Processing of Polymers and Polymer Composites

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Lecture – 15
Classification of Composite Materials

[FL] friends, welcome to this session 15; on our course on Processing of Polymers and Polymer based Composites. If you remember, just you revise what we have covered in the course still today. We have covered, the polymers, the basic fundamental, classification of the polymers; that is thermoset and thermoplastics, the properties of the polymers very fundamental information, very basic information. And then we have covered the different processes that are used for processing of polymers.

If you remember, we have covered the casting process as applied to the plastic processing. Then we have covered thermo forming, we have covered extrusion, we have covered compression molding, injection molding. Also we have covered; other processes like blow molding; which are very commercially used and transfer molding we have covered. So, by now I think all the learners have a fair amount of idea that what are the processing routes, techniques, fabrication processes that are followed for processing of polymers.

Now, in the last session we have shifted our attention from neat polymers to polymer based composites. And in the last session, I have just given an introductory aspect of the composites; that is what is a composite material actually? We have seen 2 definitions of composite materials and we have tried to understand; that there are broadly 2 constituents in a composite material. Now, what are these constituents? That these 2 constituents are; one is a matrix, another one is reinforcement. So, these 2 constituents are combined together to make a third material, which has properties, which is a best combination; of the best properties of both the constituents.

So, we have tried to understand the basic concept of composite material that; why do we need develop a composite material? What is the need for developing a composite material? And we have also understood; what are the advantages of the composite material? And we have seen that for light weight application, composites have been developed world wide. And they find lot of applications in the aircraft industry,

automotive industry and there are number of other applications; like biomedical industries, sports equipment; even household items are today being made by composite materials.

So, last class focused on the basic aspect of composite that why do we need to combine the 2 different materials; which are physically different, which are chemically different to form a third material. So, that was the basic concept and if you remember; we have taken an example of the RCC structure or other roofs also; in which we have metallic rods and concretes that; what is the purpose of combining the metallic rods and that concrete to make up structure?

Today, our focus would primarily be on the classification because composite material is a very big family, there are a lot of research scientists or engineers are working in the field of composite material. But, we have to see that; what is the broad classification? How the composites can be classified? Now, classified means that; what is of bigger family? That is a composite, then dividing them into its individual; sub families and then the further sub families; so sub, sub families.

So, we have to see how the composite materials are classified. For all composite materials, for all practical purposes; 2 constituents will remain same that we have discussed in the previous class. That is one will be the matrix, another one will be reinforcement. And the matrix will have its own role to play; in the last session we have seen what is the major role of a matrix; it provides the bulk to the composite, it is a continuous phase as well as it supports the fibers or the reinforcement; moreover it leads to the transfer or it acts as a medium for the transfer of load, when the load is applied on the composite material; among the fibers that are used as a reinforcing elements.

So, matrix has got its own application or own role as well as the reinforcement as the name suggest the reinforcement has got its own role. So, in the composite material matrix place its own, role reinforcement place is own role. And when they combined together; they made a composite and that composites has specific applications. Now, how the composite can be classified? That we are going to cover today.

So, let us start our discussion with the important point; if you remember and I feel that all of the learner should remember that what was the assignment that I have given to you

in the last class; that is, you have to find out that in naturally occurring composites; what is the matrix? And what is the reinforcement?

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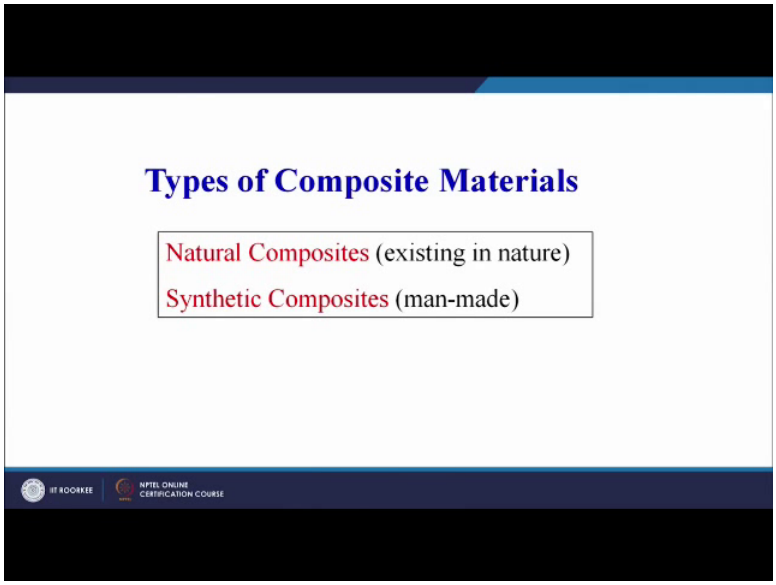

So, that all of you must have just looked into or if you are not looked into; I have, I put together the composition of the natural composites; that is wood. So, let us see; so there are naturally occurring composites all of you know. Now, what are these naturally occurring composites? Wood is one naturally occurring composites, our bones are naturally occurring composites and if you look around you; in nature, you will find a number of materials which have this property of a matrix and a reinforcement of 2 constituents or three constituents joint together to make a third material.

But that has been developed naturally so but the broad; we can say, the fundamental remain same that; there is the combination of 2 or three materials for making a third or fourth material, which is better in properties.

So, the naturally occurring composites; wood is one example; in this case matrix is Lignin and the fiber is Hemicellulose.

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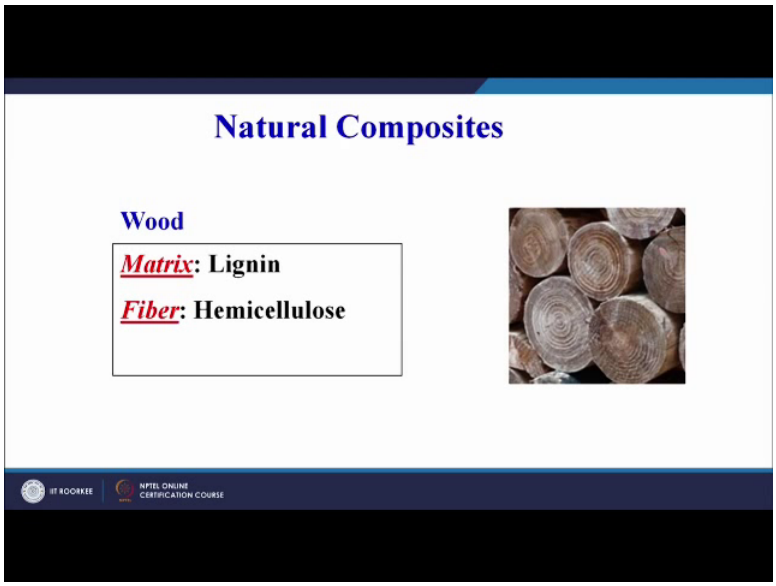

So, there is a fiber; there is a matrix they are combined together and combination of these 2 things Lignin and Hemicellulose; lead to the development of specific properties in wood. And their relative proportion may change; somewhere we may have different composition, lignin may be of a different amount; hemicellulose may also vary, depending upon the nature or tropical condition; there will be slight variation in these things and therefore, there are properties of the wood also are different.

If you see that; the wood that is used for making furniture is different, the wood that is used for maybe some other application; maybe a handle of wooden handle of a particular instrument; that is different. So, the wooden applications are also different; why are they different? Because of the properties, why the properties are different? Because of the constituents and these constituents maybe present in relative amount; somewhere one constituent maybe a larger amount, the other may be in a slightly smaller amount.

So, basically we need to understand that there are 2 or three major constituents; that add up to make wood and that defines the properties of the wood. And in the last class or last session, if you remember; we had clearly tried to understand that how we can differentiate between an alloy and a composite. And what are the three major criteria, which a material should satisfy; to be classified as a composite material.

So, that is the very common question if you will tell somebody; I have undergone a course on polymer composites or I have information on polymer composites; the first

question that you will be asked is; how to differentiate between an alloy and a composite? And how to differentiate between a polymer and a polymer blend? How to different between polymer blend and polymer composite?

So, these are some issues which are usually asks from the students and that answer, you should frame in your minds; after going through this session. Particularly, the previous session in which we have tried to see that; how you can classify your material as a composite. Classify means; what is the criteria based on which you will say that; this is a composite material. And if you remember; the 5 percent critical limit was there, but both the constituents should present in appreciable amount. But the lower constituents or the lower quantity constituents must be above at least 5 percent.

So, that was one condition; other condition was that, the 2 constituents do not chemically are soluble into each other; they are insoluble into each other and there is a interface; that separates a matrix and the reinforcement. So, there are certain guidelines, certain hints; which will help you to differentiate an alloy from a composite material. So, that is the information that you should always keep.

And here also somebody may say; bring different material; which has 2 or three constituents and ask you; rather we can ask they make this or we can classify this material as a composite material, you should look at those criteria. If those criteria; those criterion are been satisfied, then only you can say that, yes we can classify it as or you can term it or name it or define it as a composite material.

Now, there can be a question that you have a substrate or a base material and you do a coating on that base material. Now, somebody may say now there are 2 constituents; one is the coating and another one is the substrate; this can be called as a composite material. No, we cannot say that it is a composite material; why? Because one has to be a continuous phase; here there are 2 different constituents, but there is no continuity of any phase in this thing.

So, we can say yes it is a coating on a substrate; but we cannot classify it as a composite material, but there is no continuity of any material or any of the constituents. So, there are few; we can say gray areas, where we need to focus and try to understand that; what exactly are the composite materials and there is lot of we can say debate going around to

classify a define composite materials clearly. So, that learner has clear idea that this a composite material and this is not a composite material.

So, that is the purpose of defining or going through this today's session; in which we will see how to classify a material. So, first classification on your screen; one is natural composite, another one is synthetic composite. So, if you are asked that; what are the different types of natural composites; 2 examples should immediately come to your minds, that is first one is wood and second one is the bones. So, these are 2 naturally occurring composite, but if you talk about the synthetic composites; it is a very big family.

And still people are developing new and new combination of matrix and reinforcement and coming with new and new types of composite material. So synthetic composites is a very large family and naturally occurring composites is a very very very very small family. Now, synthetic composites on your screen, you can have a classification; synthetic composite materials.

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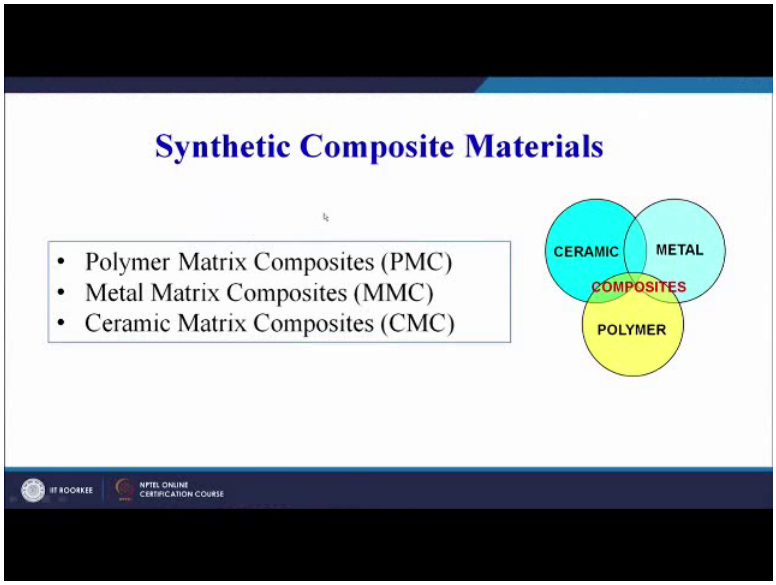

This classification is a most commonly adopted classification for composite materials. Now in this classification; you can see that we can classify the composite materials based on the matrix that is used for making the composite. And here you can see; as the name suggests; polymer matrix composite, metal matrix composites, ceramic matrix

composites. So, you should remember that based on the 2 constituents; you have a classification.

Based on the matrix, you can classify them as polymer matrix, ceramic matrix and metal matrix composites. And each one of these will have their specific application area. For example I may ask you; this is the common sense question, that for high temperature application; which type of composites you will suggest? Now, immediately the answer should come; that ceramic matrix composites, but ceramics are used for high temperature applications.

And if I ask you that for low temperature applications, which is the composite material you will suggest? Immediately, the answer should be polymer matrix composite because polymer has low melting point; they have very low glass transition temperature. So, we have to see that what type of material is suitable for what type of application? So, based on their application or based on the matrix that is being used; we can say, we can classify them as polymer matrix, metal matrix and ceramic matrix composites.

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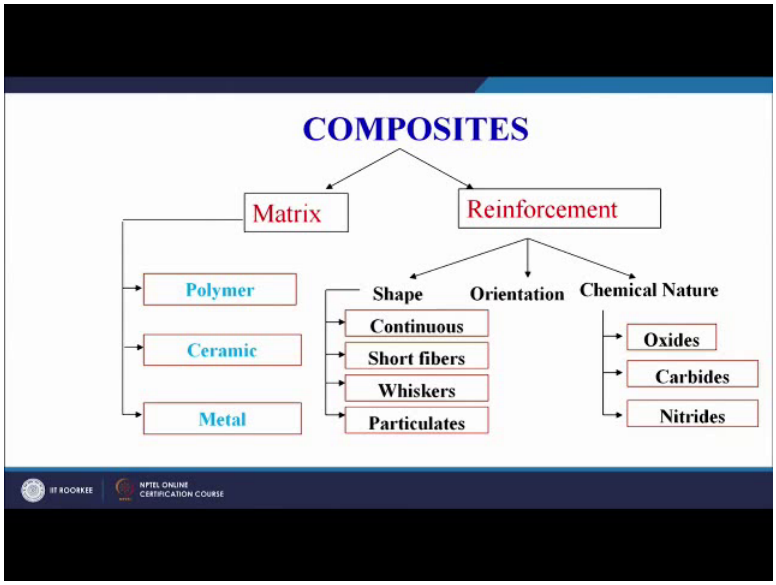

Based on matrix, you can see on the screen; we have polymer matrix, ceramic matrix and metal matrix. But based on reinforcement also; there is a classification, now based on the reinforcement we can classify them, based on the shape of the reinforcement. Now, shape can be continuous; it can be long fibers running in the polymer matrix or long fibers

running in a metallic matrix. So, that the shape of the reinforcement can be continuous; that is one thing.

Then you can have short fibers; in many applications special injection molding machine is used for making short fiber reinforced polymer composites. So, you can have reinforcement in the form of short fibers, you can have reinforcement in the form of whiskers. In the last class, we have seen that whiskers can be randomly oriented through the matrix, whiskers can be oriented or they can be having a directional orientation within the matrix.

So, you can have whiskers as a reinforcement definitely they will have some aspect ratio. And finally, the particulates; so, you can have fine particles as the reinforcing elements or reinforcing agent in a metallic or a ceramic matrix; as well as in a polymer matrix also sometimes. Sometimes nanoparticles or nano reinforcement search used to reinforce the material or improve the mechanical as well as the other property; like thermal or the chemical properties.

Many times electrical properties can also be improved or enhanced by the addition of the reinforcement. So, it is not only that reinforcement, but it added only for the mechanical properties or for improvement of mechanical property. Reinforcement is also sometimes added in order to improve the other; maybe properties such as electrical as well as thermal properties.

So, we can see; based on the shape of the reinforcement, we can have continuous fibers as the reinforcement, we can have short fibers, we can have whiskers, we can have particulates; so one assignment that is there for you. Now you should remember that what is the difference between a short fiber and whisker? That you should keep in mind and try to figure out the answer to this particular question. So, what is the difference between a short fiber and a whisker? Because continuous fibers absolutely clear; particles absolutely clear. So, there is a gray area between the short fibers and whiskers that you have to figure out and find out through literature.

Now, based on the orientation of the reinforcement in the matrix as I have told; you can have all fibers oriented in one direction or you can have randomly oriented fibers in the matrix. So, orientation also plays a significant role in defining properties of the resultant

composites that has to be taken into account that what is the orientation of the reinforcement in the matrix.

Similarly, based on the chemical nature of the reinforcement; we can have oxide like aluminum oxide, we can have carbides; like silicon carbide as well as we can have nitride and then this list is endless; you can have other ceramics or other types of materials also which can be used as the reinforcing elements. So, you can see that you have a matrix which can be polymeric, which can be ceramic, which can be metallic. We have a reinforcement which can be classified based on its shape, based on its orientation and based on its chemical nature.

So, this is one important classification of composite material that is there. Now, simple examples can be put into this; now let us take one or 2 examples. The first example that comes to my; is a Glass Fiber Reinforced Plastic GFRP; most commonly used type of a polymer matrix composite or a fiber reinforced plastic. So, these 2 names are used interchangeably; that is polymer matrix composites as well as fiber reinforced plastics.

Now, examples that we have taken is a Glass Fiber Reinforced Plastic; GFRP. Now what is the matrix here? Because, fibers are used for reinforcing or for the purpose of the reinforcement; so, glass fiber reinforced plastic means that plastics is the matrix here. So, in our diagram we can see; the matrix is a polymer matrix. Now the reinforcement is the glass fiber; now the glass fiber can be continuous glass fiber, it can be in the form of short fibers, it can be in form of whisker.

So, we have to see that what is the shape of the reinforcement; then the fibers are oriented if they are long fibers; their oriented in one direction only, we will say from the orientation point of view; the reinforcement is oriented and it is one direction only. Then the chemical nature also; we can in this case we are not bothered much about the chemical nature. But in glass fiber reinforced polymer, we know that the matrix is polymer and the reinforcement is long fibers and the orientation is oriented in one particular direction. So, that is one thing that has to be taken into account; so, that is the broad classification.

Let us take an another example of a material matrix composite. Now, suppose we have aluminum as the metal or the matrix. So, your matrix is aluminum that therefore, it falls under the category of metal matrix composite. Now, the metal is your matrix;

reinforcements suppose is silicon carbide and it is available in the particulate form. So, from the reinforcement point of view; we are taking silicon carbide. Now silicon carbide, from shape point of view; we are using particles of silicon carbide.

Then we have orientation, we can have random orientation of the silicon carbide particles in the aluminum matrix and finally, the chemical nature. So, we are using carbides that is; silicon carbides.

Another example can of metal matrix composite can be; aluminum matrix composite reinforce with silicon carbide or aluminum silicon carbide composite in which the matrix is aluminum and the reinforcement is silicon carbide particles. So, this broad classification diagram gives you so many different examples; maybe in the assignment you can take 5 different; you can search and you can try to figure out 5 different types of composite materials.

And then try to put them into this diagram that; what is the matrix? Either; it is polymer or it is ceramic or it is metal. What is the reinforcement? Whether the reinforcement is based on shape, is continuous or it is short or it is particle or it is whisker; then from orientation point of view you can classify and then from the chemical nature point of view; you can classify. So, if you do that exercise you will be very easily able to classify the composite materials.

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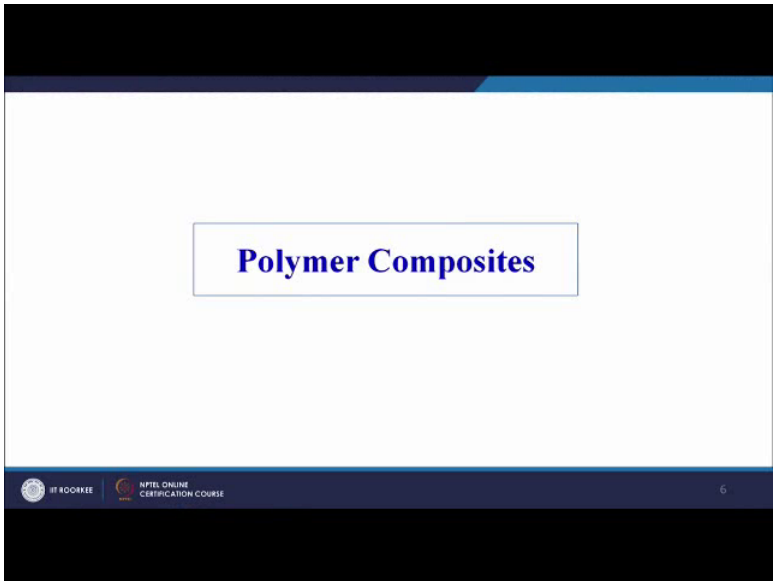

As the title of our course is polymers or processing of polymers and polymer composites. Now, we enter into the exact domain that is polymer composites; now as I have told you these composites basically polymer based composites are also called fiber reinforced plastics. Because the matrix is plastic or polymer and reinforcement is in the form of fibers; specially in case of polymer based composites.

So, we usually call them fiber reinforced polymer composites also. And here again, we can see the examples as I have told you are the last diagram whereas, generate diagram or general diagram; showing classification of composite material, but this is the specific diagram related to the polymer based composites only.

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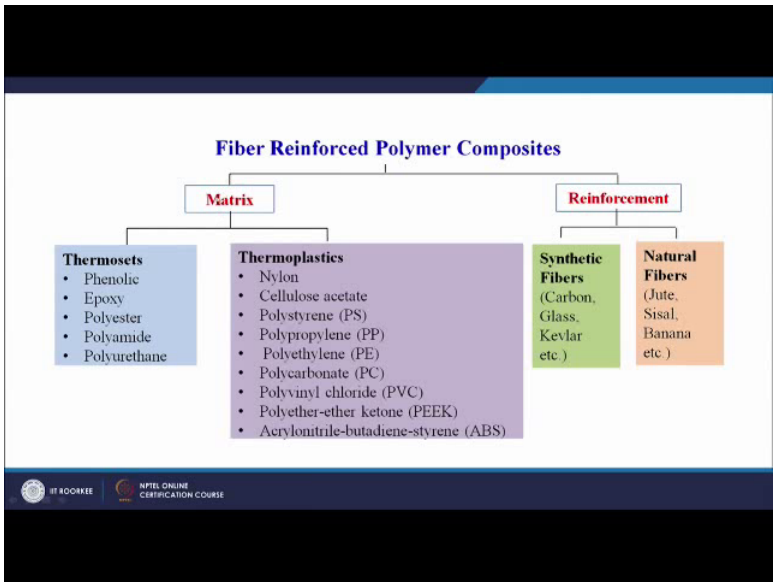

So, we can see from matrix point of view; we can have 2 types of polymers, one are thermosets and the thermoplastic. And this we have already covered in our course in the very beginning; I think in the second or the third session.

So, thermosets can be Epoxy, Polyester, Polyamide; thermoplastics can be Polypropylene, Polyvinyl Chloride, Polyether-ether ketone or ABS that is Acrylonitrile-butadiene-styrene. So, we can have a thermoset matrix or a thermoplastic matrix and must I address this point; that depending upon the type of matrix our properties will be different.

You have a thermosetting matrix, the properties will be different, you have thermoplastic matrix the properties will be different. So, from matrix point of view; in case of polymer composites we can have thermosets and thermoplastics.

Similarly from reinforcement point of view, we can use synthetic fibers as the reinforcement and we can also use a natural fibers as the reinforcement. From synthetic fibers point of view, we can have carbon, glass, Kevlar as the reinforcement. So, Kevlar is basically aramid fibe; so, the synthetic fibers, carbon, glass and Kevlar. From the natural fiber side, we can have natural fibers have long list and we will try to address it; if possible in our course. What are the different types of natural fibers? How they can be classified? How they are derived? What are sources of different type of naturally occurring fibers?

But just to introduce the concept of polymer composites, we can have matrix that is thermosets or thermoplastics and we can have reinforcement; that is a synthetic fiber and a natural fiber; from natural fiber mostly occurring are jute. banana; sisal fiber.

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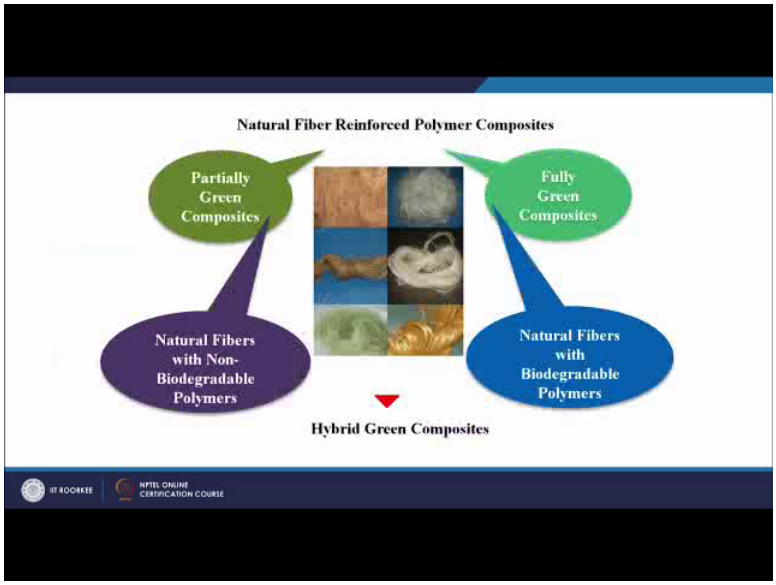

Then again we can have natural fiber reinforced polymer composites also in which the natural fibers are used as reinforcement. And all round the world, there is a trend towards biodegradable composites in which the polymer or the matrix is also biodegradable as well as the fibers or the reinforcing members are also biodegradable.

So, natural fiber reinforced polymer composites; we can see here. We can have partially green composites; in partially green composites we will have natural fibers with non biodegradable polymers. So, the reinforcing agent that is the fibers are biodegradable or naturally occurring. But the polymer or the matrix is not biodegradable; it is a synthetic matrix as we have seen in our previous slide; that thermosets and thermoplastic matrices are there.

Suppose, we use the thermosets and we use a epoxy as the matrix. So, it is non biodegradable; if we use thermoplastic and we use polypropylene or polyethylene as a matrix material; it is non biodegradable. But the fibers actually are biodegradable; so, then we get partially green composites.

But what is the trend? The trend is towards fully green composites. So, for fully green composites, we should have natural fibers with biodegradable polymers. So, our polymer or the matrix should also be biodegradable, our fiber should also be naturally occurring. And then we can have hybrid green composites; that is another category of composite materials. So, broadly we can say; if we use natural fiber as the reinforcement, we can at least get partially biodegradable composites.

And if we can have the liberty of choosing the matrix material also which is biodegradable or a biopolymer; then we can have the advantage of making a fully biodegradable composite material because there reinforcement material is also naturally occurring or derived from nature.

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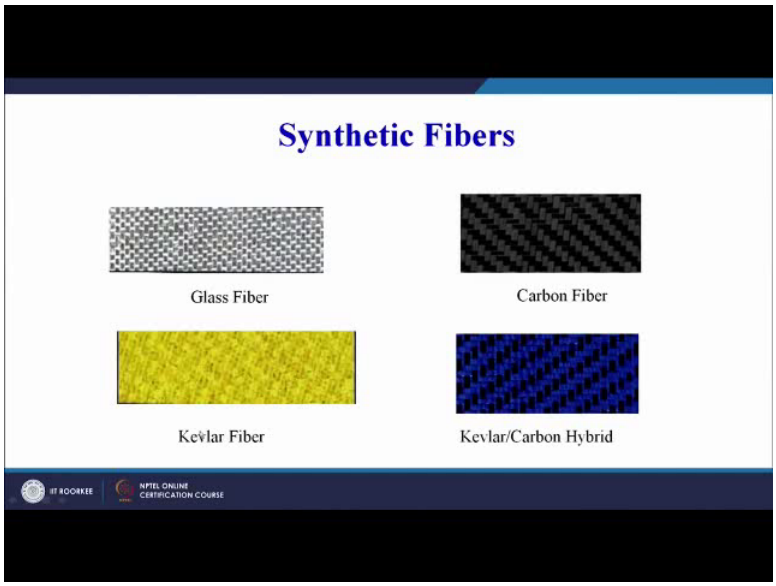

Now, on your screen; you can see the different types of synthetic fibers, you can have Glass Fiber, the Kevlar fiber; Kevlar carbon, hybrid fiber in which in one direction; we have maybe back portion is the carbon fiber, the blue portion is the Kevlar fiber. So, we can have hybrid also in the one direction and the other longitudinal and the transfers. Basically, this is called warp weft in textile technology; that in one direction, the fiber is called warp and another direction as a fibers is called weft.

So, here we can have a different fibers in warp and different fibers in weft so, that basically gives us hybrid type of fibers, which can be used as a reinforcement in case of polymer composites. And we can have neat carbon fibers, woven carbon fibers, woven glass fibers, woven Kevlar fibers. So, all these are synthetic fibers and these days even people are trying to attract; to get the best property, people are taking natural fiber in one direction may be warp or weft and the synthetic fiber in other direction; that is also possible and that type of hybrid fibers also available, which can used as a reinforcement for reinforcing the polymer matrix.

So, lot of research work is going on; even the viewing pattern people are working all around the globe to find out that which is the best viewing pattern for a particular combination of fiber? So, that we get the best property when we use these as the reinforcing elements or reinforcing members in polymer based composites.

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On your screen this is a list showing different types of natural fibers, they are in the raw form; they can be woven into the mat form and then the mat can be used as a reinforcement for making natural fiber reinforce laminated composites. But this is just showing the raw type of fiber which are available and these are these have been derived from nature.

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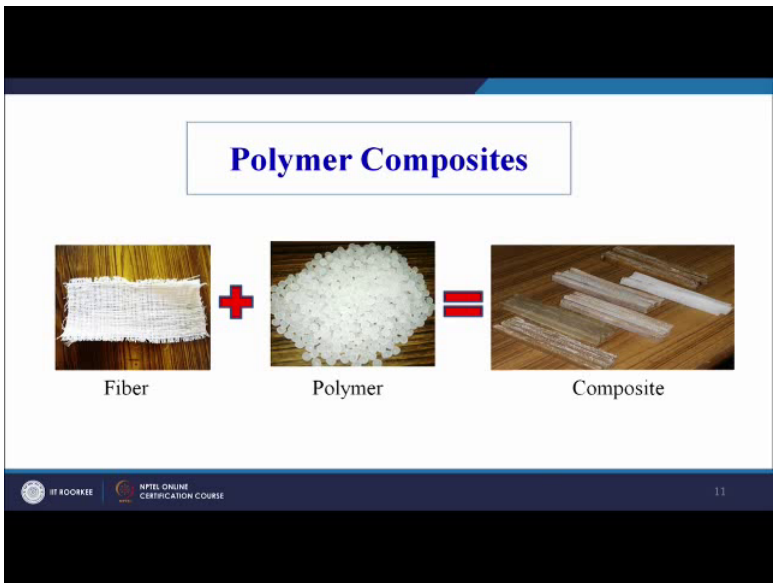

And once we have the natural fibers, we have the polymers which are the readily available; we can make a composite material. On your screen you can see, the fiber when

the raw fiber which was shown in the previous form; when it is woven in the form of a mat, this is the woven natural fiber mat and this can be used as a reinforcement agent and this is the polymer palates; thermoplastic polymer palates and when we can combine them together; we can make engineering materials like this. And these are the composite materials which can be used for various engineering applications.

So, here we can see the natural fiber is acting as a reinforcement member for the polymer and we are making the composite material. And the composite on your screen is shown here; so, you can see that a fiber and a polymer have combined together to make a third material; which can be used for various engineering applications. So, this is I think the end of today's session.

So, we have tried to classify the composite materials based on the matrix; we have try to classify the material based on the reinforcement. We have taken some examples that in this classification where; which example can be, we can fit in and then we have tried to understand; what are the different types of synthetic fibers? We have seen what are the different types of natural fibers? And how they can be used for, combining them with the polymers to make them a composite material; I thing now the classification is absolutely clear to you.

And we have taken a slight step towards our topic; that is processing of polymer composites by classifying the polymer based composites. We have seen; what is the matrix? It can be thermosets, it can be thermoplastic; we have seen what can be the reinforcement, we have seen synthetic fibers as reinforcement, we have seen natural fibers as reinforcement.

Now, we will see the last slide gives us a glimpse as well as sets; background for our further discussion. Because now we have to understand that this plus sign; which is on your screen, this plus sign seems to be very very simple, but the color signifies its importance; that how now we can combine this fiber and the polymer together to make this composite material.

So, the whole discussion here on will focus on the processing routes, technologies, techniques for combining the fiber and the polymer into a composite so, that the properties that we get, that we have planned, that we have designed the properties that we are able to get by adopting the best possible technique for combining the fiber and the

polymer together. And the combination or the processing will depend on a number of parameters which we will be discussing one by one; stage by stage, phase by phase in our subsequent sessions. So, with this we come to the end of today's session on classification of composite materials.

Thank you.