Processing of Polymers and Polymer Composites

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Lecture – 16
Processing of Polymer Composites

[FL] friends, welcome to session 16 in our course on processing of polymers and polymer composites. In our last session we have discussed the classification of composites materials, and we have seen the further sub classification of polymer composites. So, broadly the composite materials are classified based on the matrix, as well as on the basis of the reinforcement. So, based on the matrix, we have three types of composites; that is polymer matrix, ceramic matrix and metal matrix Composites. Similarly based on the reinforcement, we can have further sub classification, in terms of shape of the reinforcement, in terms of orientation of the reinforcement, as well as on the basis of the chemical nature of the reinforcement.

So, we have seen that in polymer matrix composite, the polymer is the matrix material and the reinforcement is majorly in terms of fibers, and those fibers we have seen, can be synthetic fibers, and those can be natural fibers. So, in synthetic fibers we have seen, that we can have carbon fiber, we can have glass fiber, we can have aramid fiber or Kevlar fiber. And from natural fibers point of view, we have seen we can have jute fiber, we can have sisal fiber, we can have banana fiber, we can have Grewia Optiva fiber. So, there is a big family or large family of natural fibers which have been used as reinforcement in polymer composites.

So, broadly to summarize in context of the polymer composites, we already have 2 sessions; the first session was overall definition, as well as understanding of the concept of composite materials. The second session was on the classification of composite materials, in which we are further come down to our specific family or our specific sub family that is polymer composites, and we have seen in the last slide that there is a polymer, when we add reinforcement in the form of fibers into the polymer, we get a composite material which can be considered as a engineering material, and has got wide application spectrum. And we have seen that these type of composites can be used for light weight applications; like aircraft or in marine industry, or in sports equipment. So, the application spectrum is quite wide, and therefore, we need to understand that how these products can be made, or how these composite products can be made.

So, today we are going to have introductory lecture or session on processing of polymer composites. So, we have already seen the processing of polymers, if you remember we have seen number of processes; like casting, thermoforming, extrusion, transfer molding, injection molding, blow molding, rotational molding. Some of these processes will also be used for processing of polymer composites, but with little modification, we have to see if you remember in our last session, I have told that our basic understanding has to be, that how to bring these 2 physically chemically different materials together, and make them a composite.

So, that they behave in unison, they behave synergically, and they behave in a matter or in a manner in which they are useful for the purpose for which they have been combined. So, the major challenge is to identify that how these 2 different constituents can be combined together, to make a composite material, and that is the beauty of the process, where we combined the 2 things together, and the third thing comes out to be better than the individual constituents.

So, today we will not be discussing any specific process for composites material, but we will be discussing general challenges, general problem areas associated with the processing of polymer composites. And I must emphasize here that we have three types of composites based on the matrix material. Again and again I am recreating the same thing, only to make you understand that our focus area is only one subfamily of the composites; that is polymer based composite. Otherwise we have metal matrix composites also, we have ceramic matrix composites also, and the process is that are used for processing these 2 type of composite; that is ceramic matrix composites and metal matrix composites, are entirely different from the once, of the processes that we used for polymer based composites.

So, in our sub sequent session, we will be focusing on process that are only used for polymer composites. And today we will have a introductory session on the problem areas challenges, that the polymer composites have to face, specifically in context of the processing requirement. So, let us start our discussion for today. Just to have a brief review of what we have covered in the previous 2 sessions, the constitutions of PMCs.

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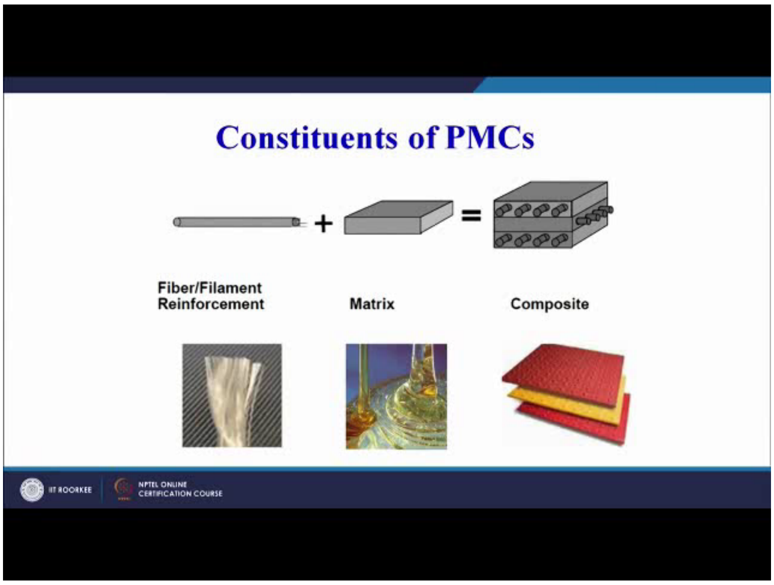

The another name if you can remember, just give a thought over it, just spend of few seconds to figure out what is a name, other name of this material PMCs. The full form of the PMCs will be polymer matrix composites. What can be the other name if you can remember. It is fiber reinforced plastics that is FRPs.

So, the 2 names are used interchange ably, some places you will find polymer matrix composites, at some other places you may find fiber reinforced plastics, but the basic fundamental remains the same, you can see on your screen. We have a we have a fiber, schematic representation of a single fiber plus or a strand of fibers plus this is a matrix, matrix will not be like this, if it is a thermoplastic we can have a thermoplastic sheet also, but majorly we will be using the granual form of polymers; that is matrix, and when you combine the matrix and the fiber together, we get a composite material like this, and this is actual representation. There is a fiber or a filament. Sometimes we call these are fiber strands also. This is the matrix in the form of viscous flude viscous gel flude, it can be a thermo set, and when we combine these 2 together, and we have add some curling agents we can get a composite sheet like this.

So, we combine the 2 constituents together to get a third constituents, or not a third constituents a third product; that is a composite product. So, this is the basic thing that we have understood in the previous 2 sessions, that there will be a reinforcement. In this case the fiber is the reinforcement, and the matrix is a polymer, which is thermo setting in this case, and when the 2 are combined together ,they made a composite material .

Again, another representation of the composite material, we can see from the mechanics point of view.

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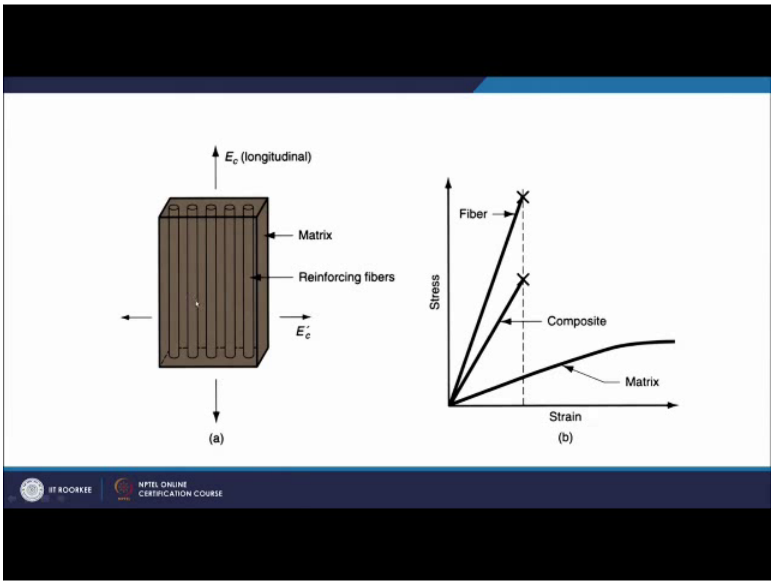

All fibers are running in this direction. In this figure there in the vertical direction; so, we have a longitudinal modulus here. We have a transverse modulus here. So, we can see that from the mechanics point of view, the composites will have different properties. So, the modulus will be different in different directions. If it is completely anisotropic composite material, and the strengths will be different in x and y direction; all the tensile strength compressive strength will be different in different direction. So, this is one representation of a composite material. The continuous face or brown color, represents the matrix, and the longitudinal fibers are is being used as the reinforcement material.

So, if we can see from the reinforcement point of view, we have seen based on the shape, there are 4 possibilities. Now first when one is long fibers, short fibers, whiskers and particles. So, in this particular type of a composite material, let us try to relate that we have the shape of the fibers; that is continuous fibers here. If this fibers are short fibers they will be distributed, and if they are distributed they can be oriented in one direction or they can be randomly distributed. So, that summarizes what we have already covered, that is the reinforcement can also be classified based on different dimensions or different cri sub criteria; that is reinforcement can be classified based on shape, reinforcement can be classified based on orientation, reinforcement can be classified based on the chemical nature of the reinforcement.

So, this is one particular diagram, which gives a schematic of a long fiber reinforce polymer composite, and this is another thing; stress strain diagram for a typical composite material. Why this diagram has been taken here. If we try to correlate this with our first session in which we have introduced the concept of composite material. We have seen that the properties of the resultant composite, must be a contribution of both the reinforcement as well as of the matrix.

Now, here you can see the stress strain behavior of the fiber. This is a stress strain behavior of the fiber. This is a stress strain behavior of the matrix. So, we can see when we combine the matrix and the reinforcement together, this is a stress strain behavior of the composite. So, the behavior or the resultant behavior of the composite is a combination or maybe a contribution of both the constituent. It is not being dictated by one constituent only and there for we call this as a composite material.

Now suppose we have made a composite material using a different type of fiber, and the stress strain behavior is very close or may be overlapping with the stress strain behavior of the matrix, we will say, no, this is not a composite material why because the behavior is influenced by the matrix material only or on the contrary if the stress strain behavior of the composites, is just over lapping with the fiber, or is very closed to the fiber, then we will say again it is not a composite material why, because the resultant, or the we can say the properties of the behavior or the mechanical behavior of the composites should be a combination of both the constituent; that is a matrix as well as the reinforcement. And why we are putting this paragraph or this figure here, because we have to now combine these 2 things together.

We can see one material is having entirely different stress strain behavior, another is having entirely different stress strain behavior. So, now, we have to combine the 2 together. So, they are the matrix and the reinforcement of the fibers, are different. Not only from the stress strain point of view, but there also different from the chemical nature point of view. They are also different from a number of other strand points also. So, the point is. Now we have 2 distinct materials, which are physically and chemically distinct, and we have to combine them together.

So, we have to see at what temperature, at what pressure at what conditions we can bring them together. So, that they form a very good bond, and we get a composite material, which has better properties than the individual constituents. So, that is you can say the challenge that we are going to address. Although we are not going to study research or development. We are going to study only what has already been established and commercially has been practiced; that is a commercially available processes that are used, or are being used for processing of composite materials, specifically polymer based composite material. So, that is our target that we are going to achieve through this course.

Now, let us see the overall properties of the PMCs. We have already seen that the properties are combination, or we can say synergic effect off both the constituents is seen in the properties or observed in the properties of the polymer matrix composites. So, overall the properties of polymer matrix composites are determined by.

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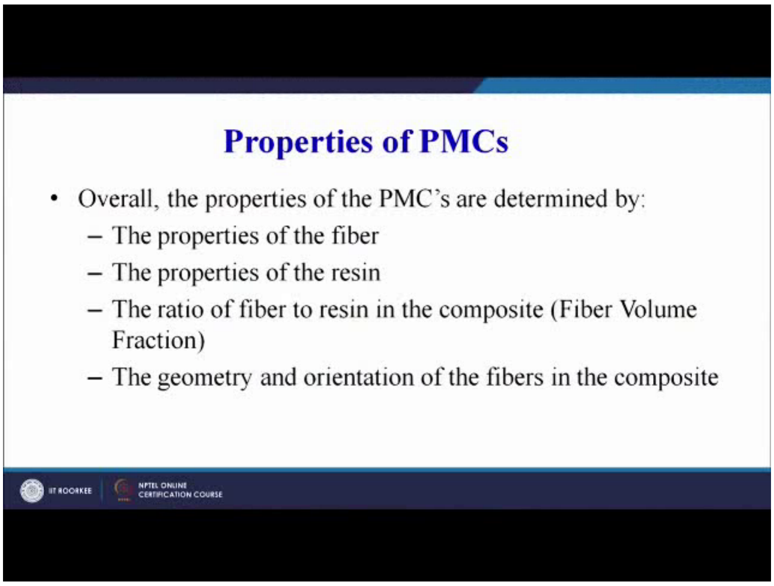

Now, what will influence as I have already told in the previous slide, we have seen that the properties are influenced by both. They are influenced by the reinforcement also they are influenced by the matrix also, same thing is written on the slide also, the properties of the fiber which is the reinforcement, the properties of the resin of the polymer or the plastic, which is the matrix. So, the properties are influenced both by the matrix as well as by the reinforcement.

The ratio of the fiber to resin in the composite. Usually we call it as a fiber volume fraction, that what is the percentage of fiber as well as the percentage of resin in the composite material, as I have already told you, all the things are interrelated. If you see the criterion to classify any material as a composite material in the very first session on composite, we have seen that minimum 5 percent of the constituent must be there; that is if 95 percent fiber, 5 percent matrix must be there, or if 95 percent matrix at least greater than 5 percent reinforcement must be there, just a rule of thumb cannot be said that it is the only criteria which will help us to classify any material as a composite material, but just as a rule of thumb, which is practiced a universally.

So, we can say that the third point on your slide, the ratio of fibers to resin that is very important, and usually we try to see, depending upon the application, we will see that how the properties can be tailored. As we have already seen one of the advantages of the composite material is that they can be tailored. So, tailored means that we can decide on the composition that how much resin should be there or the polymer should be there and how much fiber should be there, in order to make a composite as per our requirement, as per our desirable properties. So, that is also influencing the overall properties of the composite material.

So, the ratio of the fiber to resin is also important. Also the geometry and orientation of the fibers in the composites. As we have seen in the previous slide, all fibers are running in one direction, and if we apply at tensile load in that composite, in which all fibers are running in one direction, in the longitudinal direction the strength will be different. And if we apply the same load in, may be the transverse direction sorry, the properties will be different, because along the fibers the load bearing characteristics are different .Across the fibers or in the transverse direction the load has to be taken by the matrix.

So, the load bearing behavior will change. So, that is important, the geometry and the orientation of the fibers in the composite is also very important. So, from geometrical point of view, we can have different shapes of the fibers, and the orientation is the directional property. So, of both these things will influence the property. From geometrical point of view, again I want to highlight this point, specially in case of metal matrix composites if you see, the metal will be acting as a met matrix material; that is if you take an example of an aluminum alloy. So, aluminum alloy is the matrix, and we are adding some reinforcement. So, usually we add silicon carbide or aluminum oxide as the reinforcement material.

So, if all particles are spherical in nature, the behavior of composite will be different, and if you put angulars, but angular particles into the composite the properties will change. So, that is the meaning of the geometry, that if the geometry of the reinforcement will change, the properties of the composite will change. Similarly the orientation of the fibers is very clear from the polymer composites point of view as in the previous slide. If all the fibers are running in one direction, and we apply the load also in that direction, we will get very good properties, but if we apply the load in the transverse direction to the direction of the fiber, we are definitely going to get poor properties or slightly lower properties as compared to the longitudinal direction.

So, the properties of the composite will be influenced by the properties of the fiber, the properties of the matrix, the fiber volume infection, as well as the geometry and orientation of the reinforcement. This is a very important slide on your screen. As in the previous session as well as previous to previous session or the first session on composite I have emphasized this point very clearly, that whenever you come up with a new material, there will always be questions, and you have to answer those questions in order to propose the use of the new material for a specific application, and that is the biggest challenge.

Now, there are lot of innovations happening in the field of material science and engineering. So, many light weight metals are being invented. So, many other materials which are a challengers or which are competitors to the polymer composites are coming into picture, or coming into the engineering domain. So, we have to see that how polymer composite can compete with these challenges or challenging materials. On your screen we have tried to highlight some of the points, which are challenges for composite materials.

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And which need to be addressed. First is challenge from the technical innovations in metals, this I have already highlighted, that there are lightweight metals being developed or being invented, or the alloys are being developed which are light in weight have high strength to weight ratio high stiffness to weight ratio. So, that challenge is there for these materials. If you remember the first session on composite we told that, they are used for light weight applications.

So, lightweight alloys are also being developed. So, a competition is there between the light weight alloys, as well as the lightweight polymer based composites. Misconception about the durability of plastic products. Even today if you give a choice to any person who do not have engineering background, and you give same 2 products made by same geometry, all specification same, only the material is different; one is made by a metal, another one is made by a plastic. I think you know the answer the person is going to get take the metallic product only; that is the mindset that we have related to the durability of the plastic products.

Third point is combustion smoke liberation characteristics. Yes there inflammable, there are chances of plastics kept catching fire. So, that is one challenge. Forth, long term durability and fatigue characteristics when exposed to load or operating environment. So, in case of polymer composite in the first session, I told that these materials may be 60 70 years old, whereas, metals and other construction or structural materials, may be 150 200 years old. So, we do not have long term durability data of the composite materials available with us. All though accelerated, aging tests are being done and there are research tools available to find out the long term durability, but still lot of efforts have to be made in this direction , in order to a certain the long term durability of the plastic or the composite waste products. And specifically under the, of specific operating require over a requirement or environments where these materials are being, are going to be used.

Then the failure mechanisms of laminates and composite structural systems is not very well understood. So, laminates basically we will see, in our subsequent sessions we will see the process of hand layer, we will see the process of compression molding, and there we will see that how laminates are made. So, laminates basically are composites in the layered form, in which the fibers are woven fibers, and they are taken stacked layer by layer by layer and compressed together to made a composite material. So, that we will see how to define this word laminate. So, failure mechanisms are not well known. So, if under operating environment, there is an impact on this material, and there is damage to the laminate, how that damage will happen on impact; that is not very well understood.

Establishing approved industry design codes. So, that is another challenge; that is from commercial point of view. Agencies are there which are working on this and trying to come up with industrial approved design codes. Those who are technical challenges that we have seen in the previous slide.

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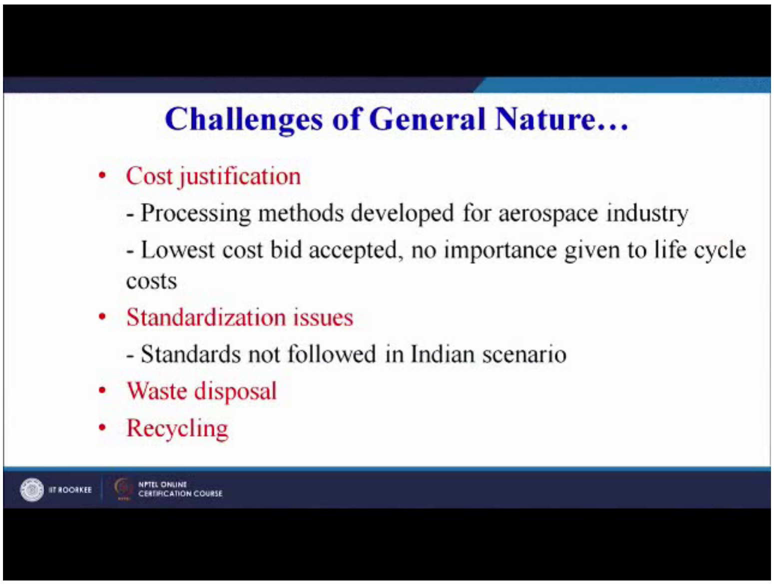

Now, there are commercial challenges also; first one is cost justification, always whenever you try to replace an existing material with the new material, the first question that you come to the minds of the managers are, managers is the cost, that how cost effective these new materials are.

Now, that can be explained with 2 points; point number one processing methods have been developed for aerospace industry. So, the point may not seem to be very clear to all of you, but let me try to explain it very briefly in 2 or 3 sentences, that the composite materials aware developed majorly for aircraft applications, as they are light invade, they have high strength to weight ratio high stiffness to weight ratio. And the processing techniques that were developed at that time, were also developed keeping in mind the quality required for the aircraft applications.

But now the composites are you being used from automotive applications, also they are being used for, sports equipment applications also their being used for, house hold applications also, but the processing methods that were developed for aircraft industry are still in use, and the same standards are being followed for making products for these applications which are not that sophisticated, not that high. And therefore, there is a need of the are to come up with materials or come up with the sorry. The process is which are there for these materials which are cost effective, which are high quality. So, that is one challenge for manufacturing engineers.

. So, then we will be able to justify the cost. The cost is higher because the methods that we were using had been developed for very high standard manufacturing of composite materials. Similarly another challenge is the lowest cost bid accepted, and no importance is given to the lifecycle cost. Now suppose we have a chair, a wooden chair. So, a wooden chair may be cost you less than the composite chair, but there are so many problems associated with the wooden chair, termite problem is there, moisture absorption can be there, then dimensional stability under moisture absorption is one challenge, where have all these challenges do not exist in case of composite materials.

So, if this is a lifecycle cost of a composite chair, it may be less, but the initial cost of composite chair is more, but as per our standards we will go for the company, which is going to supply a chair in the minimum possible cost. So, from life cycle costing point of view composite materials are advantages. For example, in under water application, if you have a metallic product, and if the environment is very cold, chilling cold, and there is a underwater installation, there is ice all around, we have to put deicing salts there. So, deicing salts, ice cold environment and a metallic installation, you can yourself imagine that there are chances is of corrosion to the metallic part, but whereas, if you use a composite product there, there are chances that it will be able to resist as it is, they we can make corrosion resistant composite materials. Frequent repainting of this structure will not be required that is under water.

So, if you see the lifecycle cost, initially we may have to spend more money for that installation if we are using the composite product there, but over a period of time, this frequent repainting were frequent stopping of the process all that will be taken care off, and the lifecycle cost of a composite product may be less as compared to the product that we have made out of metal or any traditional material. So, that is one thing, that we need to justify.

Standardization issues, for metals we have already approved industry approved design standards design, industry approved standards, but these are not maybe for composite these type of standards are still not available. If they are in the development stage, and I believe that may be in the coming 5 to 7 years, all standards in case of composite materials must be ready and ready to use.

Waste disposal is another problem as in the previous session we have seen, that there is a trend towards the development of fully biodegradable composites are fully biodegradable green composites why, because there is a challenge of waste disposal the polymers of the plastic that we are using these days are non-biodegradable, or all the thermo sets and thermo plastics that fall under the synthetic plastics category, are non-biodegradable. So, that is one challenge and that needs to be addressed.

Similarly, similar to the waste disposal is the recycling. So, that also has to be taken care off, that how we can recycle that plastic, how we can recycle the polymer based composites materials. Now we can discuss the important issue that is related to the primary processing, challenge is in primary processing . So, we have said, we have very happily acknowledge that the composite material that tailor maid, we can select our reinforcement, we can select our polymer, and we can combine them together to make a composite material, but that is one of the biggest challenge, because different fibers, different polymer, how to combined them together. Same process cannot be used, same temperature conditions cannot be used, same pressure conditions cannot be used, same operating variables cannot be selected, because the fibers are different, the polymers are different.

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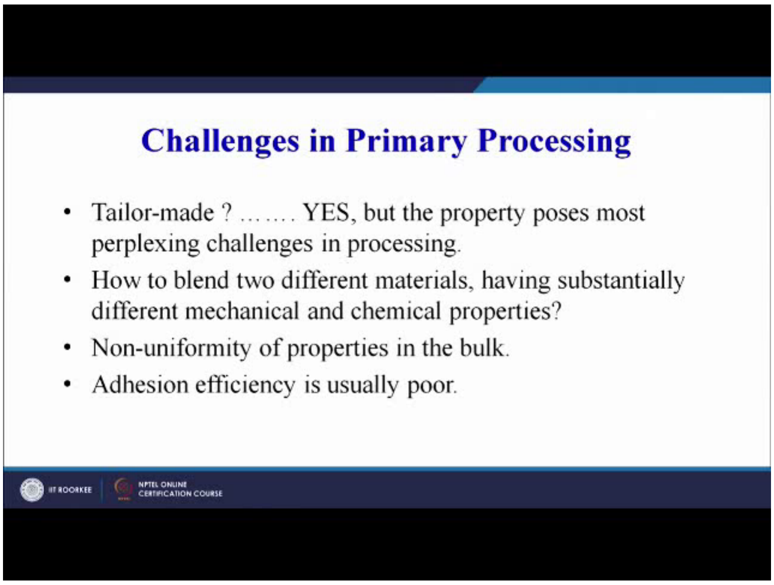

So, yes that composite materials have the advantage, that they are tailor made, but the property poses the most perplexing challenges in there processing.

So, that tailor made yes that is an advantage, but it is similar, it is simultaneously challenge also, that how to combine these are wide variety of fibers and polymers together that the challenge. Biggest challenge is how to blend 2 different materials having substantially different mechanical and chemical properties, and to add to that physical properties also are different. Then non uniformity of the properties in the bulk, that composites usually are un isotropic, and for the individual constituents also if you will see within the 5 fibers also the properties may be different, along the direction of the fibers and across the direction of the fibers; that is non uniformity of the property, another challenge.

Adhesion efficiency is usually poor slightly technical term adhesion efficiency. You can just remember, instead of adhesion efficiency use the bonding. The bonding is usually poor. Now what has to bond together the fiber and the polymer has to bond together. So, when the bonding is there between the fiber and the polymer, the bonding sometimes is poor, and therefore, we do not get the adequate mechanical properties of the in the developed composite; there are techniques to increase or improve this bonding strength or improve this bonding characteristics, that we will see in our subsequent session, but one challenge is, that when we are combining the fiber and the polymer there has to be good bonding, if the bonding is poor the properties are poor, how to ensure that bonding that we will see in the subsequent sessions.

And when the bonding is poor, the interfacial zone, or the we can say the zone between the reinforcement and the fiber, the inner zone is that is prone to (Refer Time: 28:58) as soon as you will apply the load, the matrix will not fail, the fiber will not fail the bonding zone, or the interfacial zone between the fiber and polymer may fail.

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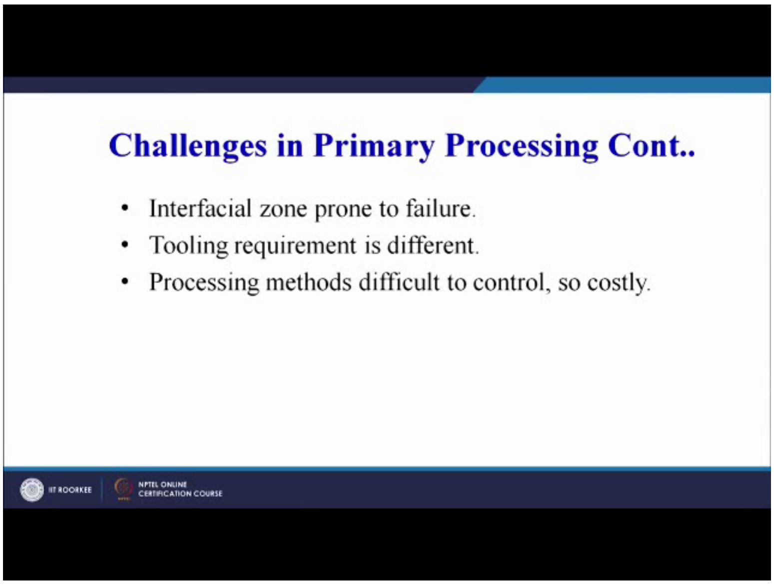

So, that is one challenge tooling requirement are different, yes, we cannot use the same tools that we used for metals, or same machine tools that we used for metal, the same process is that we use for metal that we use for metal, cannot be directly applied for the polymer composite. Therefore this course has got even more importance, that how to bring this 2 material together to make an engineering material, which we can use for any engineering application.

Processing methods are difficult to control therefore they are costly. So, that we have already seen in cost justification of these materials. So, that is, these are the challenges from the primary processing point of view, that how to bring them together the interfacial zone is, prone to failure, the adhesion between the polymers and the fiber is poor. All these challenges have to be tackled by the engineer, in order to make a good quality composite product.

Now, this is slightly from the managerial or management point of view, what are the issues to be addressed when we select a process for processing of composite materials.

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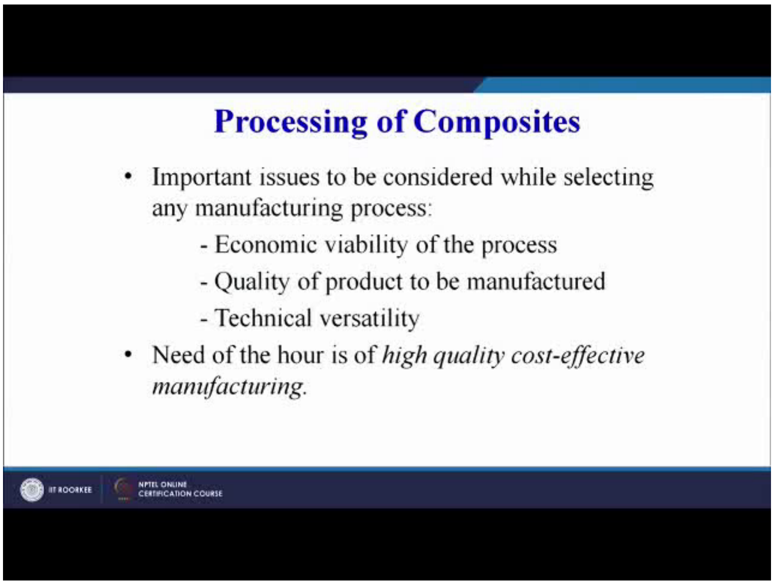

First we have to see the economic viability of the process. We have to see the quality of that product, as well as we have to see the technical versatility. So, economic point all of you know that if the process has to be cost effective, so nothing to explain, quality of the product should be good; yes, that we have to ensure, otherwise the project products will be rejected and that no company would like to afford that. And then the last is technical versatility. Technical versatility it is important, because is large family of fibers, and there is very big family of polymers. So, if the process is versatile, it may be able to accommodate at least some sub family of the fibers, and may be particular type of thermo set and thermo plastic, and there for the process should be such, that it is able to accommodate we can say, at least 1 set of fibers and 1 set of polymers. It should not be the this is specific to 1 fiber and 1 polymer only. So, that we have to ensure when we design a process for composite materials.

So, the final summation is, need of the hour is to ensure high quality cost effective manufacturing of polymer based composites, and in that regard we can have different types of process is, as I have already highlighted, there the process is will be different for polymer matrix composite, metal matrix composite and ceramic matrix composite, but our focus area is, polymer matrix composite. And for polymer matrix composite we can have broadly 2 types of processes; that is the primary as well as the secondary.

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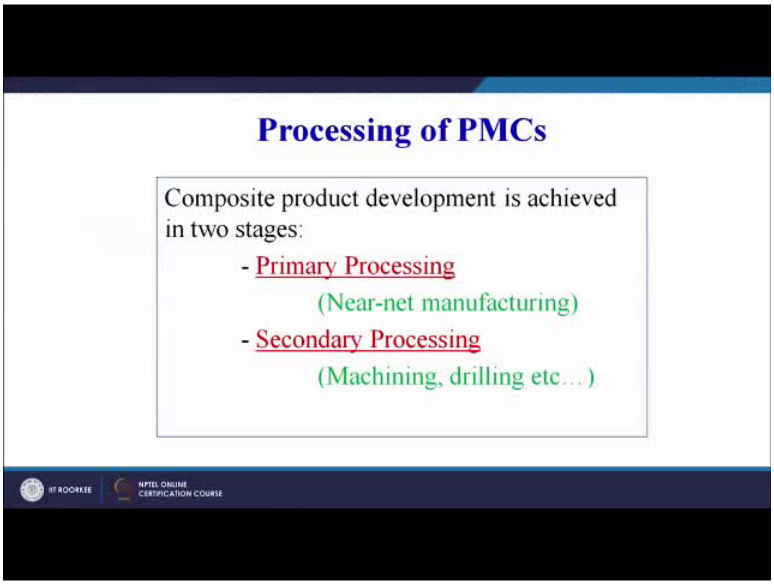

Now, primary processing is near net shape manufacturing, where we will be giving the shape to the composite material, and secondary where we joining the composite together, where will be machining of holes as a trimming of the composite part. So, machining drilling joining will fall under the secondary processing, and near net shape manufacturing, or giving the shape to the composite part will fall under the primary manufacturing processes.

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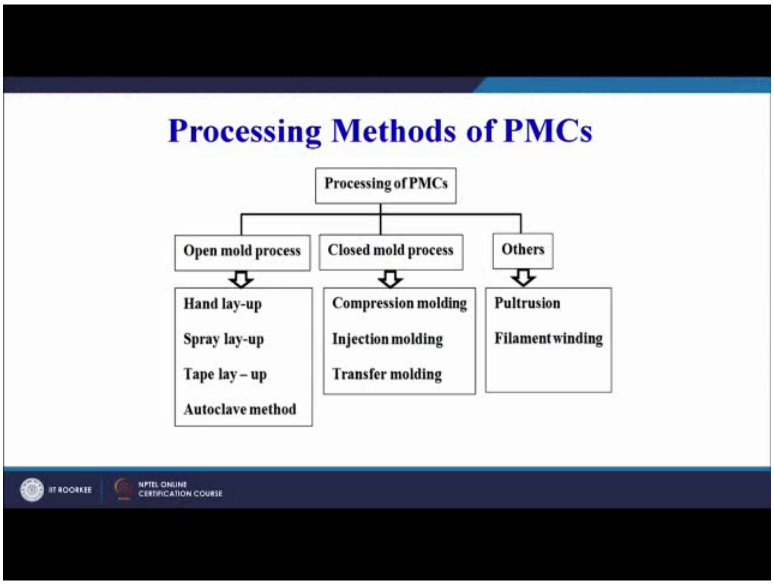

So, we will start our next session from this slide, where we will see the processing methods for PMCs. So, we can have open mold, closed mold processes and others. So, with this we come to the end of today's session on primary processing of polymer matrix composites. So, I leave you here with this figure, and we will start our discussion in the next session, from this figure only, where I will try to explain the, these are all the primary farming processes for polymer matrix composites, which can further be classified as open mold, closed mold and the miscellaneous processes

Thank you.