Blends and Composites
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Lecture - 31
Composites

Hello welcome to the lectures on polymers we are in the 5th week and we are focusing on polymeric materials of different kinds in which we are looking at copolymers, blends and composites. In this particular lecture we will take a look at composites from the point of view of their applications and what are some of the key features when we devise polymeric materials into composites.

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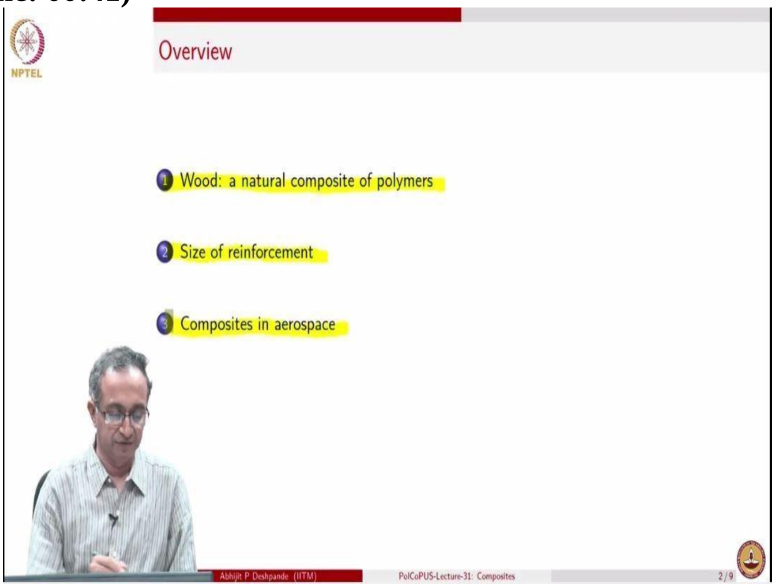

And this will be done by first taking a look at the natural composite wood it is an excellent example of how different materials can be brought together in a composite form for even purposes. And one of the key issues in terms of composite making is the size of the reinforcing component from a small particle or even a nanoparticle all the way up to continuous fibers and fabrics and even what is called 3 dimensional preforms where the reinforcement is put together in a 3 dimensional form. So we have all the diverse range of size of reinforcement which is used and we will see a quick look at why and what is the influence of such size distribution. And finally we will from a user's point of view look at specifically some applications from aerospace.

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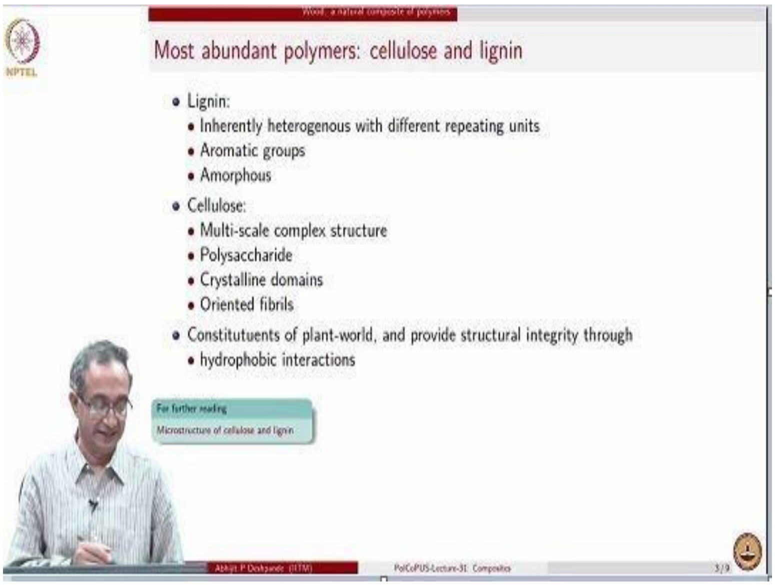

So starting at wood as an example it is in fact a composite of cellulose and lignin. Lignin is the matrix material as we have been talking about in the context of composites the resin or matrix is the continuous phase And fiber or reinforcement is the discontinuous phase, so lignin which is inherently heterogeneous with lots of different repeating units in this course we have looked at polymers and their repeating units and if it is a copolymer then there may be 2 or more comonomers.

But generally we have a finite size of finite number of monomers and even for protein there is a set of amino acids which are examples in case of lignin its far more diverse than that and generally you can identify several types of repeating units and they are repeated throughout this lignin structure it is combination of also aliphatic and aromatic group. Aromatic groups are very important component of lignin and the presence of aromatic groups will imply that these macromolecules will not crystallize.

We have seen that whenever bulky groups are part of the macromolecular chain or side groups then crystallization is not there and therefore lignin happens to be amorphous material. Cellulose on the other hand is a crystalline material it is a polysaccharide as we have seen many times in the course. And what is really interesting about cellulose it is a multi-scale structure so there is a molecular scale then molecular crystallize to form some crystalline bundles. Then crystalline bundles come together to form what is called a fibril. And the fibril come together to form what is called a fiber. So when we encounter let us say a rope which is made of coconut fibers the rope itself is made up of coconut fibers, a fiber is made of fibrils, fibrils are made of crystallites and crystallites are made of cellulose macromolecules. So there is a multiscale structure which determines and in each of these the orientation of crystal, the orientation of cellulose macromolecules are very important so it is a polysaccharide.

And a lot of emphasis in terms of how cellulose performs is based on the orientation of crystallites and fibrils in cellulose material. So if you go and search let us say for bamboo and orientation you will be able to see how in bamboo different parts of bamboo have different orientations and therefore bamboo as a structural material is a best of natural material which is available. So these of course mixture of cellulose and lignin or the composite itself is ubiquitous in plant world for structural purpose it provides the structural strength to plant species.

And a lot of what lignin and cellulose interact are through hydrophobic interactions because of the presence of aromatic groups and the nature of lignin and given that cellulose has both hydrophilic hydrophobic groups. It is the hydrophobic interaction between lignin and cellulose which determine the overall structure of the composite. So you can see that in this natural composite there is a whole lot of interplay between macromolecular structure, macromolecular interactions within reinforcement macromolecular interactions within the matrix. And then finally the interactions between matrix and the reinforcing cellulose. And so all of these determine the overall properties of wood as we know it so please go and I urge to sort of read what is information about microstructure of wood or microstructure of cellulose and lignin themselves.

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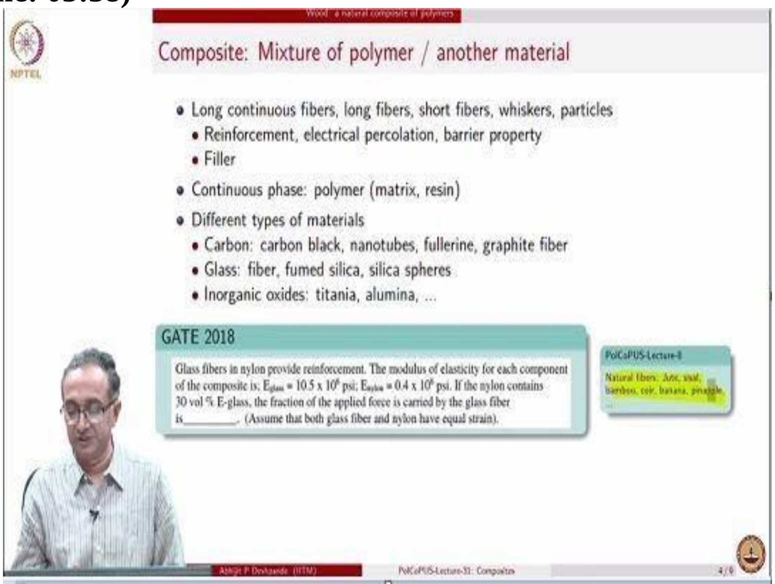

And for our course purpose we will be looking at the synthetic polymeric composites where we use reinforcement which is the other material and this could be in the form of continuous fibers, long fibers, short fibers the general nomenclature is that short fibers are basically a couple of mm 3, 4 mm and they are called short fibers. Whenever we say long fiber they can be as long as let us say an inch 25, 2.5 centimeters and so on 25 mm and that is the kind of lengths that we are talking about.

Fiber diameter is usually in micron size and this goes back to what we learn in preliminary courses regarding strength of materials where the smaller the size of the material less is the number of defects and therefore strength is likely to be higher. So fibrous form is known to be stronger forms of materials and so smaller and smaller fiber would mean better and better properties of course there is a lower end of it because in the end we have to handle these fibers we have to mix them with matrix we have to process them.

So therefore there is a shorter length scale which does not go much lower than a micron kind of length scales the other issue of course is also making of these fibers and it is reproducibility of getting a control diameter so what we have done so far in terms of use of composites is things like glass, carbon or polymeric fibers such as Kevlar they are all in this micron range size. And of course the purpose of these reinforcement in terms of mechanical, it could be in terms of providing electrical conductivity, it could also act as a barrier property to diffusion.

So especially in packaging and several applications like that where diffusion of small molecules is important composites serve a very important role of improving barrier properties. And sometimes it can just be to reduce costs and that we usually refer to these other materials as fillers we also have mineral fillers and titania, alumina depending on what is the application many of these are also used and to look at the properties of composites we will be also looking at them in lecture number 44 later on where we will look at properties of composites.

But this exam question tries to encourage us to think in terms of what happens when we mix glass fiber with the nylon and so in a composite we have glass fibers and nylon and if we subject this composite to a load what happens is part of the load is taken by glass fibers and part of the load is taken by nylon. Now what proportion do they take load so the 100 percent load in what percentage is split between nylon and glass fiber.

And if your suspicion is that glass fibers take bulk of the load then it is correct because in fact that is why we are adding glass fiber and the reason glass fiber takes more load is because its modulus is much higher compared to the matrix or the resin or the neat nylon modulus which is much lower. So just think about how will you answer this question one of the key thing is also mentioned here that we can assume that both nylon and glass will be subjected to equal strain and why is this assumption crucial?

So think about that while we proceed further in terms of looking at the composite materials of course an important type of fibers are natural fibers themselves given that wood is such a nice composite material with cellulosic fibers making the key component and providing the performance for wood why not extract these fibers and use them for synthetic composite application. So over the years if you see a lots of natural fibers are being incorporated into composite materials.

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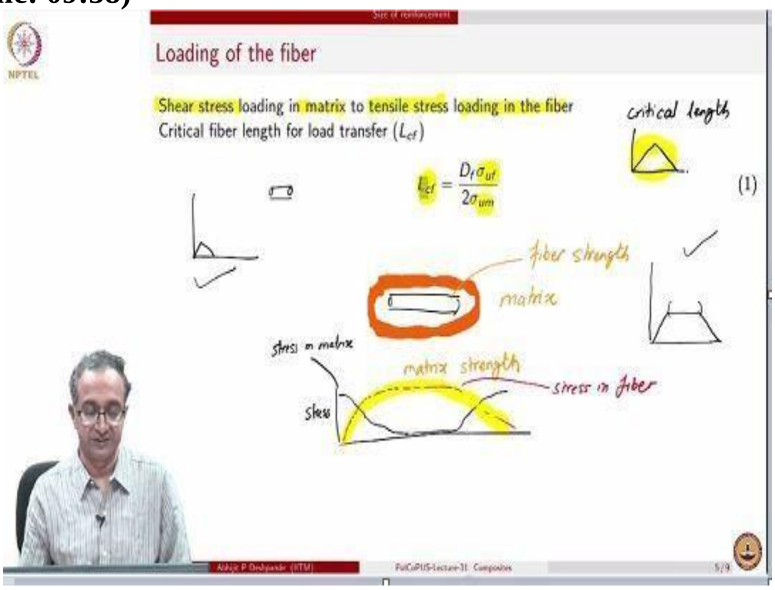

Now the key thing how reinforcing action comes about is because fiber takes the load as we have discussed so for example if we have a fiber let us say which is embedded, what we have here is a matrix material and then the fiber and the question is how does load transfer happen between these 2. So let us say I will plot stress as a function of distance so somewhere far away there is a stress in the matrix so this is stress in matrix.

And as you approach the fiber what happens is this stress decreases and because now the fiber takes all the load the stress goes to 0 and then again it increases so this is the load transfer that we are talking about. Similarly to offset this what we also have is basically the load in the fiber itself so fiber for example will have a load which is increasing so this is the stress in fiber. So basically what we have is the stress in the matrix which is in the form of shear stress becomes the tensile stress loading in the fiber.

And that is how they exchange and you can solve this problem by doing this in a more idealistic simple model case in which case what we can do is we can look at the example of load transfer like this. We can say that let us assume that the increase of load in case of fiber is linear then it becomes constant and then it decreases. So in this kind of a case what you can see is load transfer has happened and the fiber is at the maximum stress you if you but on the other hand I have a very short fiber so in case of short fiber what you will see is the load will increase.But before it goes to full value the fiber itself is very short so in case let us say you have a very short fiber then what happens is the stress never reaches the maximum that it can reach so then in that case we can say that the fiber has not really carried the load to maximum extent possible. So you can see between these 2 extremes where the length is very long so that the fiber is at the maximum stress for quite a bit of length while to a case where the fiber never reaches maximum stress there is a critical length.

And that critical length would happen when we have the stress in the fiber just reaching maximum. So if it reaches maximum and then it goes down so all these are ideal representation of what was represented here as a more realistic kind of variation and so this critical length then will depend on the what we would like is the fiber to be loaded to as much strength as possible and that is the ultimate tensile strength of the fiber itself and the matrix of course may be loaded up to its ultimate shear strength.

So based on these 2 then we can calculate so if you just work out this triangle and how much is the length required for this linear increase to happen you can get the length of critical fiber so it depends on these 2 and so it depends on the diameter it depends on the 2 strands of fiber and matrix.

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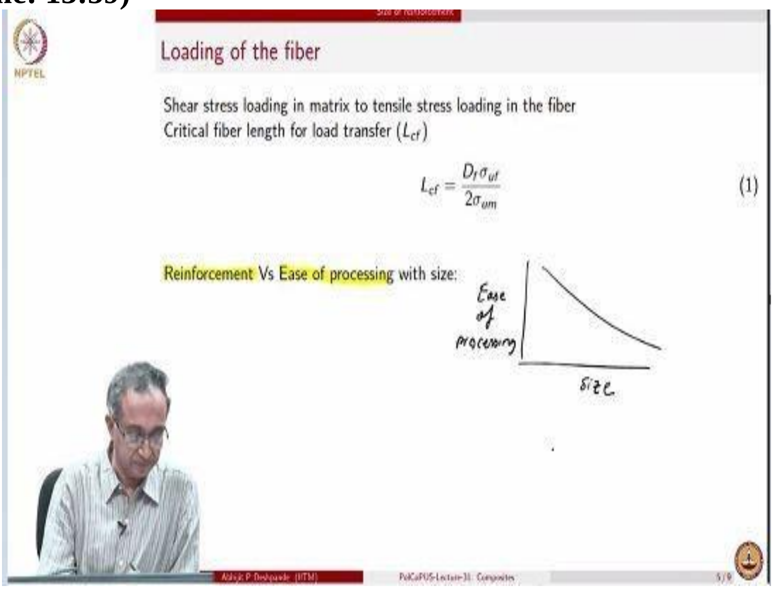

So one other thing that we need to keep in mind is we can increase the length so that the load transfer happens effectively but unfortunately there is a relationship which is opposite in terms of ease of processing. So if we plot this ease of processing with size of the reinforcement ease of processing comes down when we have larger and larger fibers. Shorter fibers, spherical particles are easy to deal with in the sense that if we use injection molding for let us say just nylon itself nylon plus some powder particle can also be injection molded.

So going using a processing technique from one which is named native neat matrix to composite is very easy but let us say if we start having long fibers then what happens is how do these long fibers orient how do these long fibers flow. will these long fibers get entangled with each other? And therefore viscosity will go to very high values. So due to all these complications the processing of longer and longer fibers it becomes more and more challenging and in fact no way this is more evident than in aerospace.

Because in aerospace our critical issue critical requirement is to get maximum possible reinforcement so therefore we try to use continuous fibers and fabrics so that we attain maximum possible properties and then processing is therefore more difficult in case of aerospace composites as we will see soon.

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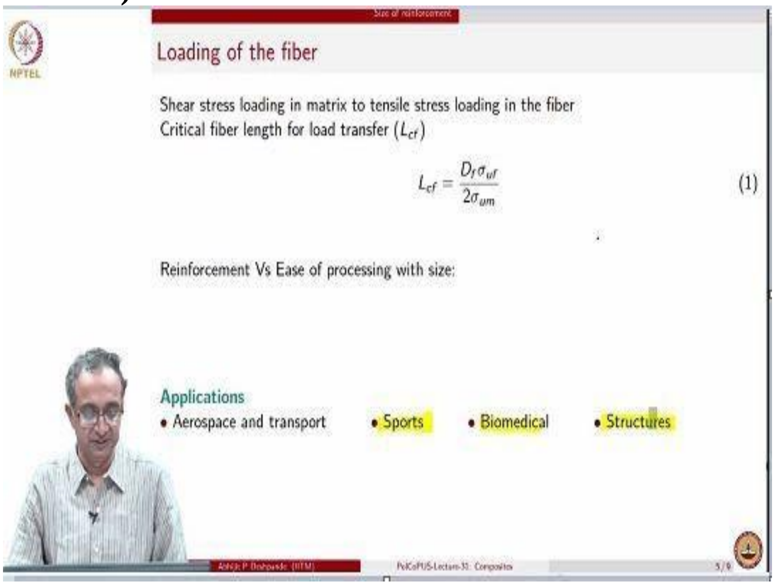

So given these kind of property improvements sports is also another area where we use composites a lot in terms of cricket bats in terms of tennis rackets in terms of golf equipment so wherever the weight is a key component polymers can be a natural material and polymers in combination with reinforcement becomes the best material of choice including things like biomedicals and structural applications these are used.

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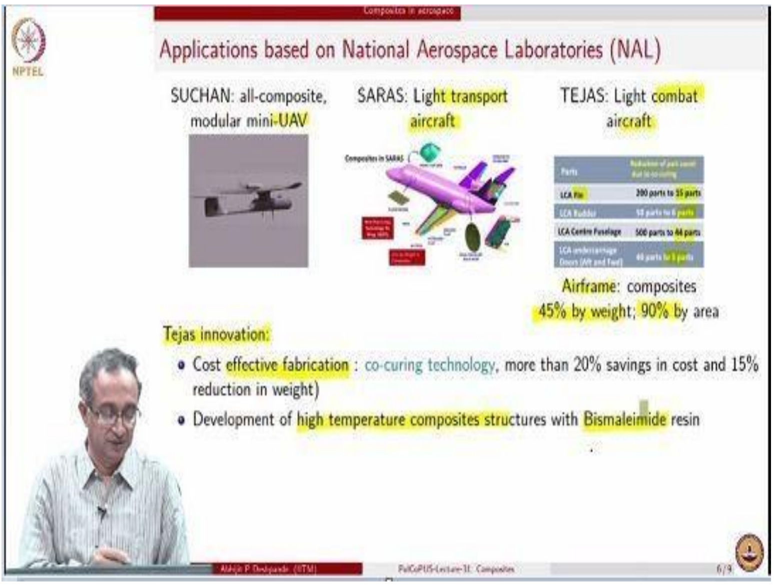

And to give some examples from aerospace what I have done is just taken few the few of these examples from national aerospace labs in Bangalore and we have a basically UAV which is all composites, we have a light transport aircraft and light combat aircraft and all of these are prominent examples where composite materials are used just go and read some of the details about what type of composites are used and why in these materials and you will get a hint about you know what type of thermoset polymers are used and why and what is the nature of reinforcement is it glass is it carbon is it Kevlar and why. And just to highlight for example here the benefit of using composites is what is shown that a fin in light combat aircraft because composites are used you can make them in one shot processing can be done together rather than making 200 different parts now you need to only make 15 parts so you can see how part numbers goes drastically down.

Whenever we start using composites so not only we are getting performance improvement due to weight savings in terms of processing also we get advantages and the airframe of this LCA is about 45 percent by weight but it is much higher in terms of the area percentage and so if you were to highlight what are the innovations it is both fabrication itself becoming very cost effective and of course you also get of superior performance for example in specifically for TEJAS a new Bismaleimide resin was used.

So the neat material the polymeric material its an example of a polymide which is very popular in aerospace and that was used as opposed to epoxy which is the most widely used resin.

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And to highlight why you can do such processing you can make a part basically which is as large as a room basically wing itself aircraft wing is very large and a large part of that wing can be made in one shot using what are called autoclaves. So autoclave is basically nothing but a pressure vessel, pressure and temperature can be varied and this is this gives you an example of how large an autoclave can be they can be larger than this they can be smaller than this depends on what is the part size being manufactured.

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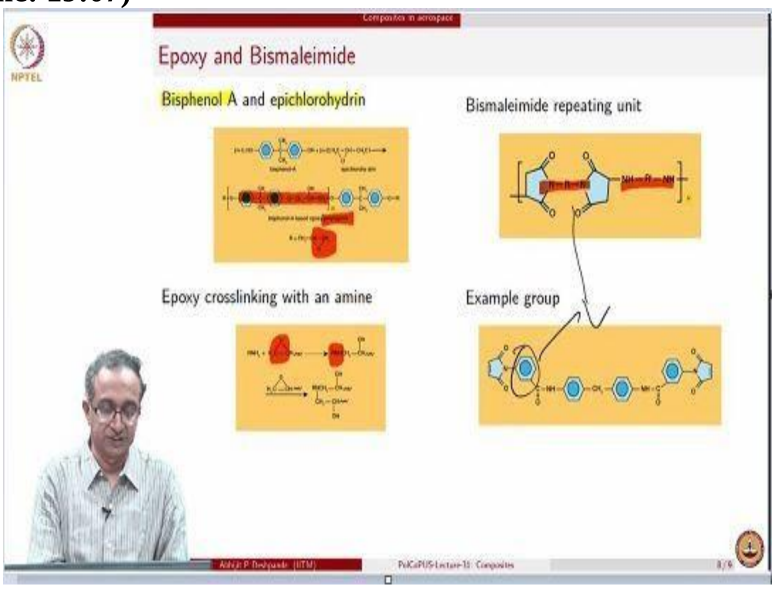

And so to close this lecture we will look at the resins which are quite common in aerospace epoxies and Bismaleimide as I said about TEJAS and epoxy is basically a polymer with bisphenol A and epichlorohydrin and it is this epoxide group which is very crucial and that reacts to give you this epoxy composite generally what we do in all of these cases is we carry out the polymerization reaction up to certain extent and get what is called a prepolymer.

And the prepolymer generally will have viscosities which are let us say 100 and 1000 of centipoise and so these fluids can be flown can be pumped and/or they can be basically handled and then we carry out the resin flow into the fibrous preforms or fibrous beds or fabrics and so on so. Where resin has to flow through between this porous media which is made up of all these fibers and then prepolymer is reacted further to obtain the final crosslink network of the thermoset material.

So therefore there is always 2 stages of processing in case of composite materials with thermoset materials and so this epoxide group interacts with an amine is an important type of hardener or crosslinker which is used. Bismaleide on the other hand has these bulky groups also present in them and one example group of what is there you can see here are these benzyl groups which are part of the backbone chain so epoxies can have glass transition ranging from 50,60 degree Celsius all the way till 200 degree Celsius.

And all the wide ranging glass transition is possible based on what is the backbone and Bismaleimide have a very high glass transition temperature also because of all these bulky groups along the macromolecules which make molecular flexibility or segmental motion quite difficult at low thermal energies so therefore you have to go to progressively higher temperature to obtain segmental flexibility in these materials and that is what we are trying to exploit when we use them in aerospace applications.

So there are several parts in the aircraft which can see temperatures of 120, 130, 140 degrees Celsius and by using these composites there with these native neat matrix materials we can easily sustain the overall structure.

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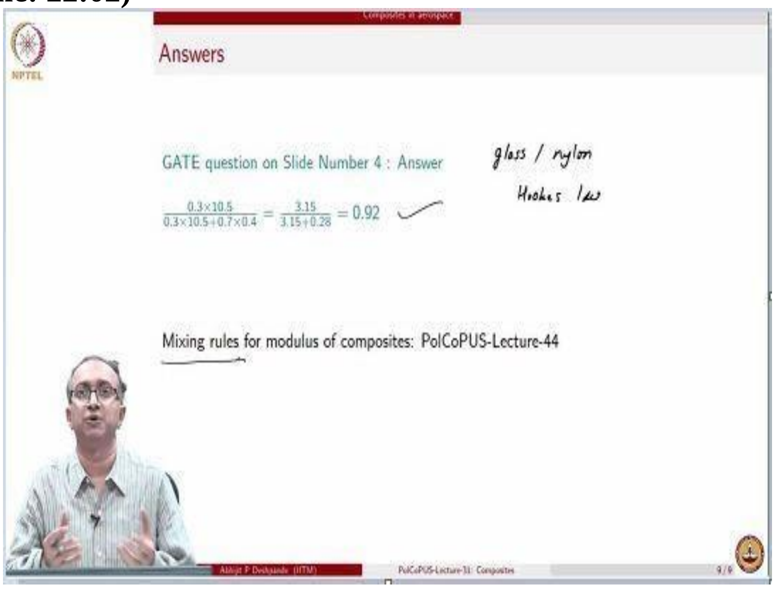

So with this we come to close this lecture I hope you have been able to formulate your answer to the question that if both of the components are subjected to the same strain that implies that you can quickly calculate what is the stress they will have because you can assume Hookean solids for both and since both glass as well as nylon are let us say Hooke's law is possible then and you know it is they are both subjected to same strain.

And so given the same strain what will be the stress they will be subjected to and so now the question is how much is the stress taken by glass fiber in relation to the overall stress and so if you do that then you will be able to get the answer. This argument that we carried out where they are subjected to same strain is one way of talking about getting a mixing rule as to how the 2 components in the mixture are sharing the load you could also do another assumption in which you say that the both the components have the same stress.

So therefore strain in them could be different and these lead to series and parallel the simplest possible mixing rules and we will discuss them in lecture 44 later on so with this we come to close this discussion related to composite materials and their applications. Thank you.