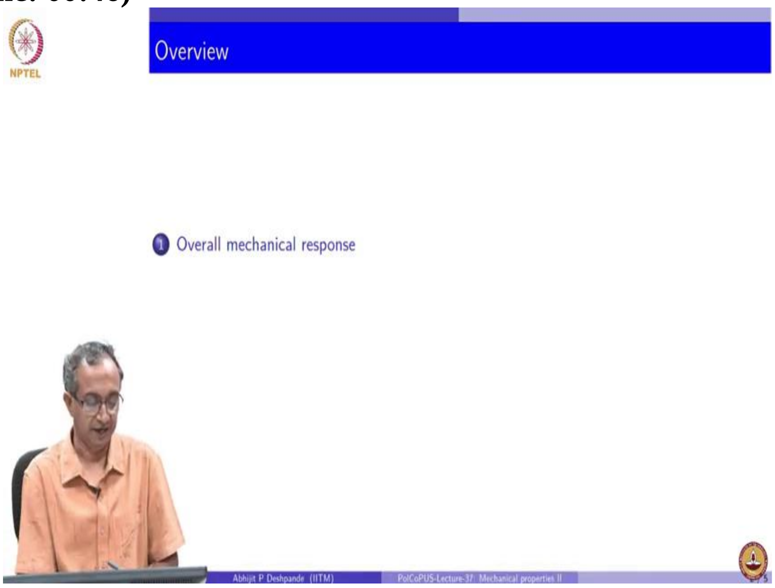
Physico - Chemical, Mechanical and Electrical Properties of Polymers
Prof. Abhijit P Deshpande
Department of Chemical Engineering
Indian Institute of Technology – Madras

Lecture – 37
Mechanical Properties II

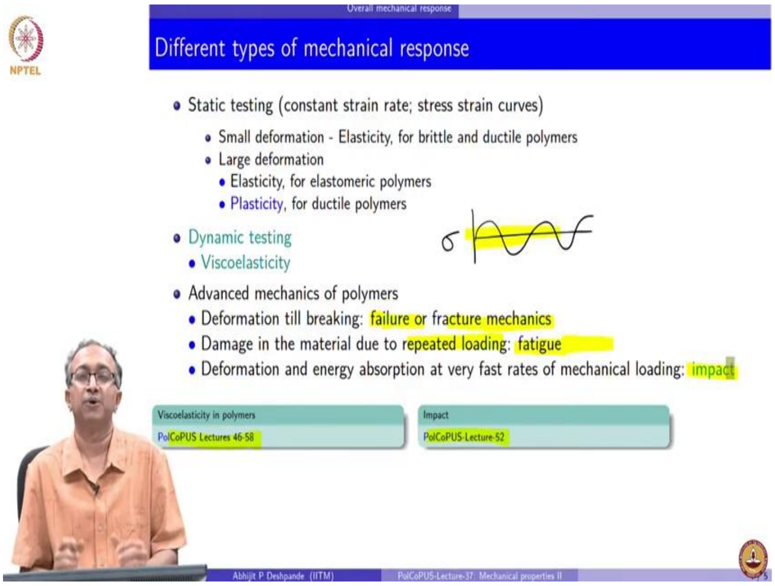
Hello, welcome to this journey of learning about polymers. In this course, we are looking at conceptual understanding of polymers, their properties, their uses, as well as aspects related to sustainability. So, in this week, we have been focusing on properties and we have already discussed aspects related to the mechanical response in terms of stress strain curves as well as the elastic behaviour. In this lecture, we will continue our discussion of mechanical properties.

(Refer Slide Time: 00:46)



And, but we will look at the overall mechanical response and the complexity of the types of response that are possible when polymers are being considered as an engineering material from structural applications into transport applications in automotive or 2 wheeler applications or in aerospace applications. So, a plethora of mechanical responses need to be considered when we have any of these applications.

(Refer Slide Time: 01:17)



So, the different type of mechanical response that we normally try to characterize and assess the property of a given polymer system can be classified as follows. So, quite often, what we have discussed so far is really only the static testing, this is quite often done at a constant strain rate. And what we look at is basically stress strain curves. And this is what we have focused so far in the 32nd lecture or the previous lecture, the 36th lecture, we have looked at small deformation, large deformation, but related to stress strain curves.

And, so, of course, the classification also is that if it is small deformation elasticity, which is present in the material and this is for brittle and both ductile polymers, we have linear elasticity, we can also have large deformation and elasticity which we saw for rubber like material in the previous lecture on rubber elasticity and, we also saw that for ductile materials, we have plasticity where we said that orientations of chains and crystals take place.

And this is all in the context of testing, which is in a particular way at a constant strain rate, and therefore, it is called a static test. Now, moving on, when we look at dynamic testing, we generally tend to assess the response of the material as a function of time. So, in case of static testing, the definition of elasticity itself took time out of any consideration, stress is dependent on strain, instantaneous value of stress is dependent on instantaneou value strain.

So, what time how much time what is the rate, all of those are irrelevant, but in case of viscoelastic material, where viscous dissipative response and elastic energy storage response are combined, then rate effects are extremely important. And so, dynamic testing is involved, considerations with respect to time is involved. And so, dynamic testing will usually be done, when we apply a constant stress and look at strain as a function of time, which is called the creep experiment.

Or we will have lot of discussion related to dynamic testing, by saying that I will apply your stress of sinusoidal kind. So, I intentionally apply a dynamic load on the material by deforming it for example, if I am applying a torsion rather than just applying a torsion and then observing, what I will do is I will apply a dynamic torsion on the material, a sinusoidal load on the material.

So, this is another way of characterizing the material, elasticity is largely to do with energy storage, and therefore, it can be characterized using static tests, but as soon as we look at dissipative materials, then rate effects and the dynamic tests become much more important. Now, so, these viscoelastic aspects, we will have a lot of discussion related to when we look at viscoelasticity in polymers in these future lectures. Impact also we will have a discussion in a separate lecture, where the strain rate is extremely high.

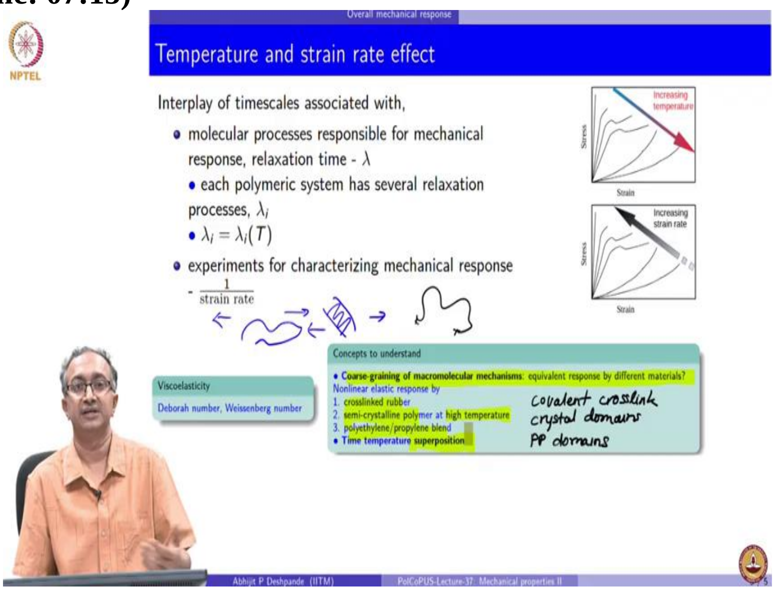
So, two materials which have let us say similar modulus and modulus is a property at small deformation, they need not have identical response at very high strain rates, because strain rates determine how the molecules and crystals and whatever is the microstructure at the microscopic scale. How does it respond to the load that is being applied on the material? Moving further down, we also have the additional properties of polymers, mechanical response, which is relevant from very practical point of view.

This is related to failure or fracture mechanics, how do the materials fail, how does crack propagate, and these are very important in terms of making design decisions with a given material. Similarly, a material may not be subjected to a very high amount of load, so that it fails. But given that it is been functioning for 10 years or 15 years or 70 years, then it gets fatigued. It is an English term which we are familiar with, but in case of polymeric or other materials, the damage starts occurring in the material and it starts accumulating slowly.

And that is why these phenomena are called fatigue phenomena, where the load applied is much less than the tensile strength and but still damage happens in the material. At a preliminary glance, you may think that the dynamic test where again there is a time varying load and fatigue test also, where there is a time varying load or similar phenomena, but if you had carefully notice the description that I used damage in case of fatigue while only structural response or macromolecular response in case of dynamic tests.

So, the two are drastically different phenomena being attempted because the loads being applied, or the strains being applied are in two different regions. Of course, there is a possibility that both of these contributions may be there at some given loads, and that is what makes mechanics of engineering materials such a challenging subject. We also have of course, the impact which we discussed; we will be looking at it in a future lecture. So, these are all gamut of aspects of mechanical response, which are important because macromolecular materials are such important class of engineering materials.

(Refer Slide Time: 07:15)



The other aspect which is related to the overall mechanical response of this macromolecular system is the influence of rate effects and temperature. And the underlying idea in all of this is associated with the timescale of macromolecular response. We have highlighted this several times that the macromolecules contain several scales of response, time scales as well as length scales, from a single bond stretching and vibration to a whole macromolecule moving there are different length scales and different time scales.

And so, generally we can quantify these timescales using what is called a relaxation time. So, if relaxation time is very small, then it is a very fast process, if relaxation time is very large, then it is a much slower process. So, therefore, each polymeric system has a collection of relaxation processes. And the key is that each of these relaxation processes depends on what temperature one is.

I hope you are able to see this in the context of segmental mobility that we had discussed or crystallization rate that we had discussed as a function of temperature, when we change the temperature at certain temperatures and segmental mobility is no longer there. So, therefore, the relaxation time of the material has changed such that flexibility is no longer present. So, therefore, each of the relaxation time or relaxation process is a very strong function of temperature.

Now, the sum of all of these considerations is the fact that temperature and rate effects have to be thought of when we look at overall mechanical response of polymeric system. This is true not just for mechanical response; it is also true for dielectric and other responses as we will see. So, whenever we look at properties of polymeric material systems, we need to take a close look in terms of what weight the material is being subjected to, and what is the temperature at which material is because of this multiplicity of timescales. And there is a close interplay between the timescale of the material response and the timescale at which we are applying the mechanical or electrical or other loading. So, for example, experiments can be characterized by a strain rate we shear the material using a shear rate. So, 1/strain rate is an indication of the timescale of experiment. So, it is the ratio between the material timescale λ and the experimental timescale, 1/strain rate, which determines the overall mechanical response.

And this is quantitatively captured using dimensionless numbers, which are very relevant for viscoelastic discussions called Deborah number and Weissenberg number and both of these we will define, when we look at viscoelasticity in these polymers. So, generally, the overall understanding of mechanical response in macromolecules also leads to a question that many times we have not really discussed the underlying atoms and molecules in a macro molecule.

When I talked about rubber elastic response, we only talked about a rubber chain, which between crosslinks can get stretched in this case of course, interactions are not important, but in case of plasticity also, I only talked about orientation or stretching of macromolecules. So, for example, if I stretch this then molecule gets oriented or if I have a crystalline lamella if I stretch it, then the crystal will also get oriented. So, in all of this, we are looking at a coarse-grained picture.

And this is possible, because we have certain dominant features which are important from bulk response point of view. So, for example, for nonlinear elastic behaviour for crosslink rubber, we can easily get behaviour based on such coarse-grained picture. And what is important is several different materials which at the microstructural level are very different. So, crosslink rubber, a semi crystalline polymer, but in its temperature above glass transition and a polyethylene polypropylene blend all behave similarly.

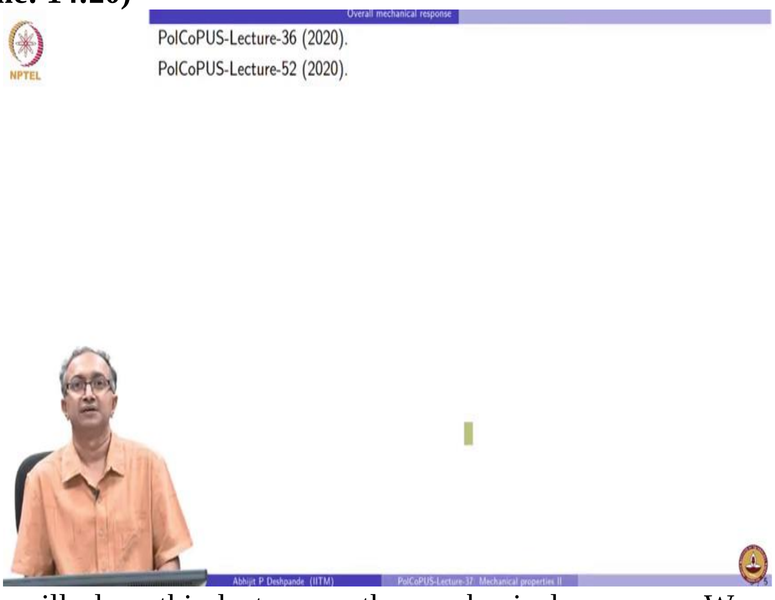
And what is remarkable about our understanding of these materials and the way we have developed theoretical formulations for these is covalent crosslink in case of rubber, crystal domains in case of semi crystalline polymer or polypropylene domains in case of polyethylene, polypropylene blend plays a similar role. These are the anchoring locations in the overall sample and between these anchoring locations we have flexible chains. So, between crystal domains we have rubber like flexible chains.

Between PP domains we have polyethylene flexible chains and between covalent crosslinks we have the rubber chains. So in all these cases even though the underlying physical chemistry of the macromolecule is different even the microstructure is very different one case we are looking at a pure polymer with crosslinks, in one case we are looking at a crystalline and amorphous mixer polymer, and in the third case we are looking at in fact 2 polymers mixed together as a blend. But the behaviour is very similar.

Therefore one of the key concepts that we need to absorb is in terms of being able to describe the response at a coarse-grain level or at a level where some of the details of macromolecules are not as important to describe the qualitative feature. One other concept, which will be very closely related to all this discussion, is related to time and temperature equivalence, where if we increase the temperature, then the time required for a similar property change will change and they are equivalent with each other.

And this is used for engineering applications where we can do accelerated testing and for a part which is supposed to be functioning for 30 years, can be actually assessed by doing accelerated tests at room temperature or higher temperature in the lab conditions.

(Refer Slide Time: 14:20)



So with this, we will close this lecture on the mechanical response. We will continue our discussion of mechanical response not only in viscoelasticity, but also related to impact and advanced mechanics of these polymeric systems. Also related is the trade tests which have to be done sometimes to assess the polymer desirability for a given application. Thank you.