Technical Textiles
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Lecture - 04
Textile Reinforced Composites (contd.,)

Hello, everyone. Now we will discuss different reinforcements and matrices used in composites.
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Reinforcement used in composites

- Fibres
- Particles
- Flakes

First I will start with reinforcement materials used in composites. If we divide the reinforcement materials as per the shapes they are divided into 3 categories. First is fibres, then particles and third one is flakes. Fibres, as we know that it is defined as that higher length to diameter ratio, length to thickness ratio so that is the fibres. Particles are very small in dimension and flakes are a little bit larger in size.

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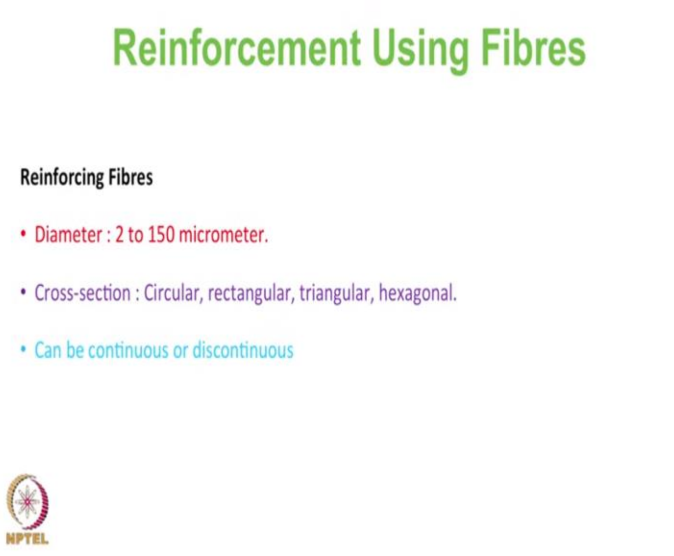

So first, let us discuss the fibre phase reinforcement. The fibres are of range from 2 micron to say 150 micron diameter. It depends on the type of materials which we use and generally the fibres, particularly manmade fibres are circular in cross-sections. But we can get different circular, different cross sections depending on the application. It may be tubular, hallow, rectangular, hexagonal or trilobal.

There are different shapes are available and fibres we can use depending on the application in the form of staple, discontinuous form or in the form of continuous that is filament form. And the continuous fibre that is filaments are long and in theory, they offer continuous path by which load can be carried by composite material.

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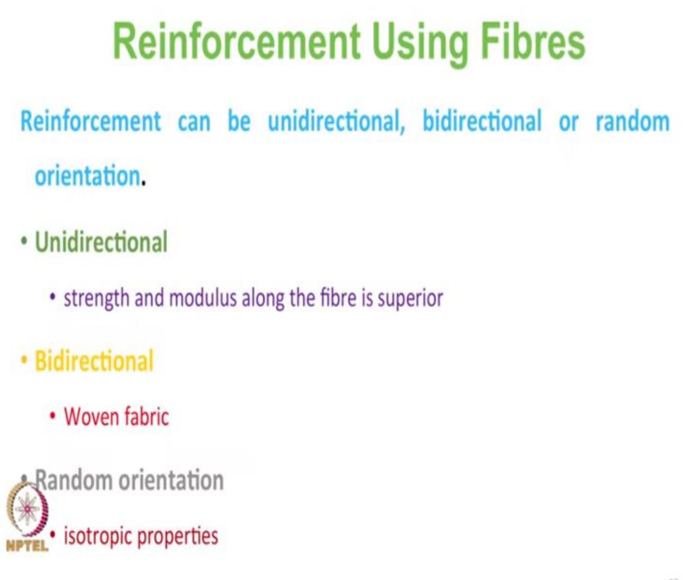
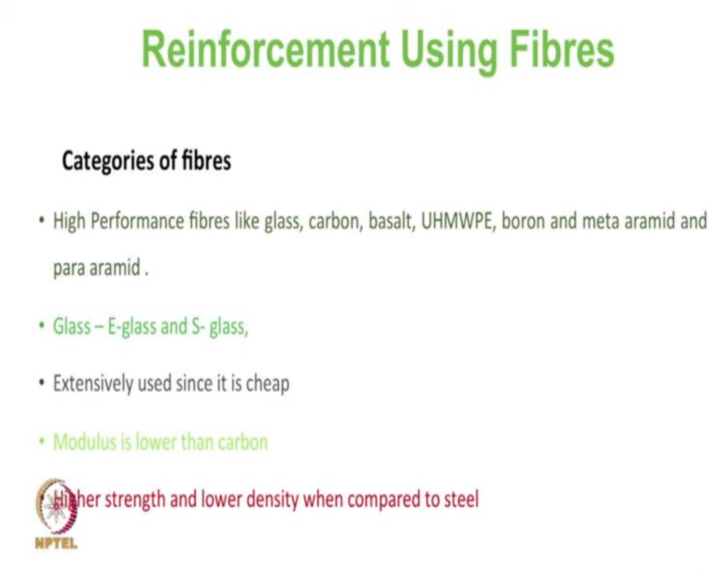


And discontinuous fibres, the load is carried by the discontinuous fibre and they shared by the matrix to the transmitted to the other fibre short fibre. The reinforcing phase can be unidirectional so we can arrange the filament or staple fibre in a particular direction. So, unidirectional reinforcing material is useful where we need strength in a particular direction as compared to other direction

Higher strength we get in axial direction and lower in other direction. All in the form of woven fabric where the strength or tensile characteristics in both lengthwise and crosswise are higher but at different angle the strength of composites are not that much as compared to the axial and cross direction. Another way of orientation is a random orientation where the short fibre mainly short fibres are oriented at random direction where we get the isotropic nature as far as tensile characteristics is concerned.

So orientation of fibre is an important consideration, so one in one dimension, maximum strength and stiffness are obtained in that direction of fibre that is unidirectional. Planner in both 2, in both in the form 2 directional strength is obtained that is woven fabric. And random or 3 dimensional strength, it is isotropic property you can get from random orientation. **(Refer Slide Time: 05:24)**



The type of fibres, we use a wide range of fibres, can be used for composite making. Most common fibres are glass fibre, carbon fibre or graphite, boron and kevlar, they are used for high performance composite application. So glass fibres are most commonly used in composite, particularly a polymeric composite. The term fibreglass is applied to denote that the composite is reinforced by the glass fibre. There are different types of glass fibres.

The E glass which is strong and relatively lower cost. But modulus is low, it is less than other fibre, typically 500000 psi. S glass which is stiffer than E glass. And it is tensile strength is one of the highest of all fibre material it is 650000 psi. It has more than 5 times the tensile strength of that steel and has density of about one third of the steel, so it is lighter than steel and it is strength is 5 times more than the steel.

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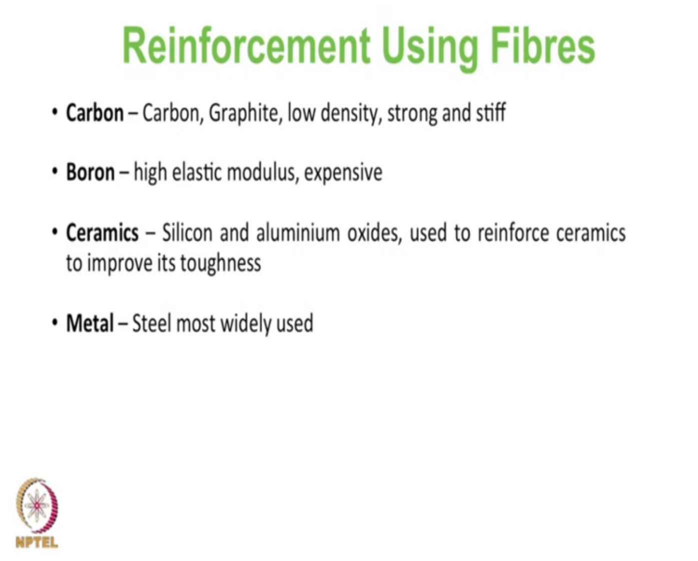

That is why the S glass is normally used for high strength composite application. Another fibre, high performance fibre, which is now used for very high performance composite application which is carbon fibre. It is a combination of graphite. The graphite has the tensile strength which is 3 times to that of stronger than the steel and has a density one fourth of that steel, so it is stronger than steel and density is also low.

So graphite is the most stable form of carbon, under standard condition, so this fibre is very stable. Boron is also used, it is very high elastic modulus but the main problem of boron is that its cost is very high. That is why it is not used in general application, but very high end application like aerospace components, we can use boron. Ceramic fibres like silicon carbide, aluminum oxide are also used, they have high elastic modulus and can be used to strengthen low density, low modulus metal such as aluminum and magnesium. Also, sometime metal fibres like steel filaments are used as reinforcement material for thermoplastic composite.

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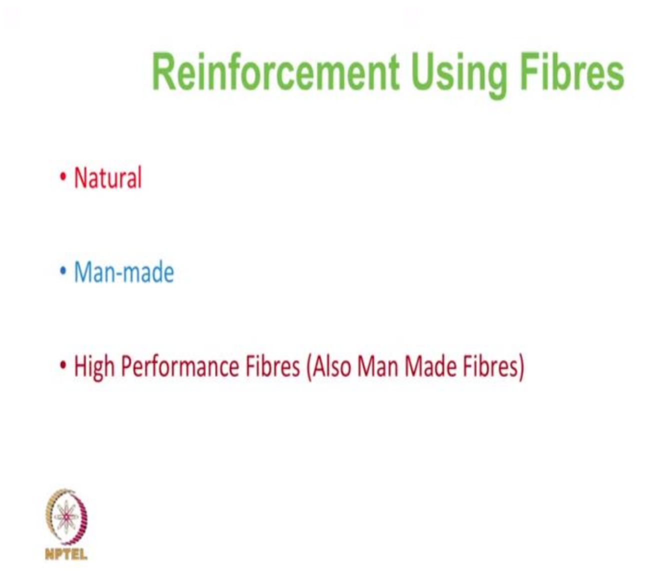

The fibres, natural fibre, manmade fibre and there are many varieties of commercially available fibres that is the high performance fibres are also used.

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These are aramid, boron, carbon or graphite, glass, nylon, polyester, polyethylene, polypropylene are also used as reinforcing material of thermoplastic composites.

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So, if we see the characteristics of this reinforcing fibres, the E glass which I have already mentioned it is the most commonly used fibre. It is high strength, good water-resistant, good electrical insulation property and lower stiffness. So these characteristics make the E glass suitable for reinforcement in composite.

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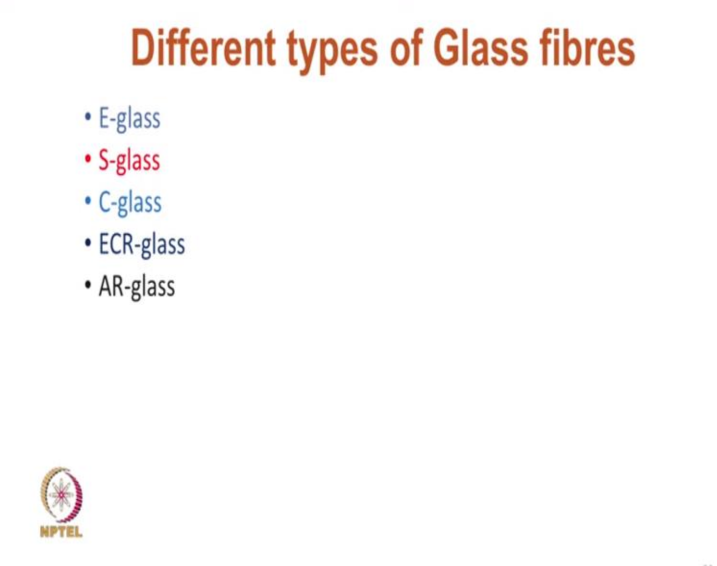

Apart from E glass, there are other types of glass fibres available S glass, C glass, ECR glass, AR glass. So these are the fibres we can use for composite applications.

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Aramid fibres, nomex or kevlars are used the superior resistance to damage energy absorption, good in tension applications, the cable, moderate stiffness, more expensive than glass. So if we want to use this fibre for very high-end application, so nomex is normally used for high temperature resistant composites.

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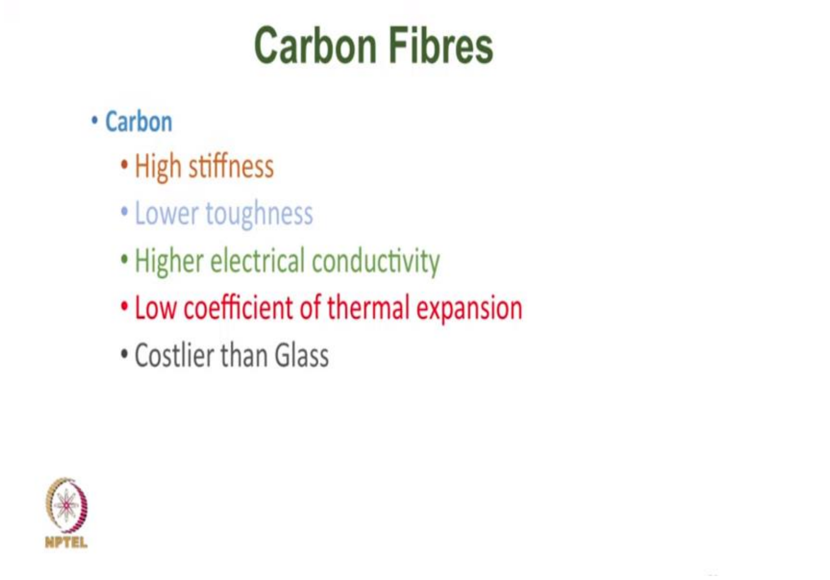

Carbon fibre has the quality of good modulus at high temperature, excellent stiffness, it is expensive fibre, it is a brittle, low electric insulation property. Thus brittleness of this fibre actually, that is why the weaving or knitting of the carbon fibres are problematic. So, one has to take precaution to convert the carbon fibre to preform.

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Advantages & Disadvantages of Reinforcing Fibres

Fiber Type	Advantages	Disadvantages
E-Glass, S-Glass	High Strength, Low Cost	Low Stiffness, Fatigue
Aramid	High Strength, Low Density	Low Compr. Str., High Moisture Absorption
HS Carbon	High Strength and Stiffness	High Cost
UHM Carbon	Very High Stiffness	Low Strength, High Cost

So these are the advantages and disadvantages of different types of fibres. So E glass, S glass the main advantages are high strength, low cost but the main disadvantage is low stiffness and fatigue characteristics. Aramid fibre, high strength, low density and it is a high moisture absorption is the main problem of aramid fibre. So that is why the sometime the aramid fibres we have to treat with some other surface active agent, carbon fibre high strength that is high strength carbon that is high strength and stiffness, the main problem with the cost. **(Refer Slide Time: 13:03)**

Particles and Flakes as reinforcement

Particle:

- Microscopic (less than 1 micron)
- Macroscopic (greater than 1 micron)
  - ✓15% or less embedment of the particles result in strengthening the matrix. (Microscopic)
  - ✓25% or more embedment of the particles serve to share the load with the matrix material. (Macroscopic)

Next type of reinforcement is that it is particles and then it is flakes. So particle reinforcing material, it is an important material for metals. And ceramics range in size from microscopic, less than 1 micron to macroscopic to greater than 1 micro within that less than one micron to more than one micron that range. It is that it is used for basically metal and ceramic composite.

In the microscopic size, the characteristics is that if it is in microscopic size range the proportion of this particles should be 15 % or less. Then the particle result in strengthening the matrix. So if we use more than 15 % larger quantity of particles, lower size practical, microscopic particle then there will be agglomeration, and strength utilisation will not be there.

So if we use the particle of lower size, microscopic size, then we must use with a lower proportion 15 % or less. So in that case, we can utilize the strength of the particle. But in macroscopic size, if the particle sizes are more than one micron, then the particle that proportion should be more than 20 %, 25 %, 25 % or more. In that case, the particles have to share the load with the matrix material.

So then if it is the size of the particle is more than 20 that more than one micron, that is it is a larger sized particles, then the proportion of particles should be more. And in that case, it will distribute the load it will start sharing the load. The form of composite strengthening occurs in cemented carbide, so this that is the cemented carbide which in which the tungsten, the matrix carbide 80 % is held by the cobalt binder. So this type of matrices are used.

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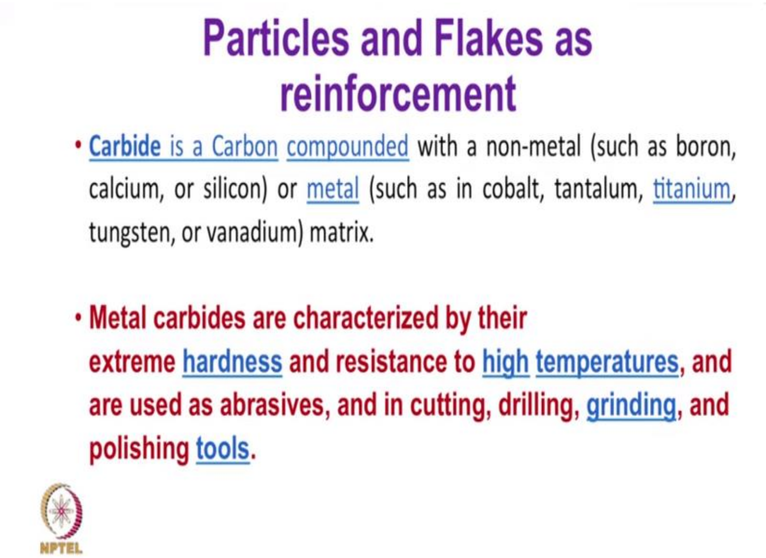

Carbide is a carbon compound with non-metal such as boron, calcium or silicone or metals such as cobalt, titanium, ok this type of matrix, so this is the matrix. And carbide, the carbon is a particle, so carbon particle is used with all this type of metal and non-metal matrix. So, metal carbide are characterised by their extreme hardness. So if we use the carbon compound carbon particle with a metal, the metal as matrix, it will enhance the hardness, so this metal carbides are characterized by their extreme hardness and resistance to high temperature, so that composite becomes very hard and it will become resistant to high temperature.

And are used as abrasive, cutting tool, drill, grinding, polishing tools. So the characteristics of this all these products, all these equipment, are it should be very hard, very it should be harder than other material.

Like polishing tools, it should be harder than the material which you are polishing, basically if you are trying to polish the iron. So it should be harder than that, so that it will is a grinding it should be it in the cutting tools. So we use this metal matrix compound.

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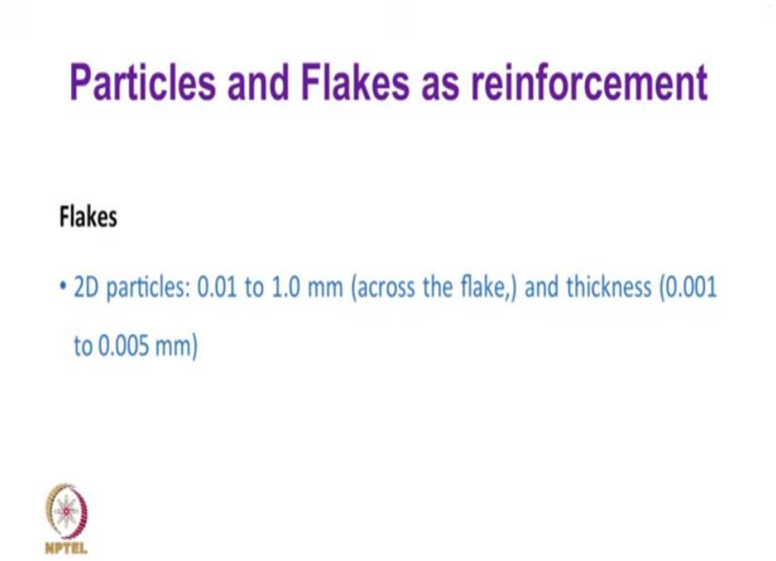

Another types of particles are the larger particle which is known as flakes. They are actually, it is a 2 dimensional particles ranging from 0.01 to 1 mm, it is a large size flakes. This flake it has thickness of 0.001 mili meter. So these are used as the reinforcing face along with other polymers also.

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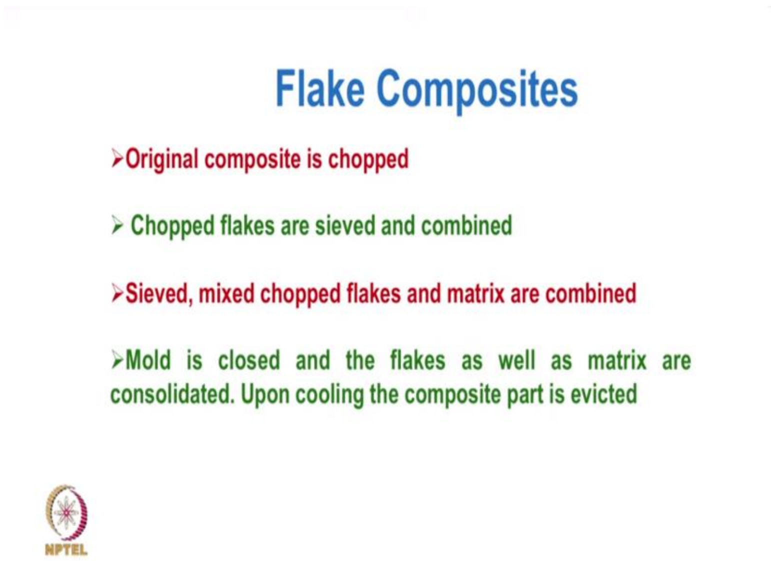

Normally, these flakes are used as reinforcing material and polymers are used as the matrix material. The system of composite making from flakes are simple. The process scrap is grounded in a grinding device which chips the parent composite into flake of a broad sized distribution.

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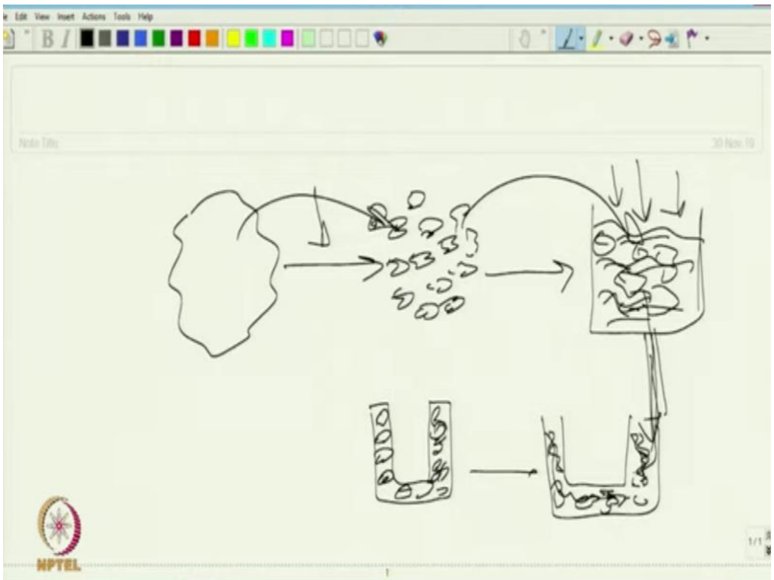

Like if we get, suppose you have one component here, it is a composite suppose it is a used composites. Now we have to grind to make it smaller particle. Normally, we can use a thermoset matrix for using. So this is actually. Then what we do, we mix with this we mix with the polymer. So this is a polymer and there we are mixing with this. After that we will send this to the mold.

There is a mold and this material is coming here in the mold with the flake depending on the size and shape we can make and ultimately will remove the mold, then we will get say this is the flake composite. So in this way, first you have to crush it, break it to smaller flakes, then we mix with the matrix material and then we use the mold. This way, we use the flake as reinforcement in the composite.

So the parent composite into flake, so initially the parent composite is normally we are talking about the thermoset matrix, so which we can actually chop it to make smaller flake. The flakes are then sieved into different classes of sizes, so we are actually we use a sieving and we to actually segregate different sizes, depending on the size requirement then we take the particular size and then mixed with the at different proportion to have specific strength properties.

The mold is filled with the flake and matrix in a molten state. So we can use thermoplastic matrix also here, molten thermoplastic matrix, then we mix with the flakes to get the mold. And then we dry it to get the proper composite. The mold is closed and the process cycle with the designed parameter like pressure, temperature, cooling rate is executed. So to get final composite and after that to eject the eject out of the mold and to get the composite.

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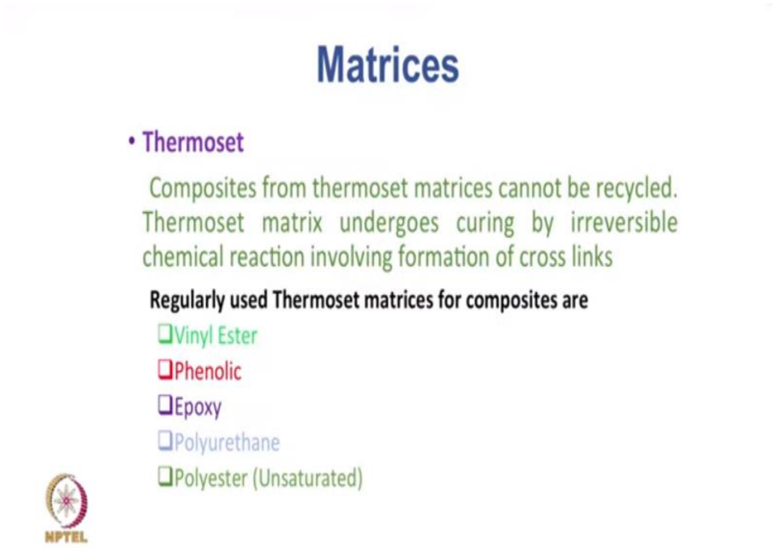

So what we have discussed till now the reinforcing component. Now we will discuss the matrix phase. The matrix phase of polymer matrix we are talking about polymer matrix is divided broadly into 2 categories. As I have already mentioned one is thermoset another is thermoplastic. The thermoset matrix this undergoes irreversible chemical curing reaction. And it forms cross link for it is geometrical stabilization.

That means once the cross link is formed, it is totally stable, it is irreversible, it cannot be reversed we cannot get the initial material. So once the curing is done then we cannot go back to this liquid or viscose stage. The most commonly used thermoset matrix for composites are polyester unsaturated polyester, vinyl ester, epoxy which is widely used phenolic ester and polyurethane, these are the thermoset polymers. Among thermoplastic polymers, basically thermoplastic is with the characteristic is that with the temperature it melts and on cooling it again solidifies.

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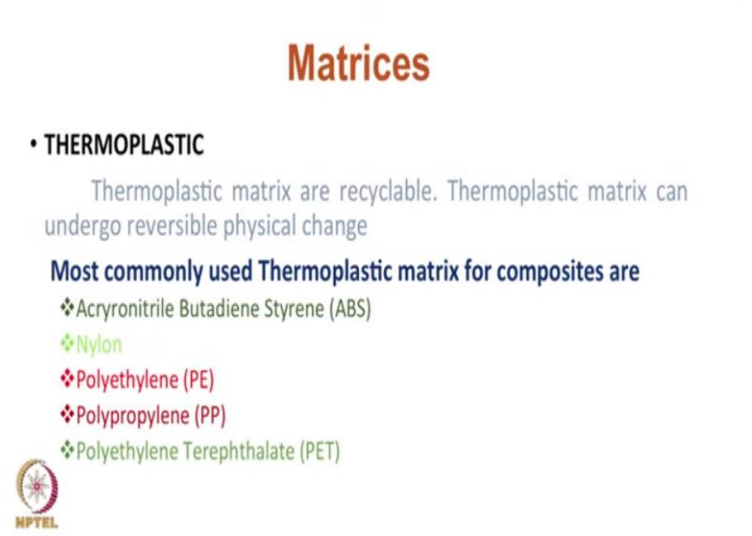

So this is totally reversible physical changes, there is no chemical linkage taking place during this process. Most commonly used thermoplastic matrix material are Acryronitrile Butadiene Styrene which is known as ABS, Polyamide it is nylon we can use polyethylene, polypropylene and PET Polyethylene Terephthalate that is it, is in it is unsaturated polyester. This is saturated polyester. So normal polyester we use, it melts and in on hitting and it is actually it solidifies on cooling.

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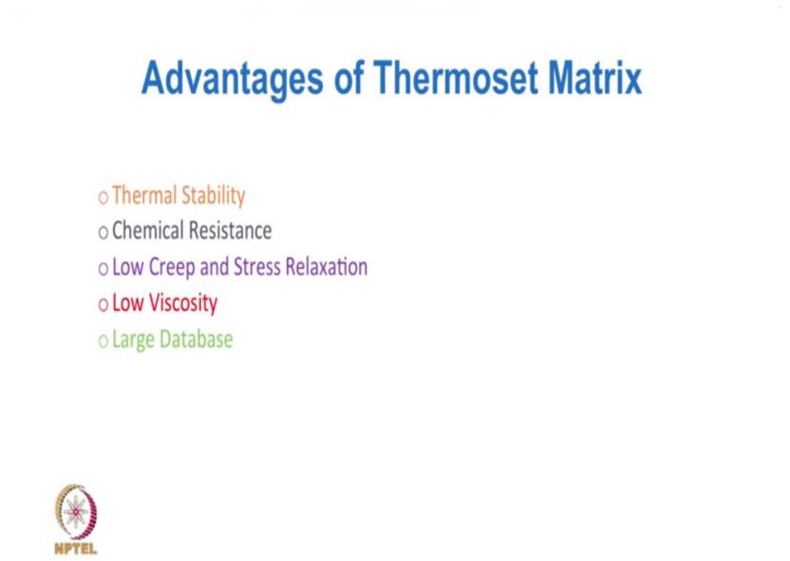

So if you see the advantages of a thermoset matrix, because at present most of the actually I can say majority of plastic composites are thermoset composites. These are due to it is a thermal stability is there. It is these are chemical resistant, reduced creep and stress relaxation, lower viscosity. So it is excellent for fibre orientation, so very low viscosity at a lower temperature. So it can penetrates through the reinforcing material very easily. And it is very common material with the fabricators because this does not need any special process. That is why thermoset is very popular in matrix manufacturing.

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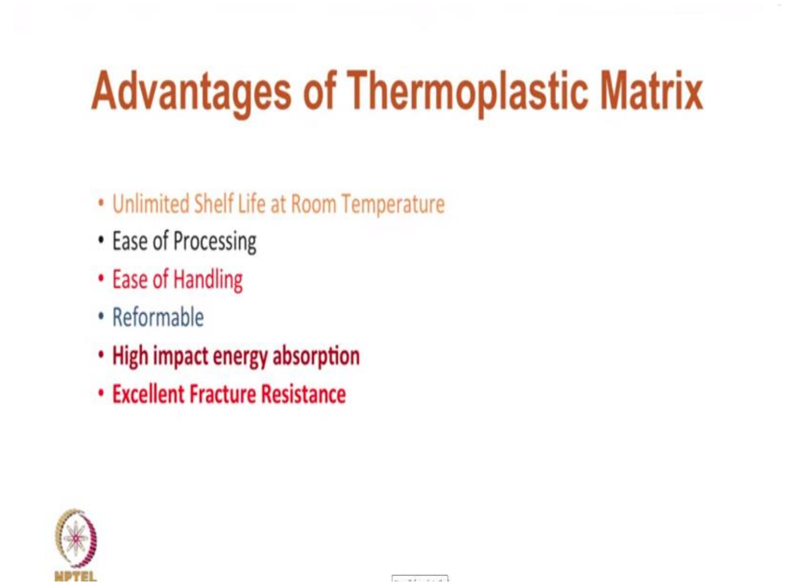

As far as thermoplastic is concerned they are actually room temperature materials today. So you can store the material at room temperature which we cannot do for thermoset matrix. Rapid process and low cost of forming, preformable we can make preform. And most important advantages of thermoplastic material matrix is that it is a these are excellent fracture resistance and excellent toughness.

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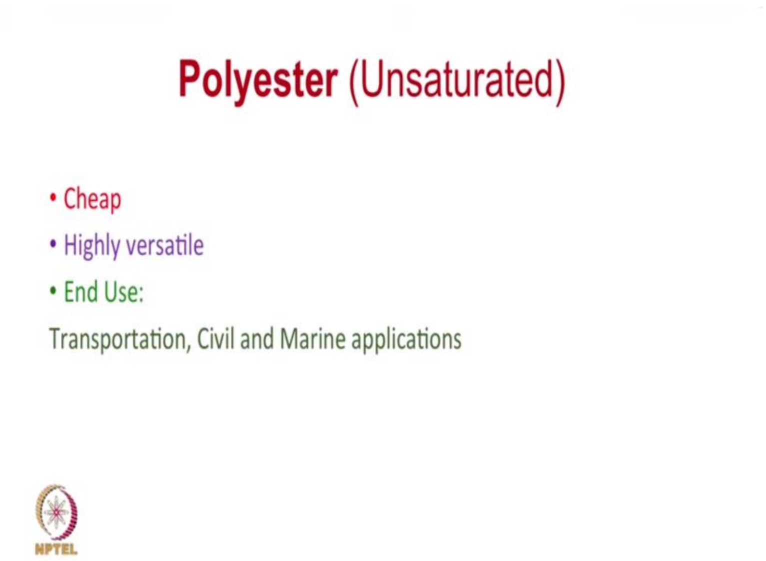

So among the thermoset matrices the unsaturated polyesters characteristics are low-cost, extreme process versatility, it is performance is good and these polyester thermoset matrices are used in transportation industry, construction and medical.

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Vinyl Ester, it is a characteristics are similar to polyester. Excellent mechanical and fatigue properties, excellent chemical resistance. And it is major uses are corrosion application where the chances of corrosions are there, pipes, tanks, ducts, so all these places we use vinyl ester as matrix material. So synthetic, the composite pipes, tanks and ducts where corrosions chances of corrosions are there.

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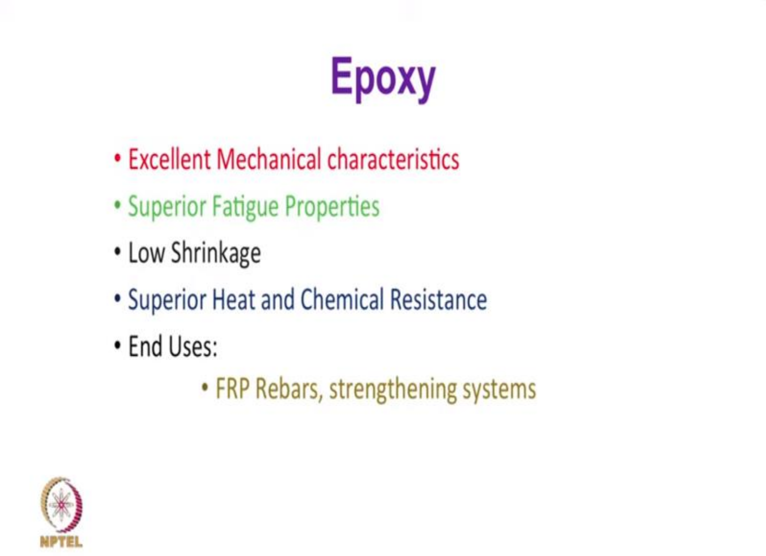

Epoxy resins they have excellent mechanical properties. Good fatigue resistance, low shrinkage, good heat and chemical resistance. And major applications are fibre reinforced polymer strengthening system. So where the reinforcement is required, we can use. So there are, these are the applications reinforcing bar.

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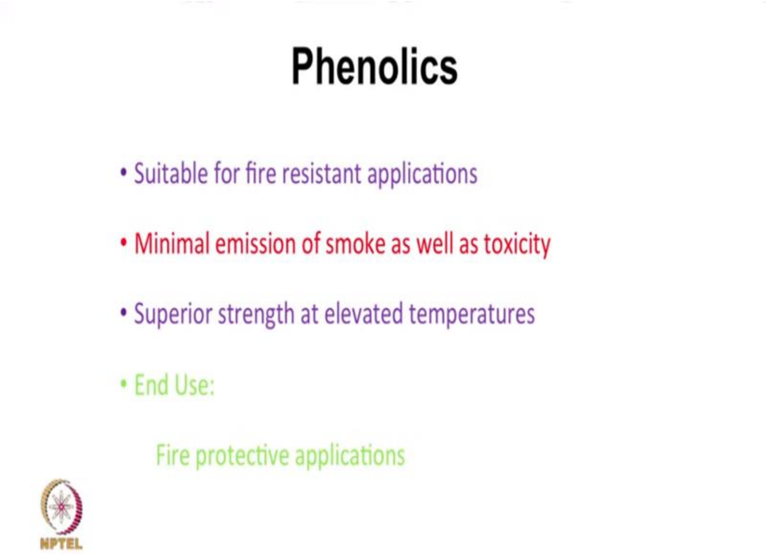

Phenolic matrix material thermoset matrix, excellent fire-resistant. So in case of the where requirement of fire-resistant products are there so we can use phenolic matrix, low smoke, and toxic emission. So high strength, at high temperature, so that high temperature application we can use. So mass transit ducting, fire-resistant, high-temperature application.

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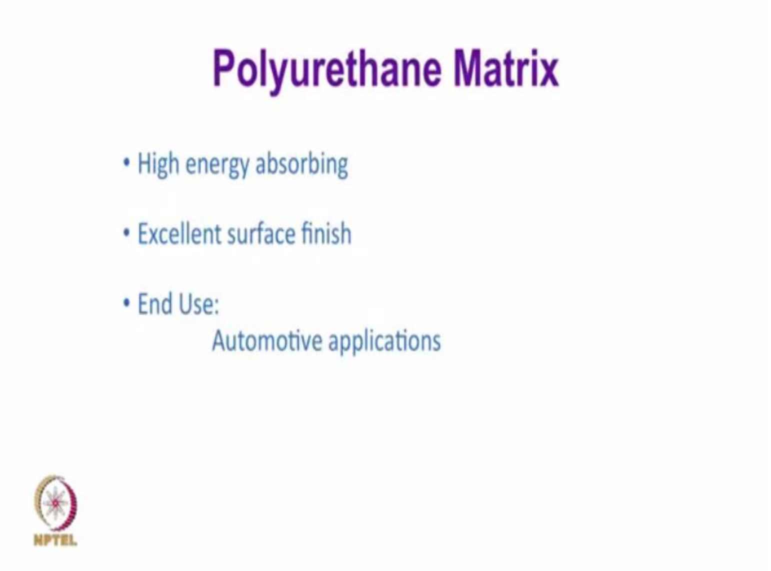

Polyurethane is another thermoset matrix. The characteristic is the tough material good impact resistance, good surface quality. So, polyurethane matrices are used in bumper beams, automotive panels, so there we need toughness. And good impact resistant characteristics, so that is why the in those places, polyurethane thermoset matrix are used.

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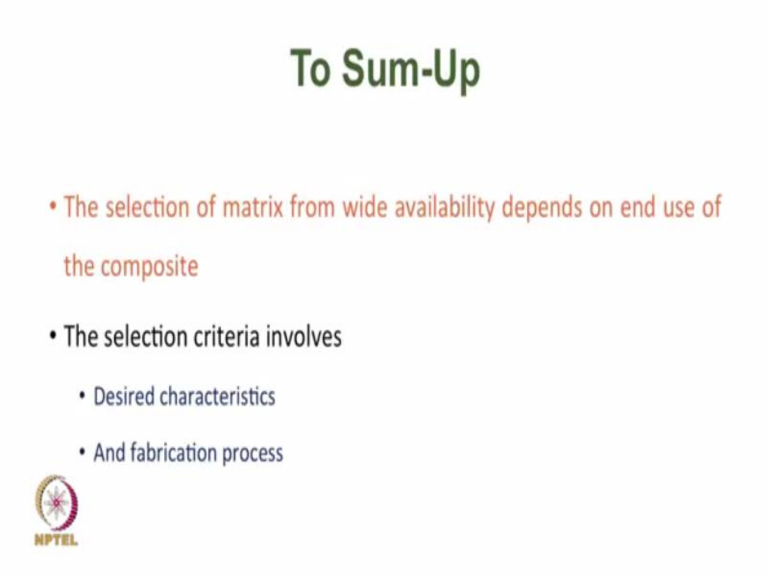

So in short, we can see the polymers which are used for matrix they have wide variety. So we can select the type of polymer based on our requirement. So their selection based on physical and mechanical properties of the product and fabrication process requirement. So the type of product we require or type of the facilities, manufacturing facilities available, so based on that we select the polymer matrix, whether it will be thermoset or thermoplastic or what type of mechanical characteristics you require, depending on that, we select our polymers.

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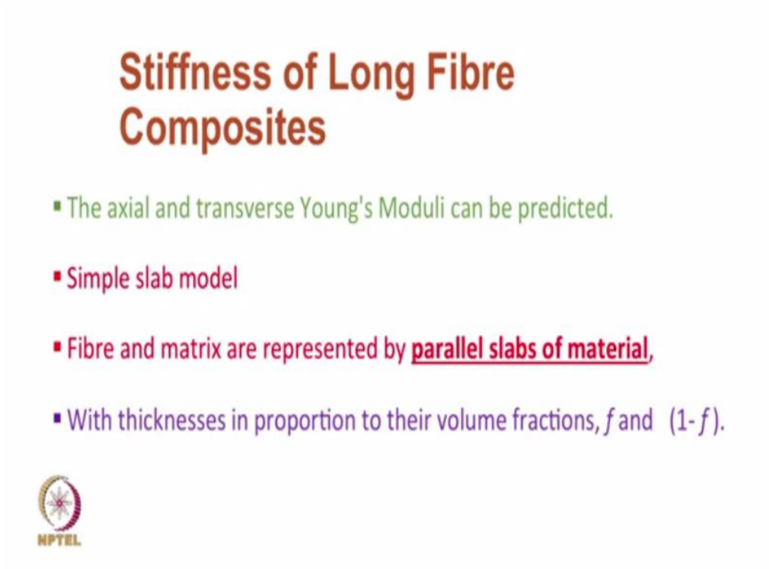

Now I will discuss the theoretical aspects or mathematical approach to calculate theoretically at least to predict the stiffness of long fibre composite. Here, we will try to discuss the measurement or predict the Young's Moduli in terms of axial direction and cross plane direction. The axial and transverse Young's moduli can be predicted. It can be predicted using a simple slab model. In which the fibres and matrix are represented by a parallel slabs of materials. With the thickness in proportion of that volume fraction, f is the fibre volume fraction and 1 - f is the matrix volume fraction.

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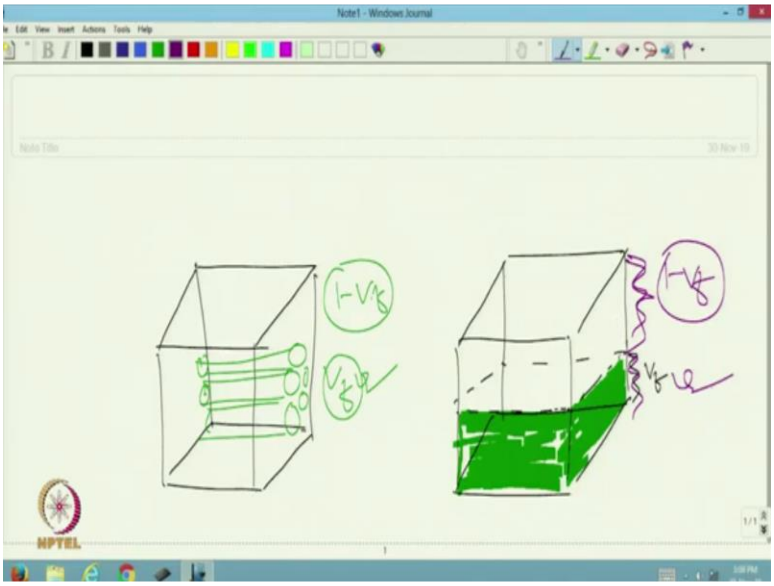

Now let us see what is the model is telling. Suppose this is a matrix, here we have fibres. So fibres are there. Now if we take the actual volume of fibre say V f and total volume is say one volume fraction of fibre is V f so 1 – V f will be the volume fraction of the matrix. So in this model, what we do? We can now, let us draw once again this is the thickness say V f. Now here this portions it is a fibre portion. And this portion is the other portion this is the matrix portion.

This one is the matrix, so 1 – V f. So that means in this model, the volume fraction for unit cross section area. So here it is thickness is the, this much is the fibre, and here it will be the matrix material.

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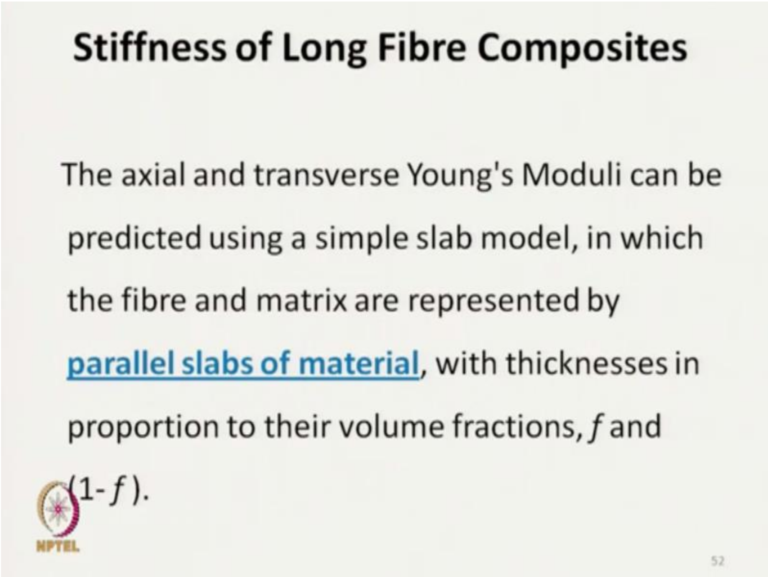

So this parallel slabs of materials, so it has been assumed that the matrix are made of 2 parallel slabs no sorry composite, it is lower portion in green color I have shown, it is a fibre of volume fraction f that is, it is shown by the thickness f and 1 - f is that the matrix.

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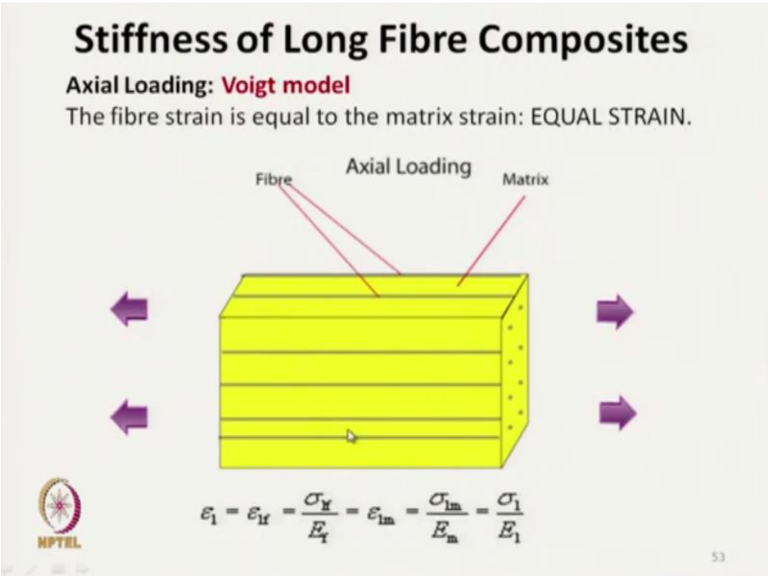

There are 2 models. One is by axial loading it is called Voigt model, another is transferred slowly, I will discuss transverse loading separately. In axial loading, this is the composite block. The black lines it is a fibre, reinforcing fibres and the yellow portion, it is a composite sorry it is a matrix portion. And when these are axially loaded that means the elongation of fibre, elongation of matrix and elongation of the composite they are exactly same.

Because they are loaded axially. So Epsilon 1 is the, this is the elongation of composite in length direction. And we will discuss Epsilon 2 will be the elongation in cross plane direction or transverse direction. So Epsilon 1 = Epsilon 1f fibre. So this is the axial elongation of fibre. Which is the ratio of the stress by the modulus of fibre which is equal to the elongation of matrix. And that is equal to the stress by modulus of matrix and it is equal to the stress by modulus of the composite.

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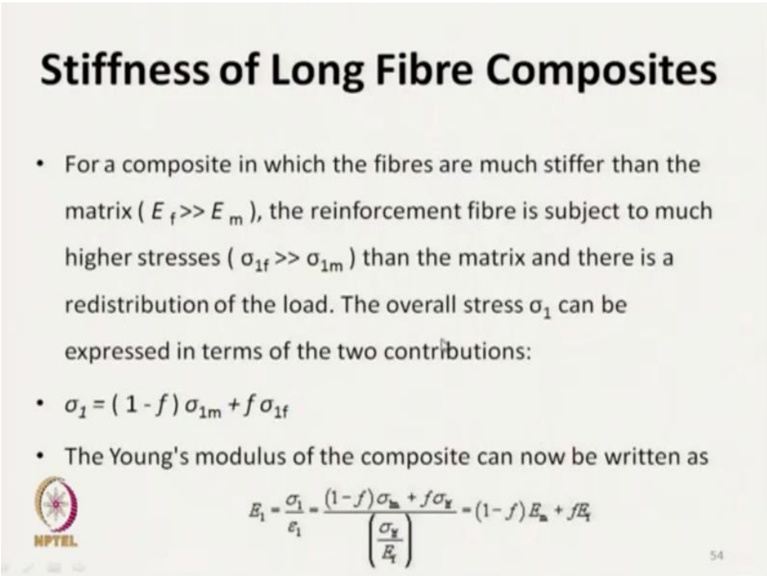

So with this assumption, if we see that the phase modulus of fibre is much more than modulus of matrix which is basic assumption, which is actually we require because fibres are much stiffer than matrix. The reinforcement fibre is subject to much higher stress in this case, because of the higher stiffness of fibre, so that means stress of fibre is much more than the stress of the matrix.

And there is redistribution of the load, so load redistribution will be there. Overall stress on matrix, Sigma 1 can be expressed in terms of 2 components. One is that based on their volume fraction that is the 1 - f that is volume fraction of the matrix multiplied by the stress on matrix plus volume fraction of fibre, multiplied by stress on fibre. So from there we can arrive at that the modulus, Young's modulus of matrix, is the proportion of their volume fraction of matrix and the fibre.

So 1 - f is the volume fraction of matrix multiplied by the stiffness, that is Young's modulus of matrix plus, if volume fraction of fibre multiplied by stiffness of fibre.

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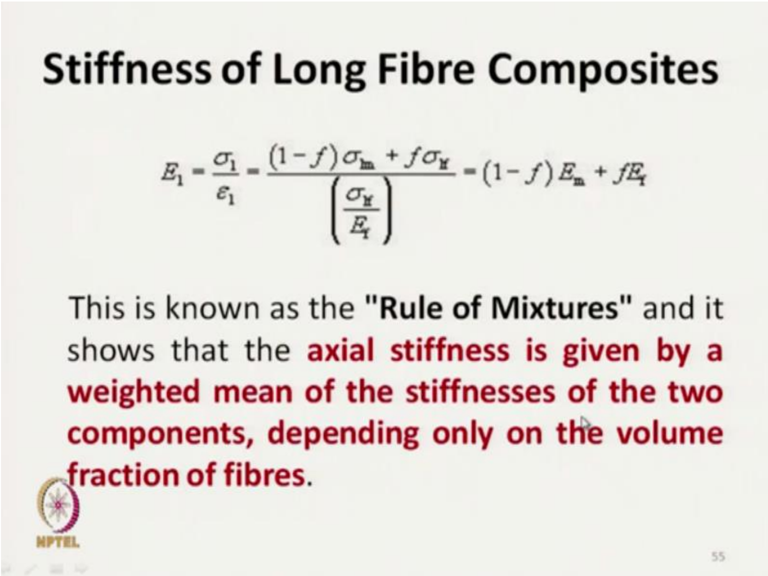

So this is known as rule of mixture. And it shows that the axial stiffness is given by a weighted mean of stiffnesses of 2 components, depending on the volume fraction of fibre. That means if we increase the volume fraction of fibre, if f is increased then the stiffness of the composite will increase because this f this E f is much higher than the modulus of matrix E m, so it is directly proportional to the volume fraction of fibre.

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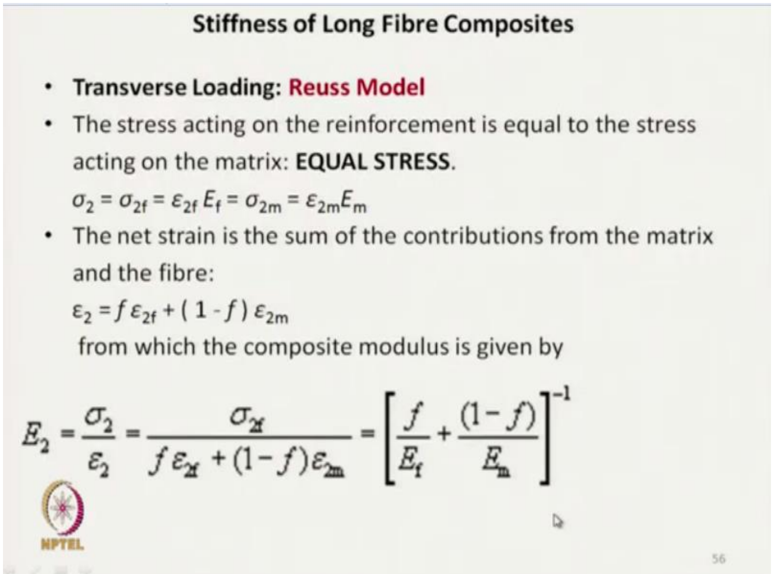

Another model, which is which predicts basically transverse loading. It is a Reuss model. Here, the stress acting on the reinforcement is equal to the stress acting on the matrix that is equal stress. In earlier case, it was assumed that strain of matrix is equal to strain of the fibre. Here, stress is assumed to be equal, the stress on composite is equal to stress on fibre, equal to stress on the matrix.

From here we can derive that elongation is in proportion of the volume fraction of matrix and fibre. So the net strain is the sum of contribution of the matrix and the fibre. And from here we can derive initial modulus, that is of composite in transverse direction is giving by this relationship f / E f + 1 - f / E m to the power - 1, so this we can derive.

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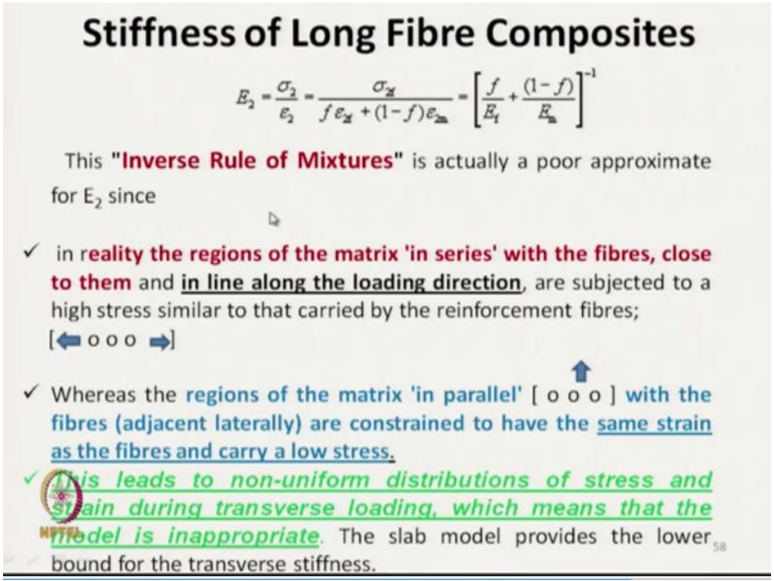

This is known as the inverse rule of mixture. But this assumption this has poor estimation of E 2 that is transverse stiffness. Why?

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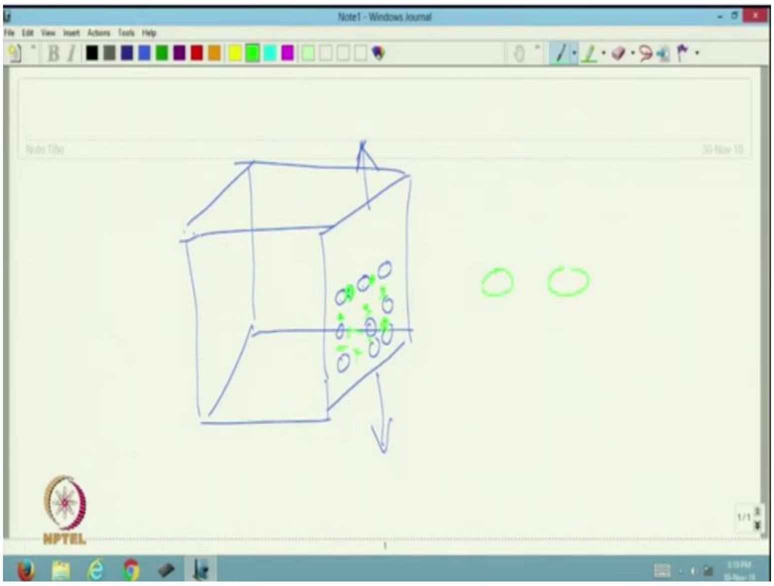

Let us discuss here. Now suppose this is the matrix. Here we can have fibres in this fashion or in this fashion. When we are applying load maybe tensile or compressive, so in this case, 2 things may happen, one the fibres and this portion is matrix portion. These are matrix portions, in between the fibres they are matrix portion. 2 things may happen either let us see here so, in reality, the regions of matrix in series with the fibres that is, these are the in series with the fibres close to them in line along the loading direction.

So when it is in line along the loading direction. These are actually subjected to higher stress that means the matrix potion in between the fibres will be subjective to very high stress because they are in series. But in other places where the regions of matrix are in parallel, this is in parallel when the loading is in this direction. In those places, what will happen, the majority of the load will be carried by the reinforcing material.

So the load on matrix in between this reinforcing zone will be low. So with the fibres adjacent to adjacent laterally, laterally it is an adjacent are considerable are constrained to have the same strain as that of fibre and carry a low stress. So the matrix in this zone is carrying lower load, but on the other end, matrix just above this fibres are carrying high load. So that this will create actually non-uniform distribution. Now let us see here.

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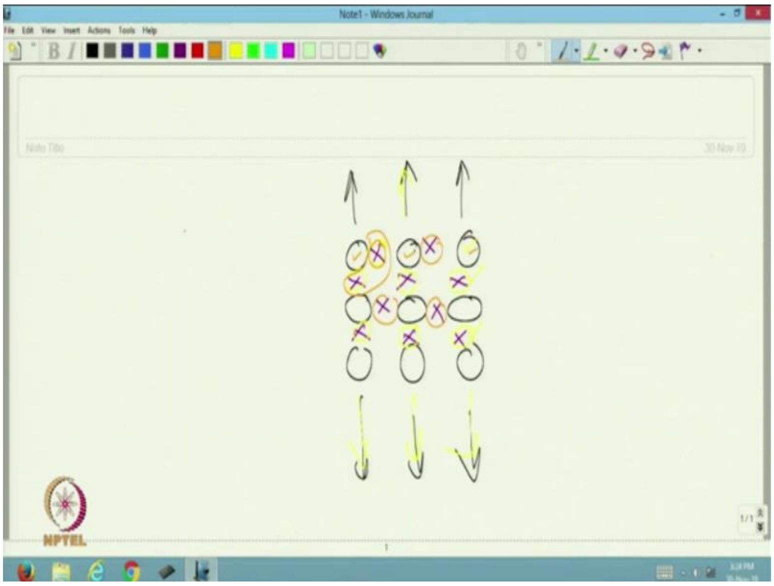

Suppose I am drawing fibres here 1, 2, 3 fibres and 1, ok, now suppose we are applying load in this direction. This is the direction of load, these are the fibres and I am drawing matrix in purple color, these are the matrix in between them. So when the load is being applied in this direction, so this fibre and this matrix, matrix in this 2 positions or this portions this matrices are subjected to a high load because they are in series with the fibre.

But on the other hand the matrix parallel to fibres, this matrices, they are not subjected to high stress because the load is being shared by the reinforcement material. So adjacent matrices in 2 different zones which are very close are where the load distributions are totally non uniform distribution that makes this model total unstable model.

So this leads to non-uniform distribution of stress and strained during transverse loading which means that the model is inappropriate. The slab model provides lower bound for the transverse stiffness. So transverse stiffness the transverse stiffness measurement is, it is difficult by this type of model, but it predicts the longitudinal stiffness well.

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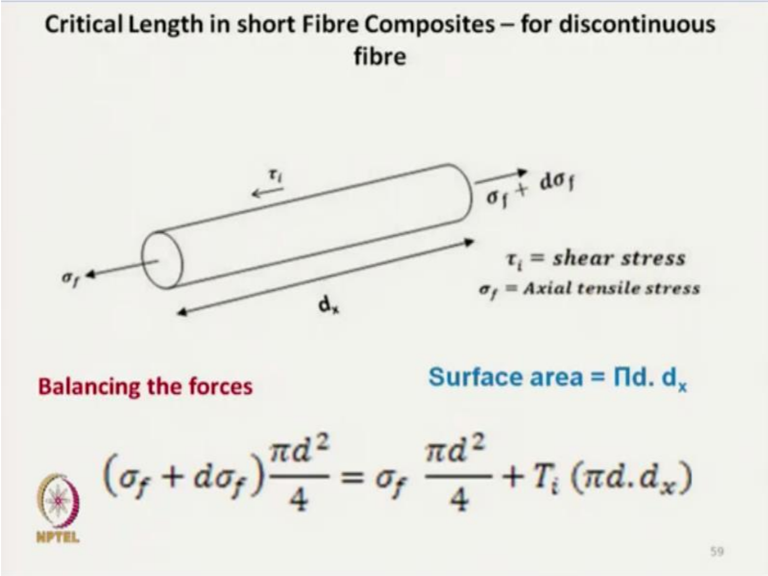

Now coming to the critical length, critical length is nothing but the length which is required, minimum length required, before the when we try to pull that it will below that length the fibre can be pulled out and just above that fibre will be broken before it is coming out from the matrix. So that critical length is important. It is very much important for short fibre composite. And it depends on the shear stress between the fibres and matrices.

So let us say this tau i is the shear stress and sigma f is the axial tensile stress on fibre. So when the fibre is stressed with sigma f and the small fibre length is d x. So this is actually given by. And on the other end, other side the stress will become sigma f + d × sigma f. So, that much increases there. So, delta sorry d sigma f so sigma f + d sigma f so this is an increase in the strength stress component.

So sigma f + d sigma f so, this multiplied by the cross section, this cross section of fibre equal to this cross section this stress plus the shear stress × this surface area total surface area, this is the equation balancing force and if we simplify and integrate.

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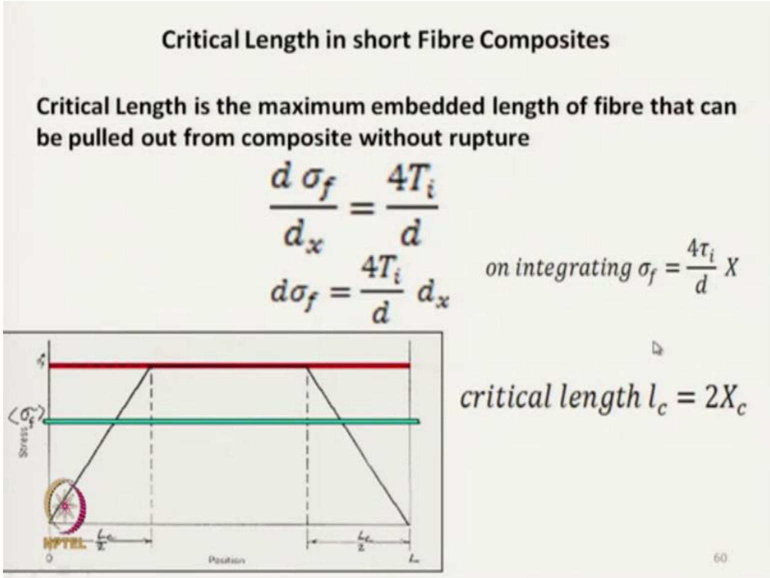

We get this equation, so this is the equation so sigma f = 4 tau i / d where and it is X where this X is the critical length.

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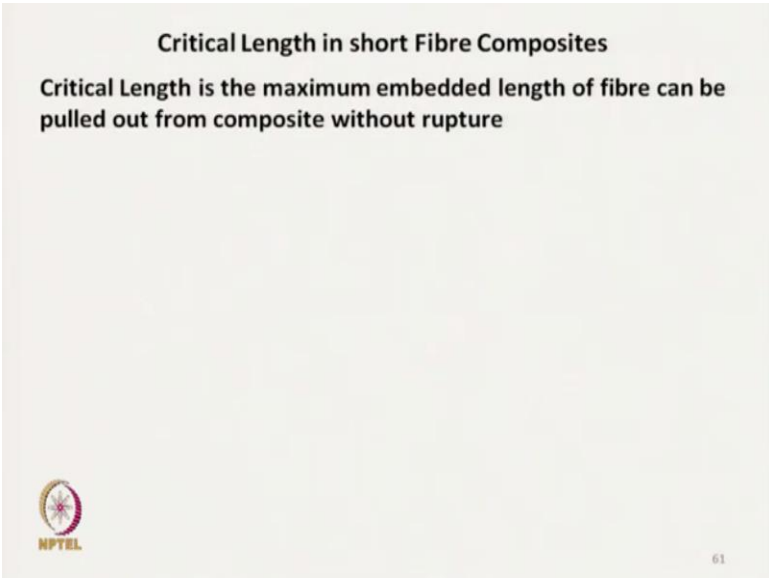

So the critical length is the maximum embedded length of fibre that can be pulled out from the composite without rupture. As I mentioned, if it is more than the critical length that fibre will not be pulled out, it will be it will rupture. Next class I will discuss how to predict the stress of matrix knowing the stress strain behavior of matrix and fibre. So, how to predict the stress of the composite if we know the stress strain behavior of matrix and the reinforcing material. Till then thank you.