Introduction to Composites
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Lecture – 40
Failure Modes of Composite Materials

Hello welcome to Introduction to Composites. Today is the 4th day of the ongoing week which is the 7th week of this course. We will continue our discussion which we initiated yesterday; specifically we had started looking at physical processes and mechanisms of failure when a composite approaches it is strength and it starts feeling.

There are 5 scenarios we are going to discuss in this ambit the first one has already been discussed yesterday, which was the failure of a composite as it is subjected to loading in the longitudinal direction and specifically if the loading is tensile in nature.

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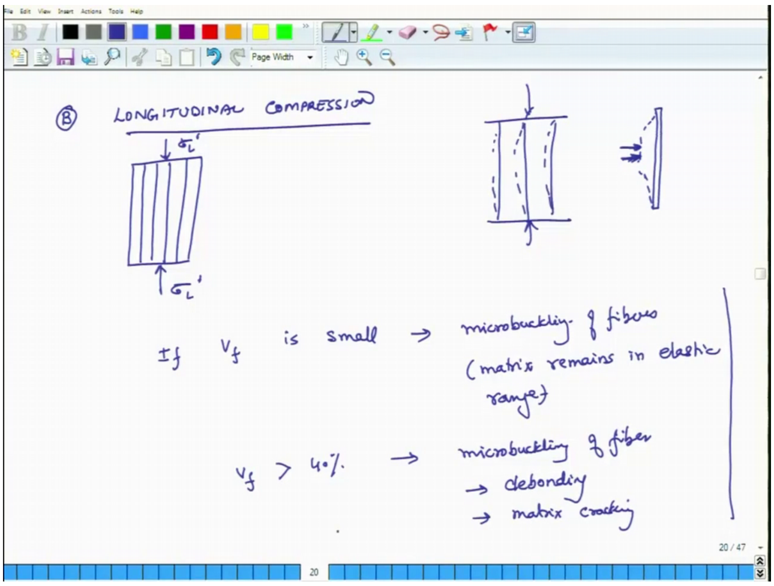

Today we will extend this discussion and the second scenario is scenario B, where the loading is again in the longitudinal direction, but compressive in nature so, longitudinal compression.

So, what happens you have a composite and you have all these fibers in it and you are applying an external force such that it is compressive in nature? So, sigma l prime, prime indicating that the direction of loading is compressive.

Now, think about it what could happen if you had us if you did not have any matrix suppose there was no matrix and there were only fibers there were only fibers. So, suppose there were just fibers and I am compressing that what will happen? As I compress the fibers after a little while these fibers will start to buckle, they will start to buckle. So, what will they do they will instead of this they will start bending.

Now, in composite this buckling of fibers does not happen early on why, because each fiber is surrounded by a sea of matrix. So, when it buckles the matrix supports the fiber and tries to keep it in it is place, but as. So, matrix tries to keep the fiber aligned in the straight direction, but as it is trying to keep it aligned in the straight direction the matrix itself experiences some forces right.

So, matrix experiences some shear forces. So, why will it experience shear force. So, suppose I have fiber the fiber is trying to do this and the matrix is pushing it in this direction. So, as it is pushing it in this direction it is experiencing some shear forces. So, because of this several phenomena could happen. So, one is if the number of fibers are really small they are very few fibers very few fibers, then what will happen they are only let us say one percent fibers and you have a lot of matrix. So, there is sufficient amount of matrix available to keep everything straight right.

So, after a time the matrix will not be able to keep it straight right and then the fiber will start buckling. So, if V f small, then the fibers will do micro buckling. Even if the material is in the elastic range, because there is a lot of matrix and the matrix can take in a lot of forces because the amount of matrix which is involved is large. So, the only micro buckling of fiber happens and what is matrix doing matrix remains in elastic range.

Now, if you have a lot of fibers. So, if you have a lot of fibers; that means, that volume fraction is large. So, let us say if it is more than 40 percent, then what happens then of course, micro buckling of fiber will happen, but it will happen and simultaneously there can happen debonding right which means that the bond between the matrix and fibers can get removed and there may be large forces, which are being exerted by the fiber on the matrix. So, the matrix can crack also matrix cracking that can also happen.

So, these are some phenomena and we will organize these whole phenomena for different situations. So, in general the composite which is loaded longitudinally in compression it can fail you fail in 3 4 important ways.

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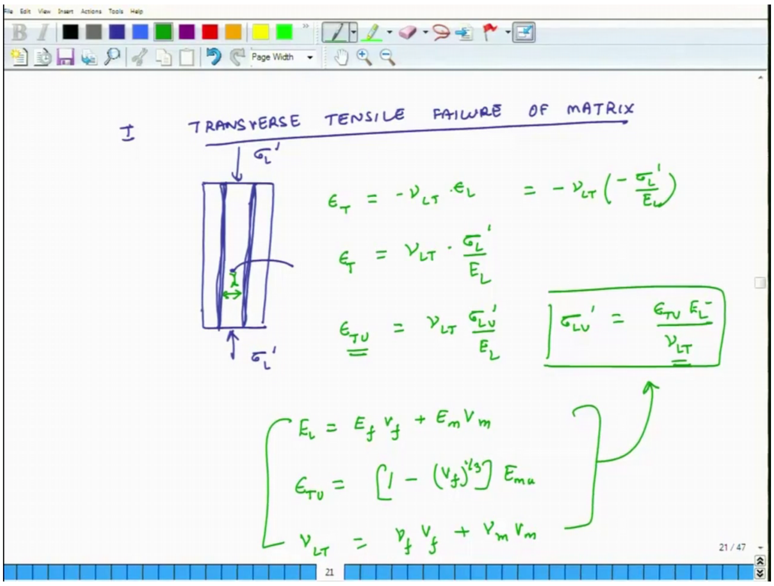

So, the first one is so first failure mode is transverse tensile failure of matrix. So, what is happening let us draw a simple picture and hopefully that will help you understand. So, this is my composite let us say this is one fiber and I am blowing it. So, it is a thick fiber this is another fiber and I am compressing it like this.

So, my external stress is sigma l prime and as I am doing this one possible so, as I am compressing it the matrix will experience what it will experience of course, the tensile strain, but it will also try to expand it will also try to expand due to the Poisson's effect right. So, the matrix is trying to do this and also of course, it is also trying to get compressed, but because it is trying to get compressed it is also trying to expand it is also trying to expand.

So, it will experience a transverse strain. So, what will be the transverse strain in matrix it epsilon T is equal to minus nu T L times epsilon L right and what is epsilon L? This will be equal to minus nu L T times negative of sigma L prime divided by E L. Why is sigma L l prime negative because it is compressive in nature? So, the transverse strain will be nu L T time's sigma L prime by E L.

Now, as I keep on increasing my load sigma L prime will keep on increasing and as a consequence epsilon t will also keep on increasing till it reaches a failure point. So, if the matrix gets stressed beyond a certain limit it will crack it will crack and when it cracks what is the strain in it the strain in it I can designate it as sigma T U, ultimate tensile strain in the matrix, sigma T U not sigma epsilon T U in the transverse direction and this is equal to nu L T and the corresponding failure stress is sigma L U prime divided by E L.

So, this is a material property of the matrix epsilon T u. So, from this I can calculate the value of sigma L U. So, sigma l U prime equal's epsilon t U times E l divided by nu l t this is what it is.

So, this is how I can compute this? Now I know what is E L E L I can go so what is E L? E L is E f V f plus E m V m. We have computed this right. So, we know how to calculate E L and then epsilon T U we have developed in relation for this earlier, it is know what one minus V f to the power of one by 3 times E m u, we have done this and we can also compute this thing.

So, nu L T is equal to nu f V f plus nu m V m. So, we can put all this information in this relation and compute the failure strain a failure stress. Now this calculation is valid only if the failure mode is such that the matrix starts cracking that is the first thing, which happens to the system and the fibers are not buckling at that point of time.

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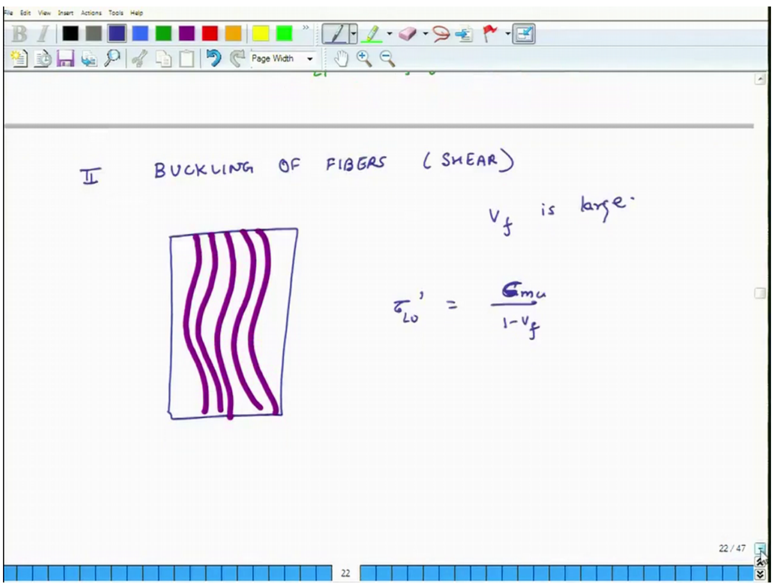

The second scenario could be buckling of fibers this is a special name for this type of buckling we call it shear buckling.

Shear buckling. So, when will this happen. So, consider the case when you have. So, this happens when volume fraction is large. So, suppose you have a fiber when the volume fraction is large let us say this fiber buckles like this. And when volume fraction is large the next fiber to it is very close to it. So, the next fiber will also buckle like this it cannot buckle in the other direction, because the space available you know available for it to buckle is very limited it can only deform the matrix.

So, this is shear buckling the pattern of buckling of all the fibers is something similar. And in this case I am not going to there is an empirical relation that sigma L U prime is nothing, but G m over 1 minus V f, this is actually sigma m over 1 minues E f sigma m u.

So, this is shear buckling this is the case when V f is large where if one fiber bends in one direction all other fibers will bend in the same direction, but then if suppose the number of fibers in the system is very small.

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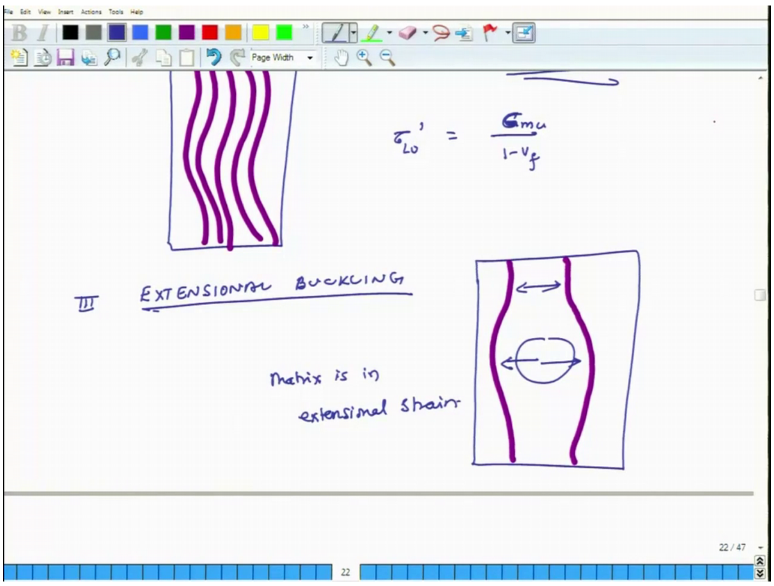

Then we have a third mode of failure where we have extensional buckling extensional buckling, what happens here? You have let us say this is your original composite and you have several fibers and the point is that these fibers are far apart, because the fiber volume fraction. So, if V f is small then what will happen suppose this fiber bends like this there is no reason the next fiber may be far from it.

So, it can bend like this it does not have to bend in the same direction, because the next it is distance is far. So, this type of pattern emerges this type of pattern emerges. And in this case what happens is that the stresses in the matrix. So, this is the matrix the stresses are in extensional direction, either the matrix is in compression in some locations at other locations it is in tension here the matrix is not in tension or compression, but it is shearing.

So, that is why we call it shear buckling here it is in. So, here matrix is in extensional strain and the fourth case could be shear failure.

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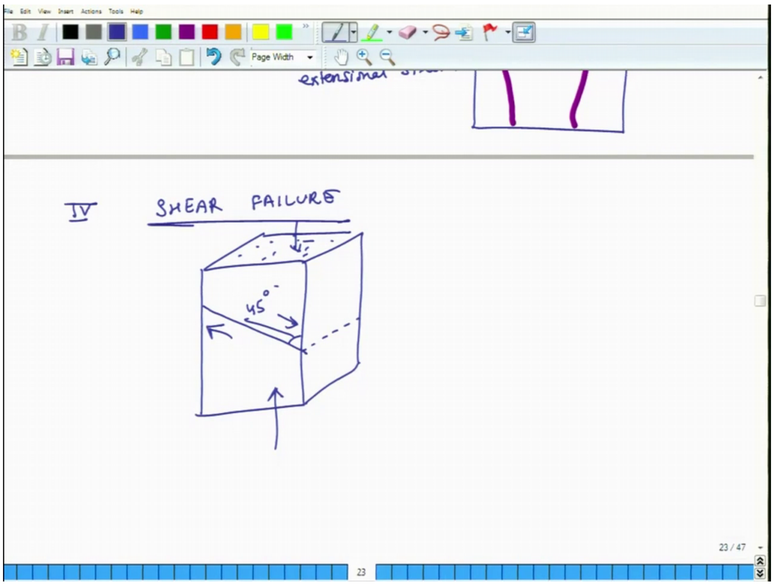

So, what happens here? You have the composite and these are all the fibers I am applying a force like this and there is a failure along a particular plane like this. So, this slides in this direction. So, this is a shear failure typically this angle is 45 degrees.

So, these are 4 important modes of failure when a unidirectional composite is loaded in longitudinal compression. So, we will continue this discussion tomorrow also and we will discuss 3 other scenarios and then we will move on to a different topic, but this discussion is important.

So, that you become aware of the physical phenomena which is happening when composites fail. So, that concludes our discussion for today tomorrow we will continue our discussion till then have a great day bye.