Processing of Polymers and Polymer Composites

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Lecture – 14
Composite Materials: Basic Concepts

[FL] friends. So, we are done with our discussion on Processing of Polymers and we are going to start a completely different aspect of polymer based composites or we are going to start our discussion on composite materials. Now, the today's session will be a kind of a fundamental lecture or fundamental discussion on the concept of composite materials.

Now, we have discussed polymers. So, we can add you can say there is different types of polymers we see around us. They have different types of colours; red colour polymer products or plastic product, blue colour plastic products, green colour plastic products, yes they do exist. But, the basic colour of the polymer which has been used to make that product may be different. So, some colouring agents are added into these polymers.

So, can we call these products as composites products? No. So, we have to be very clear that which material we are going to call as the composite material and that is the object of our discussion today that we try to understand what is the composite material. There are large number of lectures available on composite material. So, we will just try to understand of their minimum fundamental of a composite and then our topic is processing of polymers and polymer based composites or polymer composites. So, our focus would be to discuss the processing routes, processing technologies or fabrication technologies for various types of composite products and specifically polymer based composite products. But, as one word that is coming in our title that is processing of polymers and polymer composites, composite, word we should try to understand that.

What is a basically a composite material and if we can understand what is a composite, we can work in different dimensions of composites, right from conceptualization that what can be a matrix under reinforcement to the fabrication, to the characterization then finally, into the application part of the composite. So, first and foremost we should try to understand what a composite material is? There are number of naturally occurring composite materials.

Our forefathers used to make the mud walls in mud houses. So, they used to mix the vegetable waste, the agricultural waste with the mud in the form of small fibres and then they used to paste it around the mud walls. So, what was the purpose of that, we need to understand it and composites give us the answer to this question that why do they add all these agricultural waste into the mud? Why? What was the purpose of that? So, that is one fundamental query that we need to answer. Then our bones, human bones, animal bones are also examples of naturally occurring composites; even wood is an example of naturally occurring composite.

So, I am not going to explain what are the constituents of wood or human bones? But you need to find out as an assignment that what is present in the wood, what can be termed as matrix in context of a wood, what can be termed as reinforcement in context of a wood. Similarly, in bone, what is matrix, what is the reinforcement? But what are the basic terminologies related to matrix and reinforcement, that we are trying to cover today in the form of our session and we will see that in a composite what is a reinforcement what is a matrix.

So, let us start our discussion with the composite material and first example that usually may not be that true civil engineers can give better representation of that you can say analogy, but one example that I usually quote whenever we start our discussion on composite materials is the RCC structure. So, we have concreted the metallic rods. Now, the concrete if you see all the time it is made up of so many different mixtures of so many different civil engineering materials; but cement is also one of the important parts there. And, in cement always we talk of the compression always you talk of the compressive strength.

So, we can say concrete is good in compression, but it is poor in tension whereas, the metallic rods are good in tension but are poor in compression. If you apply a compressive load the buckling may take place, simple example just to explain the concept of matrix and reinforcement. Now, we have combined concrete and the metallic rods together into a civil engineering structure, why, because we are want to take the advantage or the best properties of both the constituents; that is, the concrete as well as metallic rods.

So, from here we derive the concept of reinforcement and a matrix. In this case the continuous phase is concrete. If you see first we have a network of the metallic rods and then we put concrete. Concrete, you can say encapsulate all the rod. So, concrete is the continuous phase here and therefore, we can say that concrete is the matrix in this case and the reinforcement is being provided by the metallic rods. So, we see the metallic rods are acting as the reinforcement and concrete is acting as the matrix material.

So, for all types of composites we will see that it can broadly be categorised into 2 main constituents; one constituent will be a matrix, another constituent will be reinforcement. And based on the matrix and the reinforcement, their chemical nature and further their physical form, further their properties, mechanical properties, we can have different types of composite materials. We can have matrix which can be ceramic in nature, we can have a matrix which is metallic in nature, as well as in our case we can have a matrix which is polymer in nature. So, based on the matrix we can have different types of composites.

Similarly, based on the reinforcement also we will have different types of composites. Now the reinforcement can be continuous as in the case of RCC structure. It can be discontinuous or randomly oriented in case of metal matrix composite. So, depending upon the types of reinforcement we can have different types of composite materials. So, with this basic, may be discussion let us now switch over to our presentation and try to understand the basic concept, the basic definitions of the composite material.

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Now, when we talk of composite material we need to understand definitions. We need to understand the constituents as I have told you every composite material will have a matrix, it will have a reinforcement.

Now, the properties of both, the properties of matrix will be different, the properties of reinforcement will be different, now we are combining 2 different materials with different properties and we are trying to make a single material. Now, the single material will have property distribution or a combination of properties derived from these 2 constituents. So, we need to understand what are the constituents? What are their properties that are forcing us to bring them together? So, that, we need to understand.

Similarly, if we are developing a new material, what are the application areas for that material, that, also we need to understand and finally, whenever you propose a new material now researchers, scientists, whenever there will be some new thought some novel thought some innovative thought coming into the market or coming in discussion there will always be challenge, because always we resist the change. So, whenever a new material is developed we have to ensure, we have to prove, that this material is better than the existing materials. So, we have traditional engineering materials like steel, we have traditional engineering materials like wood, we have so many structural material which are in use for may be in last 150 to 100 years. Now, whenever you propose a new material that material has to challenge and it has to overcome, we can say the mind set

then it has to prove that it is a better material based on the properties, based on the performance, based on the in-service performance.

So, that is also very important, that is, the comparison of a properties of the new material as compared to the already existing traditional, conventional, engineering materials. So, we have a whole list of conventional materials and composite materials were developed in the may be 1960s or 70, so, they are materials which are 50, 60 years old or 5 or 6 decades old. So, other materials are in maybe if you talk of the importance of materials there are ages, historical ages named after materials only. The importance of materials is there since so many years. Whenever a new material is developed it has to overcome that challenge that what is it going to achieve, which cannot be achieved by the already existing material. So, comparison always becomes very important.

So, when we end today's session I think not all, but answers to some of the points raised or points highlighted in this slide should be clear in your thinking process.

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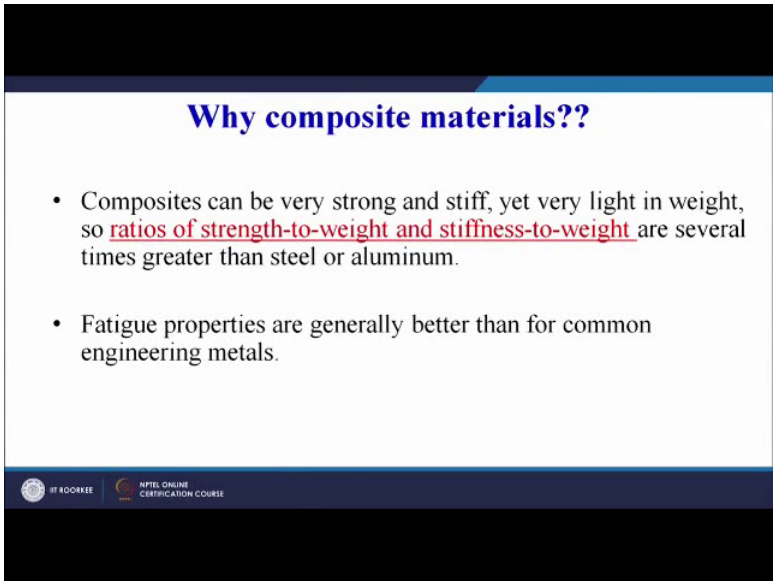

Why composite materials now, first question. Now, composites can be very strong and stiff yet very light in weight. So, majorly if we talk of the polymer based composites that is, our topic, our topic is processing of polymers and polymer composites, if we focus of polymer based composites one of the major advantages is that they are light in weight.

Similar, thing may not be true in case of metal matrix composites, but if we focus on polymer composites only these are very strong and stiff and yet they are very light in weight. So, the ratio of strength-to-weight as well as stiffness-to-weight is very high and comparatively higher than steel or aluminium. That is the point in the last slide I was highlighting that whenever a new material is proposed it has to face the challenge of the traditional material. So, for light weight applications we can conclude that these composite materials specifically polymer based composite materials have high strength-to-weight ratio high stiffness-to-weight rate as compared to the traditionally used metals that is steel and aluminium. More over the fatigue properties are also better than most common engineering metals.

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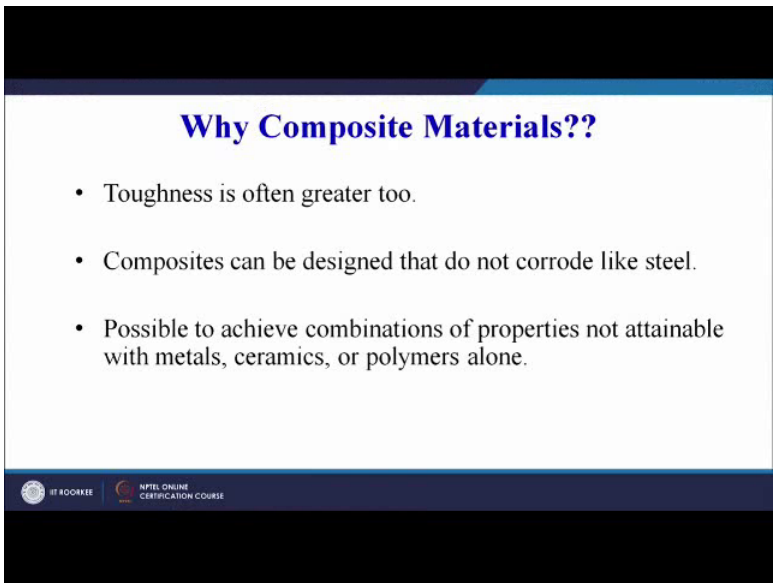

Toughness is often greater too. We are comparing them from the mechanical engineering point of view. So, we are talking of strength-to-weight ratio, we are talking of stiffness-to-weight ratio, we are talking of fatigue, we are talking of toughness.

Now, all these properties are important from the applications point of view. So, we can see that wherever we are using metals or wood we can think of replacing these traditional materials with advanced materials, with material which are light in weight. Now, whatever discussions we have done till now I may put a simple question to all of you, where do you feel that the maximum application of these materials can be? Just give it a thought.

Where these materials can be used? Now, if you can just look at the properties, strength-to-weight ratio is high, stiffness-to-weight ratio is high, lightweight applications. So, very easy you can say they can be used for aerospace industry, they can used in aircrafts, they can be used in automobiles, they can be used in marine industry, they can be used in sports equipments, like long tennis rackets, they can be use for making hockey sticks, they can be used for making medical assistive devices like our crutches. So, you can just from lightweight aspect only you can find number of applications where these materials and find usage.

So, the mechanical properties therefore, we are highlighting that these properties are comparable or many times better as compared to the traditional engineering materials. So, therefore, we can coming to slightly on the chemical side. Composites can be designed that do not corrode like steel. So, mechanical properties are comparable or better corrosion resistance, the resistant they can be made or they have the property of corrosion resistance.

Possible to achieve combination of properties not attainable with metals, ceramics or polymers alone. Now, we can combine 2 or 3 materials together to make a composite material which will have better properties as compared to traditional metals, traditional polymers or traditional ceramics. Now, maybe the ceramics is the last word coming in our discussion. Ceramics all of you know has poor fracture toughness. We can improve on that property by adding some filler, adding some fibres into the ceramic and it has been proved in research, that addition of reinforcement in monolithic ceramics or may be pure ceramics improves the fracture toughness property.

So, therefore, we make the composite material in order to develop a material, in order to conceptualize the material which will have better properties as compared to the constituents. Now, why composite materials? I think is very clear, that, we can attain the properties which are not available or not attainable by the constituents alone. So, we combined constituents together to make a third material which has better properties or a combination of properties of the constituents.

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Now coming onto the advantages: advantages are, they have tailor made properties. Now, depending tailor made means that we can design, we can make the measurements in such a way that fits the application. Now, tailor made property is mean that these materials we can select what is going to be the matrix, we can select what is going to be the reinforcement, we can select the type of reinforcement. Type of reinforcement based on the shape, the size of the reinforcements, the form of the reinforcement, the quantity of the reinforcement. So, as per the application we can design our material. So, that is first advantage of composites that they have got the tailor made properties.

Similarly, low weight already I think in our discussion today we have highlighted, that they have high strength-to-weight ratio high stiffness-to-weight ratio and therefore, they are light in weight. Good mechanical properties too, we have already touched toughness and fatigue. So, they have mechanical properties, which are comparable even better than the existing metals.

Integral design and parts integration; now, this is very important because here the product is made in the form of dies or in the form of molds. So, they have got integral design. We need not make too many different parts and then have problems of assembly. So, here we can have a integral design and parts integrations. That is the second point that we need not make so many parts, direct product can be made. We will see, there are

challenges in parts integration, also in case of composite material; but yes that is one advantage.

And another advantage of the composite materials is a last point I am just jumping 2 points. Last point, that is coming from integral design and parts integration; ease of fabrication and installation. Now just take an example of a concrete bridge or a traditional bridge that is made or a over bridge that has to be constructed. It may take 6 months to 1 year time to construct that bridge, whereas, in case of a composite material if you want to make a same bridge, same span length, all other dimensions or all other specifications remaining same, it will take maybe months or 1 and a half months time. Why? Because, the composite slabs or the composite sections or the composite structural members will be fabricated in the industry or in the factory. They will be brought from factory to the construction site and there only the final assembly will be done.

So, that is one advantage of with that is available with the composite materials, that it is easy to fabricate and easy to install. Then other advantages are inherent surface finish; as I have already told you composites will be made in molds and dies, so, the surface finish of the dies will be replicated on the composite products and therefore, we can attain or we can achieve very good surface finish, as well as corrosion resistance. So, I must address here that this list is not very exhaustive, only 6-7 points are given whereas, composites have got lot of applications and lot of advantages over the traditional materials.

But, yes, there are certain dark phases also, there are certain limitations also. For example, the flame retardancy or the flame retardant behaviour, in flammability, high temperature applications, this specifically polymer based composites are not very good for high temperature applications. So, there are problems also, but, must I address that these are not the only advantages that composites possess, they have number of other advantages also which have been listed in different books and the learners can address those points maybe on their own. But, these are the major advantages that every engineer who has fundamental knowledge of composite materials must know, that, what are the major advantages of the composite materials?

Now, coming onto the definitions, fundamental we have already seen that why do we need to understand, why do we need to study composite materials. Now, let us try to enter into the family or enter into the basic concepts of composites.

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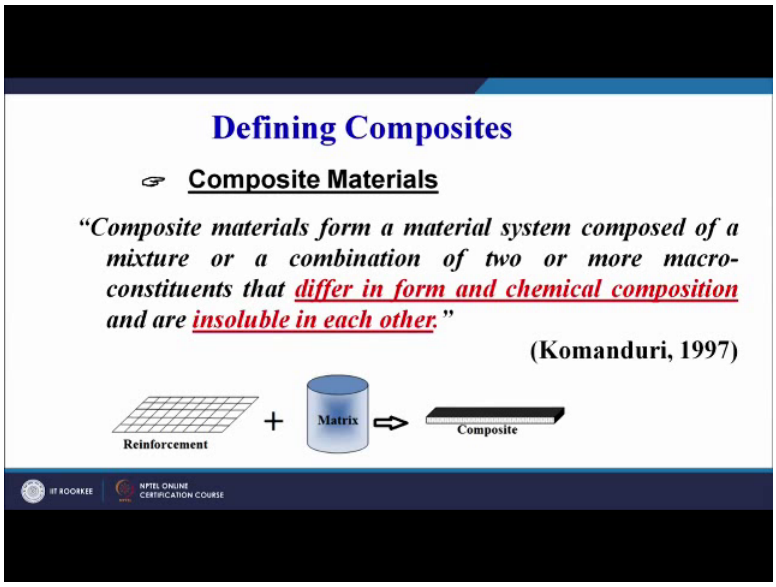

On your screen you have a very fundamental definition given by Komanduri in 1997. Composite materials form a material system composed of a mixture or a combination of 2 or more macro constituents. So, that is one point, they are combination of 2 macro constituents. Second point that differ in form and chemical composition.

Now, you can see that there will be macro constituents that there can be 2, they can be more than 2, they can be 3, they can be 4, they will differ in form and chemical composition. So, maybe one can be you can say in the form of a polymer or a viscous fluid other can in the form of a powder and then you are combining them. So, they are different in forms. One is viscous fluid and other one is powder. So, that is the difference in the form as well as their chemical composition is different.

And the last point that is most important that they are insoluble in each other and therefore, I have given the example of RCC structure. If you break it you can separate the concrete and you can separate your metallic rods. So, the 2 constituents that is the matrix and the reinforcements are not soluble into each other. They are insoluble into each other, means they will retain their individual identity even after composite has been

formed and there will be interface that separates the 2 constituents that is the matrix and the reinforcement.

The figure is shown here. There is reinforcement, there is a matrix. In our case, polymer composites, polymer is the matrix material and they combine together that is addition sign is shown here, they combine together to make a composite material.

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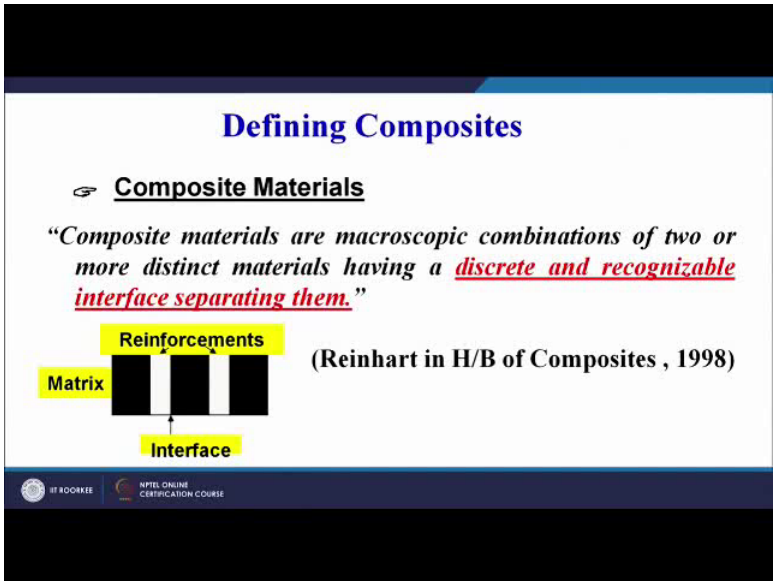

Another definition Reinhart, Hand Book of Composite. Composite materials are macroscopic combination of 2 or more distinct materials having a discrete and recognising interface separating them.

So, again you can see, there are again macroscopic combination of 2 or more materials. So, there can be other 2 more than 2, 3, 4 materials and they have a discrete and recognizable. If you see under scanning electron microscope you must be able to see at high resolutions that this is the reinforcement, this is the matrix and in between there is a interface, that separates the matrix and the reinforcement.

So, on your screen we have shown exaggerated view. The interface will not be this much thick in any composite, but just to explain we can see there will be a reinforcement. So, there is matrix may be the black colour is the matrix and the white colour is the reinforcement and there is a interface between the black and the white. There will be a

interface running along this line and there will be a interface running along this line. So, there will be a interface that separates the matrix and the reinforcement.

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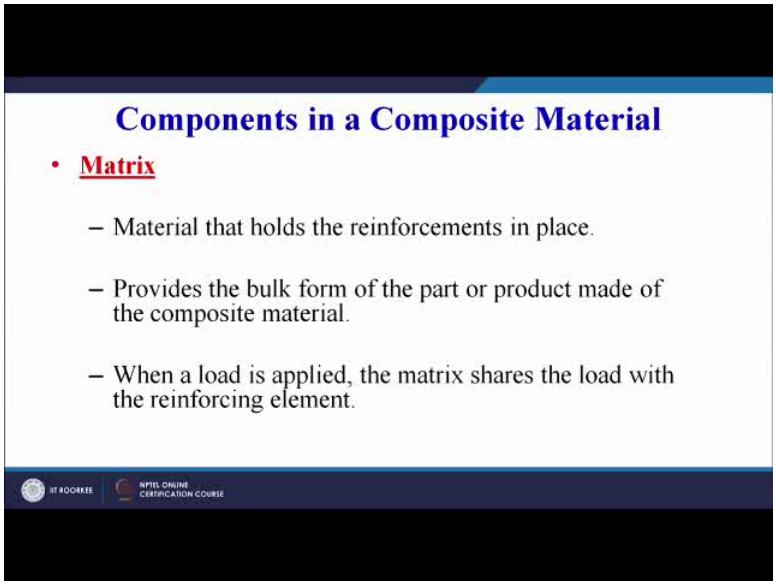

Now, let us try to understand the fundamentals of matrix and reinforcement. Though components or constituents of a composite material, what is a matrix? What is the role of the matrix?

Matrix that holds the reinforcements in place. So, it will keep the reinforcing materials together, reinforcing agents together. Provides the bulk form of the part or product made of the composite material, so many times you may have 70 percent matrix material, 30 percent reinforcement; 80 percent matrix material, 20 percent reinforcement. The matrix forms the bulk of the material it is the continuous phase and we reinforce it by putting some reinforcement. So, matrix is the bulk or the main constituents we can say of the composite material. When a load is applied the matrix shares the load with the reinforcing element. In more technical terms we can say that matrix acts as a agent for distribution of load among the fibres that are used for enforcing the structural member. So, matrix acts as agent for transfer of load that is also one of the key objectives of the matrix.

So, majorly we will have 3 types of matrices; one is a polymer as in our case, then it can ceramic matrix, it can be a metallic matrix. So, for example, in metal matrix composite we have aluminium alloy as a metallic matrix and it can be reinforced with certain

ceramics such as Al 2 or 3 or Boron carbide. Depending upon the combination, depending upon the application, depending upon the desired property, we may choose the metallic material as a matrix and we can use another may be metal or it can be a ceramic as the reinforcing agent. So, based on matrix we can have 3 types of composites; polymer matrix composite, ceramic matrix composites and metal matrix composites.

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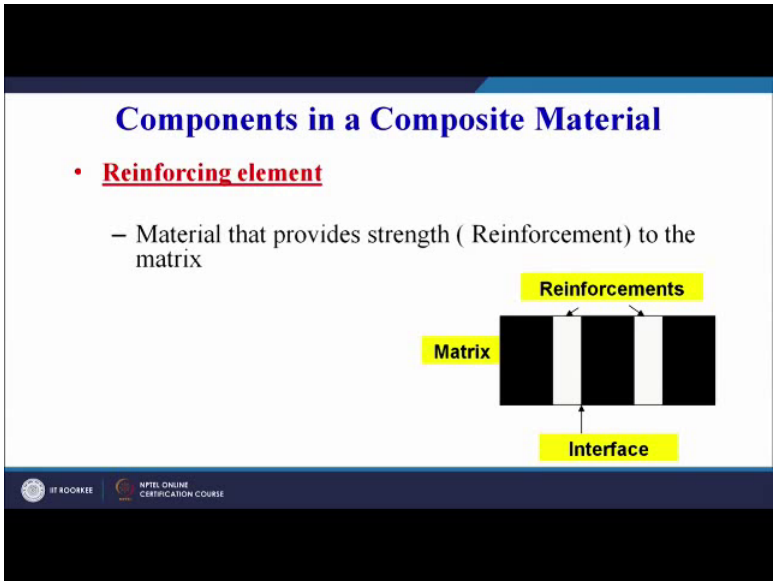

Now, the reinforcing element: material that provides strength or reinforcement to the matrix. So, we have this again the same diagram is shown here the white colour portion is showing the reinforcing or it can be reinforcing fibres, the black portion is showing the matrix and there is a interference between the black and the white portion which is separating the matrix and the reinforcement.

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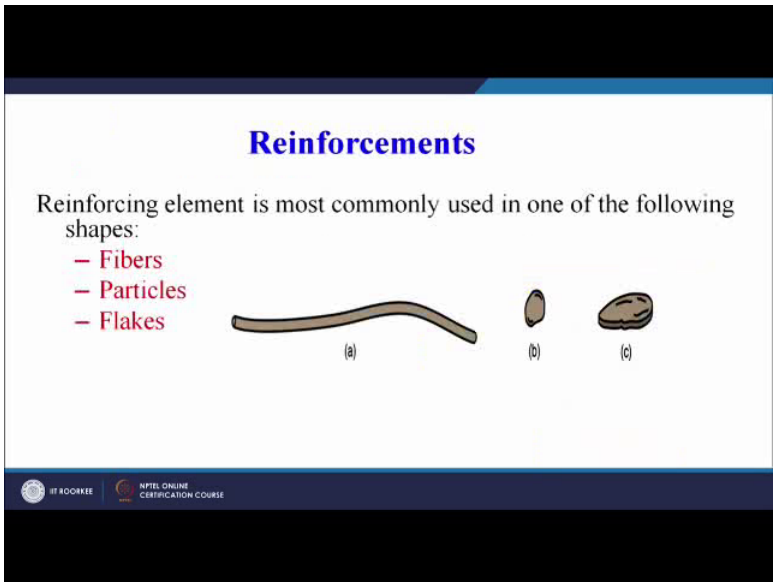

Now, we can have different types of reinforcements. Reinforcing element is most commonly used is one of the following shape. So, may be on your screen you can see different types of reinforcements can be used. It can be fibres, it can be particles, it can be flakes, it can be layers, it can be whiskers. So, different types of reinforcements can be used for reinforcing the matrices.

Now if the reinforcement concept is clear, the matrix concept is clear. Now, clearly we can have a definition which will help us to differentiate the composite material from a alloy. It can help us to differentiate the material from a blend. So, let us see how a material can be classified as a composite.

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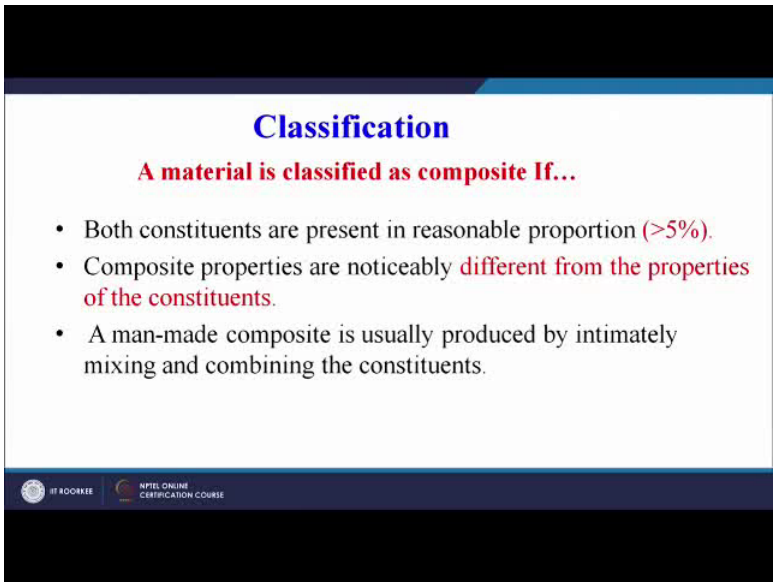

Now, we can see both constituents are present in reasonable portion, that is, the matrix and the reinforcement. For example; in RCC structure we can say the metallic rods, as well as the concrete, both of them should be present in the RCC structure in appreciable amount or in significant amount and the bottom line; rough you can say rule of thumb is given that 5 percent is the minimum. So, maybe it can be a combination that matrix is 95 percent and reinforcement is 5 percent. So, we can say ok, we can classify it as a composite material or a better composite can be 10 percent reinforcement by weight or by volume and 90 percent matrix or it can be 60 percent matrix, 40 percent reinforcement.

And we can say that is one condition that both should be present in appreciable amount then composite properties are noticeably different from the properties of the constituent. If one of the constituent may be suppose the matrix is dictating all the properties of the composite, we may say that what is the need of adding the reinforcement into the composite material, when all the properties are been dictated by the matrix only. Or on the contrary all the properties are dictated by the reinforcement the matrix has no contribution in the properties of the resulting composite, then we may say that what is the role of the matrix, only reinforcement is may be playing the most important role in dictating the property. So, that is one important point that when we are combining 2 different materials together, we want to take advantage of the properties of both the

materials, so that, the third material or the composite that we are developing must have the properties or the better properties as compared to the 2 constituents.

All the properties may not increase, but maximum properties should improve by this combination. Otherwise there is no need of combining the 2 different constituents which are physically different, which are chemically different, what is the purpose of combining them together if we are not getting desirable properties. So, second point is the properties of the constituents should be different from the properties of the composite or we can say the properties of the composite should be an improvement over the properties of the constituents.

Last point a manmade composite is usually produced by intimately mixing and combining the constituent. So, specifically manmade is written because I have told in the very beginning of today's session, that there are naturally occurring composites also like wood and bones. So, a manmade composite if we will classify any material as a composite, must have been made by physically mixing the reinforcement and the matrix together. So, physically means we will combine them using a machine or using a setup or using a maybe physically maybe manually also by manual labour we are combining the reinforcement and the fibre together.

So, we will see there are different types of processes that are used for processing of composite materials and that we will see that what are the some processes are manual some are semi automatic and some are fully automatic and that is the major topic of our discussion, which will start in the next session with discussion on processing techniques for composite materials. And we will see if some other introductory part is required we will cover that also. So, now, I think it should be clear that how you will differentiate a alloy and a composite, how we will differentiate a polymer blend and a composite material.

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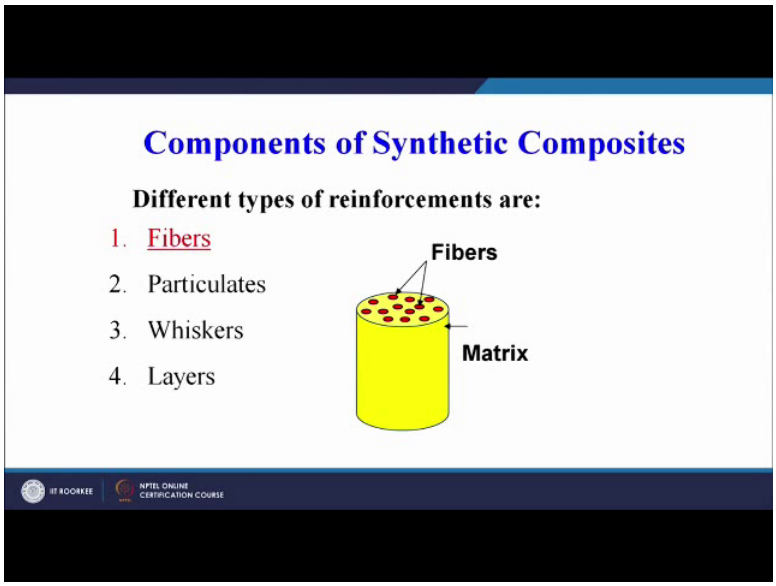

Now, very quickly let us just see the different types of reinforcement. So, in case of synthetic composites which are manmade composite different types of reinforcements can be used.

So, on your screen you can see yellow colour is representing the matrix. The yellow colour on your screen is representing the matrix continuous phase and the red colour are showing the fibre tips, the fibres may be running all along the matrix. So, this is one type of reinforcement.

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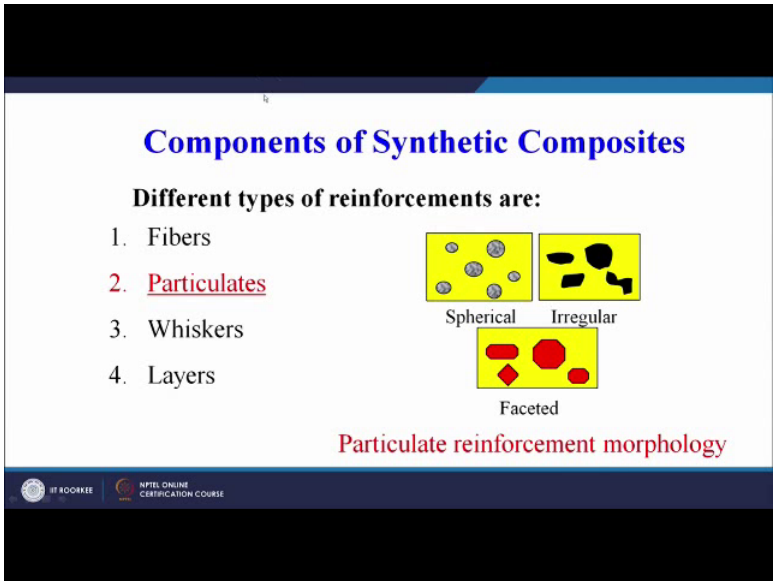

Then, particulate; you can see the yellow colour again is depicting the matrix and there is different types of reinforcements. Spherical reinforcement, irregular shaped reinforcement and regular or faceted type of reinforcement. So, depending upon the shape of the particles that are used for reinforcing the matrix, we can have different types of particle reinforced composites.

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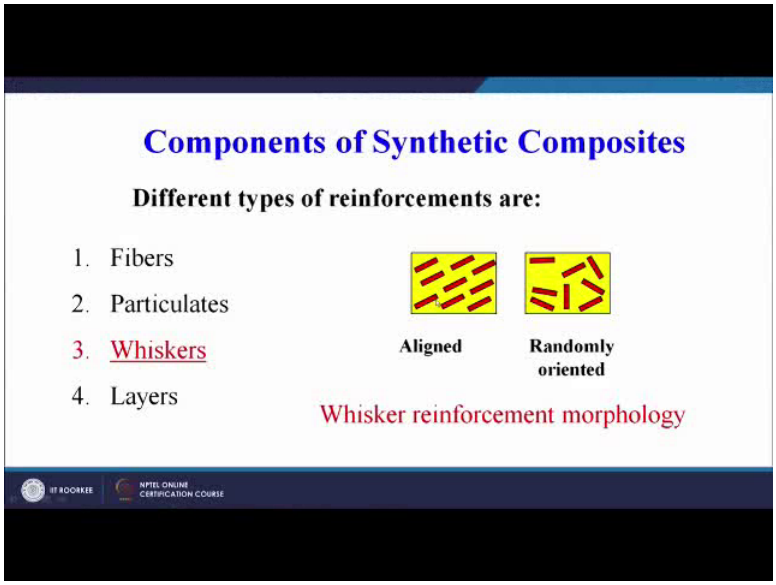

Then we can have whiskers, which will have an aspect ratio. So, we can have aligned whiskers. Red colour are the whiskers, they have a length and they have a width. Definitely they will have a thickness also. So, these whiskers are aligned whiskers and then they are randomly oriented whiskers. So, we can have reinforcement in the form of whiskers.

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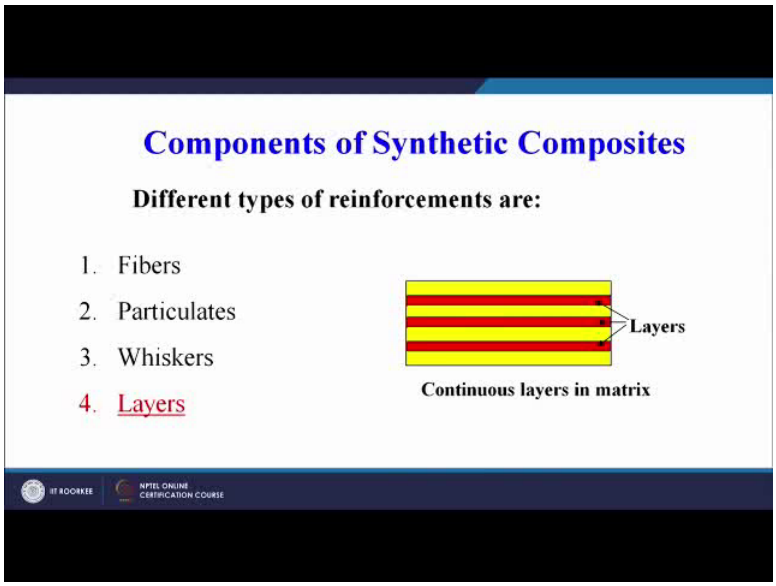

And we can have the reinforcement in the form of layer. So, again yellow is depicting the matrix material and the red is depicting the layer. So, here we have 3 layers in case of continuous layers reinforced composites. So, if sometimes we call 4 layered reinforced composite or 4 layered reinforced laminate. That terminology we will cover may be in the subsequent session.

So, with this we come to the end of our first session on Composite Materials and we have not yet discussed the fundamental of polymers and polymers or polymer based composite. We have just discussed the overview of the composite material, that what is the composite material, how we can classify a composite material or how we can classify any material as a composite material. And we are tried to understand the basic aspect of matrix and reinforcement and in our subsequent sessions we will try to understand what are the various processes that are used for processing of polymer based composite materials.

Thank you.