Introduction to Composites
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Lecture - 14
Thermoset and Thermoplastics Matrix Materials

Hello, welcome to introduction to composites. Today is the 2nd day of the 3rd week of this course. Yesterday, we just started discussing different type of matrix materials and specifically we started discussing the details of polymer matrices, we have explained that polymer matrices come in 2 flavors, thermosets and thermoplastics and then we also introduced the concept of amorphous thermoplastics and semi-crystalline thermoplastics and we explained that because of the semi-crystalline structure of polymer chains present in thermoplastic materials their density is in general higher than that of the amorphous versions of the same plastic.

We will continue and extend this discussion today and we will also see how other properties of thermoplastics change based on the fact whether they are semi-crystalline or amorphous and also how do materials such as thermoset plastics, their properties change as temperature changes. So, 1 thing we will look at is density as a function of temperature.

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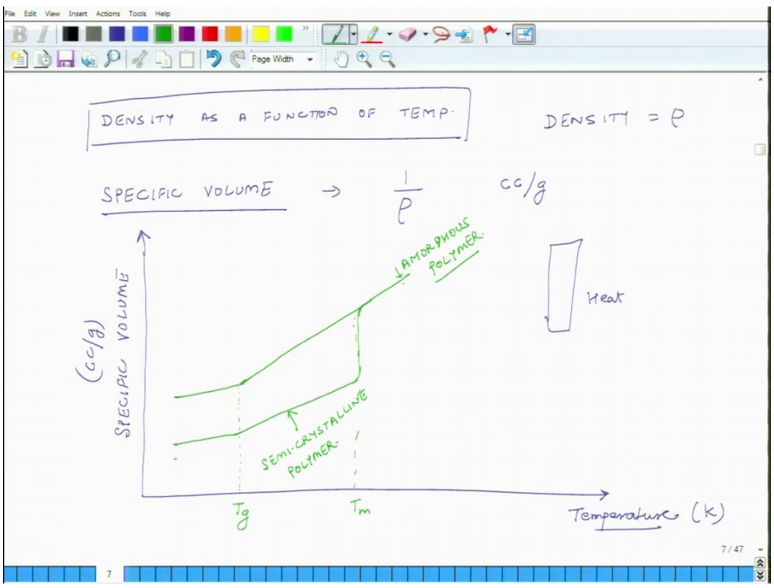

So, what we will define here is let us say a term called a specific volume. So, what is density? It is the amount of material contained in a unit volume, suppose you have 1 cubic meter is your unit volume, how much material is contained that is called density.

So, if it contains; for instance water, if you take 1 cubic meter of water it contains 1000 kilograms. So, density of water is 1000 kilograms per cubic meters or 1 grams per cubic centimeter. The specific volume is just the inverse of it; it is just the inverse of it. So, another you can define it as amount I mean the volume required to hold 1 kilogram or you know of material. So, that will be inverse of density, so specific value. So, if density is rho, then the specific volume is 1 over rho. So, it is units would be cubic centimeters per gram or cubic meters per kilogram.

So, what we will do is, we will generate a plot. So, on the x axis, we will have temperature. So, what is it that we are doing we are taking a piece of plastic, in this case it is a thermoplastic, this could be either semi-crystalline or amorphous and we are heating it up and we are seeing how it is specific volume changes. So, how do we figure out this specific volume, we it is mass as we heat it, it is mass is not changing mass is still the same, but as I heat it, it is volume keeps on increasing. So, I measure the volume and I divide it by it is mass and then I get 1 by rho. So, on the y axis we will plot a specific volume, cubic centimeters per gram and on the x axis I am going to plot temperature. So, this is whatever, in degrees not degrees we do not write degree Kelvin we just write Kelvin.

So, first we will look at the behavior of an amorphous thermoplastic. So, I have I mentioned this earlier, amorphous thermoplastic if I heat it, what happens. It will slowly expand, so it has a positive slope, but that slope is not very large and then if I cross it is glass transition temperature Tg, then all the bonds between the different chains they break, in amorphous polymers the bonds break and as a consequence it expands and this slope increases all of a sudden. So, this is for amorphous polymer, excuse me, so we are not talking, we are talking about thermosets.

So, what I am saying is initially it just increases above glass transition temperature, this is what happens and it just keeps on increasing. Now, in case of semi-crystalline materials, so in semi-crystalline materials what happens? They are much more well organized and crystal structures are more stable. So, they can take a lot of heat. So, initially when I heat it, the density what will be the initial density? Initial density of semi-crystalline materials is going to be.

Student: Higher.

Higher; so initial specific volume will be less.

Student: Less.

It will be less and as I increase it, as I increase the temperature the volume is going to increase because things are going to expand, but it does not. So, it does not do much, but it increases slightly and after the glass transition temperature has caused, then this also increases at a rapid place, but once your melting point has crossed, then all of a sudden it becomes like this.

So, this curve is for semi-crystalline polymer. So, for semi-crystalline structures all of a sudden, there is some change in density, density goes down a specific volume goes up, but after the melting point it really goes up at significant thing, for amorphous polymers and this is how it changes, so that is how the thing behaves. Next, what we will look at how does E?

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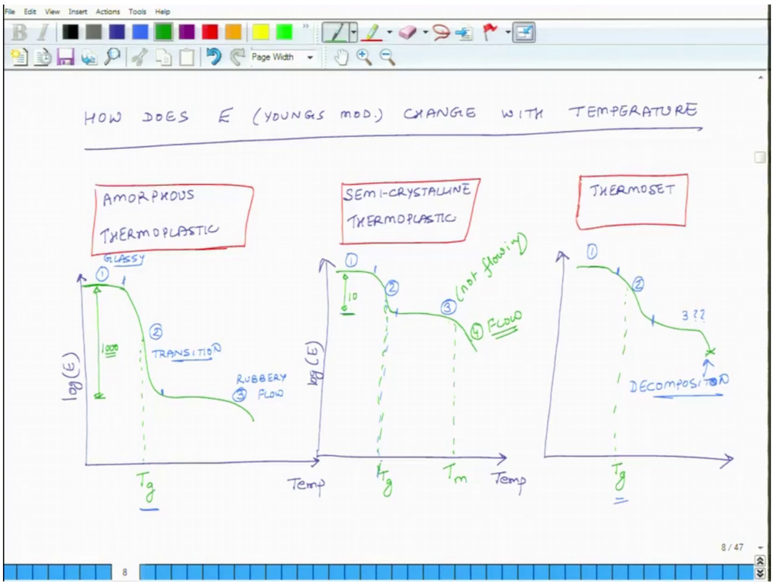

So, what is E? Youngs modulus, change with temperature. How does E change with temperature? This is important to understand.

So, what we will. So, as I keep on increasing the temperature, we would expect that the modulus will come down, things will become softer and we expect that the modulus will come down. So, we will do this, we will try to understand this for all 3, thermosets.

Student: (Refer Time: 09:39).

Student: Thermoset.

Thermo amorphous thermoplastics and semi-crystalline thermoplastics, so first we will do it for amorphous thermoplastic.

So, x axis, y axis and here we are plotting temperature and on the y axis we are going to plot youngs modulus, but because the changes in youngs modulus are so significant, that if I just plot it on a linear scale I cannot plot it in a small zone. So, we will plot log of E, because lot of times the changes are more than by a factor of 1000, note them. So, you may start with 100 mpa and you may come down to point 1 mpa or you may start with not a 100 mpa maybe 20 gpa and you go down by a factor of 1000. So, you come up with to 20 mp or something like that. Let us look at the behavior of amorphous thermoplastic.

So, you start with a very high modulus at then the temperature is not high. Now, in amorphous thermoplastics only the glass transition temperature is important. So, this is what happens. So, you heat it, initially it does not change and then once you clause the glass transition temperature there is a sudden drop and it behaves something like this. So, your glass transition temperature may be somewhere here. So, here in this zone, this is zone 1, this is zone 2 and this is zone 3 and this is your Tg glass transition temperature this drop may be significantly high. So, it may be something like 1000 sharp drop.

In zone 1, the plastic behaves as a piece of glass, it has high viscosity and does not flow much easily, like you glass material is considered to be some sort of a plastic, it is not a metallic thing and it has it is considered to have very high viscosity. So, below the glass transition temperature, this material has a glassy type of behavior. So, you break it, it will crack and things like that, but if you heat it, it becomes soft and you break it I mean you bend it, then it will not crack it will just deform. Same thing happens to glass also, at room temperatures you bend it, it cracks, but at high temperatures you bend it, it will just change it is shape.

So, this is glassy behavior and then in region 3 it is it behaves as if like rubber is flowing. So, this is rubbery flow in region 3 and this is transition, so this is our the case of amorphous thermoplastic. Now, let us look at semi-crystalline thermoplastic, now in semi-crystalline thermoplastic it is a little different. So, let us see how it looks like on the x axis I have temperature, y axis is again log of E and in semi-crystalline we have 2 temperatures which are important, the first 1 is glass transition, add glass transition there will be sharp decrease, but it will not be as sharp as the case was there in amorphous because the crystalline structure it still causes it to maintain it is shape somewhat, but then once you have crossed the melting point it goes into the rubbery flow state.

So, the curve is something like this. So, you have the glassy state and then there is some drop and then it is like this. So, this is your Tg, excuse me this is region 1, this is region 2 and this is region 3. So, in this case typically the modulus may fall by an order of magnitude maybe by a factor of 10 and the next thing we look at is thermoset. Now, in thermoset what did we say that, once the structure breaks down there is no melting, it does not flow the whole structure just collapses. So, this is what happens in thermoset.

So, you may have something like this and here it just breaks down, there is no not a whole lot of flow. So, here you have rubbery flow, here you have some rubbery flow, but here what happens is, so I will just first write it down. So, this is where your glass transition temperature is, this is your region 1, this is your region 2, here things become very soft, maybe, but the thing is not that things are flowing, the material becomes soft and then it just decomposes, it does not become like a fluid; perfect fluid. So, and then here you have decomposition, excuse me decomposing the material just breaks down.

So, in thermoset only Tg is important, in amorphous only Tg is important and in case of what did I say that.

Student: Thermoset.

These semi-crystallines, so I forgot to put another temperature. So, here it is, so maybe I should put another line here, this is here you are having a flow, it becomes fluid. So, this is Tm, this is region 3; in region 3 it becomes rubbery, but it is still a not flowing, but not flowing, but in region flow it actually starts flowing. Unlike in amorphous, where region 3 still corresponds to rubbery flow because amorphous guys do not have a sharp melting point, they do not have a sharp melting point.

So, this is again, overall it gives you some idea of how do different polymers behave as they are subjected to temperatures. So, what we will do is, this is a large area of discussion we will continue this discussion tomorrow also and then hopefully tomorrow we will start looking at some of the important polymer based matrix materials. So, with that I close the discussion for today and I look forward to seeing you tomorrow.

Thank you very much.