Introduction to Composites
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Lecture – 30
Failure Modes of Unidirectional Composite

Hello. Welcome to introduction to composites. Today is the last day of the fifth week of this particular course and we have started discussing the behavior of unidirectional composites when they are subjected to tensile loads. And so far; what we have discussed till so far discussed is; how can we predict the Young's modulus of unidirectional lamina or a laminate for that sake, when it is subjected to load in the L direction that is the longitudinal direction in tension.

Today, we will start discussing how these composites that is unidirectional laminates fail when they are subjected to tensile loads and before we start developing formula or formulae for their failure, we have to understand the failure behavior of different types of matrix materials and different types of fibers because unless we understand; how individual constituents fail, we will not be able to figure out how the composite fails.

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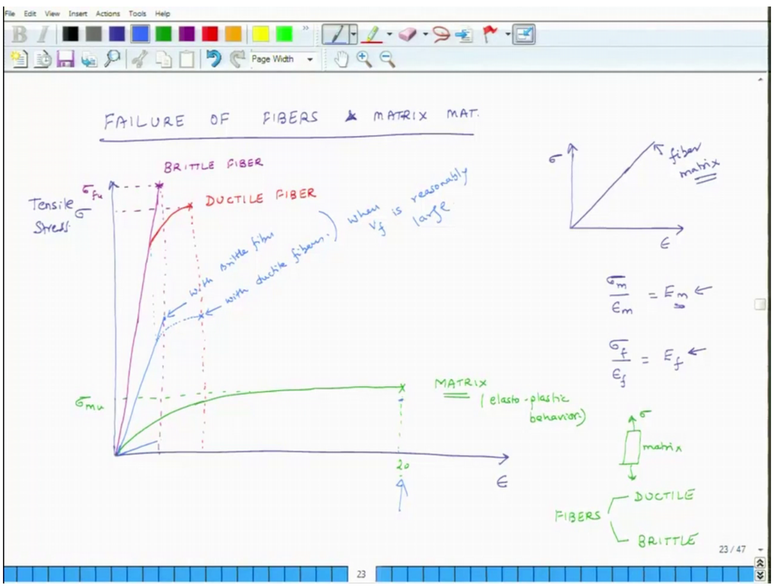

So, let us look at failure of fibers and matrix materials and we will understand this by developing a graph; through a graph. So, on the x axis, we are going to plot the strain and on the y axis, we are going to apply going to plot stress and specifically, it is tensile stress; tensile stress till so far, we have assumed that the fiber is always linearly elastic till so far, we have assumed that fiber as well as the matrix is linearly elastic; what does that mean what; that means, is that if I have the fiber and if I pull it and I plot its stress strain curve, the stress and the strain in the fiber is represented by a straight line.

So, this is the type of behavior we have assumed till so far when we were developing relations between for the Young's modulus E L. This is the type of behavior we assumed for both fiber and matrix, where did we assume this type of behavior? Remember at one point, we said that sigma m over epsilon m is equal to E m this is something we wrote when we were developing the relation for E L. Similarly, we also wrote sigma f over epsilon f equals E f.

Now, particularly for the matrix this particular relation may not be that accurate in general for a lot of fibers this may be somewhat accurate, but it is certainly not accurate for most matrix materials. So, how does an actual matrix material behave? So, let us see it. So, if I have a matrix material and I keep on applying some stress to it. So, if I have just a pure matrix material and I apply a stress sigma and I plot the strain stress; strain curve, it looks something like this. So, it keeps on. So, what happens is that as I increase the stress strain increases, initially it increases somewhat linearly and then it starts increases, it starts increasing very rapidly and then it becomes flat and then after a certain point it the matrix breaks.

So, this x represents the point where the matrix breaks. So, this is the stress strain curve for matrix. This is the stress strain curve for matrix and this type of stress strain curve is shows that the matrix is initially somewhat elastic and then later it exhibits plasticity. So, it has a elastoplastic behavior. So, what does that mean that if at some point after it has caused the point of its elastic limit, if I pull it; it may not get back to its original configuration; completely this is how matrix materials behave.

Typically the strains at which matrix materials fail can be a 20 percent or sometimes several 100 percent. So, I just wanted to give you a perspective, but it is certainly not 1 percent, 2 percent, 3 percent and 4 percent. They do not fail at 2, 3, 4, percent, they fail at 20, 30, 40, 100, 200 percent range.

If it is a thermoplastic material, it will take a lot of strain because it keeps on getting stressed and in some cases it may even go up to seventy eighty percent if it is a thermoset may be that failure strain may be less, but it will still be fairly large. So, this is how matrix materials behave.

The next thing we have to see is how do fibers behave now fibers come in 2 varieties the first category of fibers are ductile and the other category is brittle an example of brittle fiber would be a glass fiber. So, you pull it. It keeps on getting stretched and this stress strain relation as it keeps on getting stressed is elastic and all of a sudden at certain strain level it cracks and it fails. So, a brittle fiber would fail would behave something like this. So, this is a brittle fiber now you see a typically a brittle fibers failure strain is significantly less than that of matrix.

So, lot of times these fibers may fail at 2, 3, 4 percent. There is a significantly less value. So, this would be the case of brittle fiber would be the case of say graphite or.

Student: Glass.

Glass fiber, but then there are fibers which are not brittle they are ductile and how do they behave initially they behave same as brittle fibers and so, you keep on pulling them and they exhibit elastic deformation.

But after a certain threshold they start becoming plastic. So, the slope starts reducing and then after a certain value of strain they also break. So, that is how ductile fibers behave examples of ductile fibers may be Kevlar may be some metallic fibers and things like that. So, let us look at the stress strain response for a ductile fiber they behave the same as the brittle fibers, but after certain point of time they have a different path and they may fail at some other value.

So, this is how a ductile fiber fails, but in case of ductile fiber also the failure strain of fiber is much more much less than that of matrix. So, 2 3 important observations for brittle fibers ductile fabrics matrix matrices fail at very small amounts of stresses the breaking strain of matrix is extremely small you see that it is extremely small.

So, let us call this sigma m u ultimate tensile strength of a matrix material the tensile strength of a ductile fiber or a brittle fiber it is significantly higher several orders of at least in order of magnitude higher in contrast the tens failure strain of matrix is significantly higher than that of fibers. So, fibers fail at very high stress levels, but low strains matrix fails at very high strain levels, but at low stress levels this is important to understand.

Now, what happens to a composite? So, this is; first I will just plot a graph and may be later, we will start discussing the mathematics of how composite fail. So, suppose you have a composite which has a moderate amount of a fiber let us say 50 percent, what will it do how it fails will depend on whether it has a brittle fiber or a ductile fiber. So, if it has a brittle; brittle fiber. So, what happens? Initially, the composite if it has a brittle fiber once the fiber experiences this strain till we have reached this point the stress in the fiber the stress in the matrix and the stress in the composite they are all the same. So, the stress in the composite has reached this threshold value.

Student: stress strain.

Strain same, strains in fiber matrix and composites they are all the same and once the strain in the fiber reaches this threshold value the fiber is brittle and it cannot exceed this threshold value. So, the fiber fails and we know that fibers in general carry most of the load of the system.

So, suppose I apply 20,000 Newton's in the overall system may be 1000 Newton's is being handled by the matrix, 19,000 Newton's is being handled by the fiber. So, and now the fiber has filled. So, where does that 19,000 go, it get shifted to matrix, but the matrix cannot take a lot of stress. So, the whole system fails at this point and this is something we will mathematically understand in detail later. So, this is with brittle fibers.

So, this is something we are trying to have a qualitative understanding and then we will have a quantitative understanding of the situation. Now, suppose the fiber was ductile, then what will it do? It will start at this strain level, it will start deforming right and the composite will start taking less load and once the strain in the fiber reaches this level which corresponds to the failure strain in the ductile fiber the fiber fails and that entire load gets transferred to the matrix and the matrix does not have the capacity to take all that load. So, that entire thing fails catastrophically. So, this is with ductile fibers.

So, this is when V f is reasonably large when V f is reasonably large and what is the definition of this reasonably large this is something we will understand later how can we compute what is reasonably large what is reasonably small there could be another situation when the volume fraction of fibers is extremely small when it is extremely small consider a case when you have a matrix and let us say you have only 1 or 2 fibers.

Now the cross section of these fibers is very small. So, they; in this case, they are taking almost negligible load, right. So, suppose I have applied total of 500 Newton’s of load on the composite may be they are taking only 0.1 Newton’s because it is just one single fiber this is an extreme absurd example, but it will help you understand.

So, I have just total load on the composite is 500 in that composite, I have just one single fiber and may be that takes only 0.1 Newton’s of load. Now if I keep on stretching fi matrix or the composite, the fiber will break after a certain strain whether it is ductile or the or brittle, but once it breaks it is at that point it is only taking 0.1 Newton’s.

So, that 0.1 Newton gets shifted to the matrix and the matrix it; this is not a lot of shift of the load. So, matrix can still handle this extra 0.1 Newton of load. So, now, I can still keep on stretching it further and once I reach a certain threshold when the matrix has to fail that is which corresponds to this strain value, then at that strain the matrix will fail. So, this is with when V f is reasonably large, but when V f is very small, then this failure may happen somewhere at a lesser load somewhere here for a smaller values of this thing.

Or actually it will be some this failure curve will be or this stress strain curve will be fairly close to the green curve actually. So, this curve may not be true, but it will be yeah. So, this is the overall phenomena which is happening in the system and with this understanding, we will now develop a model for the failure of fibers and matrix and the overall composite when the composite is subjected to tensile loads and this is specific to unidirectional composites.

So, we will conclude we will stop this discussion today now that we have qualitative understanding of this failure mechanism, we will continue the discussion and close this discussion on failure of unidirectional composites subjected to tension in that next class which starts next week.

Thank you very much, bye.