Introduction to Composites
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Lecture – 04
Why are Fibers so Strong?

Hello welcome to introduction to composites today is the 4th day of this inaugural week of this course. And yesterday we had closed our discussion with the point that we were wondering as to why fibers are having better properties than bulk material that is if I take a piece of glass sheet, and I cut a portion of it and I do a tensile test on it.

It may fail at some party stress level, but if I take very thin glass fiber and I do a tensile test on this glass fiber then I will find that the tensile strength of the glass fiber is significantly higher, than that of the tensile strength of glass which is available in common stores and market. So, and this is something we see consistently for different materials. So, you take a piece of steel fiber very thin steel fiber and compare its strength with the strength of a regular piece of steel you will see the same distinction.

So, that is an important question. So, let us just look at some of the numbers which will give us an idea as to what we are talking about. So, we will look at the strength of fibers and their respective bulk materials.

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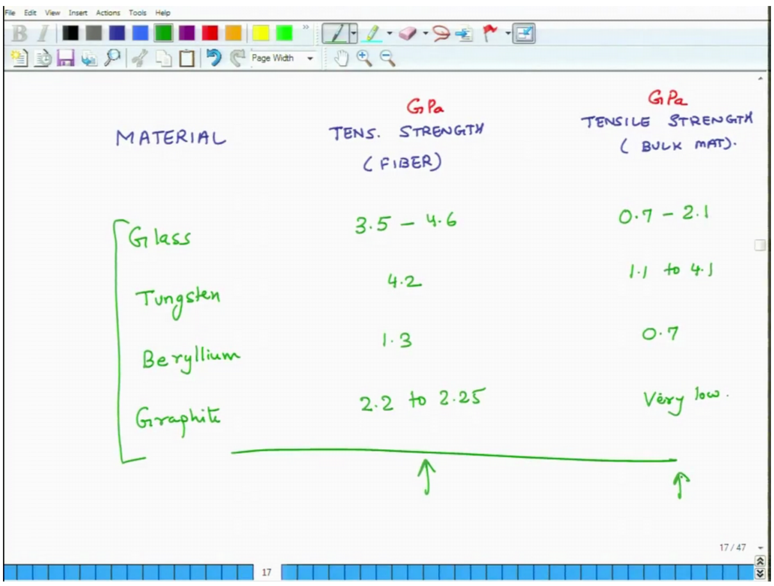

So, let us look at this table. So, we have three columns, so, the first column is for material then the tensile strength and here we are going to write down the tensile strength of the fiber. And then let us look at the tensile strength, and here it is of bulk material and both these tensile strengths what are the units the units would be let us say gigapascals so GPa.

So, let us look at several materials a very common material is glass whose fibers are very easily available in the market. So, if you look at the bulk material strength its strength is anywhere between 0.7 GPa to 2.1 GPa. So, 700 mega pascals to 2100 megapascals, but if you look at the tensile strength of individual fibers you will see that this number is significantly higher 3.5 to 4.6.

So, significantly increase in the strength of the fiber. Let us look at another material tungsten, so the first example which we discussed was glass nonmetal now let us look at metal fibers. So, the bulk material strength is anywhere between 1.1 GPa to 4.1 GPa. So, I will write it clearly 1.1, but the bulk material is 4.2. So, it does not have a lot of variation and it is much on the higher side another fiber, we will consider is beryllium B e or let us the whole thing tensile strength of bulk material is 700 mega pascals or 0.7 GPa tensile strength of the fiber is 1.3 GPa.

And lastly we look at a non metallic fiber graphite fiber and the tensile strength of graphite fiber is very low its. So, very low means it is several orders of magnitude. So, it is not even in GPa range or MPA range it will be very low so, I will just write it very low for instance, if you take a piece of pure coal pure coal anthracite coal which is almost 99 plus percent coal and you pull it will break it does not require a lot of strength effort to break it.

But if you take a graphite fiber and you measure it is a strength it is extremely high 2.2 to 2.25 gigapascals. So, this is what I was talking about in the last class that why is it that fibers if you take the fiber strength it is high, but if you take the strength of the bulk material it is not that high, and when composites we actually exploit this extra strength of fibers. Because we do not use bulk materials rather we have use fibers to build composites so, that way we make things stronger. So, the question is why is it that these fibers are stronger and bulk material is not and the answer to that lies in the structure of materials.

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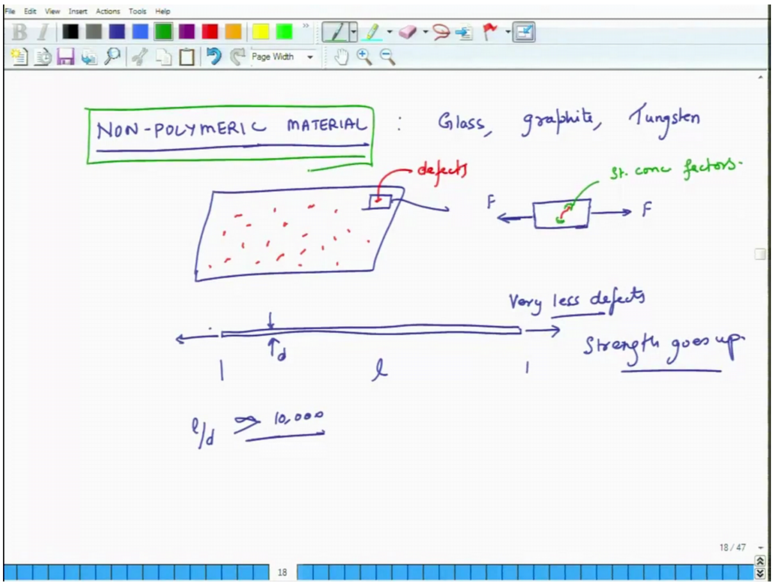

So, we will consider two types of materials the first is non polymeric materials, non polymeric materials examples would be glass graphite, we also saw the example of tungsten and so on and so forth. Now if you look at the bulk material and you make a cross section of it and you look at it very closely what you will find is that in the bulk material there are very small flaws defects.

These defects could be anything so, these are all defects. So, these red things are defects and if I zoom in this much small area then what do I see I will see. So, this is a zoomed in version I will see it defect something like this. And now if I pull this material in this direction, so I apply a force f it because of the presence of defect what you will have a stress concentration factors at the ends of defects a stress will be accumulated will get accumulated there. So, these are zones of a stress concentration factors.

So, you apply a force F and the cross sectional area of your sample is a then the average stress is F over a, but the stresses are extremely high at around the defects around the defects. So, this material fails at a much lesser stress, but in a fiber the wave fibers are made they are they are very long something like this. And they have very little defects less number of defects. So, in the along the length of the fiber, there are hardly any defects because that is the process through which they are made this is the by virtue of the process through which they are made they are very less number of defects in the fiber.

So, it is like a perfect material and because of this, so it has very less defects. So, if you take this kind of a sample from here you may see the chance of finding a crack will be less and as a consequence of this their strength goes up the strength goes up. So, what do I mean by fiber, the by fiber I mean a geometry whose length. So, let us say this length and this is diameter. So, l by d ratio is more than maybe 10000, it has to be more than thousands first sure. So, that is why the strength for these type of materials goes up. So, this is about non polymeric materials.

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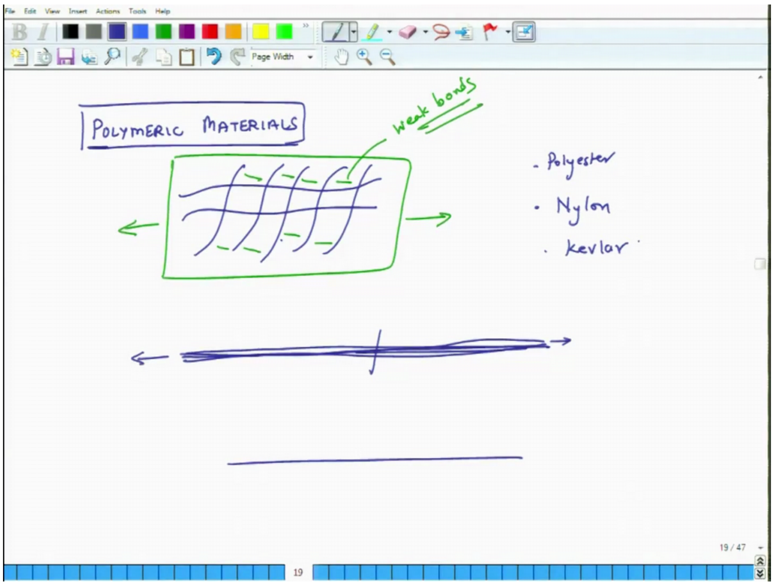

Now we will consider another class of materials, and we call them polymeric materials. So, what are polymers they are basically chains the chains of monomers. So, monomer is a building block for organic materials and if these building blocks are tied together in a long line in one directional thing then it becomes a polymer. So, polymeric materials if you look at a polymeric material it may have all sorts of chains. So, these are all chains. So, along the length of the chain the monomers are connected, and these chains are attached to each other through some very weak forces wander wall forces, and some other weak forces.

So, the connection between the chain is weak the so, this is the overall material and it is made up of a crisscross of a lot of chains. And these chains are connected to each other through weak where weak forces, weak inter forces which join different chains to each other. So, that is how the polymeric material is there in bulk situation. So, if I have to if I pull it the bonds between chains it is not difficult to break them because these bonds are weak bonds these are weak bonds.

So, it is very easy to break them, but if I take a fiber polymeric fiber in reality, and I pull it in this direction a polymeric fiber is essentially a long chain of the molecules or maybe several chains which are aligned in one direction they are not in crisscross direction so they are like this. So, if I have to break this I have to actually break the chains I have to break the chains I do not have to break just the bonds and what; that means, is that if I have to break it I have to break the chains, and the bond within the chain is much significantly higher than these weak bonds so, it is much more harder to break again fibers of polymeric materials compared to the bulk material.

So, we have looked at both the materials polymeric materials and non polymeric materials, example of polymeric material will be polyester you go to market and you buy polyester cloth, what does it made up of it is made up of polyester fibers and it is not easy to if you just take a piece of polyester fiber, and try to pull it and you take a piece of.

So, the stress required to break it is how much higher, than if you take a piece of polyester plastic from the market and try to break it. So, that is one example another example would be nylon Kevlar and so on and so forth. So, this is the reason why the strength of fibers both for polymeric as well as non polymeric materials is much higher than the strength of the same materials in bulk form. Next what we will do is we will look at and compare advantages and drawbacks of different composites.

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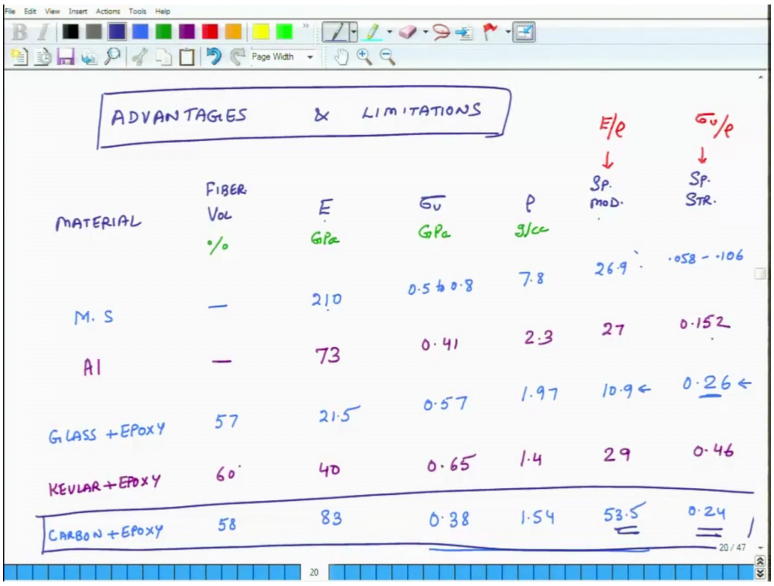

So, we will look at advantages and limitations of composites composite materials what are some of the important advantages and limitations of composite materials, and before that I will like to make a small table for you so, what I am going to do is in this table we will look at, we will have several columns. So, the first column is material the 2nd column is volume of fiber.

So, fiber volume in percent the 3rd column would be young's modulus e or in GPa units, the 4th column would be tensile strength sigma u, the 5th column would be of density, the 6th column would be a specific modulus. And I will explain what it means and the seventh column would be a specific strength. So, what do I mean by specific modulus by a specific modulus I imply E over rho and by specific strength I imply tensile strength sigma over density.

So, this is how I find a specific modulus and let us write down the units of these this is in percent this is GPa this is MPa this is let us say grams per cubic centimeters, and this is what ah this is MPa this is the ratio of E and rho. So, that is there so let us look at some materials. So, the first material is mild steel M S mild steel.

Now this is not having any fibers. So, we are not going to worry about the fraction of fibers in the material its modulus is about 200 and 10 GPa it is strength depends on what type of steel we are using it can be anywhere between 500 actually I am going to change the units of this it this is a let us also just to be consistent we will still have this as GPa.

So, this is anywhere between 0.5 to 0.8 the density of steel is does not matter what steel we are talking about its about 7.8 grams per cc. So, the a specific modulus if you take the ratio of 210 divided by 7.8 you get 26.9 and the specific strength is anywhere between 0.058 2.106.

So, that is for mild steel, now what do what does a specific modulus mean physically it means to produce same amount of stiffness see this E is related to stiffness. We talked about it couple of lectures back and strength relates to the ultimate tensile strength of the material. So, to produce same amount of strength here I have to use a heavier material 7.8 is the density. So, this gives us an idea that to produce if this number is higher if this number is higher what it means that for less amount of weight I can produce same amount of stiffness.

Specific strengths gives us an idea if the specific strength of a material is high it means, that to produce to have same strength, I need less mass of material and specific modulus gives us an idea that to produce same stiffness I need do I need a lot of material or do I need a less amount of material in terms of its mass. So, this is one now let us look at another metal. So, mild steel is a metal let us look at aluminum.

So, aluminum is again no volume fraction modulus is about 78 GPa, actually the 1 which I am using is a different alloy so, it is slightly less 73 GPa it is strength is about 0.41 mega pascals density is 1 3rd of steel. So, look at this between mild steel and aluminum E is of by a factor of 370 times 3 is 200 and 10 and density is also about of by a factor of 3 it is of by a factor of 3. So, when you compute its specific modulus it comes to pretty much the same 27. So, if you use an aluminum structure which has exactly the same geometry, and make another structure from steel and that let us also say it has exactly the same geometry, then the ratio of stiffness of the aluminum structure to its mass will be same as the ratio of mild steel structure to its mass.

And the specific strength is 0152 so, this is higher it is much higher than that of steel. So, if you want to make a structure light without and also maintain its strength maybe aluminum is the thing to go, if you want to have let us say same strength, but you want to reduce the mass because it is a specific strength is less. Now let us look at three composites. So, the first composite is glass plus epoxy. So, epoxy is the matrix and you would wonder where do I get these numbers you will learn later how to compute these numbers, but today we are just going to discuss these numbers glass epoxy, and here this is have this composite is having 57 percent of glass. The modulus of this is 21.5 it is strength is 0.57 its density is even lesser than that of aluminum.

So, it is 1.97 slightly this not whole lot it is specific modulus is 10.9 and its specific strength is 0.26. So, what does this show they have to produce same strength you need less heavy structure made from glass plus epoxy composite, because this number is 0.26 if you see it for steel its 0.58, and if you look at aluminum its point one five two. So, in terms of providing more strength for the same amount of mass this is advantageous, but it is not that advantageous if you are targeting for stiffness.

Because the stiffness is specific stiffness here is less than that for steel or for that for aluminum let us looks at some other composites. So, this is having Kevlar fibers plus epoxy. So, Kevlar plus epoxy and here the volume fraction of fiber is 60 percent the modulus is 40 sigma u is 0.65 density is even less or lesser 1.4, and a specific modulus goes up it exceeds that of steel or aluminum by some amount and what you really get a lot of benefit is on the specific strength side 0.46. And then finally, we can look at a 3rd type of composite it is having carbon fibers plus epoxy, and its having about 58 percent of fiber the young's modulus or the modulus of this is even higher 83 GPa.

So, you can guess its E over rho that is specific modulus will go up significantly high its strength is 0.38 density is pretty low, 1.54 and when you look at its a pacific modulus it goes up really high it is 53.5. So, it is almost 2 times that of steel or aluminum for that sake and if you look at its a specific strength it is 0.24. And if you look at this table it is for this reason so, if you look at carbon epoxy composite for the same amount of mass it gives you a lot of stiffness and it also gives you a lot of strength.

And that is one reason 1 very strong reason that in aircrafts where you want to reduce the mass, without reducing the stiffness of the structure or without reducing the strength of the structure people use a lot of times carbon plus epoxy type of composites for this reason. They do not use Kevlar to that extent Kevlar has other important applications, but carbon epoxy composite its really popular in applications where you need to reduce the mass without necessarily compromising on stiffness and strength. So, this is an overview I wanted to give you we will continue this discussion on advantages and limitations of composites in the next class. Until then have a great day and we will meet once again tomorrow.

Thank you.