Introduction to Composites
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Lecture – 11
Ceramic Fibers

Hello, welcome to introduction to composites. Today is the fifth day of this particular week. And yesterday we just finished discussing boron fibers. Today, we will continue our discussion on fibers at least in this lecture. And we will discuss two different categories of fibers today; the first category is ceramics and the other one is HPPE high performance polyethylene fibers; and both of these fibers are very interesting in their attributes. So, we have discussed glass, graphite, boron, Kevlar or aramid fibers and move all these fibers belong to different categories. Now, we are talking about ceramic fibers.

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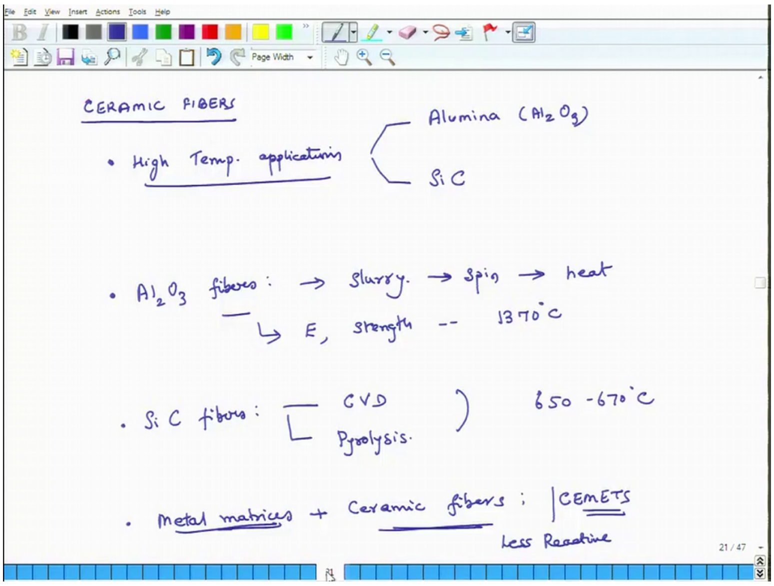

And typically these ceramic fibers, they are used in high temperature applications because the nature of ceramic material is that it can take a very large amount of heat without getting burnt or distorted or without getting chemically degraded. So, a very important application of ceramic fibers is high temperature high temperature applications and that is because they have high strength, high modulus at even elevated temperatures. So, you can raise the temperature in case of silicon carbide fibers, these are ceramic fibers even up to 600, 700 degrees centigrade and the properties do not change or in case of alumina fibers Al 2 O 3 you can go even up to thirteen or fourteen hundred degrees centigrade and still the properties will not change.

So, common examples of these fibers to vary examples are fibers made from alumina and then fibers made from silicon carbide. So, this is Al 2 O 3. So, very quickly how are alumina fibers made Al 2 O 3 fibers. So, you have aluminum oxide and from that you make a slurry. So, you mix it with the water and you make a paste; and through that paste you make a slurry and then you spin it. You spin it, and then you start getting fibrous shapes. And while you are spinning it into fibrous shapes, you also heat it. And you heat it and then you get these fibers. And these alumina fibers have shown it has been shown that they can retain their mechanical properties that is young's modulus, the strength etcetera as high as 1370 degrees centigrade. So, this is about alumina fibers.

About silicon carbide fibers, so what do you do either these are made from CVD process which is chemical vapour deposition or they are made from the process known as pyrolysis and we have discussed this earlier. And these fibers they can retain their strengths up to 650 to 670 degrees centigrade, where do you use these. So, I have already said that you use them in high temperature applications, but what kind of applications are there. So, here the fiber is ceramic, but the matrix if the matrix is it starts degrading at low temperatures then there is no point in using these things. So, you want also a matrix to withstand high temperatures.

So, they are typically used in metal matrices, metal matrices plus ceramic fibers. And these types of composites we had earlier mentioned they are known as CEMETS CEMETS earlier yesterday we had discussed boron fibers and boron fiber and a problem with boron is that it tends to react with metal very vigorously, so that can create some problems because of reactivity, but if you embed ceramic fibers ceramics are very inert materials. So, if you embed them in metal matrices there is not a whole lot of reaction between metal matrix and the ceramic. So, chemically they are much more stable they are less reactive. And also they are less reactive and they are high resistance to high temperatures.

So, some applications I had mentioned that CEMETS are used in cutting tools, where you want to cut metals which are very hard you can use these types of composites or in aircraft blades, these blades run at extremely high rpms and they experience sometimes very high temperatures. And you want to make sure that at these high temperatures they do not wear outs soon, they are strong, they are stable. So, in engine aircraft engine blades, turbine blades, these are typical applications of these fibers. So, this is about ceramic fibers.

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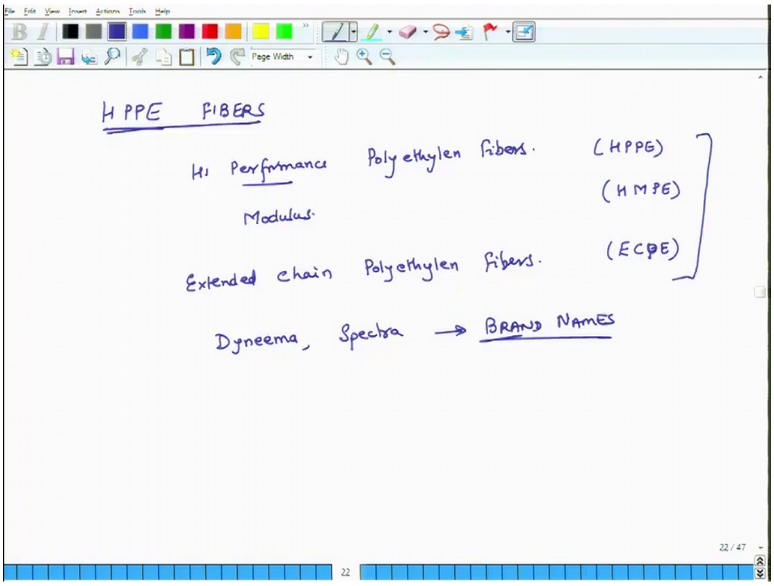

The other class of fibers is called HPPE fibers HPPE fibers. So, what are HPPE? This is high performance polyethylene fibers. Now, these are very interesting fiber and they have some very neat applications, but before that they come in different names. So, this is HPPE; sometimes we also call them HMPE. So, what is M, M stands for instead of performance here we have modulus, high modulus. And another name for them is ECPE. So, these are all common names, it is useful to know that. What is ECPE - extended chain polyethylene fibers. So, let us ECPE, but all of these three four names they mean essentially the same. In markets some of the brand names which are known are Dyneema, spectra. So, you say I need spectra fiber that will imply one of the HPPE fiber, but these are brand names. Let us look at some of their special attributes properties.

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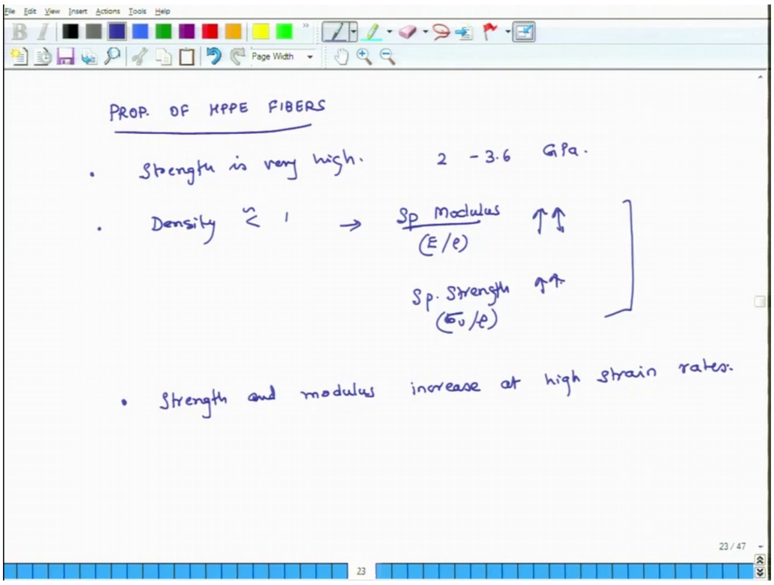

So, we will look at actual numbers later, but let us look at some of their attributes. A typical plastic, a typical plastic for instance ABS plastic or polyester, if you pull its strength will not exceed maybe 10s of MPs, some super good plastic maybe 100, 200 MPa. But these HPPE fibers they are strength is very high and what do we mean by high it could be anywhere from 2 to 2.6 GPa - gigapascals. They are stronger than regular steel. So, these are made of plastic, but they are stronger than steel stronger than steel, steel some of the best steel may break at about 1 GPa these are stronger than steel fiber. So, this is something similar to the fibers which are made by spiders, they are also very strong they are also very strong, they are also stronger than steel. So, these are fibers of that type.

Second thing density is slightly less than 1. So, they are slightly so less than slightly less than 1. So, they are slightly less than lighter than water, slightly lighter than water. What that means is that their specific modulus so what is the specific modulus it is the ratio of e and density. This is very high. So, for less weight, you can get a lot of stiffness, and similarly their specific strength this is also very high. So, this is sigma u over density. So, you can use these fibers to make things super light without making them weak or without making them flexible. So, these are very special applications.

Third thing and this is really where is the important thing to understand their strength and modulus strength and modulus, they increase at high strain rates. So, what does that mean and that is something I will explain it to you, but this is important and very interesting to understand.

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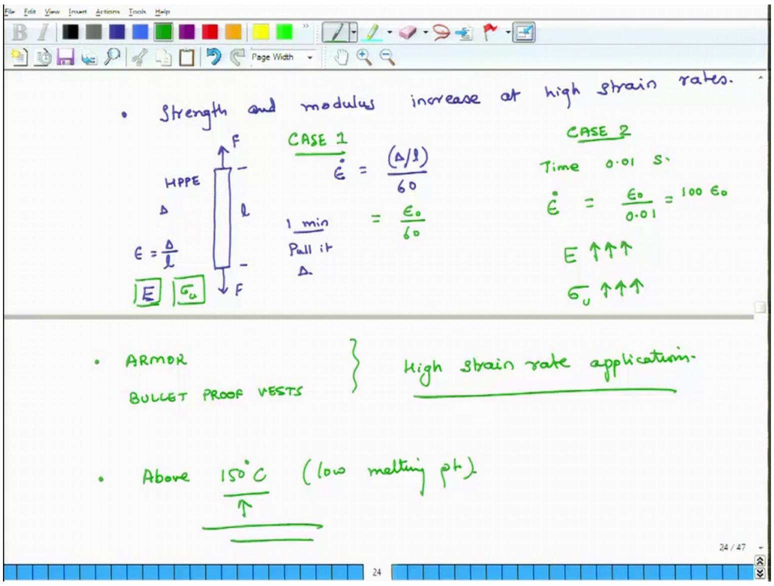

So, if I have a piece of material made up of HPPE, so this is made up of HPPE, and I pull it. And when I pull it, it will experience some elongation. So, let us say the elongation is delta, and the length is l, then what is the strain in this thing. The strain will be in the length direction it will be delta over l and let us say its modulus is some number E in the length direction in the length there, let us say its modulus is E. So, let us say that when I pull it I pull it very slowly maybe over so in 1 minute I pull it by delta in 1 minute I pull it by delta. So, what is the strain rate, a strain rate the strain rate will be what, delta over l is the total strain and I have pulled it 1 over 60 seconds that is 60 that is a strain rate . So, this is case one.

So, in this case, a strain rate is this epsilon naught divided by 60 - case two. So, when I pull it at in 60 seconds in that situation the modulus is E and also the strength is let us say sigma u when I am pulling it over 60 seconds. So, I am pulling it very slowly in the second case let us say I pull it. So, in the second case, let us say time is 0.01 seconds . So, what will be the value of strain rate, a strain rate will be epsilon lot which is delta over l divided by 0.01, so that is equal to 100 times epsilon naught. So, a strain rate has gone up significantly, it has gone up how much it has gone up by a factor of 100 times 60 right 6000 times, I have increased the strain rate 6000 times.

And in this experiment if I measure the young's modulus, I will find that the young's modulus in this case is extremely high. And also its strength if I apply strains very fast this HPPE material does not break at the same value when the strain rate was low. So, its modulus and its strength increases very significantly at high strain rates; at low strain rate it will have some value; at high strain rates, it increases very significantly.

Now, with this a special feature of HPPE, it is for this reason a lot of times these fibers are used to make armor, bulletproof vests, so you use the even Kevlar for this type of application, Kevlar also can take a lot of energy, but these guys are very light compared to Kevlar because its density is lighter. So, they are even more efficient. So, wherever, so in bullet what happens when bullet comes you have to stop it in very small time and in that case the strain rate has to be is very large because when bullet comes it goes into it at a very fast speed. So, a strain rates are extremely high, and the more is the strain rate is strength and modulus becomes even higher. So, these are very efficient materials for these kinds of high strain rate applications, and they have less density.

So, Kevlar is also good for high strain rate applications, but Kevlar density is how much we saw it earlier what is Kevlar density, it is about 1.4 or 1.5 these are lighter than Kevlar they are less than water. So, there is a, they are less than 1. So, for even lesser material you get similar type of benefits which Kevlar's gives you. So, for that reason these materials are very useful, but having said all this they have a weak point that they start becoming very soft above 150 degrees centigrade, so because they have low melting point. I do not remember whether this is the exact number, but at low temperatures at not very high temperatures, they start melting.

So, if the overall temperature of the system is very high or even moderately high we cannot use these types of fibers, but Kevlar you can use Kevlar you can go up to 500 degree centigrade. This guy may be around 100 degree centigrade it can work, but above that it will not work, but if at room temperature, you want some bulletproof vest or some high strain rate application, this will do just fine. So, this is about HPPE fibers. Now, we have discussed ceramic fibers and HPPE fibers.

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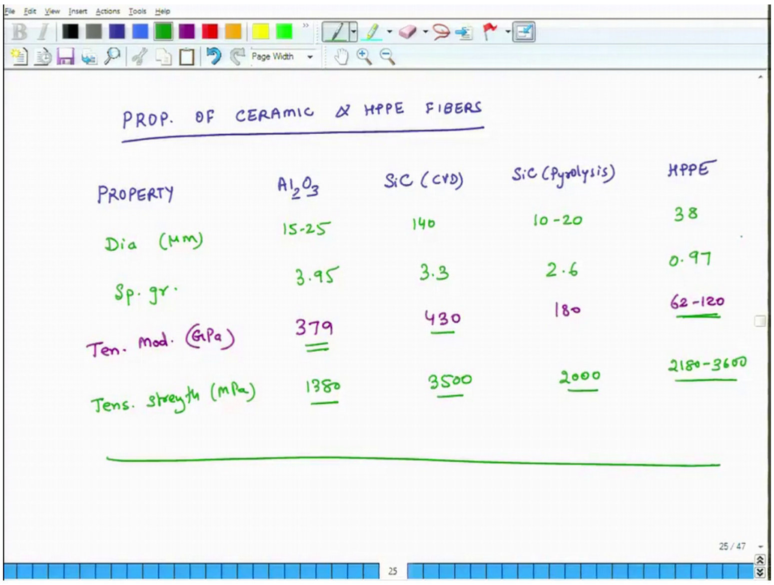

So, finally, what we will do today and we will close the discussion for today with that is we will actually look at some of the properties in terms of actual numbers. So, properties of ceramic and HPPE fibers, some properties it is important to look at properties, so that we appreciate some of the unique things about these materials. So, we will again construct a table property and let us look at different fibers. So, the first one is from alumina Al 2 O 3, second one is from silicon carbide fiber made through CVD process, third one is silicon carbide process made through pyrolysis process, and the fourth one is HPPE.

So, let us look at dia in micron micrometers or microns 15 to 25, 140 so silicon carbide fibers are fat they are thick, but if you make it through pyrolysis, you can make them really thin. So, 10 to 20, and this is about 38 - 40 microns. A specific gravity - 3.95, so these are heavy 3.3, 2.6, 0.97. And then you have tensile modulus GPa, so this is about 379, 430, 180, this is 62 to 120. And then let us look at strength, this is MPa, so 1380, 3500, 2000; and this is 2180 to 3600. So, this is the main thing.

So, if you divide this number by their respective densities, you see that the a specific of strength of HPPE is really very high, it is really very high. Even if you divide its tensile modulus is also pretty high compared to that of aluminum and silicon carbide fibers, because once you divide 120 by .097, you may get something like 130, but if you divide 379 by 4 you will have been less than 100. So, this is something important to understand.

And with this we close our discussion on fibers. And I hope what you have understood through all these discussions; and also through our tables which we have written slowly rather than just showing all data and saying that oh these are the values is that you would have somewhat good understanding of the world of different fibers used in composite materials, becoming all sorts of with all sorts of properties. And it is really upon you to figure out as to what your needs are what are the economic constraints you have and which particular fiber meets, your needs to the best possible situation.

So, with that we close our discussion and tomorrow which is the last day of this week. We will start a new topic and we will start a discussion on different matrix materials, which are used in different types of composites. So, till then have a good night, and we will meet once again tomorrow.

Thank you.