Physico - Chemical, Mechanical and Electrical Properties of Polymers

Prof.Abhijit P Deshpande
Department of Chemical Engineering
Indian Institute of Technology – Madras

Lecture – 32
Stress Strain Response

Hello, welcome to this week of lectures on polymers. In this week we are focusing on the properties of polymeric systems. And we are looking at physical, chemical, mechanical and electrical properties, as we have seen that polymers are used for structural applications or sensors and actuator applications. So, varieties of properties are of relevance. And in this lecture, we will start looking at the mechanical response in more detail.

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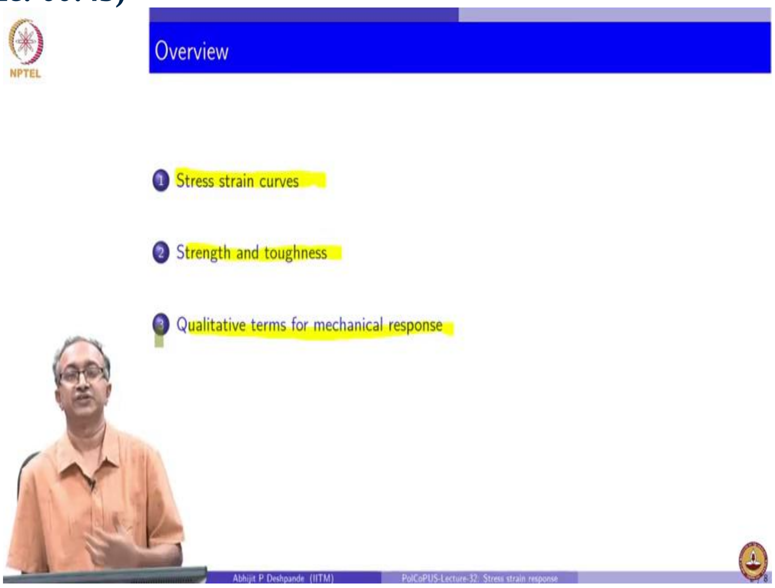

And the way we will do this is first look at the stress strain curves. Many of you should be familiar with some of these curves from strength of materials or any solid mechanics course, but we will quickly review them and talk about the properties which are important for polymers. In addition to modulus, strength and toughness are important characteristics. And we will finish by quickly looking at some of the qualitative terms which are sometimes used in engineering applications to describe the strength or weakness of a polymeric system for a given application.

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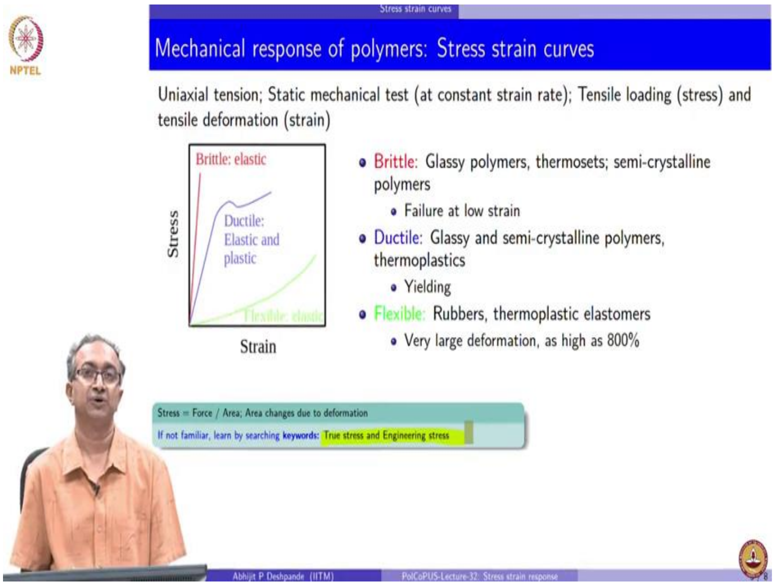

So, mechanical response of polymers is generally assessed using the stress strain curves, but this is only one among several ways in which you can look at mechanical response, but generally when we say stress strain curve, we actually are looking at only uniaxial tension. So, basically just pulling a polymer sample with a extensional force and then looking at what happens to the deformation. So, deformation and loading is being imposed on the material and generally these experiments or this characterization is done at a constant strain rate.

So, the rate of pulling is constant. Sometimes these experiments depending on the capability and the material can be done at constant load conditions also, but in the context of polymers, it is very important to discuss the strain rate effect, how fast or slow the deformation is being imposed on polymers is a very strong factor in determining its properties. And we will soon start discussing viscoelasticity of polymers and the rate effect will become more and more clear as to why they are so important.

When we look at the stress strain curves, they look like this and I am sure you are familiar with a brittle kind of material ductile and flexible rubber like material. And so, what we will do in the next 2, 3 slides is look at these graphs not for the graph itself, but what is the underlying macromolecular features which lead to such behaviour. So, for example, brittle response is generally observed for glassy polymers, also polymers which are thermo sets and or they are also could be observed for semi crystalline polymers.

So, you can see that these are slightly different set of polymers one has crystalline and ordered region and other one has none, but both of them may present this and the question is why does this happen ? Why is it that either amorphous material or semi crystalline material both break at a very low strain itself and also if you look at how the curve is basically you have a sudden rise of load or stress and then there is a failure.

So, something to think about. The other is of course, related to the ductile behaviour. And this is generally observed again for glassy and semi crystalline polymer and most of thermoplastics belong to this category. So, you can see that a semi crystalline polymer or glassy material can have both of these responses. So, clearly, we need to know a little bit more about specific macromolecules and maybe the temperature or maybe the strain rate under which the behaviour is being observed.

And the ductile behaviour is associated with yielding behaviour and which all of you must be familiar with. The third type of responses is rubber like are also some thermoplastic elastomers. Rubber like we will generally say materials which are crosslinked, lightly crosslinked materials, while elastomer is a generic category which talks about extension, easily under load. And so, the extension can be very high in this case.

And just to remind you that one very textbook idea related to such curves is through stress versus engineering stress. And if you are not already familiar with it, just quickly search and find out and make sure that you understand this difference between the 2.

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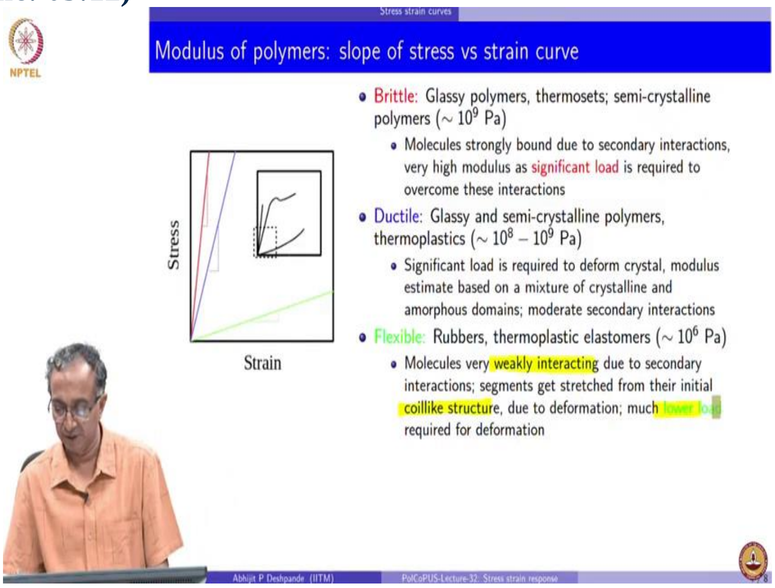

So, the first property which is defined is the modulus, based on these curves, and that is nothing but the slope at load deformations. And in fact, this is the region where the behaviour is elastic. And, by this, there are multiple things, it is also linear, and it is elastic. So, if I unload the sample at this point, it will go back and forth on the same curve. But more importantly, current discussion is focused on the slope.

So, the slope indicates basically what is the modulus? And so for glassy polymers, the molecules are strongly bound due to secondary interactions. And that is why to stretch the sample to pull molecules apart from each other, we have to apply a lot more force and therefore, very high modulus is present in this case, to overcome these interactions, in case of glassy and semi crystalline materials, which showed ductile behaviour, quite often the forces will be the secondary interaction.

So, it be weaker and therefore, the modulus is maybe slightly smaller. Again, just reminding you that all of these are generic types, it is certainly possible that a ductile polymer can have a very high modulus and a brittle polymer may have slightly lower modulus it again, all of it depends on secondary interactions. And these interactions we have discussed in lecture 20th lecture, where we looked at all different possible interactions which are present in macromolecules.

So, in case of semi crystalline polymers, what happens is we have to deform the crystal and also, we have to deform the macromolecular chain. And so, generally, the modulus in case of a semi crystalline material can be explained as a combination of response of amorphous regions and crystalline regions. And this is called a mixing rule. And again, in later on, when we look at blends or composites, we will look at mixing rules which can be used where you look at behaviour of 2 components.

And, then based on that you look at the overall behaviour of the material. And given that the modulus is slightly lower, the interactions are much less compared to brittle material and of course, in case of flexible rubber, we have already seen several times that here interactions can almost be ignored. And therefore, these are weakly interacting molecules and from their coil like structure, they can deform and therefore, much lower load is required for deformation.

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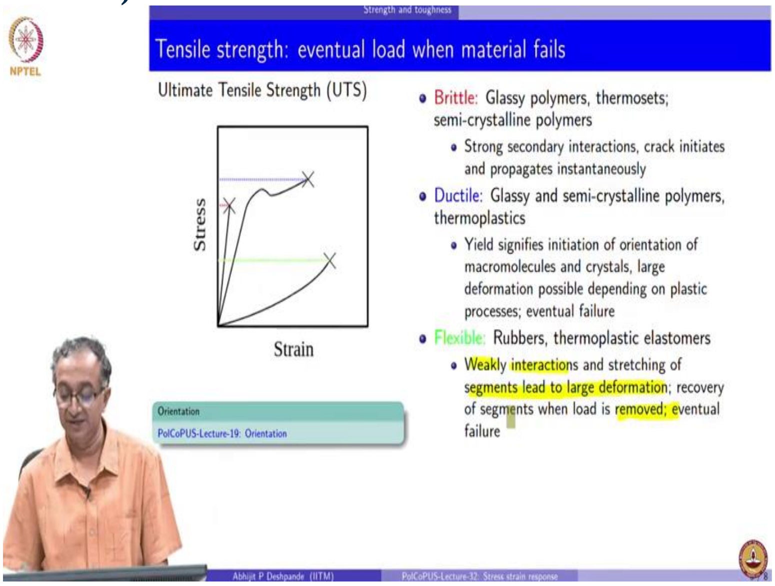

So, moduli in general is a strong function of what are the nature of interactions at small deformation. The other property, which we will define are related to strength and toughness, this is where not just initial deformation in the material is important, but how does the material fail also becomes important. So, in terms of the load that it can take and the extension it can take before it eventually fails, because of crack generation and material basically breaking into pieces.

So, because in case of brittle materials, there are strong secondary interaction, once a crack starts, there is nothing else is there to stop it and therefore, say it is like an unzipping of macromolecules and molecules. So, it is crack starts, and it propagates and therefore, we have catastrophic failure and strength may not be as high as in case of the other materials. In case of ductile materials yield actually signifies that there is orientation and again, in a earlier lecture, we have taken a close look at orientation of different entities in polymeric materials.

So, therefore, macromolecules chains as well as crystals can orient and because of this orientation, deformation keeps on continuing and due to this deformation, we have what is called plasticity in the material, which leads to basically deformation in the material which is not recoverable because chains and crystals are getting reoriented. If you were to unload the sample after this, it will unload like this leaving a plastic strain in the material.

So, that is why yield is associated with plasticity and plastic deformation. This is one of the reasons since large class of polymeric material belong to this class, we end up calling many of the polymeric materials as plastics. The rubbers on the other hand, since have very weak interactions and stretching of segment leads to extremely large deformation, whenever we remove the load it comes back.

So, in this case also there is a stretching and orientation, but because there is segmental mobility present, remember that rubber is a material where segmental mobility is present, while a glassy and semi crystalline polymer has no segmental mobility. So, because of these segmental mobility recovery is there, and in fact, eventual failure can only happen when we stretch the material so much that all the chains have got stretched and now, they start breaking and leading to eventual failure.

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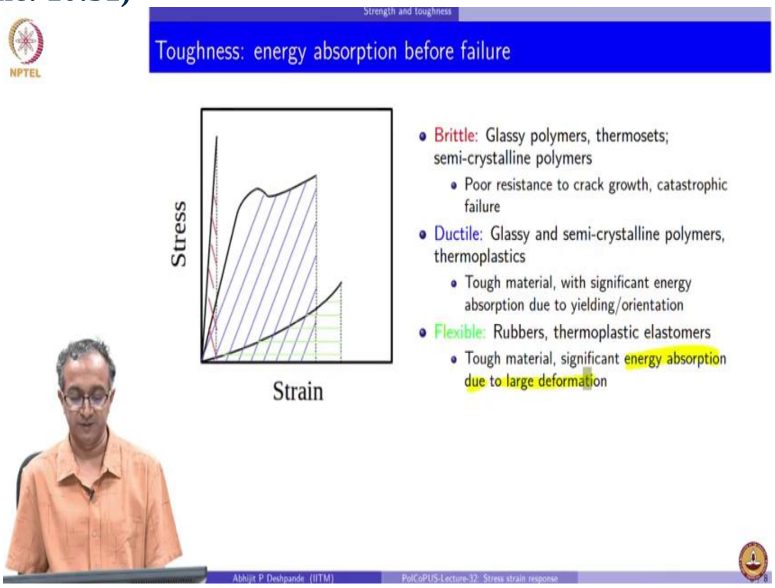

So, one other way in which we can look at the ability of the material to withstand loads is in terms of the energy that it absorbs, and energy is nothing but force into distance. And in this case, stress is force per unit area and strain is distance per unit distance. So, stress into strain or the area under these curves is energy per unit volume. So, therefore, we can look at the area under the curves and that gives us an idea about the toughness of the material.

So, whether a material is tough or not in an engineering parlance depends on this quantitative measure of area under a stress strain curve. And given that there is a poor resistance to crack growth in case of brittle materials, the toughness is low, ceramic materials of course, also belong to this class and therefore, they are not tough, they may be strong, which means the strength is very high, they may be hard or stiff, because modulus is very high, but they are not tough.

On the other hand, many of the polymeric systems may not be strong, may not be hard or stiff, but they will be tough. And it is not surprising that many applications where energy absorption is required, you can look at automotive applications and try to spot where are the parts where polymers and plastic materials are used. So, in case of ductile materials, they are generally tough material with significant energy absorption.

And the key to this significant energy absorption is the yielding and orientation processes that happen in the material. So, plastic materials can dissipate and absorb lot of energy. Because of these mechanisms we are macromolecules are orienting crystals are orienting in the sample. The rubbers also can absorb a fair amount of energy because of large deformation that is possible. Since 400%, 500% deformation is possible, they can again also be tough materials.

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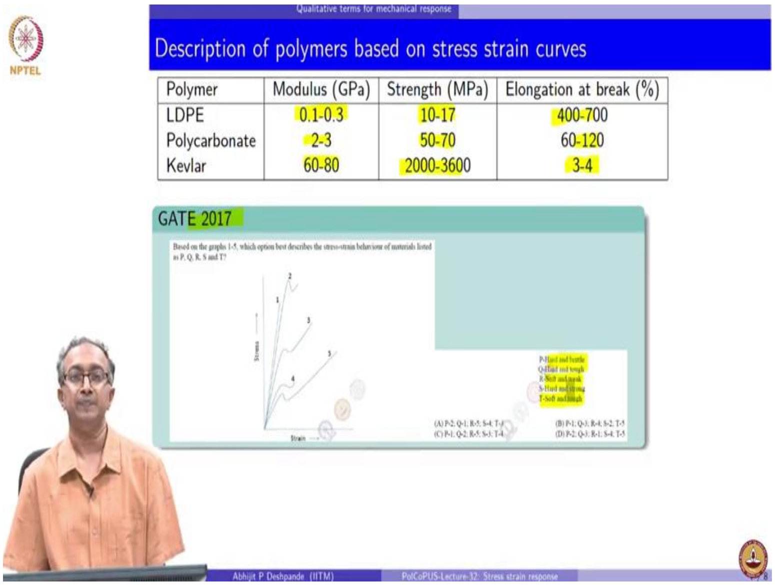

So, with this we have done a quick recap of many of the properties which are important for engineering polymers. And here you can just see that for polymers, the numbers are widely varying from LDPE, which is a very flexible polymer it is not as stiff as let us say Kevlar. And even from the point of view of strength, the Kevlar fiber is extremely strong. But on the other hand, if we look at deformation at break, it is exactly reverse polyethylene can deform a lot while Kevlar can hardly default.

So, this question here from exam actually tries to look at all this description. So, weak implies low tensile strength, tough implies higher value of toughness. So, you can try to see this and then see which of these curves stress strain curves based on our discussion correspond to this. I would suggest that you pause here and then try to answer this question and then only proceed further.

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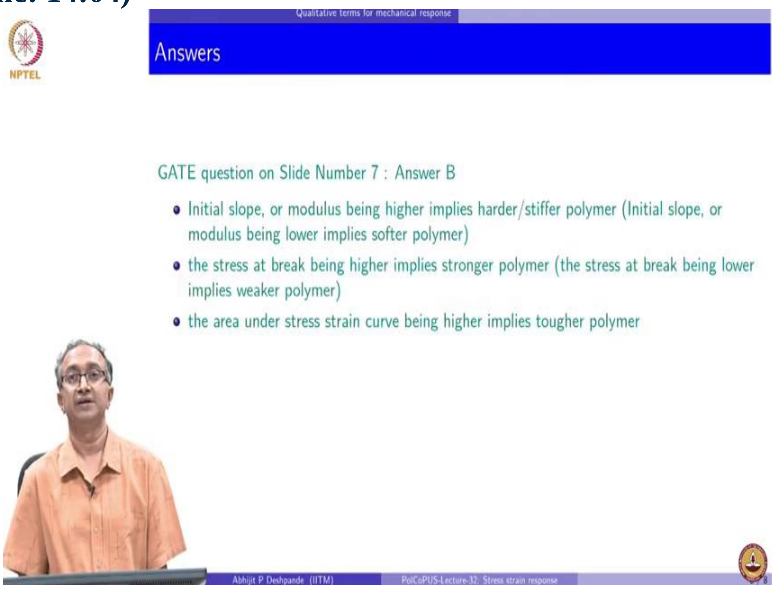

So, with this, we close the lecture on basic ideas related to mechanical response of polymers. Thank you.