Introduction to Composites

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Lecture – 13
Polymers as Matrix Material and their Classification

Hello, welcome to introduction to composites. Today, we start the 3rd week of this course and we will be focusing heavily on description of different matrix materials and maybe later in the week we will start discussing some of the important ways through which composite materials are fabricated and manufactured. Now, in the last class we had just started laying out what types of matrix materials are there and what kind of functions does a matrix material perform and then we had also discussed that based on the temperature range of the application which the material is going to be subjected to, we have different classes of materials for used in matrices.

So, if the temperature range is low, if the maximum temperature application temperature is not is reasonable, then we go for polymer based matrice materials. If the temperature becomes higher, then we look for ceramics or metals and then if it is even higher, then we look for ceramics as matrix materials. So, today we will start discussing about polymers, their properties and what types of polymers exist and what are their application ranges in context of composite materials; where these polymers are used as matrix materials.

So, first let us look at some of the important features of these polymers as matrix materials.

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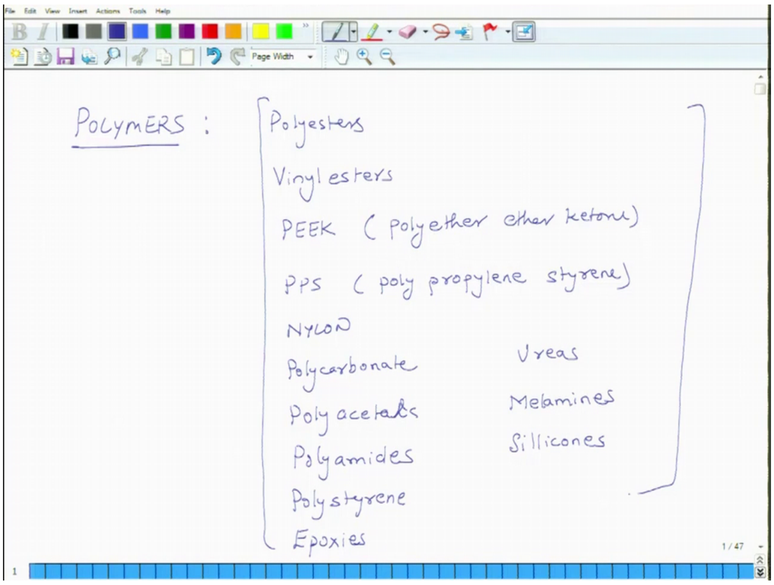

So, let us first write down what are some of the important materials; examples of materials. So, we have polyesters, then so these have esters, then we have vinyl esters, then there are materials known as peek, this is the short form for polyether ether ketone and we will learn more about some of these materials, then we have PPS, this is polypropylene styrene nylon and we have polycarbonate materials.

So, it is important to be familiar with at least the names, we do not have to be experts in each of these materials, but at least we should have be familiar that these are some of the names which are commonly used, then we have polymers which are used as matrix materials, known as poly acetates; poly acetals or actually acetals acetals, polyamides, polystyrene, we have epoxies, ureas, melamines, silicones. So, you see that there are of large number of now large categories, so large categories of polymers and it is a big wide range. Next, we look at some of the advantages and limitations if we use polymers as the matrix materials.

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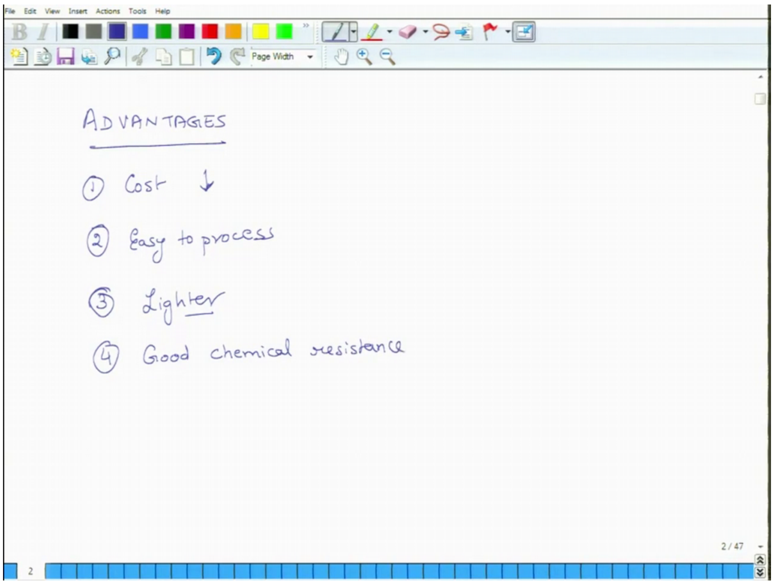

So, let us look at some of the important advantages. So, the first important advantage is cost. Compared to other matrix materials, which are metal based or ceramic based polymer based matrix materials are the least expensive, they are the least expensive, so this is an important advantage. Second thing is, again compared to ceramic and metal based matrix materials, it is they are these types of polymer based matrix materials are easy to process. So, cost is less, they are easy to process again easy is a relative term. Third thing is, the density of metal based matrices it is pretty high.

So, suppose you want to use aluminum as a matrix material density will be 2.78 specific gravity but a lot of these plastics, their densities are much less. So, they are in the range of 1, 1.5 somewhere in between 0.8 to 1.5 or something like that. So, they are lighter and what that means is that, if you use these types of matrix materials and mix them with fibers, the overall specific modulus and the specific I mean specific stiffness, specific strength of the overall composite will be less because their density is less.

Student: Specific strength.

I am sorry, specific strength and specific stiffness it will be high because the density is less.

Fourth advantage is that, these materials have good chemical resistance. So, they may be exposed to harsh environments, saline environment sometimes slightly acidic environment so on and so forth and they do not get degraded easily. So, these are some of the important advantages.

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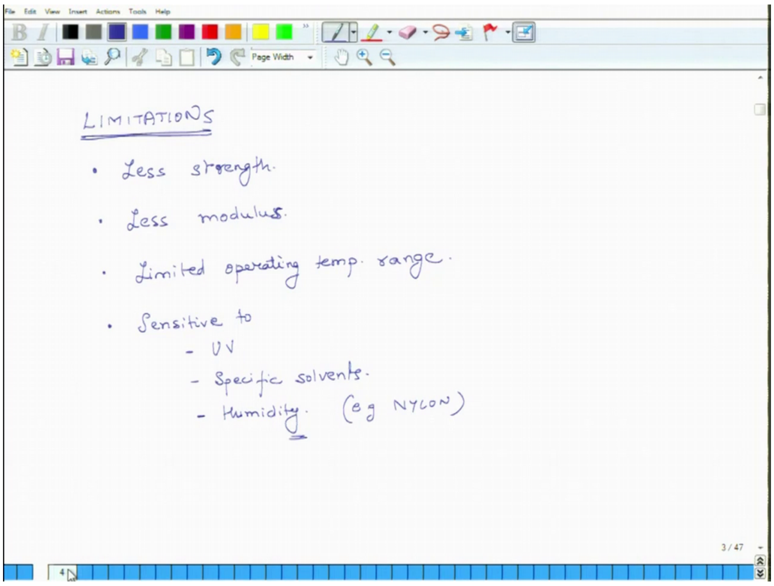

Now, let us look at some of the limitations. Now, again these are in general advantages of and limitations of the whole class of matrix material, which are based on polymers. Now, individuals may have more specific advantages and limitations, but overall we are looking at advantages and limitations.

So, compared to metals and ceramics if we use them as matrix materials these have less strength. So, we cannot rely on these materials to provide the strength to the composite, the thing they do is they can glue all the composites together, but they cannot provide a lot of strength to the composite, unlike ceramics and metals which by themselves can provide a lot of strength also. Second thing is, their modulus is not very high and we will see some of these numbers, modulus is not very high, so that means, the materials by themselves do not, cannot provide a lot of stiffness to the system. Third thing is, limited operating temperature range, most of these materials they do not survive maybe after 150 160 at the most 180 degrees of centigrade's with the exception of materials like Teflon.

So, if you really want to use these materials at elevated temperatures, we cannot use them and the other thing is that a lot of these materials are sensitive; sensitive to ultraviolet rays. So, you expose these materials to UV rays, they start decomposing over a period of time, they become weaker, they develop cracks. So, all that is you have to be sure that somehow you protect these materials from UV radiation, specific solvents organic solvents, so they may be sensitive to that and several of these materials they also are sensitive to humidity. What does that mean? For instance nylon, it absorbs a lot of moisture. So, you have a composite, it will have some volume and you put it in moisture and slowly it absorbs moisture and because of moisture absorption the overall shape it starts deforming because of internal stresses which it develops.

So, this is another limitation, that some of these materials absorb significant amount of moisture which causes deformation of the overall structure, bends and twists. So, these are the advantages and these are the limitations. Next, let us look at the classification of these materials.

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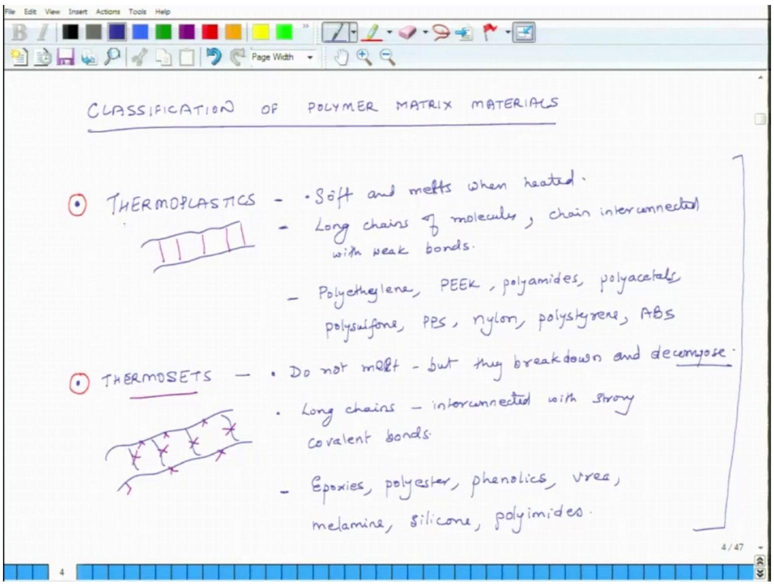

So, classification of polymer matrix materials, now broadly speaking you can break all these different types of matrix materials which are based on polymers, all these guys into 2 big groups. So, the first group is known as thermoplastics and the second group is thermosets and let us understand, what these, how are these different categories I mean how are these different.

Now, what happens to thermoplastics? So, if you take a piece of thermoplastic and heat it, then it becomes soft. So, it becomes soft and then finally it and melts, when heated. This is 1 important in the thermoplastics, they become soft and then it is eventually they become they melt when they get heated and then if you cool it again it will solidify and become stiff.

So, if you have a piece of plastic which is thermoplastic; suppose, I make this from thermoplastic and I heat it, initially it will become soft and I can press it and it may change it is shape or if I do not press it then it will become soft and if I cool it down, then it will retain it is shape and it will again become stiff, but if I heat it beyond the melting point it may change and then it will never get back to it is original shape.

Now, unlike thermoplastics these guys; thermosets, they do not soften up appreciably rather so they do not melt, but beyond a certain temperature they breakdown and decompose, so this is important to understand. So thermosets, you keep on heating them not much happens to the overall structure, but if you cross a certain threshold of the temperature, then all the surface in the whole thing starts developing cracks and it decomposes and then if you cool it, it does not get back through it is original situation because the material itself has broken down.

Second thing is that, these have; the thermoplastics have long chains of molecules and so it has several long chains of molecules and chains interconnected with weak bonds. So, the chain itself is a strong, but then the bonds between 2 chains of molecules; is connected by weak bonds, hydrogen bonds. So, these are weak bonds, so you have a chain, this is a chain and then they are connected with weak bonds.

So, what happens is, when you heat it, these bonds they break and then the chain starts, so 1 chain slides at the over another chain. So, that is why it becomes soft and eventually it starts flowing very easily, so this what happens and when you cool it, these bonds again develop and things become again strong. So, that is why this starts; thermoplastics starts flowing as you heat them.

Now, thermosets they have a different structure. So, they have long chains, but they are interconnected with the strong covalent bonds. So, you have a chain, you have another chain and these are connected with the strong bonds. Now, what happens in this case, when you heat the whole thing, the bonds in the chain and bonds between the chains there are strong and they do not do much, nothing happens, but you keep on heating it all of a sudden at a particular temperature, these bonds they break and also you start having breaking of bonds along the chain.

So, once these bonds break and these are covalent bonds and you cool it, they do not develop any further remember. So, as a result once you heat it up and cross a certain threshold, these thermosets do not get back to the original configuration. So, once you heat it these bonds, especially these bonds between the chains they breakdown and they cannot be recovered.

So, let us look at some of the examples of thermoplastics. So, thermoplastics could be polyethylene or poly ethylene; then we have PEEK, polyether ether ketone, polyamides, polyacetals, polysulfone, PPS. So, PPS is a short form for polypropylene styrene; PPS, nylon, polystyrene, ABS and so on and so forth, some examples of thermosets epoxies, polyester, phenolics, urea, melamine, silicone, polyamides, so these are examples of thermosets. So, this is the broad classification.

Now, we will refine this classification a little further, we will actually break this thermoplastic into 2 separate categories, but before we do that we have to understand 2 important terms.

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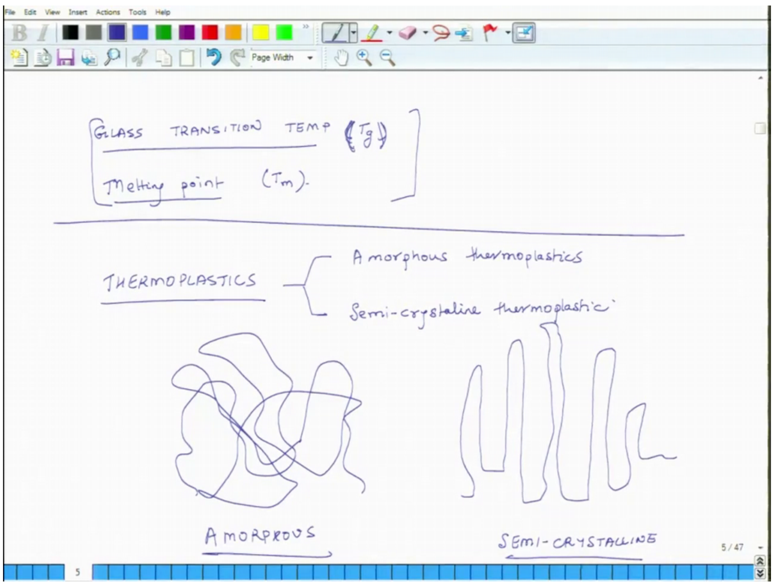

So, first term is glass transition temperature, lot of times in literature it is written as Tg and then you have melting point. So, lot of times it is written as Tm. So, what happens is that, if you heat a material and you keep on heating it, in context of thermoplastics because thermoplastics have a melting point, thermosets do not have a melting point. So, in context of thermos plastics you will cross a Tg, glass transition temperature.

So, below the glass transition temperature the density and everything of the material does not change much, above the glass transition temperature it undergoes some change and then you can keep on heating it further and at the melting point all those bonds which we have talked about cross linking, they get totally broken and things start flowing.

So, at the melting point everything's start flowing, so it becomes a fluid, is very viscous fluid, but at Tg things start softening up, below Tg or below glass transition temperature, if you heat it, it is modulus does not change, it still retains it is stiffness significantly, above glass transition it becomes soft and above melting, but it still remains solid and above melting point it starts flowing. So, this gives you a physical idea and essentially this glass transition is related to the phase of the material, but I do not want to go into the chemistry of the thing, but at melting point it goes into fluid phase, so this is there.

Now, with this context what we can do is these thermo plastics. So, now we understand what is Tg and what is Tm, thermoplastics we can bring them into 2 groups. So, first 1 is amorphous thermoplastics and the second 1 is semi-crystalline thermoplastic. So, you have amorphous thermoplastics and semi-crystalline thermoplastics and you would wonder what is the difference; you can have for a instance nylon and nylon can exist in both phase types, you can have nylon as amorphous or you can have nylon as semi-crystalline, the chemical formula is same, but the difference lies in how the molecules and chains are organized.

So, in amorphous, suppose there is a chain it may be all sorts of zigzag. So, this is how the chain of molecules is arranged in amorphous version. So, you can, we remember we talked about lot of polyethylene, you can have a lot of these materials both as amorphous versions or semi-crystalline. Now, we know that when we have crystals, the molecules are organized in very set pattern, but in plastics, this pattern is not 100 percent organized very predictable, but still there is some good amount of arrangement between the molecules and chains. So, that is why we call them as semi-crystalline because it is not repeating after itself again and again and again. For instance, you can have the same chain and you can have something like this.

So, there is some pattern, it is not all (Refer Time: 23:39) as in amorphous, that is why we call these semi-crystalline. So, if the thing is 100 percent crystalline, it will be called crystalline, but because in case of plastics nothing is 100 percent repeating after itself, so they are semi-crystalline materials, so that is the thing. Now, think about it, if the chains are all (Refer Time: 24:18), then you cannot put a lot of chains in small volume because they will be lot of blank spaces between those 2 things and you cannot put more stuff, but if things are more organized, you can put more and more number of molecules in lesser amount of volume.

So, in general amorphous plastics, their density is less compared to semi-crystalline per plastics, so I will give you some examples.

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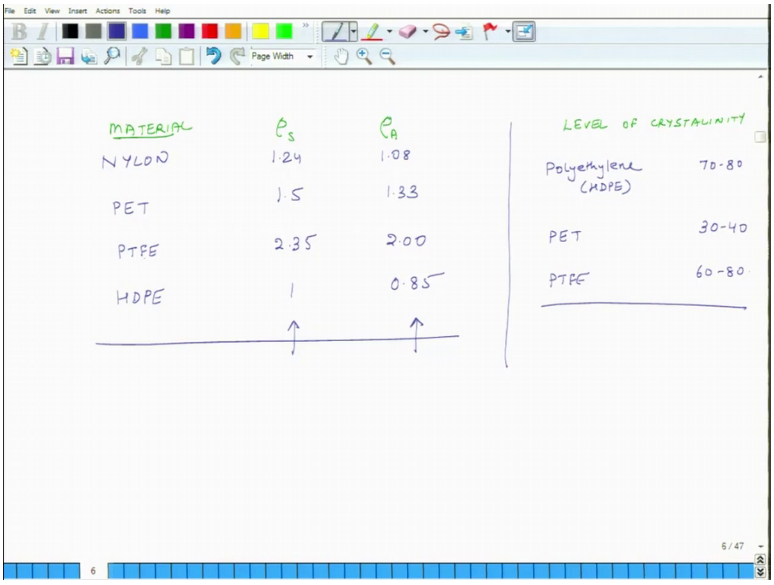

So, we will just look at some plastics, so this is material. So, it is rho semi-crystalline, so first we will specify the density of semi-crystalline version and then of the amorphous version. So, for a instance, you have nylon it is semi-crystalline could be as high as 1.24, but amorphous version 1.08, so it is significantly different. PET, this is another thermoplastic this could be high 1.5 and this is 1.33.

PTFE, what is PTFE? PTFE is poly tetra fluoro ethylene, it is a chemical name for the material which we known as Teflon, poly tetra fluoro ethylene. So, this could be 2.35, 2.00. HDPE, in a lot of plastic parts or bottle things like that if you see on the backside, you will see some letters written on these plastic parts either you will find it HDPE or IDPE. What is HDPE? HDPE is high density polyethylene.

So, high density polyethylene, the density could be as high as 1 and this could be 0.85 and similarly you have low density polyethylene. So, you see that the semi-crystalline version has the straighter, it has more; it is more compact, so it is density is higher, amorphous version has in general lesser density and you will wonder, what is the level of semi-crystalline, this crystallinity in these things. So, if it is 100 percent everything is very nicely organized, then it is 100 percent crystalline, but in general well let us look at some numbers, crystallinity levels; level of crystallinity.

So, let us look at polyethylene and so which polyethylene we are talking about high density polyethylene. So, in high density polyethylene, you can have something 70 to 80 percent crystallinity; then let us look at PET. So, what is PET, polyethylene terephthalate, this is 30 to 40, PTFE, this could be anywhere between 60 to 80, that is why when you go to the market, each time you by a new type of Teflon, they come in different flavors. You have to actually test the material and figure out what is it is exact density because they can come in all sorts of flavors based on which factory is making it and you cannot be really sure what is the exact property. So, you have to test it, it is density, it is modulus, it is strength and everything and then you can do your other things, so these are the levels of crystallinity.

So, we can have again, we can have thermoplastics and we can have thermosets and thermoplastics we can bring them further into semi-crystalline or amorphous versions and the semi-crystalline versions have high density, chemical structure is same, amorphous versions have lower density and what we will do tomorrow because the time for today is over, we will continue this discussion on semi-crystalline and the amorphous versions of polymers and figure out, what is the relationship between the glass transition temperature, the melting point and different properties of these types of materials.

So, that concludes our discussion for today and I look forward to seeing all of you tomorrow, bye.