers and polymer composites. We are going to switch gears today and we are going to venture into a different aspect of processing of polymer composites, as well as polymers. Therefore it becomes imperative to just understand that what we have covered till now.

Today we are going to have our last session; that is session number 27, related to the processing techniques for polymers and polymer composites. The first 13 sessions were focused on the polymers, the basic properties of the polymers, then we have seen the various processing techniques, that are used for processing of polymers. And if you remember the types of techniques we have used, or the different types of techniques that can be employed for processing of polymer, you can just count the techniques on your fingertips.

We have discuss thus normal casting process, as applied to polymers. We have then seen compression molding, we have seen transfer molding, we have seen injection molding, we have seen rotational molding. These are the, as well as we have seen an important process that you can relate with your day today life blow molding. So blow molding transfer molding, rotational molding, injection molding, compression molding, casting. So all these processes we have seen for processing of polymers

Then in the second phase of our discussion, we shifted from session number 14 into polymer based composites; that is we have seen that what is the concept of composite materials, how the composite materials can be classified. Then we have seen that what are the various processing techniques that can be used for processing of polymer matrix composites, in which we have try to understand from hand lay up to spray layup, then compression molding, injection molding, extrusion, then we have seen autoclave molding, then we have seen resin transfer molding, pultrusions. So number of processes we have covered for processing of polymer composites.

In our last session, we focused on a different type of compound; that is the sheet molding compound which is further used as a raw material for making of composite products. In the same series, we are going to consider today another process that is called prepregging, which is also preprocess, before we make a composite part. So if you remember we have explained, or I have tried to discuss this word prepreg in one of our previous sessions, and if you remember the process was autoclave molding.

So today again we will refer back to that particular video, that we have seen that particular animation that we have seen, and we have tried to understand that is the process of autoclave molding, but the raw material that was used for autoclave molding was coming as a prepreg. So let us try to understand the process of pre pegging, but before going to the process, I would just

like to come back or go back sorry, to that animation and try to explain that where is that pre pregging helping us in making the composite product.

So let us start our session today. This video we have already shared, available on YouTube.

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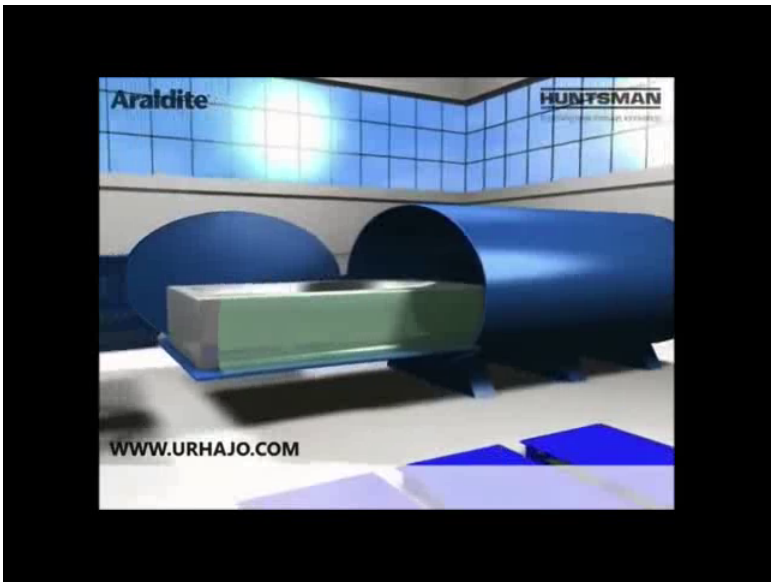

So this is a autoclave, this is the mold of the final product that we want to produce. I will try to stop it in between to just explain.

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This is basically the prepreg; that is coming. This is the role of the prepreg, and the prepreg is moving in this direction, and here we have a cutter which will cut the size as per the required dimensions. Now let us start it. So this prepeg, two sheets are being removed from there , at this prepreg is finally a stacked prepregs are going inside the mold, the next prepreg will come and it will again fit inside the mold, as per the required design of the mold.

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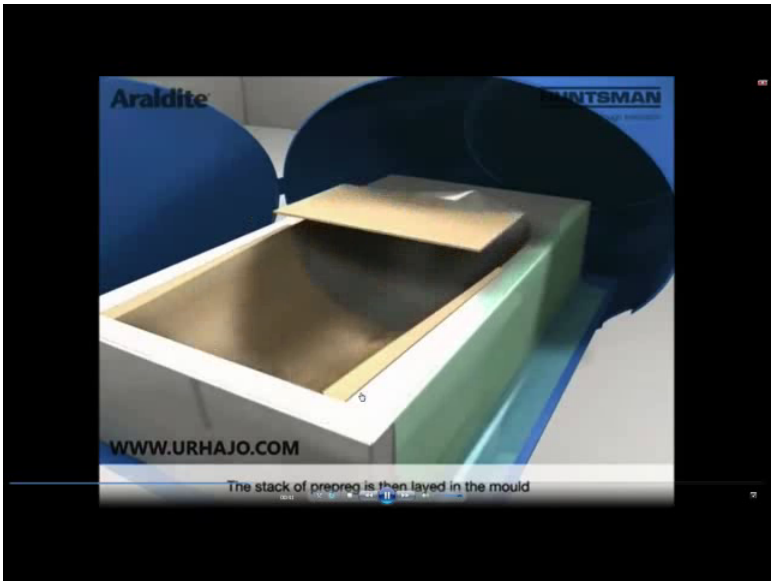

This is a third prepreg, and the final one will come and fill the mold completely. This is the final prepreg which has come and filled the mold completely. So this is basically the process of preparing. I will just like to go back, and again start the process, just to make it clear. This is autoclave molding process, but we are trying to understand the importance of prepreg. So prepregs are the raw materials. This is the prepreg, that is coming, and just prior to that we can

try to understand the top and the bottom film in the prepreg, but these are the two films that are there, which cover our prepreg. So these two films are removed, and the prepreg moves forward and it is laid up. This is a prepreg this will move forward and it is being laid up. This is another , we can try to understand, this is again prepeg and this is being laid up.

So this is basically the basic process of using the prepregs as a raw material for making our final product. So we have prepregs, that are the pre blended polymer and fiber together. So we have pre blended raw material available. If you see, the handle lay process that we have seen what we do. We take the fiber separately, and we take the resin separately, and we combine them together to make a composite product. Where as in prepreg the resin and the fiber are pre blended, but the resin is not fully cured, it is maybe we can say in a semi cured state, and then with this pre blending five, pre blended fiber and polymer we bring together. Although it is covered the top film is there the bottom film is there, it has to be protected from the environment, it has to be stored in very specific environment, so that because of the temperature or the heat, the curing process may not get initiated. So the storage of these prepregs is also an important challenge.

So how the prepregs are prepared, what are the material that are used for prepregs, what are the advantages, what are the limitations of the prepregs, that is the target of our session today. We will try to achieve and this target, by understanding the basic concepts of the prepreg or the process of preparing. Now what are prepregs?

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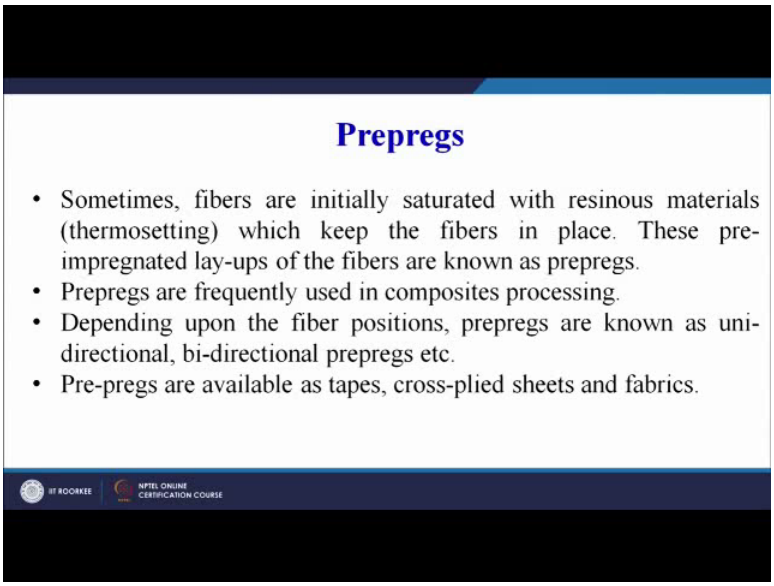

Sometimes fibers are initially saturated with resinous materials, specifically used for thermosetting type of polymers, which keep the fibers in place. These pre impregnated layouts of fibers are known as prepregs.

So already I have explained that we will have resin also, we will have fibers also, and we will combine them together, and pre blended fiber resin mixture is called prepreg. Prepregs are frequently used in composite processing, as we have tried to understand in the video, that we have prepregs coming. The bottom and the top sheets are being removed that is that, these two protective layer, thin protective layer from top and bottom are removed, the prepreg moves

forward, and then it is used in the mold for the layup process. So prepregs are frequently used in composites processing. Depending upon the fiber positions prepregs are known as uni directional bi directional prepregs.

Now we can have all fibers running in one direction like this. These all are fibers running in one direction, we can have unidirectional fiber. There is no fiber across the direction of the fibers, at a particular distance we may have low strength, fibers or threads, which are there to just to keep them at their place. So these unidirectional fibers are the main load bearing members, and therefore we called it as a unidirectional prepreg. In bidirectional way we will have fibers running in both the direction, a longitudinal direction also, as well as in transverse direction also, and they may be viewed as per the specific pattern, or as per the specific weaving pattern.

Prepregs can have both unidirectional and bidirectional fibers. Prepregs are available as tapes, cross plied sheets and fabric. So type of form of prepregs that are available is tapes cross plied sheets and fabrics. Sometimes fibers are initially saturated with resinous materials which keeps the fibers in place. These pre impregnated lay ups fiber are called prepregs. This is just the definition that we are trying to understand. Once again now, what are the raw materials that are used for prepregs.

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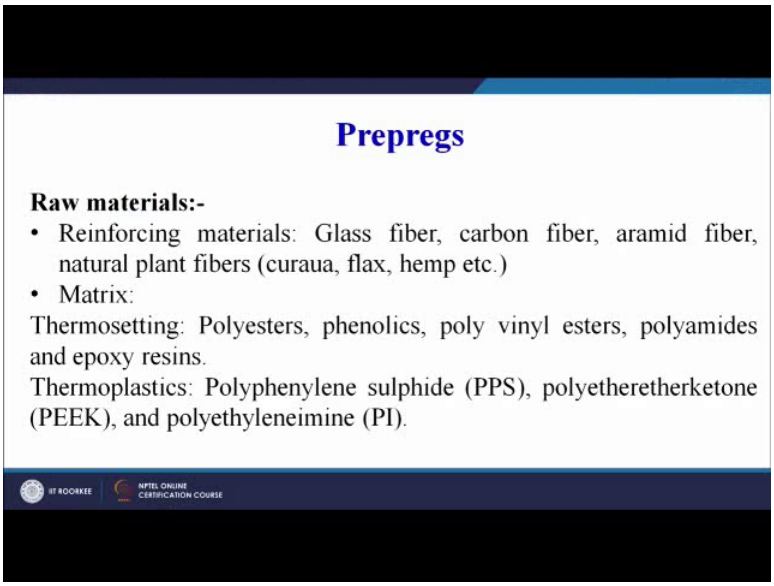

So the raw materials that are used are glass fiber, carbon fiber, aramid fiber, natural plant fibers like curaua, flax hemp. So for both synthetic type of fibers also as well as natural plant derived fibers also, we can prepare the prepregs and use them for further processing of the composite products.

The matrix usually is thermosetting; that is polyester phenolics, polyvinyl ester, polyamides and epoxy resin. Sometimes we can a thermoplastics also like PPS, polyetheretherketone, or polyethyleneimine PI. So we can have, we can use thermoplastics also were most commonly whatever I have seen, in my experience mostly they are prepared by using thermosetting type of polymers. Now this is the basic diagram on your screen, the processing of prepregs, let us try to see one by one.

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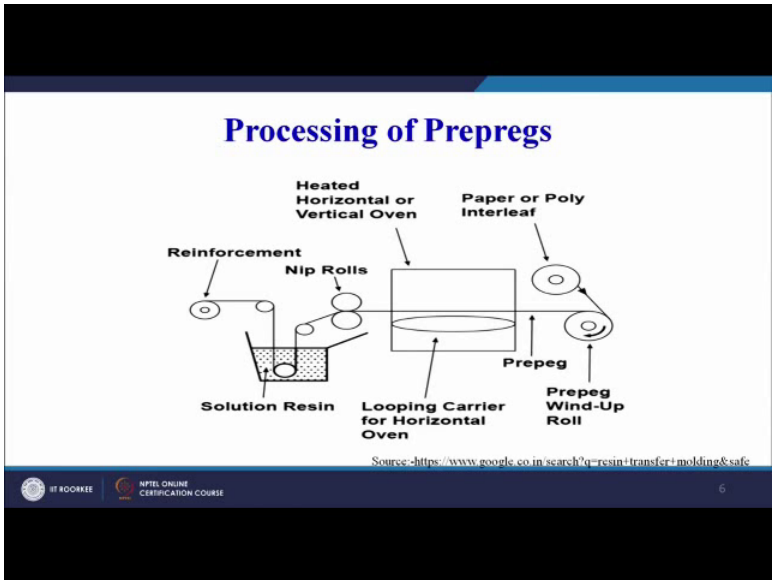

So basically in every process what is our major objective? Our major objective is to combine the fiber and the polymer together, and here we see the fiber is coming from this screen. This is a fiber. The reinforcement is coming from here, then it is dipped in the resin, so it carries the resin along with it. These are the guide rolls, then it goes into the nip rolls function or the objective of the nip rolls is to remove the excessive resin that is travelling with the fiber. Then it goes intoheated horizontal or vertical woven. This is the woven, which is pa which will partially cure the thermosetting resin looping career for horizontal woven. So we can have horizontal as well as vertical woven, but the major purpose or major objective of this woven is to provide heat, to our assembly or to our mixture of fiber and the resin.

And finally paper or poly interleaf, this is coming from here, which we are seen in our animation, that there was a green and a blue color coverings, a thin sheets on to the prepregs which were acting as a protective layers on the either side of the prepreg, these two sheets are being deposited here. This is a paper poly interleaf this is, and then the prepreg wind up roll, which will be taking up the prepared prepregs, and this has to be stored very carefully, so that the auto curing of the process may not initiate. So basically the process is very much similar to the process of pultrusion, where we the fibers are coming, they are getting wet and then they are moving through the die. And but in this case we are preparing a roll or a wind up roll, but in a that case in case of pultrusion the fibers move through the die, and then they are cut as per the required length and pultrusion is a continuous process, which makes products of uniform cross section, but here we are preparing tapes of prepreg, which hascoating, protective coating on either side.

So this is a simple process, and but there are a number of parameters that need to be controlled, the movement of the reinforcement, the time the fiber spend inside the resin tank, the thickness of the tape that we are producing, then the temperature that we are subjecting or exposing, our mixture of fiber and resin, then the speed of the take up roll. All these things are very important that need to be controlled, in order to make a good quality prepreg, which will help us to produce very good quality composite product.

Now processing of prepreg, whatever we have tried to understand with the help of the diagram or the figure or schematic. Let us try to understand it with the help of very simple sentences.

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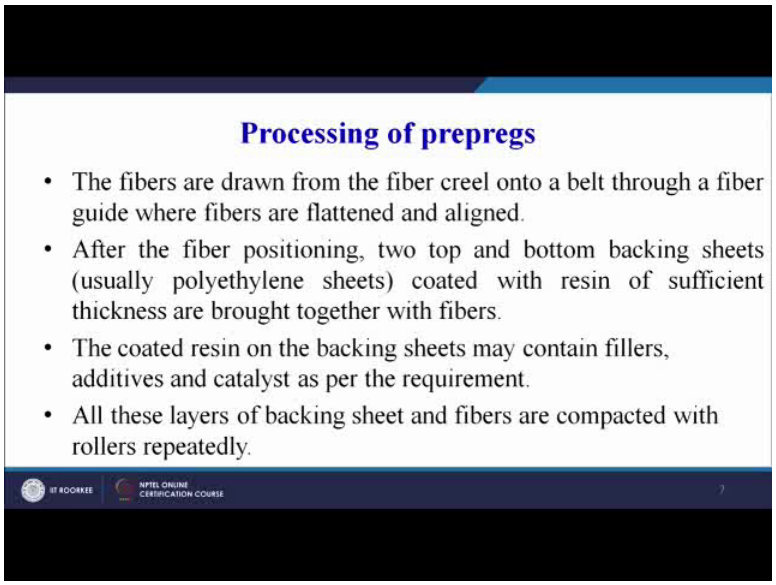

The fibers are drawn from the fiber creel onto a belt, through fiber guide ware fibers are flattened and aligned. So first stage is, there are two major constituents in a prepreg. The first constituents is the fiber. Now from where the fiber is coming that we are trying to understand here. The fibers are drawn from the fiber creel onto a belt through fiber guide, where fibers are flattened and aligned. So the fibers are coming from the creel, and then there is a fiber guide which is where fibers are flattened and aligned, because we want fibers in one particular direction only.

After the fiber positioning two top and bottom backing sheets, usually polyethylene sheets. So that if you remember in the animation, there were two sheets which were being removed from the prepreg one was green color on the revise one was blue color. So those sheets are put after the fiber positioning, two top and bottom backing sheets, coated with resin of sufficient thickness are brought together with the fibers. So in this is trying to explain we know the diagram we have seen, the fibers are moving through the resin tank, and keep taking the resin alongside it, and there are nip rollers which remove the excessive resin.

But here we are trying to explain another mechanism of depositing the resin on to the fibers. Now we have taken fibers, we have flattened, then we have positioned them, then the top and the bottom protective sheets will carry a inner layer of the resinous materials. The top layer will also have resinous material on the inner side, the bottom layer will also have the resumes material on the inner side. The bottom layer will also have the resinous material on the inner side and in between, we will stack up our fiber layer. Now maybe this is my fiber layer, this is bottom sheet top sheet, and we will press it and make a sandwich like this, and what is the role of this sandwich. Now when we will heat it, the resin from the top and the bottom sheet will flow into the fiber and it will impregnate the fiber, so that we get our prepreg.

So after the fiber positioning two top and bottom backing sheets coated with resin of sufficient thickness are brought together with fibers, though this sandwich is ready. Now in between we

have fiber top and bottom sheets carrying the resinous material on the inner side have been stacked together. The quoted resin on the backing sheets mat contain fillers additives and catalyst, as per the requirement. So it may not only be a neat polymer, it may have some additives in the form of. Sometimes it will may be fire retardant, sometime there maybe coloring agents or there will be catalyst, which will help in the process of partial curing all these layers of backing sheet, and fibers are compacted with rollers repeatedly. So we will compact them together we will a compaction means we will alloy, allow for certain degree of pressure acting on this sandwich.

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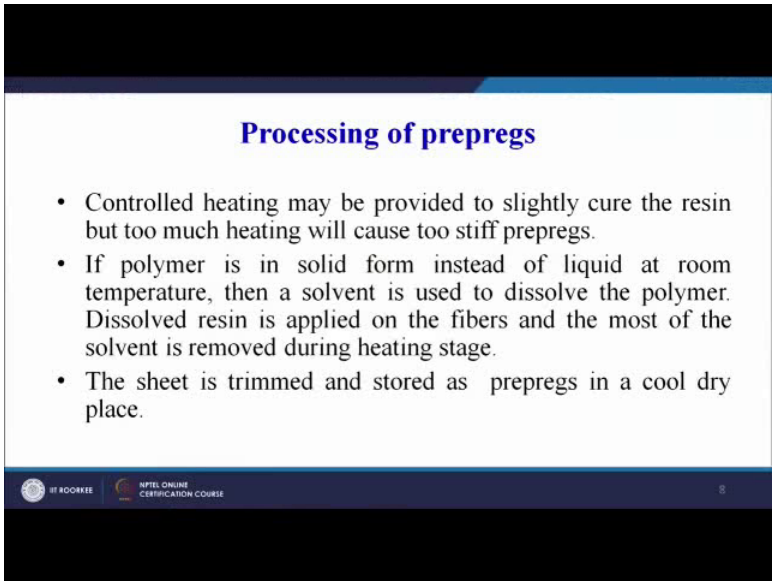

Controlled heating may be provided to slightly cure the resin, but too much heating will cause too stiff prepregs. So we do not want too much stiffened prepregs. So they will control the heat that we will supply to this sandwich. Now how this sandwich has been made, inner layer is fiber, top layer is one sheet, bottom layer another sheet. Top and bottom sheet has the resin plus the additives on the inner side, so that now this sandwich is ready. Now this resin has to be transferred to the fibers, from the top as well as the bottom as well as from the bottom, so that our fibers now contain the polymer also and our prepreg is ready.

So two things have come here which are the important control variables; first one is the compaction, that is a pressure that we are applying on to this assembly, and second one is the temperature that we are giving it, the temperature that we are exposing this sandwich assembled two, or sandwich assembly two. So controlled heating may be provided to slightly cure the resin, but too much sweating is also not required, but it will be the prepreg too stiff . And if you remember in the simulation we have seen, the prepreg have to go and they have to mold themselves as per the shape of the mold.

So that if the prepregs are too stiff, it will be difficult to put them inside the mold as per the shape complexity of the mold. If the mold is simple flat plate, only yes we can very easily cut the prepreg and put it on the flat plate, but if it the mold has got up profile, or the product has got a specific profile. We do not like to have a very stiff prepreg. Therefore the heating rate of the

these two three layers; that is a top or bottom layer and in between the fibers, these heating should be given only up to a particular level only.

So that the prepregs that we are getting are not too stiff. If polymer is in the solid form instead of liquid. Resinous material we have seen, is applied on the inner side of the sheet, but there is another case; that is polymer is in solid form, instead at liquid at room temperature. Then a solvent is used to dissolve the polymer. Dissolved resin is applied on the fiber and the most of the solvent is removed during the heating stage. So if the resinous, if the fiber is present, sorry if the polymer is present in the resinous form, we can very easily use it, but if our resin or the polymer is in the solid form.

Now can you give an example where the polymer will be in the solid form, just think over it, if you see the polymer pallates, those are solid, and we want to use a thermoplastic for this process, then there is additional stage, but first we have to dissolve. You can see if a polymer is in the solid form instead of liquid at room temperature, because thermosetting resins may be in the viscous form at room temperature, but many thermoplastics maybe in the solid form at room temperature, then a solvent is used to dissolve the polymer.

So we will again make solution with the solvent, and we willdissolve this polymers the dissolvent is used to dissolve the polymer dissolved resin is applied on the fibers, and most of the solvent is removed during the heating stage. So both if our polymer is available in the liquid form, well and good, who can apply it on the inner side top layer, and the bottom side of the, sorry top side of the bottom layer, and in between. We can all the fibers place them together apply pressure give some heat, the polymer will impregnate the fibers and our prepregs is ready, but is the polymer is available in the solid form dissolved in a solvent. Now apply the solvent and the dissolved polymer on to the fibers. And then maybe once you take it to our woven. If you heated the solvent can be removed during the heating stage, the sheet is trimmed and stored as prepregs in a cool dry place.

The sentence is very very simple, very easy to understand, but it is very difficult to manage the sheet is trimmed and stored as prepregs in a cool dry place. Now cool dry place, maybe we are recording this session in our recording studio, it is also a cool dry place, but these prepregs cannot be stored in this type of conditions. Sometimes the temperature that is required for a particular combination of fiber and polymer maybe minus 18 degree. Sometimes it may be minus 20 degree. So depending upon that we have to ensure that prepregs are stored safely, and the curing of the process or curing of the prepregs do not start automatically; that is the major purpose of limitations of using the prepregs.

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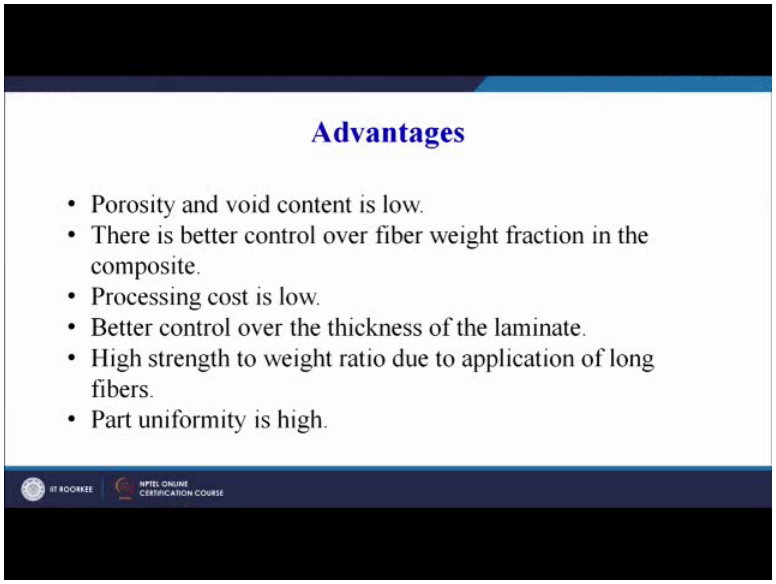

What can be the advantages of using the prepregs. Let us try to understand that. First is a porosity and void content is low, as we have seen their fibers, then there is top and bottom layer, there is pressure, so when the pressure will act the words, there are chances that the words may get removed. So the porosity and void content is low. There is better control over the fiber weight fraction in the composite, so we can control the fiber weight fraction; that is the percentage of fibers by weight in our resultant composite. So that is better in case of prepregs, because here you see that control slightly isdifficult, in case of short fiber reinforced composites, but here the examples that we have taken, and we have read. We are using the continuous fibers either in the uni direction or in the bi direction woven mat.

So basically every reinforcement is in terms of continuous fibers, in the form of unidirectional woven mat. Therefore we can try to have that, we can achieve better fiber weight fraction as compared to short fiber composite. So there is better control over the fiber weight fraction, there is another advantage processing cost is low, better control over the thickness of the laminate, because now we have the thickness we are not applying the resin separately. So the composite product that we are making, we will see that if we want 6 mm thickness, we can very easily calculate what is the thickness of the individual layer of the prepreg. So we will say ok, it is 1 millimeter, so maybe we will use 6 sheets of prepreg or 6 steps of prepreg, and stack them together to make a 6 millimeter composite products, because the thickness of 1 prepreg is 1 millimeter, so 6 millimeter means 6 prepregs we can use, so that is maybe rough estimation can be done like this. So we can have a control of the thickness of the laminate.

Whereas in case of hand layup process, we are applying resin by hand or manually, so we put layer by layer by layer and then we keep on applying the resin, and when we apply pressure on to the laminate, sometimes the control of the thickness is a limitation; why, because we are not calibrating the load or the pressure, that we are applying on the composite. Whereas here the control becomes better, because resin and fiber pre blended. And therefore the chances of variation in thickness are reduced. So the better control over thickness of the laminate, then we have high strength to weight ration due to application of long fiber.

So that is this point is quite similar to the second point where we have better control over the fiber weight fraction. So high strength to weight ratio is possible, because we have high fiber weight fraction in the composite, as well as we have long fibers in the composite. So instead of long fibers we can say the high fiber weight fraction will lead to better high strength to weight ratio, or high strength to weight ratio, because the fibers have less density in most of the cases as compared to the polymer. So high strength to weight ratio is also possible for the prepregs, then part uniformity is high, so that it also quite important and that isin case of composites, that is additional advantage or additional requirement. The uniformity in the part, why that is important. Because when we are doing hand layup process and we are doing spray layup process in many corner areas, it is difficult to control the thickness of the product. Whereas with prepregs that part uniformity can be achieved easily. So part uniformities high when prepregs are used.

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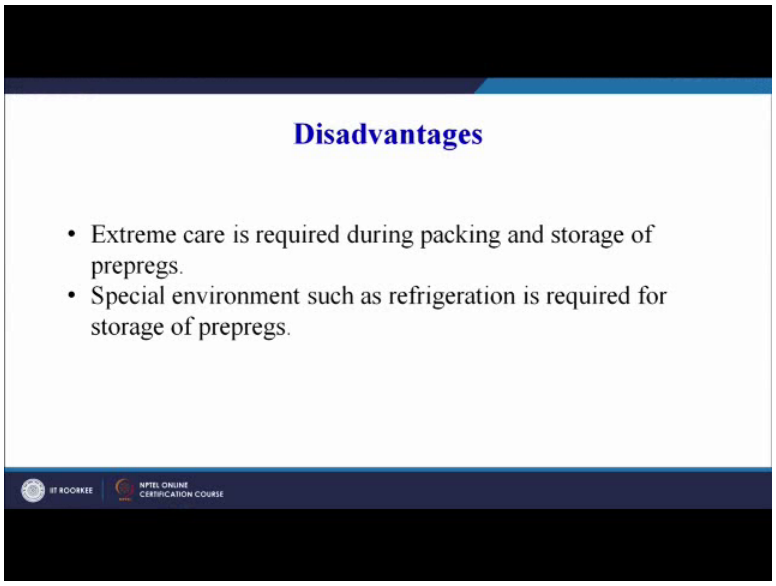

What are the major disadvantages extreme care is required during packing and storage of the prepregs. I think this is a third or the fourth time in today's session only, that again we are coming to the same point, the storage of prepregs is the one of the major limitations, special environment; such as refrigeration is required for storage of prepregs. What are the application areas?

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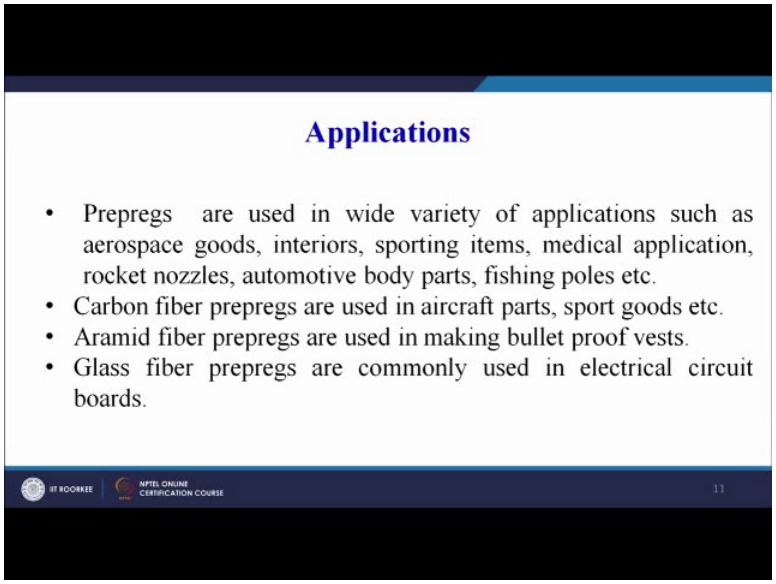

Now let us quickly see prepregs are used in wide variety of application; such as aerospace goods, interiors, sporting items, medical applications, rocket, rocket nozzle, automotive body parts, fishing poles, at etcetera, because the fiber and of either and polymer is pre blended. We can have a mold of the product rolled or lay the prepregs, and then cure them completely we will get our final product.

Carbon fiber prepreg are used in aircraft parts, sport goods etcetera. Aramid fiber prepregs are used in making bullet proof vests. Glass fiber prepreg are commonly used in electric circuit board, because glass fiber is poor conductor of electricity, and polymer is also not very good conductor of electricity. Therefore they can be used as insulation purpose is also.

Now as I told in the very beginning of our session today, that we are closing our second phase of the course; that is first phase was related to polymers only, and the processes that are used for processing of polymer. The second phase was regarding composite materials, specifically polymer matrix composite materials, and then finally we have seen different processing techniques that are used for processing of polymer matrix composites or fiber reinforced plastics, just to revise what we are covered in context of polymer composites. We started up with hand layup process then spray layup process.

Then we have seen compression molding as applied to composite materials, then we have seen injection molding, even extrusion can be applied for composite materials, then we have seen resin transfer molding, we have seen filament winding, we have seen pultrusion process. Then we have seen that how sheet molding compounds and prepregs can be used or can be manufactured, which are further used for processing of polymer product or polymer matrix composite products.

So that is the second phase I can very comfortably say that learners might have now, by now got an fair amount of idea that have polymers are processed, and how of polymer matrix composites are processed, but certainly there are challenges which we have already discussed. Again I am

summarizing those challenges that what are the problem areas related to processing of polymer matrix composites.

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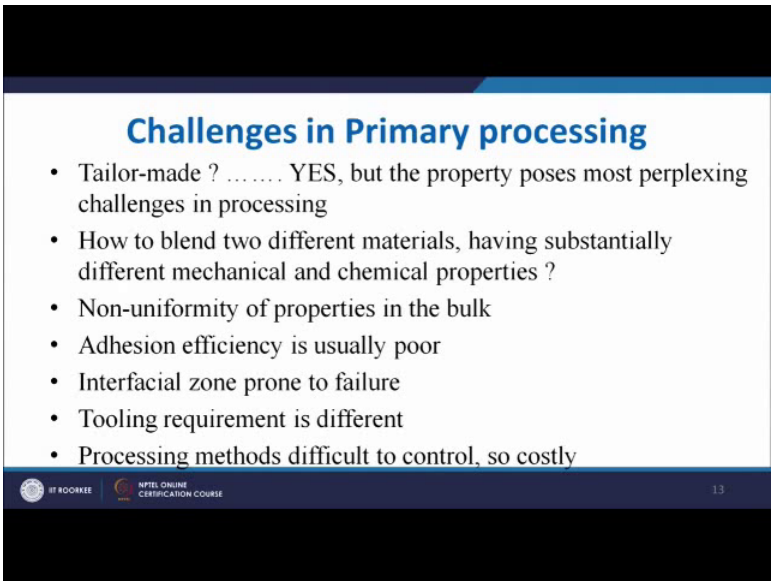

So first is tailor made. Tailor made means the properties are designed by the designer. We can choose our fiber and polymer accordingly, but for processing if you see we have seen the general mechanism of processing of different types of fibers and polymers, but if you see, if you change the fiber you change the polymers certain degree of fine tuning. A tweaking is required for the same process, or we can say the operating variables will change as soon as our fiber and polymer will change. Therefore, yes, from designing point of view our composite materials offer lot of versatility but from manufacturing or processing point of view, they are providing us ,or they are putting us a lot of challenges; why, because different polymer matrix compositions require different types of settings, even for a single process.

Similarly, how to blend two different materials together. I have been emphasizing this point, I think in every session that we have taken on processing of polymer composites, that fibers have different properties, polymers have different properties. How we have to combine them together; that is one challenge. Then the properties are not uniform, if you remember in the todays session only, we have seen that if we use prepregs our partuniformity is achievable. Where as in other processes that is a challenge.

Adhesion efficiency between the fiber and the polymer is usually poor , and therefore we try to do certain treatments of the fibers in order to improve their attention with the polymers interfacial zone between the fibers and polymers is prone to failure. The tooling requirements are different, the molds, the dies that we used for metals cannot be directly duplicated in case of composite. Materials processing methods are difficult to control, and therefore they are costly. I think all these points we have discussed earlier also, when we started our discussion on processing of polymer matrix composites.

Again I have come back to this challenges and now you can better appreciate, when we have seen all these processes that; yes, these are the challenges which still exist, and therefore there is a development of new and new processes for the processing of polymer matrix composites, but

for a learners, for a beginners in the field of polymer matrix composites, the discussion that we have done till today is I think sufficient for giving you a platform to further build up your knowledge in the area of polymer matrix composites more specifically, processing of polymer matrix composites. So with this we end our phase two of our course. In the last phase of our course, we will focus on the secondary processing techniques for polymer matrix composites.

Thank you .