Polymer Chemistry
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Lecture - 38
Polymer Properties and Evaluation: Mechanical Properties (Contd.) and Other Properties

Welcome back to this course on polymer chemistry. In last lecture, we started our discussion on polymer properties, and their evaluation. And in last lecture we discussed mainly mechanical properties, the stressed in behavior in tensile testing. We also discussed the other testing behavior like, impact testing, and flexural testing or bending testing. At the last (( )) lecture what we discussed was the relationship between the mechanical properties, and chemical structure or polymer chain properties.

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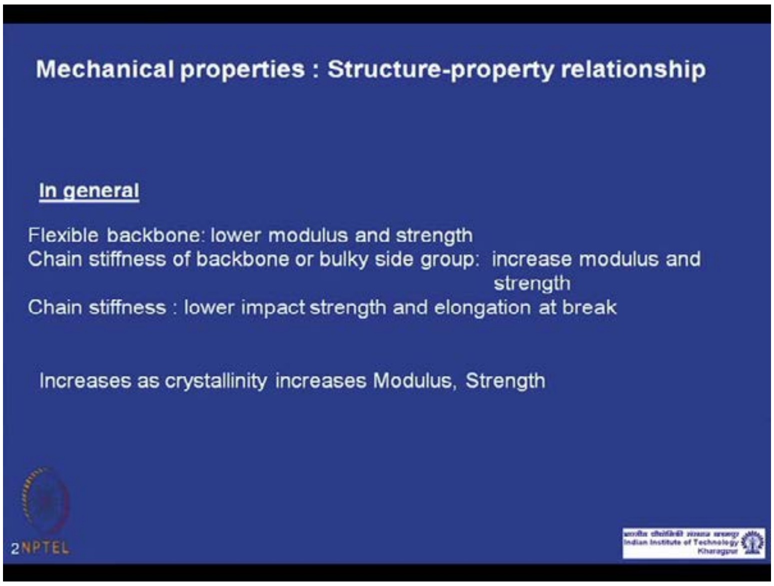

Mechanical properties : Structure-property relationship

In general

Flexible backbone: lower modulus and strength
Chain stiffness of backbone or bulky side group: increase modulus and strength
Chain stiffness : lower impact strength and elongation at break

Increases as crystallinity increases Modulus, Strength

And we found that in general, flexible backbone, if you have a flexible polymer chain backbone

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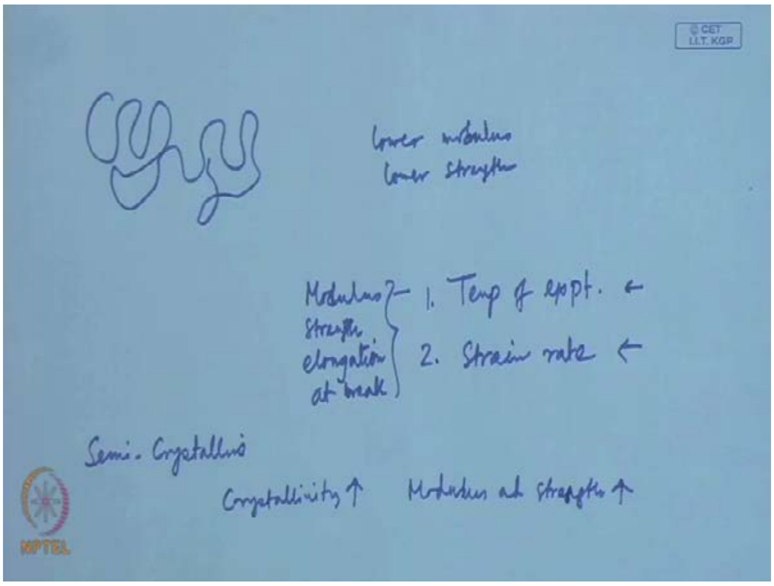

lower modulus
lower strength

Modulus
Strength
elongation at break
1. Temp of expt. ←
2. Strain rate ←

Semi- Crystalline
Crystallinity ↑ Modulus and strength ↑

Obviously, if I want to write here, if you have a flexible polymer chain backbone, then it is easier for somebody to apply stress and deform. Now with which basically gives lower modulus, lower strength, however the same flexible behavior can be helpful in case of impact properties. Why, if you impact, because of its flexibility it can absorb that impact energy more effectively, and gives you a higher impact strength or it does not give a better facture on getting hammered by a impact or gamma by a load. So, flexible backbone gives lower modulus and strength, and chain stiffness of the backbone and the bulky side groups, increases modulus, and strength which is self-explanatory. If you talk about backbone stiffness, then they increase the modulus, and strength. Increasing stiffness also gives lower impact strength, and elongation at break, because if you a stiff back bone, you cannot elongate before it breaks.

For a same, we also have seen that the modulus on mechanical properties, of a polymer, very much dependent on the temperature of the experiment, which means finally, if we when you using the polymer in a particular application, you must remember the temperature of the application. And second, the strain rate, if you think about the application with the material will come up, come across some load, which will come at a higher strain rate, then the behavior will be different, if you talking out just simply dead load bearing capacity of the material. So, modulus and other strength, or elongation at break, which means we are talking about brittleness. All this mechanical properties depends on temperature of experiment, and the strain rate or the stress rate. If you compare semi crystalline material, semi crystalline polymer at same temperature, and same rate. Obviously, we know that with increasing crystalinity, the modulus and strength goes up, whereas with a if we cross link this material with cross linking, the modulus goes up.

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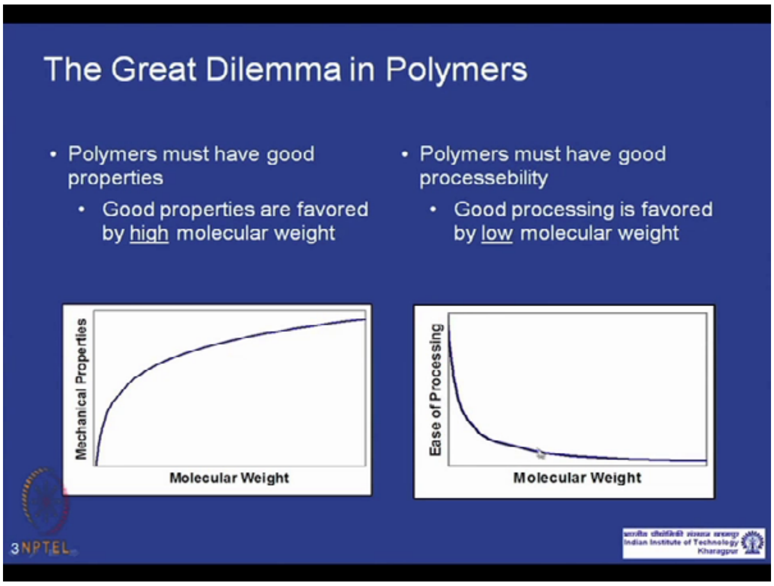

The Great Dilemma in Polymers

- Polymers must have good properties
  - Good properties are favored by high molecular weight
- Polymers must have good processebility
  - Good processing is favored by low molecular weight

Now, let us talk about great dilemma in case of polymers. Now we know that, or you can anticipate, that the properties; mainly mechanical properties of a polymer materials, which should increase with molecular weight. It does increase, and then become steady after very high molecular weight. So, basically good properties are favored by high molecular rate of polymers. So, this is nothing unusual, so you should expect this being. So, that is the advantage of a polymer. So, high volume molecular weight, it gives the mechanical properties. Other properties do not changes in molecular that much, though it also increases with molecular weight, but it does not keeps on increasing, even if it slightly with molecular weight, the other polymer will study it at a high molecular weight.

Whereas, we have seen that, you after making the synthesizing the polymer you have to go through the processing step, to make the final part. So, you must make some polymer, some molecular weight we should be able to pass through the processing step, so that you can get the final product. And process ability actually becomes easier, as you can understand the, if the lower the at the molecular weight lower at the viscosity, so process ability becomes easier, if you have the low molecular weight. So, processing good processing is always favored by low molecular weight. So, e is a processing will, means the high her the molecular weight, it will be difficult for process, so e is a processing will be lower, with increasing molecular weight. Now, just to spend a minute why these are processing is so much dependent or molecular weight.

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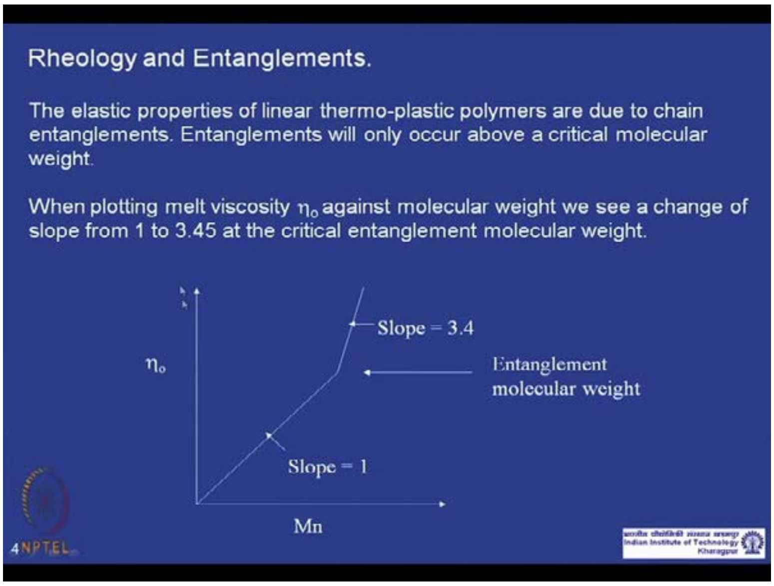

Rheology and Entanglements.

The elastic properties of linear thermo-plastic polymers are due to chain entanglements. Entanglements will only occur above a critical molecular weight.

When plotting melt viscosity η_o against molecular weight we see a change of slope from 1 to 3.45 at the critical entanglement molecular weight.

Just talk about Rheology and entanglement of polymer molecules. The elastic properties of linear thermo plastic polymers, are due to chain entangle. do we the We described in last lecture that, the elastic that the resistance to deformation, is due to the chain entanglement, because of presence, because of chain entanglement, the chains are presence other, may be intra molecularly, or other chain, the intra molecular chains segments are present in the vicinity of a particular polymer chain, which basically resist the deformation. So, if you have some polymer molecular weight, which is polymers which is having molecular weight, such a small number, such a small value that it does not entangle mean entangle efficiently. Then we do not get the desire property of a polymer material, which will be useful for the applications of the polymers we usually use. Entanglements will occur for polymer chains above a critical molecular weight, and we call that molecular weight as entanglement molecular weight M E.

Now if you look at the experimental value of a viscosity versus molecular weight of a polymer; viscosity tilled entanglement molecular weight, viscosity increases steadily with a slope of one, but above entanglement molecular weight the polymer chains and the entanglement. If the polymer chains and entangled, the polymer chains and entangled, then moving fast each other, going fast each other, is become more and more difficult, very difficult because they are entangles, so the viscosity becomes much higher after the entanglement. So, before entanglement, the viscosity scales to the, with the power of one, with molecular weight, whereas the slope changes to about 3.4, after the entanglement molecular weight. So, if you increase the molecular weight further, above this entanglement molecular weight; the viscosity goes up drastically, and the processing, these are processing become difficult and difficult more difficult. See always you want a polymer somewhere; above the entanglement molecular weight, and just above the molecular weight, so there it can be processed easily.

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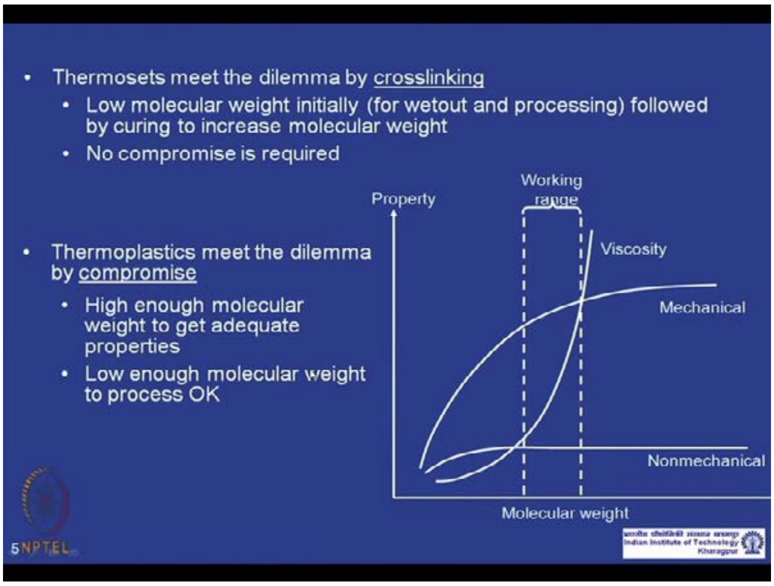

- Thermosets meet the dilemma by crosslinking
  - Low molecular weight initially (for wetout and processing) followed by curing to increase molecular weight
  - No compromise is required
- Thermoplastics meet the dilemma by compromise
  - High enough molecular weight to get adequate properties
  - Low enough molecular weight to process OK

So, this is the dilemma which molecular it should make, it will make high, very high molecular weight; your properties will be higher. Similarly the same time you lose the processibility to the way difficult to process. So, you have to have some compromises, you have to make molecular weight somewhere intermediate, so you get the best of both. In case of thermosets, you do not need that compromise, because thermosets are generally starts with low molecular weight polymers, and you make the final product or you process that low molecular weight, and then subsequently you cross link that, to increase cross link or cure in other term, and increase the molecular weight, so you do not have to compromise anything. Whereas, in thermo plastics you have to compromise between these two, you have to choose a molecular weight somewhere in between, so that your mechanical properties is just above a critical value of your requirement, and your process ability also is handable, means you can do processing. So, high enough molecular weight to get adequate properties, and low enough molecular weight, so that it can be processed, so you have to compromise between these two.

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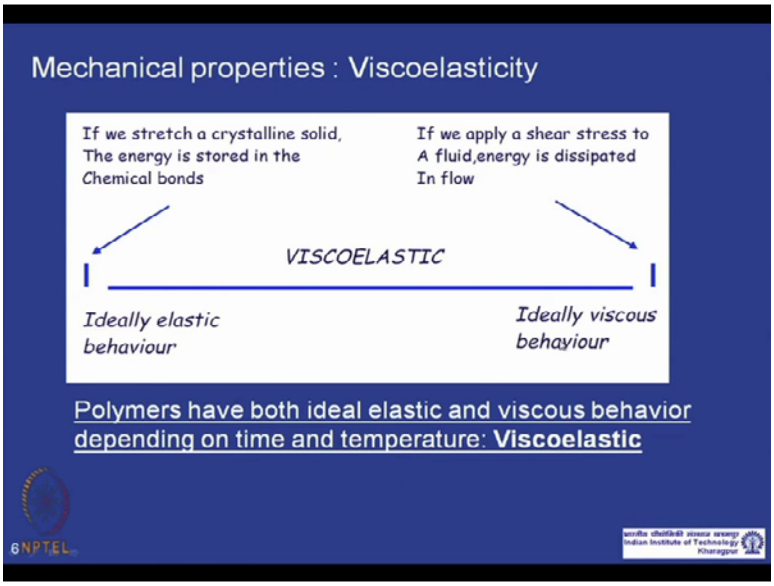

Mechanical properties : Viscoelasticity

If we stretch a crystalline solid,
The energy is stored in the
Chemical bonds

If we apply a shear stress to
A fluid,energy is dissipated
In flow

VISCOELASTIC

Ideally elastic behaviour

Ideally viscous behaviour

Polymers have both ideal elastic and viscous behavior depending on time and temperature: **Viscoelastic**

We talk about continue our discussion on mechanical properties, and we come to a concept of viscoelasticity. We have seen in our discussion, when we were doing this as stress strain curve, we have seen that the curve stress stain curve depends upon the temperature, as well as the strain rate. Now if you think about the pure elastic material, if we stretch a crystalline solid what happens? The energy stored in the material, and if we in the chemical bonds, and then if you release that stress, it will come back to the original state. We are talking about this is a ideal elastic behavior. Similarly if you have a liquid, then if you apply strain stress, if I have a liquid glass of water, and then pour it, then it will basically flow it, if I remove the stress it does not come back to the original state.

So, in case of a liquid, or a fluid if I apply as a shear stress to a fluid, energy dissipated in fluid, basically flows and energy is dissipated, energy is not stored. So, in case of elastic material energy is stored, in case of a fluid, energy is not stored, and it dissipated in the flow, so it a ideal viscous behavior. Now polymers are somewhere in between, they have depending upon the temperature, and time of straining it. They vary from elastic to, completely elastic to completely viscous behavior, and most of him in the conditions they are viscoelastic, so they have properties of both ideal solid, and viscous liquid or viscous fluid. So, polymers are both ideal elastic and viscous behavior, depending on the time and the temperature, so we call polymers are viscoelastic.

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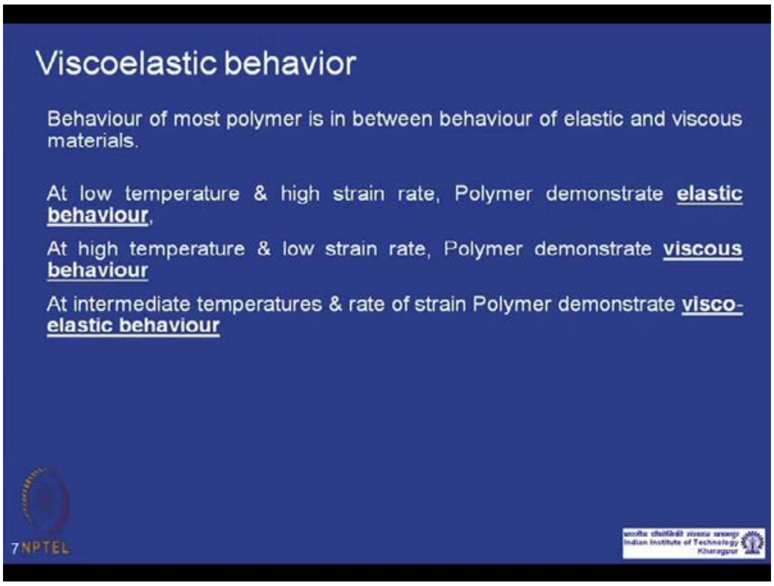

Viscoelastic behavior

Behaviour of most polymer is in between behaviour of elastic and viscous materials.

At low temperature & high strain rate, Polymer demonstrate **elastic behaviour**,

At high temperature & low strain rate, Polymer demonstrate **viscous behaviour**

At intermediate temperatures & rate of strain Polymer demonstrate **visco-elastic behaviour**

At low temperature and high strain rate, polymer demonstrates elastic behavior, as we have seen earlier in our strain stress discussion. There are low temperature polymer becomes brittle, it does not elongate much. So, polymer behavior, elastic behavior similar in high strain rate also, at temperature and high temperature and low strain rate, polymer demonstrate viscous behavior, and an intermediate temperature, the rate of and rate of strain polymer big demonstrate viscoelastic behavior. Now you can seen this viscoelasticity behavior if you have a silly putty, the toy material silly putty in home, but I do not have that material with him.

So, I have, what I have, I have the dove made of wheat flour, and I just made this dove from wheat flower, I just put some water to make it soft. Now basically what happened, this is not a ideal viscoelastic material to demonstrate, but I can show it, so that you can understand what do I mean by viscocity. this is a dove made up of wheat flour, and when I stretch this slowly, what happens, it just elongates, is basically it flows, so it keep on increasing if I apply this stress, or strain in a slower rate, so its keeps on stretching.

Now, if I apply this strain rate, high strain rate from both sides, much faster strain rate what happen, what happen, let us see what happens. Again I am saying this is not a example of a perfect viscoelastic material, but this is what, I have in hand, at this moment to demonstrate, so I am trying with whatever available at home. Now I have this and I do it very fast, what happened, it just breaks. So, what happened, again I am saying is not a perfect material to show, if you apply the strain at much faster rate, it breaks, it shows elasticity, elastic behavior, like a solid, but when you apply this strain very slowly, then it flows up chains, actually move past each other, shows flows behavior and it shows viscous behavior.

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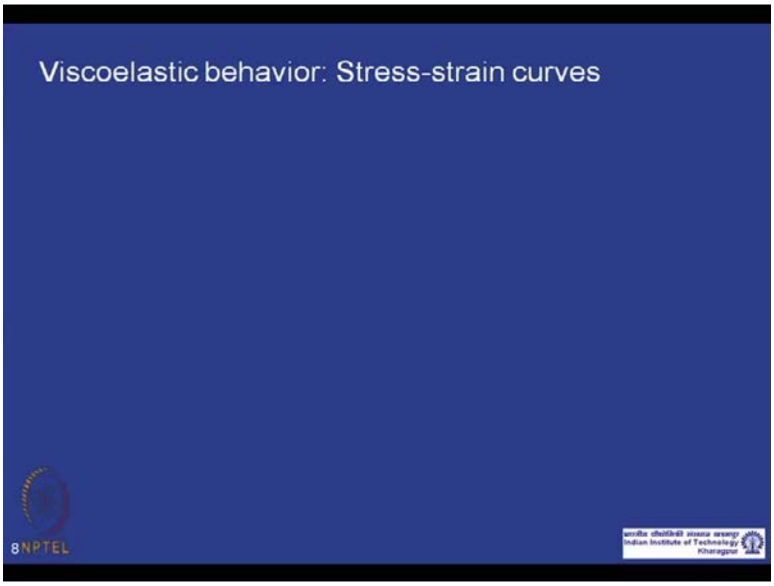

Viscoelastic behavior: Stress-strain curves

So, if I consider the strain stress curve, how does it look like, for a viscous and elastic material. First of all when we do instant testing, we… One thing we must remember that; as we do this test, the dimension of the specimen changes.

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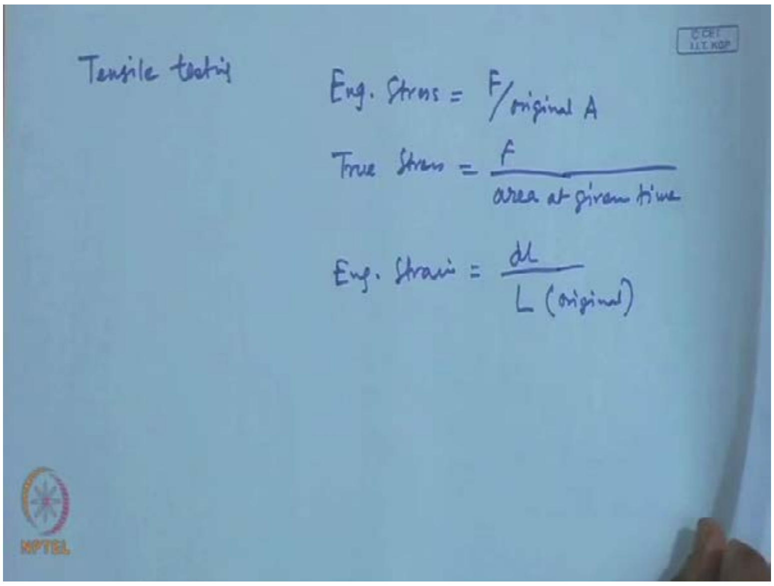

Tensile testing

Eng. Stress = F/original A

True Stress = $\frac{F}{\text{area at given time}}$

Eng. Strain = $\frac{dL}{L\ (\text{original})}$

So, actually thus the strain, and the stress, or the state actually changes, because the original dimension changes. So, this are the term sometime used; engineering stress is F force by original A, and true stress is changing, is actually basically the force by the area at given time, by similarly engineering strain is given by dL by this original length. Whereas true strain would be the L at a given time; that is the true strain. This true stress and this true strain is difficult to measure. So, generally we actually consider engineering stress and engineering strain all the time. Let us see how the stress strains behavior of this visco elastic material.

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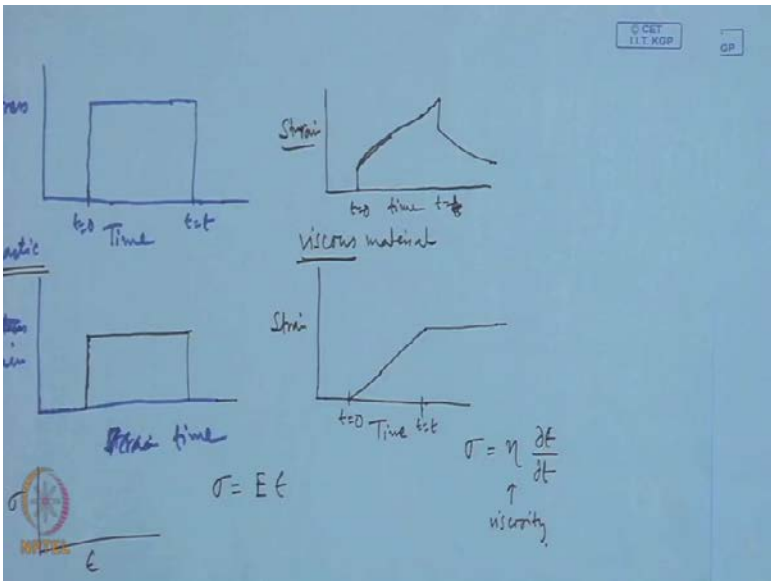

Now let us see I apply, this is stress or load. I apply some time t 0, and keep at a constant level for some time, and then release again, make it 0 at sum t t. Now what we will do, elastic material will do; elastic material, all the stress by strain curve will look like. It will change, and then go back, and then of the strain will apply, the time when you apply the stress. There will be a definite strength, this strain and stress are related by hooks law, will come back to that. Now at the time, when this stress is released it will come back to the original state, and this stress and strain is related by hooks law, they are linear and is related by elastic modulus in between, as a proportionality constant. Now what happen to a perfect. So, this is a perfect elastic material, what happened to their perfect viscous material, how the strain will change every time. Same stress is applied, same load is applied here, so with time, how the strain will change for a viscous material.

So, the time t 0, it will start straining till load is present, or stress is present, it will continue deform, and the time the stress is removed, it will remained deformed permanently. It does not come back to the original state, or end there is not any recovery at all, so this is a perfect viscous material. And here stress is linked to the rate of change of strain with time, and the proportionality constant is the viscosity. What happened to a polymeric material; the visco plastic material, how does it happen, how does it respond with time. It basically, let me show here strain. So, at the time, you apply the state, it will strain to some extent, and then keep on continually forming, till the load is present. And when the load is removed at t is equal to t, it will recover some part, and then stay somewhere, so it does not come back to the original so on. So, this is a, basically example of visco elasticity.

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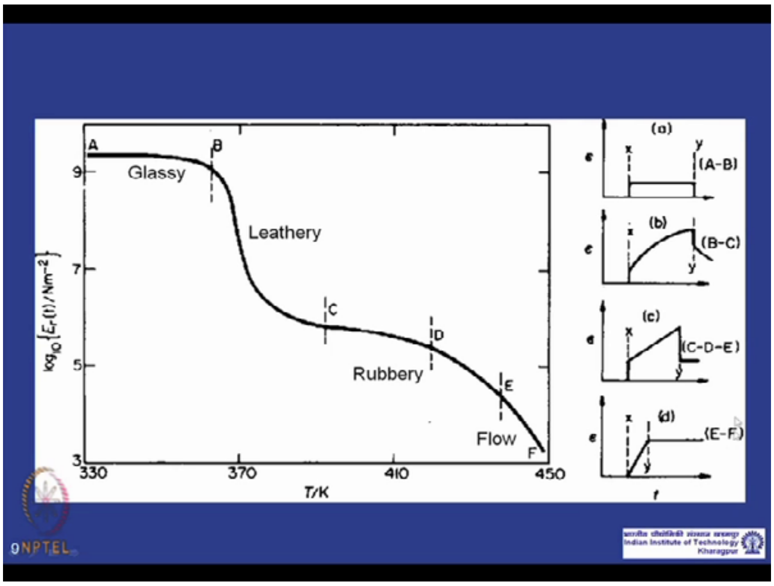

So, if for a polymer, with temperature you can, see all this behavior. Let us talk about a amorphous material; the glassy state A to B is a perfect glasstic material, so if you apply stress strain, apply a stress it will strain, as long as stress is there, strain will be there, if you remove the stress the strain will become 0, so that is the example of perfectly glassy material or elastic material. So, this part glassy part will behave like a perfect elastic. what about the leathery part, B to C. When you apply the stress apply the load, it deform fast, and then as long as the stress is present it will continually deforming, and the movement this stress is removed, it will come back, the elastic component is recovered here, and then slowly recover some of the strain, but it will not come back to the 0 strain value, there will be a permanent deformation here, so this is example showing visco elasticity. So, the fact that it is not coming back to the original state, it is showing some loss of energy, some viscous behavior, and part of it is actually getting recovered, which is the behavior of a elastic solid, so that is the reason, it is a example of the visco elastic behavior.

Similarly in case of rubber, a similar behavior, and in case of above very high temperature is like a polymer melt, it does not recover at all, and it continually gets deformed as long as stress is present, so you get a complete viscous behavior. So, with temperature a polymer material can show different types of visco elasticity behavior from a perfect elastic to a perfect viscous behavior, within (( )) behavior of visco elasticity. Similar thing can be shown in case of that strain rate, with higher strain rate, it will behave more elastic, and is very slow strain rate, it will be close to perfect viscous and intermediate strain rate, it will be, so visco elasticity. Now, let us move to the other properties of polymeric materials, what we discuss, we just completed discussion of mechanical properties. Now we will talk the other properties, and again we will not go into very detail description of these properties, and how it is evaluated. We will just give brief introduction, brief description of those test.

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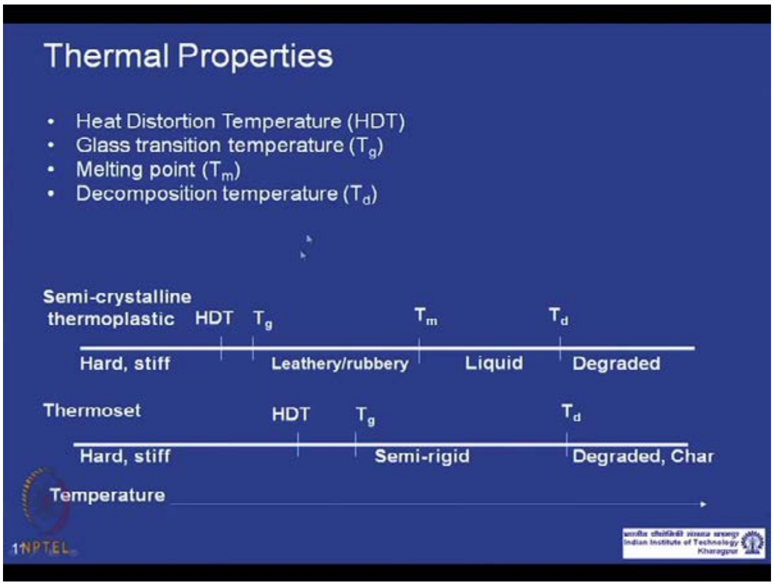

Thermal Properties

- Heat Distortion Temperature (HDT)
- Glass transition temperature (T_g)
- Melting point (T_m)
- Decomposition temperature (T_d)

Semi-crystalline thermoplastic
HDT T_g T_m T_d
Hard, stiff | Leathery/rubbery | Liquid | Degraded

Thermoset
HDT T_g T_d
Hard, stiff | Semi-rigid | Degraded, Char

Temperature

Let us first talk about thermal properties, we discussed about the glass transition, and the glass transition and melting behavior of polymer earlier. Thermal properties are basically the response of polymeric material, when the temperature increase or heat is supplied to the polymeric material. Now besides the glass transition temperature and melting point, the other behavior polymer material can show is the heat distortion temperature, or has a softening temperature, and very high temperature, above of T m, when if you keep raising the temperature k if you keep raising the temperature, the polymer might decompose and gives decomposition temperature.

So, in a general, in case of semi crystalline thermo plastic material, you have; first you have heat distortion temperature, the softening temperature. Then you have glass transition temperature, then you have melting point or melting temperature, and then the degradation temperature or decomposition temperature. For thermo sets, you do not have

T g you have thermosets, you have HDT and T g, and then finally, the decomposition temperature. We talked about the glass transition temperature, and melting point earlier.

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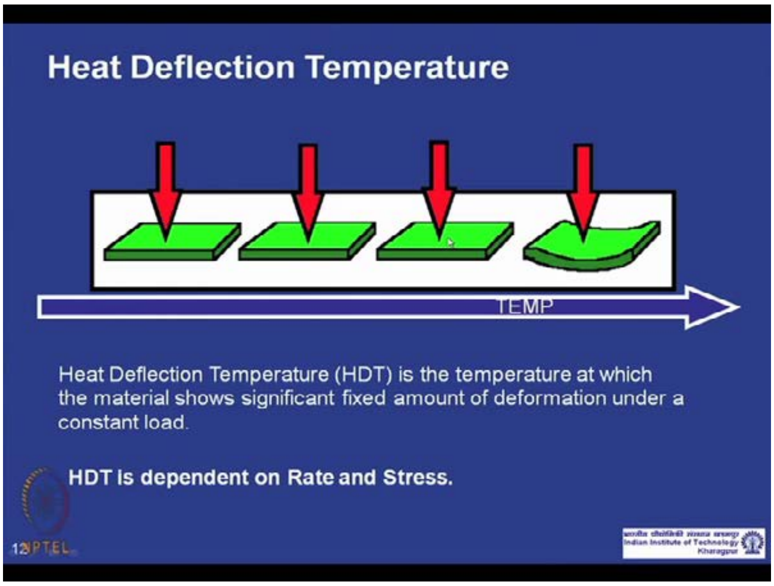

Heat Deflection Temperature

Heat Deflection Temperature (HDT) is the temperature at which the material shows significant fixed amount of deformation under a constant load.

HDT is dependent on Rate and Stress.

So, we want to discuss about other thermal behavior, with of all the polymer behavior with temperature. This is from a practical point of view; this is the temperature where its starts softening, the polymer actually starts softening under some load. So, heat deflection temperature is a temperature at which, the material flows shows significant amount of the deformation, under a constant load. Now this significant amount, fix amount is basically is prefixed. So, if you compare, you want to compare between materials, you can compare with the amount of deformation, same amount to deformation between the materials.

So, basically what is the test is done, that one polymer samples is specimen is taken, and one load is applied; a definite load, constant load, and then temperature is slowly increased, at a given rate. And at some temperature, this deformation happens, and that particular temperature is known as heat deflection temperature. And like other HDT temperature will depend upon how fast you are heating up this material, how fast you changing the temperature, and obviously, the amount of load is present. The higher is the load, lower will be the temperature, heat distinction temperature.

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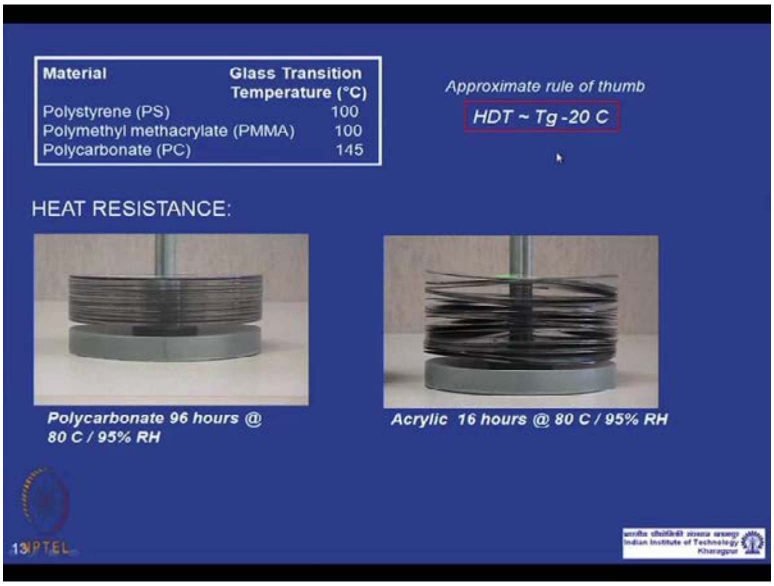

Material	Glass Transition Temperature (°C)
Polystyrene (PS)	100
Polymethyl methacrylate (PMMA)	100
Polycarbonate (PC)	145

Approximate rule of thumb

HDT ~ Tg -20 C

HEAT RESISTANCE:

Polycarbonate 96 hours @ 80 C / 95% RH

Acrylic 16 hours @ 80 C / 95% RH

Now why it is important, let me you a example. Now these are all amaphorous material; polystyrene, poly polymethcalate, and polycarbon BPA polycarbonate, and Tgs are, approximate Tgs are listed here 100 145. So, looking at this material, if you say that, if you make some specimen or some product of the material, this materials will survive till around 100 degree centigrade, but that conclusion will be erratic, if we see this example, these are CD disc made from polycarbonate, and these are made from polyemethylene immaculate. Now, these were subject to a, heating conditions for 96 hours at 180 degree centigrade and 95 degree erratic immunity. Same thing here, but much lower, the picture is after much lower duration, at 80 degree centigrade.

Now 80 degree centigrade is actually below the Tg, well below the Tg of the PMMA sample, so you should expect, the polymer should survive. But when you make a part its has its own load, it has some weight, so it has own load, and when you stack it this disk, basically the lower one will also have load from top. So, at 80 degree itself it is deforming, which means it should not be used. A disk cannot be made up of PMMA, will not survive a temperature of 80 degree centigrade. So, this is what signifies, so if you want to make a disk and find the, which will be used for an application at higher temperature, you must know the HDT of that particular material. HDT is typically as general rule of terms about Tg minus 20 degree centigrade. So, Tg is not sufficient for practical point of view, you must know the softening temperature.

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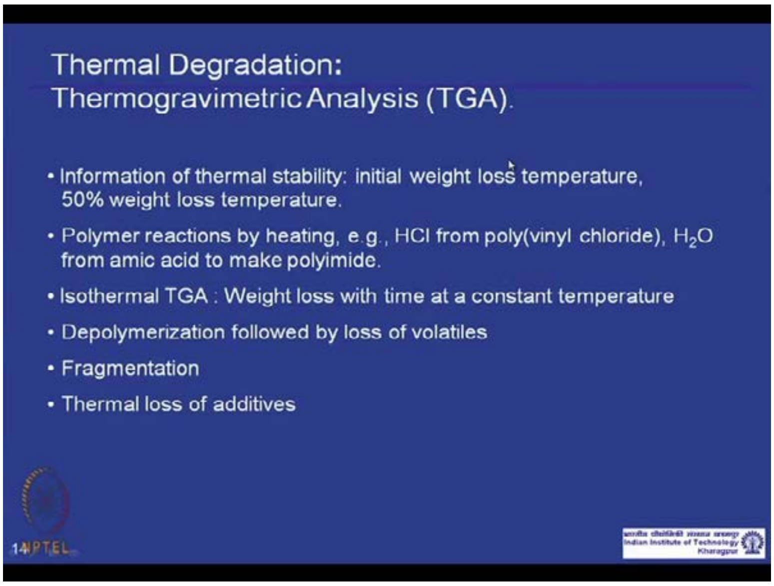

Thermal Degradation: Thermogravimetric Analysis (TGA).

- Information of thermal stability: initial weight loss temperature, 50% weight loss temperature.
- Polymer reactions by heating, e.g., HCl from poly(vinyl chloride), H_2O from amic acid to make polyimide.
- Isothermal TGA : Weight loss with time at a constant temperature
- Depolymerization followed by loss of volatiles
- Fragmentation
- Thermal loss of additives

Now, if you increase the temperature of polymer, polymers typically degrade. This is very important in processing point of view, because while processing the polymers, are subjected to very high temperature. And as we have seen that T g plus sometime 150 centigrade at T m plus 50 degree centigrade or even more, and under shear, in case of processing with applying this melds and mixed to with (( )), so does in case of molding, which mean that is undergoes polymer might degrade, and decompose of those conditions. So, to find out, what is inherent thermal degradation behavior, the thermogravimetric analysis is done, which is in short called TGA.

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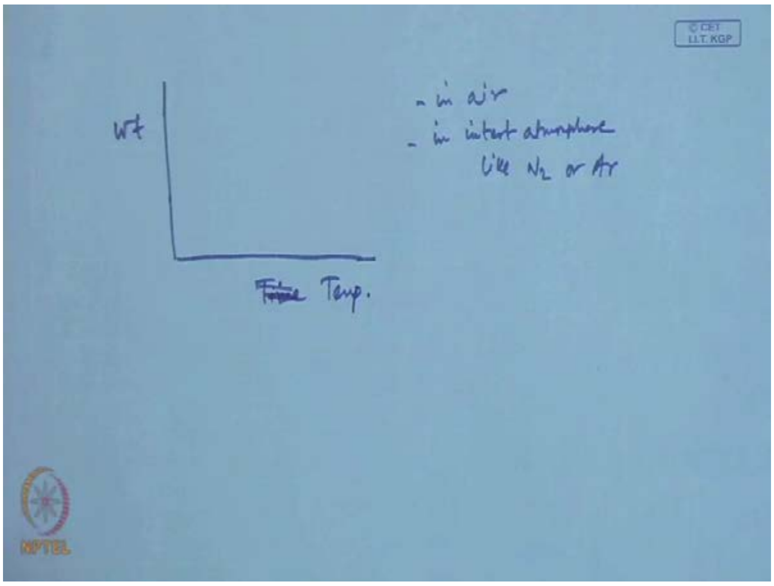

Now T g is basically plot of white class of temperature, is just nothing but plot of weight or mass to utilize for this, the temperature. Again the heating can be done at in air, or intent atmosphere, like the nitrogen gas or organ gas. Obviously, in air the decomposition rate, and the decomposition will be a much lower temperature, compare with situation, where the heating is the temperature is increase under, nitrogen organ. So, it is floated against temperature. Now with, you can get this information from this test, basically we can know, at what temperature this polymer start decomposing or degrading, and we can basically find out the temperature at which 50 percent weight loss or complete weight loss, whatever is you interest. A sometime small molecule comes out of the polymer, though we are heating, like is HCl from polyvinyl chloride H 2 O from amic acid.

So, if you can from the weight loss, we can get some idea about whether that this type of reaction is happening. You can also do isothermal T g where weight loss is monitor, with time and constant temperature. So, basically that will give us some idea, if we keep that polymer material at that particular temperature for long time, as especially in elevated temperature, where there is some degradation or decomposing happening or not. And at higher temperature, polymers some time depolymerisation depolymerise, which might lead to some volatile monomers. So, which we can get some idea about TGA, fragmentation happen during heating or as we have seen that some time additives are used during polymer formulation, so if they are, on heating if there is some loss, thermal loss of those additives, that can be also found out.

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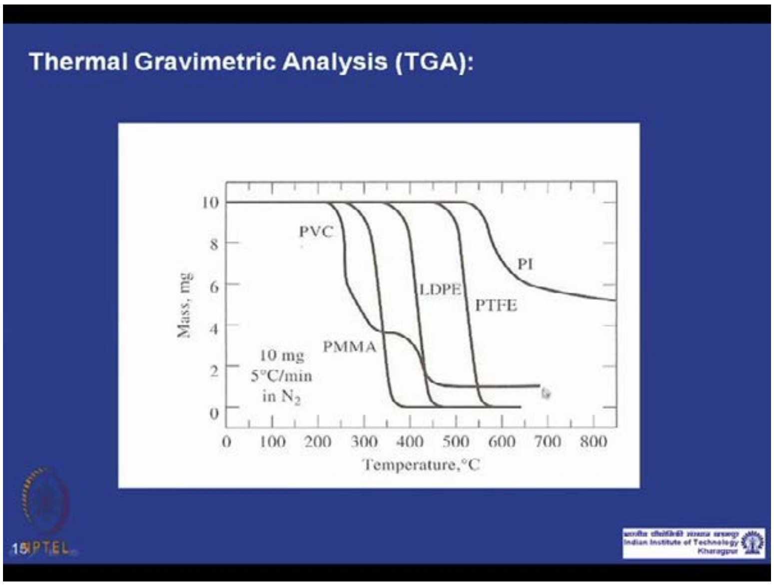

Thermal Gravimetric Analysis (TGA):

This is typical thermo gravimetric curve of different polymers, PVC PMA LDP PTFN PI in nitrogen, and these temperatures are corresponding on said temperature, and the 50 percent temperature, the temperature for example, for PMA this is the temperature correspondence to 50 percent weight loss. Now the amount of mass is remaining after complete bonding, is what, is char, what is the char, means formation after heating, and that is very important when you talk about the flammability, and fame resistant behavior of the polymer. So, in this case, basically it is showing that there is no char formation is taken place, basically entire polymer is de composed off, and as gone out. If in this case for PVC, there is a significant amount of materials remaining, even after complete bonding. So, there is some char formation as happened in case of PVC. Obviously, it also depends on how fast you are heating.

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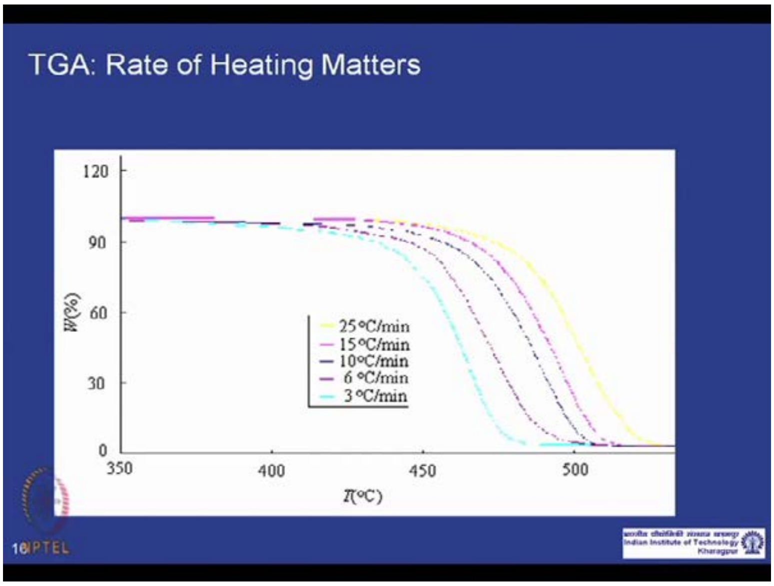

TGA: Rate of Heating Matters

So, the slower the heating, you will see the decomposition temperature, at lower temperature, where as higher heating will take to higher temperature, basically polymer cannot follow, the heating, if you are doing the heating in much faster rate, the polymer cannot follow the heating profile. So, the effective temperature actually becomes slower, if you increase the heating rate. So, if you want to compare between different polymers, the thermal stability at higher temperature you must compare, at same heating rate.

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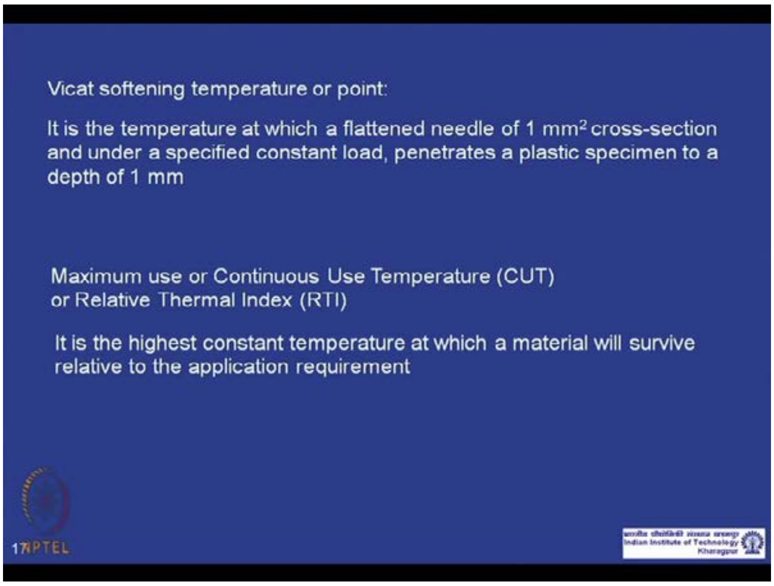

Vicat softening temperature or point:

It is the temperature at which a flattened needle of 1 mm^2 cross-section and under a specified constant load, penetrates a plastic specimen to a depth of 1 mm

Maximum use or Continuous Use Temperature (CUT) or Relative Thermal Index (RTI)

It is the highest constant temperature at which a material will survive relative to the application requirement

Now there are other like thermal behavior, thermal test basically done, is high cut softening temperature point. It is the temperature at which a flatten, needle of one mille meter square cross section, under specific constant load is applied, and the temperature at which penetrates, the plastic specimen to a depth of one mille meter, it is known as high cut softening temperature. Another important parameter, or thermal behavior is, the maximum use, or continues use temperature, or it sometime called relative thermal index. It is the temperature, the highest constant temperature at which the material will survive, related to a application requirement, what does it mean.

It means that, you can use how long, and what is the service temperature, if you can make like that example I showed in the C D, what is the service temperature, that like means what is the maximum temperature, it can survive for long duration, at a for the particular applications. If you want your C D material to survive for ten years, then you must specify what is the temperature? You can find out what is the maximum temperature it can be use. So, you know like in hot countries, the temperature may go up to 45 50 degree centigrade. So, if you want to survive, then your material, the maximum temperature at least should be 45 degree or 50 degree. If we talking about a plastics, which I used in a car bonnet, then you know that on getting constant heat from outside, the bonnet temperature may go up to 80 degree 90 degree centigrade.

So, if you want to design one material, or test some material, which will survive the duration of cars life time about 20 years, or 15 years, then you should test that in advance. So, this done in laboratory, in a escalated way, where basically the specimens are heated, in a elevated temperature, with some relative humidity, and with time the retention of properties are monitored, and then compared with an existing material, which is already in application, for long time. So, if you compare, with material which is existing in that particular application for long time, and if you compare your material, test material, which is as good as that particular material, or even better that particular material in the escalated lab test, then you know that you material will survive that particular temperature, at least as good as the material, which is in the market.

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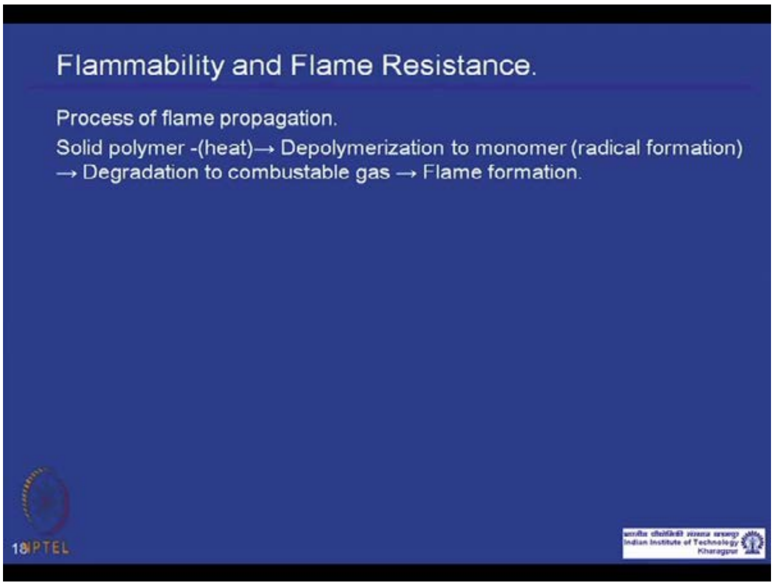

Flammability and Flame Resistance.

Process of flame propagation.

Solid polymer -(heat)→ Depolymerization to monomer (radical formation) → Degradation to combustable gas → Flame formation.

Let us go through the next property, which is flammability, or flame and flame resistance properties of a polymer. Now again this will be just briefed, we will have a brief discussion on this properties, and subsequent properties. Basically when you, basically put fire on a polymeric material, it basically de polymerized to monomer, and it degrades to combustible gas, and in the presence of heat it basically have form flame and it burns. So, that is the original flammability of polymer materials. So, if you want to decrease the flammability, you basically have to remove this combustible gas, from the system, and basically has to reduce, when the heat formation, heat generation on bonding this polymeric materials.

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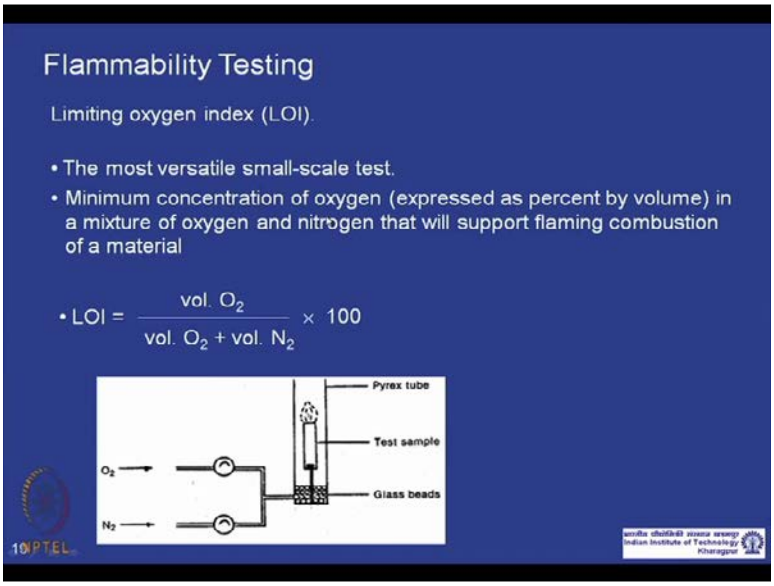

Flammability Testing

Limiting oxygen index (LOI).

- The most versatile small-scale test.
- Minimum concentration of oxygen (expressed as percent by volume) in a mixture of oxygen and nitrogen that will support flaming combustion of a material

- $\text{LOI} = \dfrac{\text{vol. } O_2}{\text{vol. } O_2 + \text{vol. } N_2} \times 100$

How the testing is done. In the lab the testing which is done is, call limiting oxygen index, it is most versatile small scale test. It is defined as the minimum concentration oxygen, expressed as percentage by volume; a volume percentage in short, in a mixture of oxygen and hydrogen that will sufficient, enough to support flaming combustion of a material. Now, how many how long the flaming will happen, that has to be fixed for, comparing between materials, typically it is three minute bonding or flaming. So, what is the experiment is done, oxygen and nitrogen are mixed, and basically starts with pure nitrogen, and oxygen is increased slowly, to find out that the minimum oxygen required in terms of volume percentage in this mixture, to sustain this flame for a specified time said for three minutes. So, limiting oxygen index is basically, the volume of oxygen required, by the total volume into hundred that gives a percentage of material. Now the other test also there, which have done in a real applications, where basically, which is been guided by U L laboratories.

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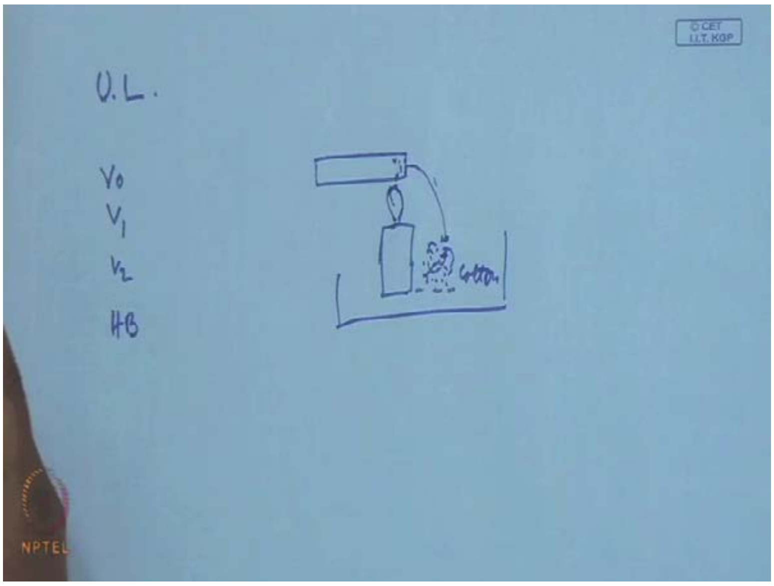

And the rates the rate materials, in terms of different, this gives the different ratings like V 0 V 1 V 2 H B and those things. In this case they keep this specify specified geometry of sample like, and this states, this states are very difficult to carry out repeatedly, and the only trained and certified person actually do test, for this a comparing material, or give the rating. What happened you basically take the sample, and applied the flame, from a particular distance, and some cotton are placed. These are cotton placed in the container below. So, if it burns, and the while burning the sparks comes and ignite the cotton, which basically gives lower rating.

So, a sample, which burn from less time, and which also does not ignite the inflammable material like cotton, present in the bottom of the container, they actually gives the best ranking. It basically try to mimic the applicable a actual application, when the polymers are, actually used in a application, what you want you want the polymers in case of a emergency, what do you want. You do not want the polymer to burn, with a flame, and even if its burn, then it should not actually gives, or ignite the other material, other inflammable material in the. It should not drip to the floor or some other inflammable or combustible material, so that the fire spreads. Also important is that, it should not generate toxics smoke; that is also important. So, in case of fire resistance material, flame property it should not burn, if it burns, it should not drip and ignite other inflammable material, and third it should not generate toxics smokes. So, these are the three criteria of a very good flame resistance polymer.

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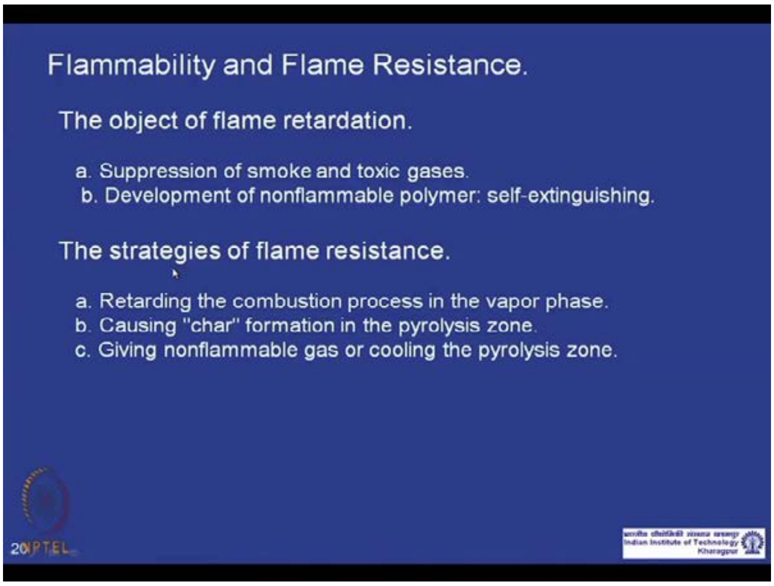

Flammability and Flame Resistance.

The object of flame retardation.

a. Suppression of smoke and toxic gases.
b. Development of nonflammable polymer: self-extinguishing.

The strategies of flame resistance.

a. Retarding the combustion process in the vapor phase.
b. Causing "char" formation in the pyrolysis zone.
c. Giving nonflammable gas or cooling the pyrolysis zone.

So, objective of flame integration, which to suppress, suppression of smoke, and toxic gas, it is actually is a known fact that, when something burns, it is a, if the causality or fertility of the people is mostly, because of the toxic gases, at first few minutes. So, if you suppress the toxic gas generation, for first few minutes, then in case of emergency, people can go out of the situation, and survive. Whereas if the toxic generates immediately after burning, then what happened, they cannot, they actually get ill immediately, and they cannot run away and find a safer place. So, strategies to flame resistance is, to retard combustion process in differ phase, and char formation, causing char, if you have a polymer which forms high level of char, typically halogen containing polymers, and also inorganic polymers, and sometimes added additives, which does not, ceramic additives for example, which does not burn and just go out of the system.

They actually contribute to char conformation, and which actually suppress there, is basically prevent supply of this compostable gases, to this pyrolysis zone, and just by decreasing the met flammability. We just go to the next set of the properties, where is basically expo. What happened to the polymer getting exposed environmental situation; for example, polymers will come across different chemicals, if you talking about a medical devices, doctors or medical persons, always apply some rectifies spirit, ethanol to disinfect, so your material has to survive, so that has to be chemical resistance of the chemical, medical professions are using.

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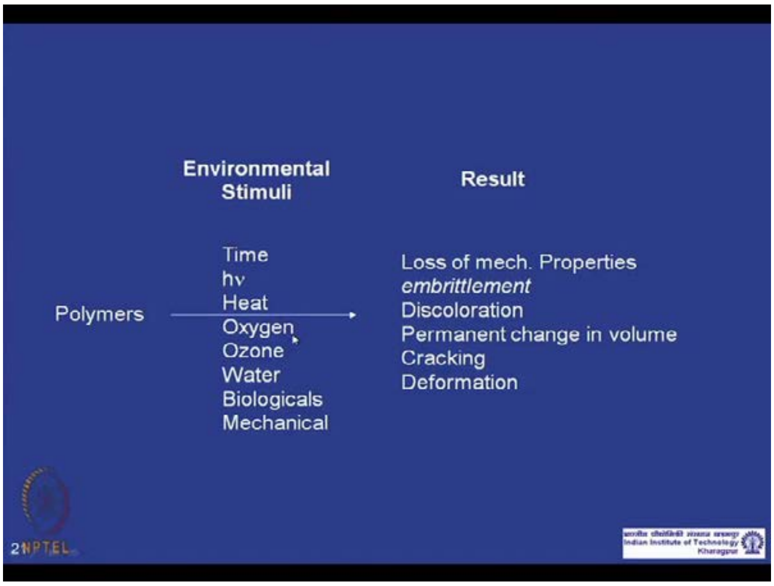

Environmental Stimuli

Result

Polymers

Time
hv
Heat
Oxygen
Ozone
Water
Biologicals
Mechanical

Loss of mech. Properties
embrittlement
Discoloration
Permanent change in volume
Cracking
Deformation

It has to be, any outdoor materials, plastics material they come, every day come across the UV light, heat, outdoor heat, rain, and the bacterias and the viruses present in the material, so that is in oxygen of the environment. So, basically that combine, we call that weatharability basically, when some polymer, or some plastic material is applied, we find weather ability. Weatherability is basically combination all this effects; like rain, air, heat, light, so combine all this we call of. So, if a material or plastic which survives longer, in that outdoor condition, it is a weatharable material. So, we test weather ability in the lab, in the accelerated chamber, which basically may make the outdoor condition, with control parameters, and we subject the experimental specimen in that condition, and after in a frequent interval, we basically test there mechanical, other properties like optical properties to find out where it is sustained in the particular, weather condition or not.

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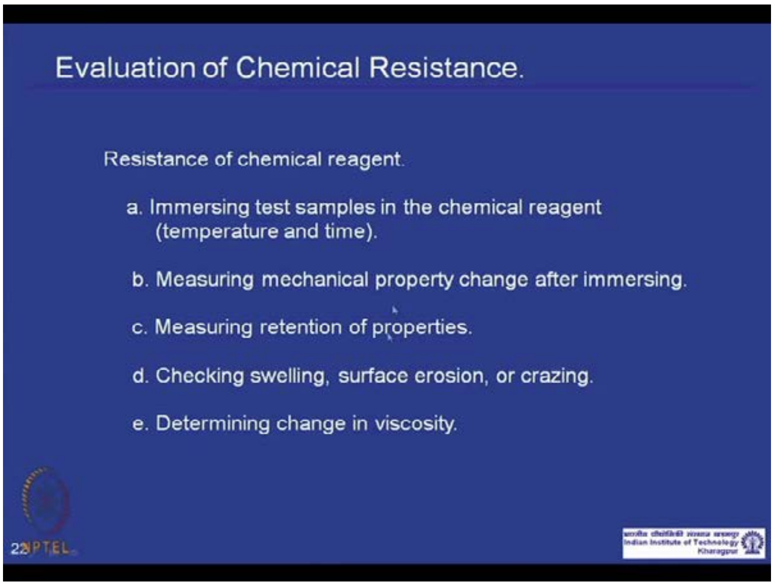

Evaluation of Chemical Resistance.

Resistance of chemical reagent.

a. Immersing test samples in the chemical reagent (temperature and time).

b. Measuring mechanical property change after immersing.

c. Measuring retention of properties.

d. Checking swelling, surface erosion, or crazing.

e. Determining change in viscosity.

In case of chemical resistance we basically apply. Say we actually immerse the test sample in that particular chemical agent, for that particular temperature, and for a particular specified time. And after that we take out that material, and measure the mechanically property change, whether it survived or not. We see, we visually inspect the material, whether any swelling has happened or in surface eroded or some cracking and crazing is happened. And we also see whether the molecular rate of the material has changed, by the applying the coming in contact with chemical agent, which can be done by the measuring the viscosity of material.

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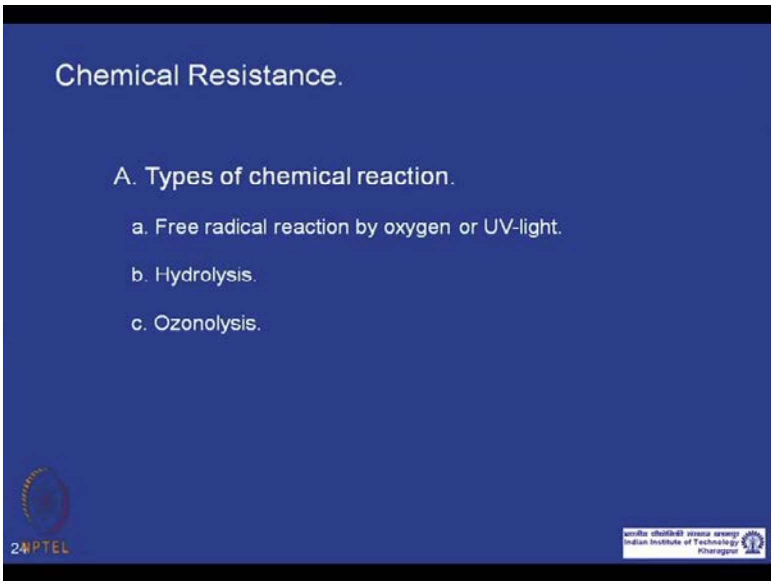

Chemical Resistance.

A. Types of chemical reaction.

a. Free radical reaction by oxygen or UV-light.

b. Hydrolysis.

c. Ozonolysis.

So, what will do we stop here for this lecture, and we will talk about other properties like, optical property, and barrier property, and surface property in next lectures. We will also talk briefly, that most often polymer are not used as such, they are basically used with other radiatives, which basically protect some of the, this polymers, this external agent we talk about, or this enhances the property, which can be used from outside. So, we stop, and start with the rest of the property in the next lecture.