Polymer Chemistry
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Lecture - 37
Polymer Properties and Evaluation: Mechanical properties

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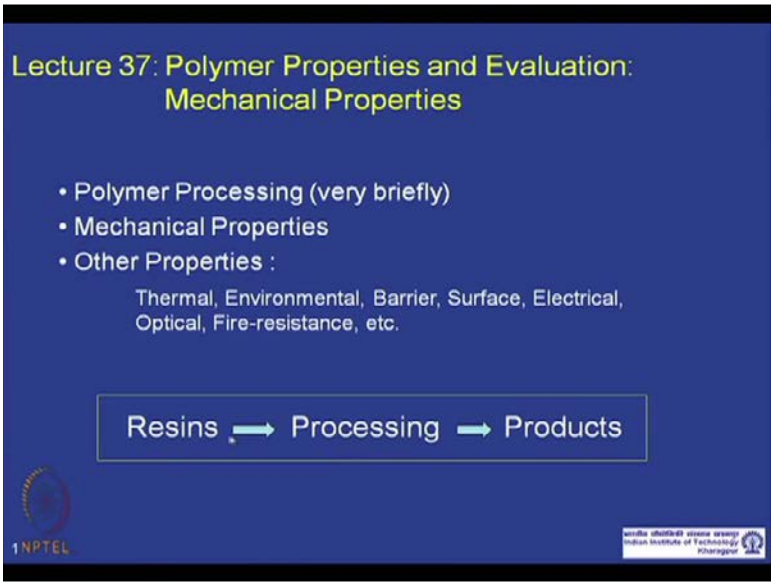

Welcome back to this course in Polymer Chemistry. And in today's lecture, we are going to start our discussion on polymer properties and how they are evaluated, this properties are evaluated. And today we will start how discussion in mechanical properties, which may be continued in next lecture as well and then, eventually we will discuss very briefly the other properties. Now, this lecture and probably, next one or two lectures is not directly related to chemistry for say but, as a polymer chemist, if we if you are hired in a company then, you must know the polymer properties.

Because, this is when you doing some polymer synthesis and characterizing them, finally you are targeting for some application and applications are linked with polymer properties. So, unless you do not know, what the power polymer properties means, how their evaluated and how they are related structure how they are related to the polymers structures then, it is difficult for you to design a new polymer and then, synthesis it. So, it is very very need a basic need to understand the polymer properties at least in brief.

And out of the polymer properties, I will spend more time on basically, we will discuss in detail about mechanical properties because, as you will see in next one or two lectures, this is the most important properties of the polymers. And some other properties like thermal properties, environmental properties, they are linked to the mechanical properties. Linked means, what I mean that basically, the polymers are exposed or be in contact with heat or some environment conditions and then, the properties mechanical properties of polymers are followed according after exposure.

So, mechanical properties is the most property for polymer and I will discussed the mechanical properties in the detailed. And I will very briefly covered the other properties like thermal, environmental, barriers, surface, electrical, optical, fire resistances, etc. And before I start discussion on polymer properties, I want to very briefly talk about polymer processing. Mainly because, the fact that, till now we have understand or we have gain the knowledge of polymer resins, you know how to synthesis them, how to characterize them.

And then finally, these polymers will be applied in product, in applications and the step which converts the polymer resins into product is called processing. So, polymer properties are tested on the final product or final specimens so, unless we know the polymer processing step, their it there will be gap between resins and a product or applications. So, this is again not directly related to chemistry but, you must know the basic nomenclatures and basic techniques, how which how by which the polymer is converted from a resin to a product for final applications.

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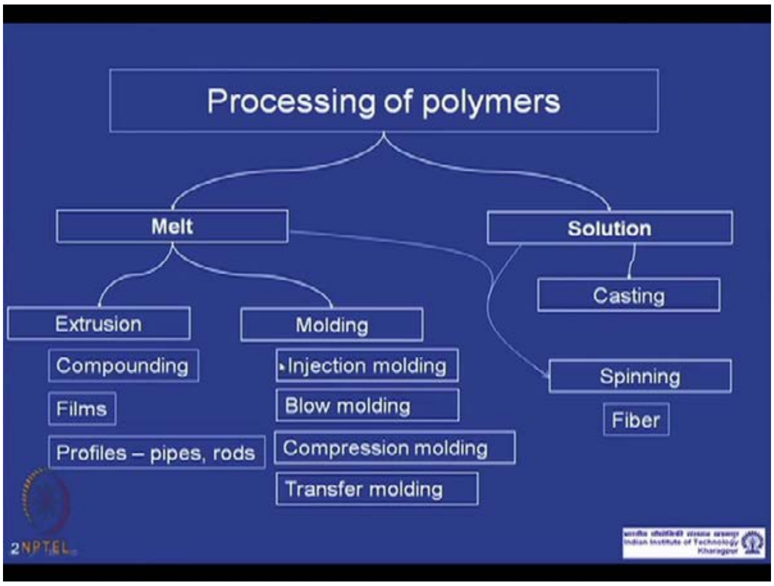

So, let us start our discussion on polymer processing very briefly as I said, polymer processing can be done from a melt state or a solution state. Melt state, there are two three techniques mainly, extrusion, molding, thermoforming, by which the polymer converted to final specimen. And for solutions, we can do casting is applied to making films and spinning is applied to both from polymer melts or polymer solutions for example, making fibers.

Now, as I as I said that, melt from the polymer processing from melt state are mainly three types, we can mainly two types, we can say extrusion and molding. Extrusion is basically a step where, a compounding is mixing is done between the polymer resin and other other additives or reinforcement colorant and all these things. And then, taken to the molding state to give the final part or extrusion techniques can be used for making final parts like, very simple parts like film, profiles like pipes, rods and so on.

Moldings are are these, these are techniques of molding injection molding, blow molding, these are applied for thermoplastics and compression molding transfer molding design applied for thermo sets. So, what I will do, I will discuss this techniques important techniques like compounding, injection molding, blow molding, compression molding in very briefly. So that, you know you have some idea about how this extrusion molding is done.

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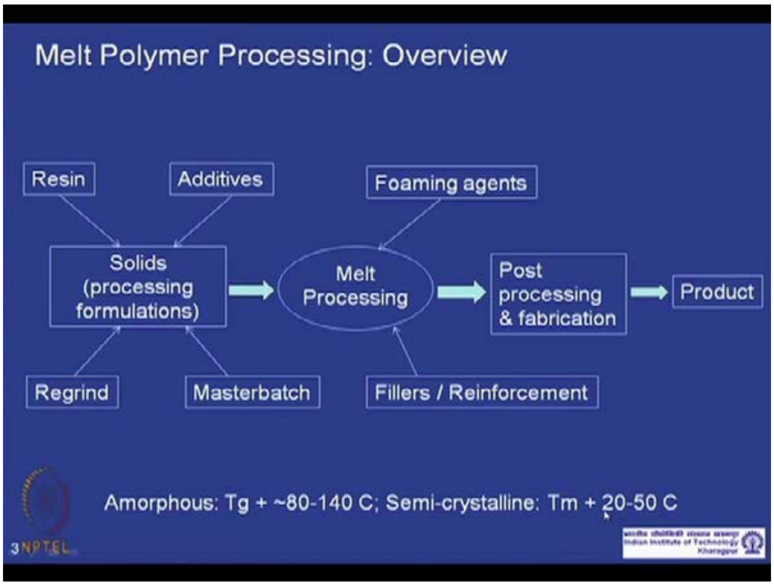

So, how the as the overview of the main processing technique, there is a formulation where, this poly solid polymer is added. And if you need additives, invariably we need really, that the 100 percent polymer is used for any formulation. There will be invariably some additives added and they can be mixed well and if there are color master batch or some other master batch, they can be added here. So, this is the formulation and then, they are taken to melt processing steps like extrusion, it could be two step extrusion followed by molding or it can be just extrusion step.

And then, you finally get a the specimen where, some post processing steps are done like for example, if you are making a DVD then, the polymers are taken and then, extruded and finally, injection molded to a DVD form. And then, the company takes it and put the data in it and put the decoration and finally, sell it as a product. In this stage, you can add other agents like foaming agents, which makes the final product foam product or you can add the other fillers and reinforcement material.

Typically, amorphous materials are processed melt process at T g plus sum or 80 to 140 degree centigrade temperature. Higher and semi crystalline materials as processed at melting temperature placid, temperature 20 to 50 degree centigrade.

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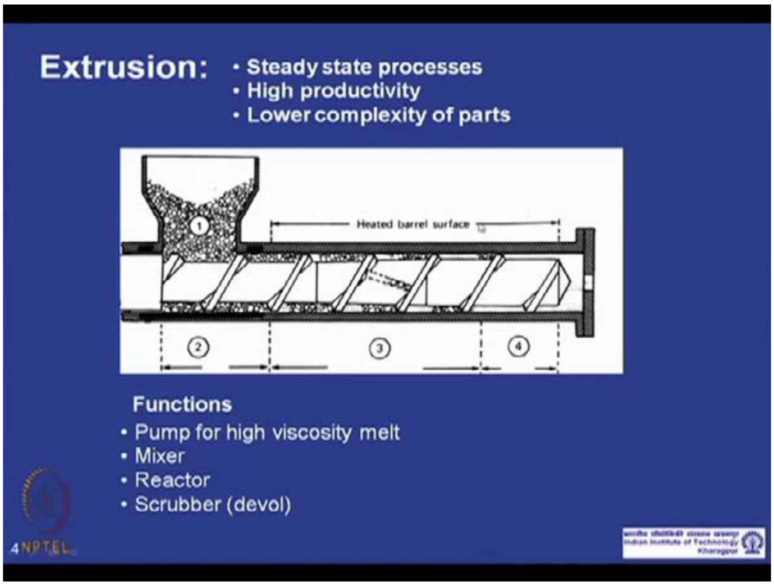

Talk about briefly extrusion process, extrusion process as said, this is steady step process, this is continuous process having high productivity and it is used for making low complexity of parts like pipes sheets and so on. This is a schematic or structure or a scheme of a extruder where extrusion is made, a one screw is shown, this is a single screw extruder. That in some other cases, there could be two screw, which makes that instrument as twin screw extruder.

It has different zones having different temperature within increasingly, if you go from left hand side to a right hand side, the temperature generally increases and becomes steady somewhere in this region. And there is a dye, by which the molten polymers are extruded out and cooled with the real cooled or cooled in a in water medium, it could be cooled in a both the ways. So, basically in the first part, all the ingredients are added and those ingredient are mixed here, molten in this part, melted in this part and mixed thoroughly and as the screw rotates, the melt is pushed forward.

And finally, the melting is comp and melting and mixing is completed here and this this polymer melt is comes out from this dye. And if you have different shape dye like sheets, you can form sheets or pipes here itself or if you want to use this material for for further injection molding or some other molding, still you can cut into granules in small pieces and make them as a granules. Some other large companies, large polymer manufacturing companies, they just mix all this ingredients and extrude the polymer and make granules and sell those granules in big bags.

And those are purchased by the final or original equipment manufacturer, they just take those granules and do the molding at there there into make the final product. So, the function of extruder is to pump the high viscosity melt, also mixing the ingredient. Sometimes, if you add some, if deliberately wants some reactions to happen at higher temperature then, you can do in extruder. Sometimes, they are unwillingly or unwantedly some reaction also take place inside extruder. And if there are volatile materials then, you can add some vacuum somewhere here to remove those volatiles materials.

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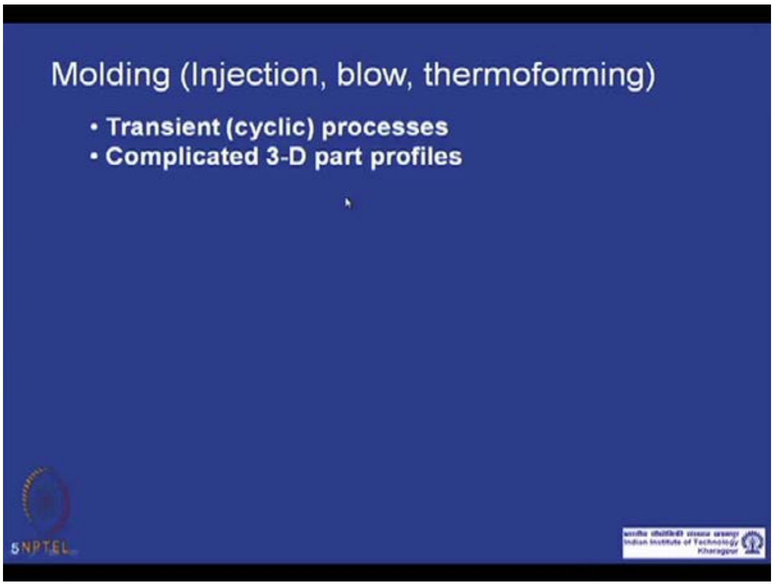

So, going to molding and molding is a cyclic transient process and is molding can be used for making complicated three dimensional parts, as I said it could be injection molding, blow molding, thermo forming.

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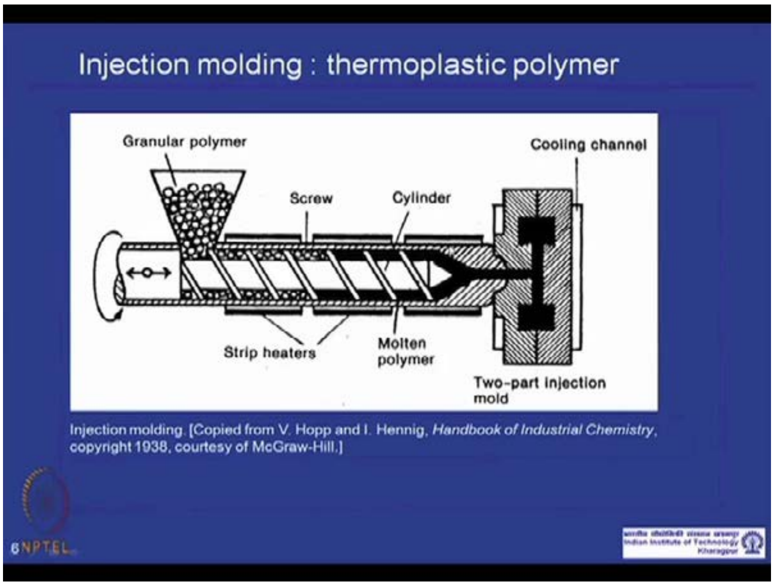

Injection molding is done mainly for thermo plastic material and it is similar to the extruder machine, there is a hopper where, you add the gremial polymer material and some additives, which act as a mold release agent. So that, after the part is formed, it can easily taken out from the mold, there is screws, it basically melts and mix those those polymers with additives here and this screw by rotating it, takes it forward.

There is a cylinder somewhere here, which basically pushes the polymer melt mix polymer melt in the mold and when molding is done, it is cooled and the part is ejected from this material this mold.

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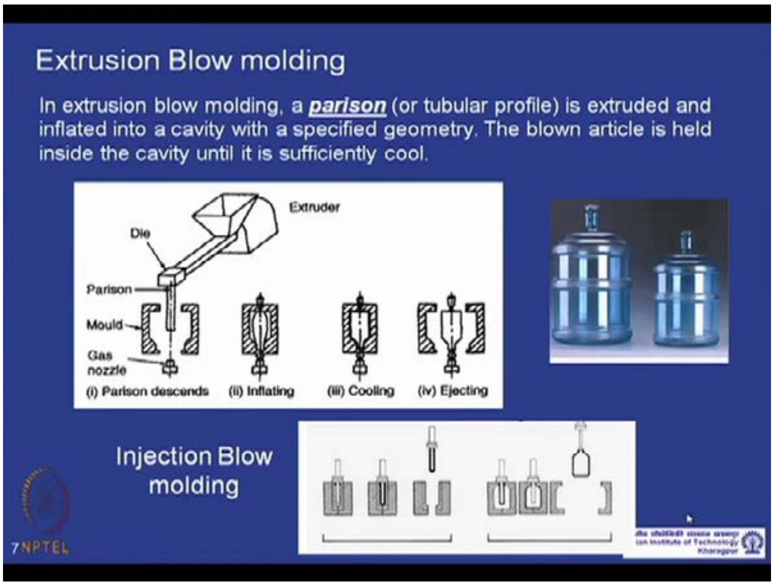

Other techniques like extrusion blow molding where, the extruded polymer is placed in form a tubular profile is like this, this is a tubular profile and it is placed inside the mold. And then, the inherent gas is injected through to inflate this tubular profile, till it get the shape of the mold. And finally, it is cooled here and the part is taken out, it is used mainly for bottles, hallow materials like bottles and similar materials. Similarly, in in adjacent to extrusion blow molding, injection blow molding also can be used where, this parison, this tubular profile is basically injected in this mold.

And the rest of the steps are similar where, it the molds inflated with the inner gas and then, cooled and the part is taken out. So, injection blow molding and extrusion blow molding is similar, except the the way this parish ion is inserted in the mold so, this scheme is shown here.

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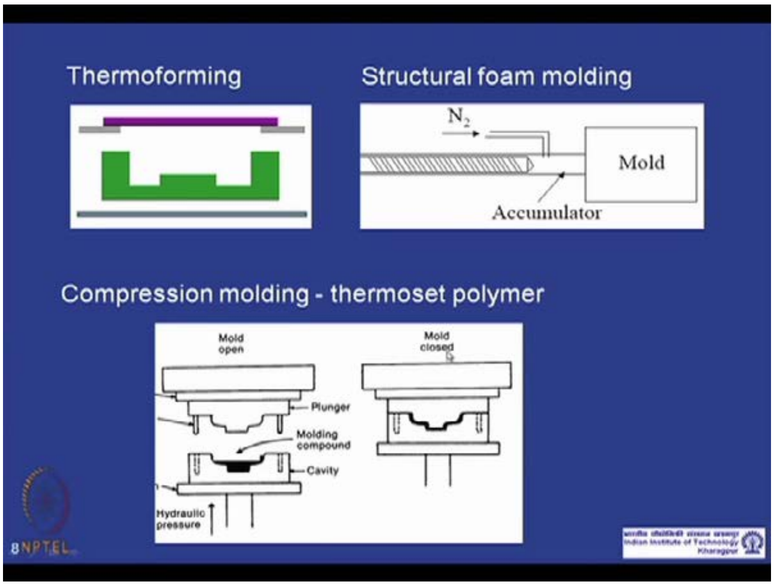

The other techniques in very briefly thermo forming where, sheets is first extruded and then, it is heated to a temperature just below the, just heated to the softening temperature then, vacuum is applied. So that, this sheet is formed thermo can be thermo formed in the shape of the mold similarly, in injection molding machine, this is the place where the polymer melt is accumulated. Now, in this case, if you can if you want to make a foamed polymer, you can add some inner gases here.

And then, make a short short which means, you can inject less material, which was supposed to be filling the entire mold. So, if then what happens, this this material fill the mold with this gas in a foam a foam in between. So, the surface would be in contact with the mold, it will be plain which would not have any bubbles, it will be smooth but, the bulk will have lots of inner gases as a foam so, it will so, you get a foamy material.

So, thermoset polymers are molded using compression molding basically, as you know that, thermo thermoset polymers cannot be flown at higher temperature, they are (( )) material. So, they do not flow. So, basically what you do is, you basically melt in a cavity and then, with particular shape mold, you just compress them and leave it. You close this, compress them and close it and once it cools, you can take out this mold and you can form this shaped article or part so, this is in brief about compression molding.

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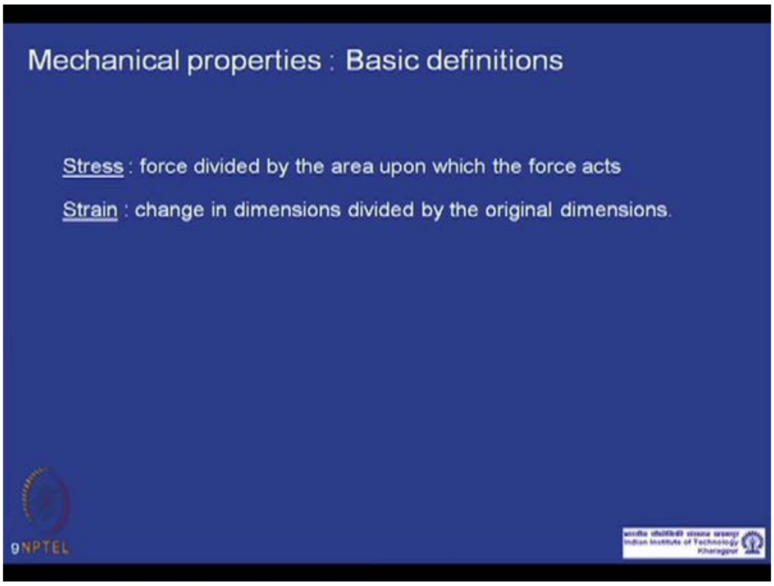

So now, you have seen, how this polymers are converted to the articles now, we will discuss about the properties of this final polymer and this properties are very essential for the applications. So, you have to make a proper polymer article or part having particular properties so that, you can sustain or you can apply to the application you are looking for. And as I said that, I will be mainly I will be discussing the mechanical properties in in details, basic some basic terms in, when you talk about mechanical properties, stress you know that, it is force divided by the area upon which the force acts. So, it is a stress is given by force so, stress is forced by area.

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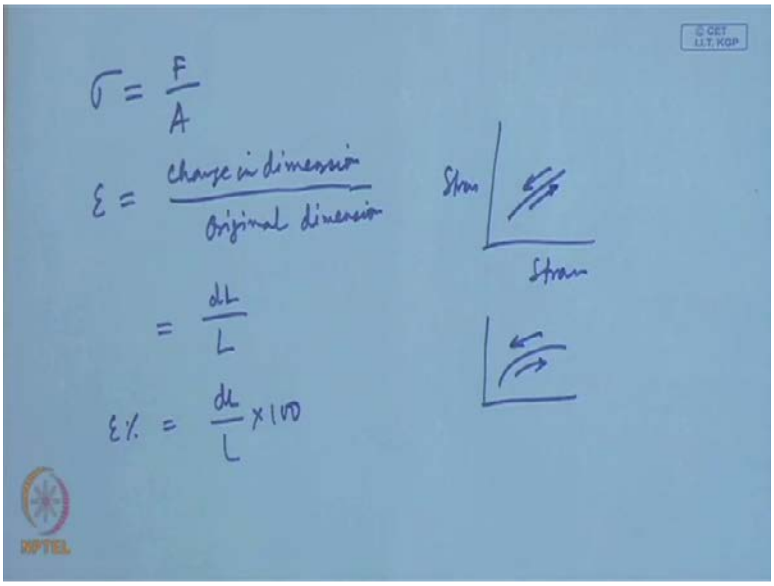

And strain is basically is the change in dimension change in dimension divided by the original dimension. So, if you talk about length then, it will be change in length by total length typically, we express strain in terms of percentage. So, strain percentage is given by d L by L into 100 so, that is the strain percentage. We will be using this stress and strain very very frequently in coming coming discussion.

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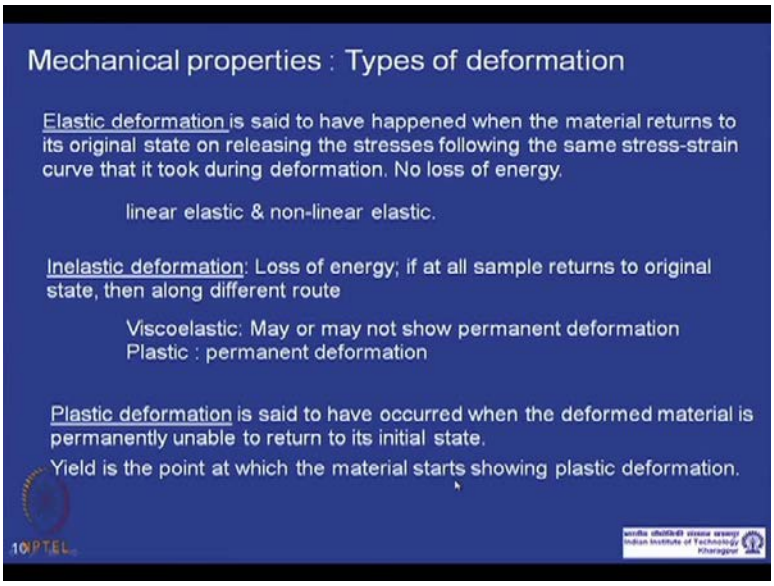

Now, mechanical probabilities is polymers, mechanical prosperities is related to deformation, what happened in when you apply some force or a stress to polymeric material or plastic material, it it deforms. And the deformation (( )) is basically a but, what we discussed, what we talked about mechanical properties. So, you first know, how many different types of deformation that a polymer undergo, under applied stress or applied force.

So, there could be three types mainly, one is elastic deformation you probably know that, we say that, elastic deformation happen when a material returns to its original state, releasing the stresses on releasing the stresses, following the same stress strain curve that it to deformation. So, while if you apply stress it will deform, if you release the stress it should come back in the same path, stressed and come original state then, we called this is a linear this is elastic deformation. It could be linear, if the stress strain behavior is linear, it goes from here and come back in the same path.

It is linear behavior and if it is something like that, it goes in this way and come back then, it is a nonlinear, nonlinear elastic behavior. Second is your inelastic deformation where, basically inelastic behavior what happened, if you give the stress, give the force, the energy stored in the material. So, when you release stress, that energy is given back so, you gave you get back to original state. Whereas, in case of inelastic deformation, when we apply the energy or apply some force, the energy is lost.

So, it may deform permanently or even if come back to the original state, it it do not follow the same path. So, in inelastic deformation, loss of energy happens and if at all it returns to the original state then, it does in a different route. It could be two different type, visco elastic which may and may not shows permanent deformation and there is another type of deformation deformation where, the plastic deformation where, permanent deformation happen.

So, plastic deformation is said to have occurred when the deform material is permanently unable to return to it is initial state and yield point is that where, the materials start showing the plastic deformation.

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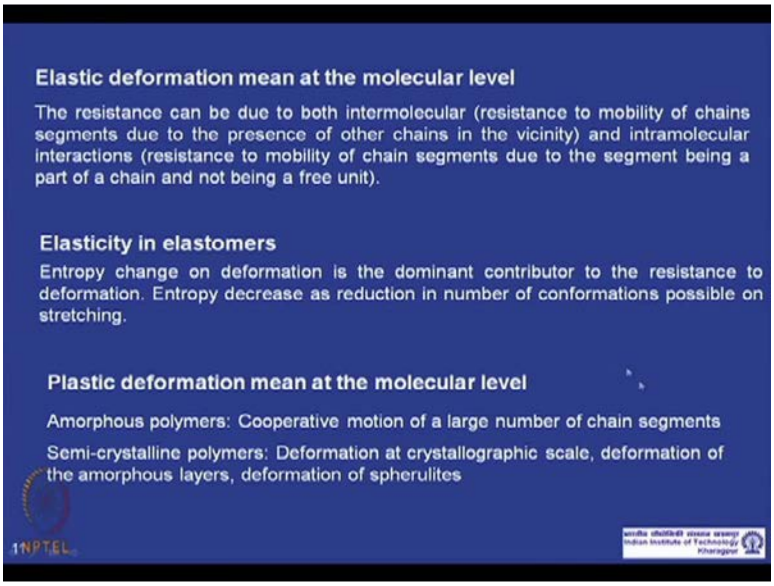

What happen to in at the molecular level, in inelastic during elastic registration, the the resistance to deform the resistance to deformation can happen both intermolecular. The polymer chains are you know entangle to each other so, polymers, the resistance to deform may happen, because of presence of the other polymer chain segment in the near viscidity. Or it could be due to resistance, due to intra molecular because, the polymer chains are entangle so, different parts of the chain are linked.

So, they they they resist times they resist to give a resistance to deformation, elasticity elastomer you know elastomers are very very elastic. So, it elongates quite high and entropy change on the deformation is the dominant factor in to the resistance of deformation. In case of elastomer, the polymers are you know having conformation, quailed type conformation in in normal case.

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So, if you write just polymer chain conformation like this and in and in real polymer, these are basically different chains are entangled with each other. So, if you want to stretch, deform it like in elastomer what happen, this conformation entropy is a lost. So, when you release that stress to gain that conformation entropy, it comes back to it is original state. So, that is what this entropy change and deformation is the dominant contribution in the to the resistance of the deformation in case of elastic material.

And in case of plastic deformation in the polymers especially, in case in case of amorphous polymers, cooperative motion at of a large number of chain segments happen together, large say number of chain segments corporally move with each other. And in case of semi crystalline polymer, deformation at crystallographic scale crystal state so, polymer chains might sleep with respect in the direction of the applied stress or it could move in the perpendicular director direction.

And there the could be deformation in case of semi crystalline polymer could be deformation in in the amorphous region or in case of spur light region. So, we will we we talking about elastic deformation and plastic deformation, elastic deformation where on a plain releasing the stress, the sample comes up back to the original state and in case of plastic deformation, it it come it come does not come back. The polymer sample on releasing the applied stress, it does not come back to the original state, there is a permanent deformation.

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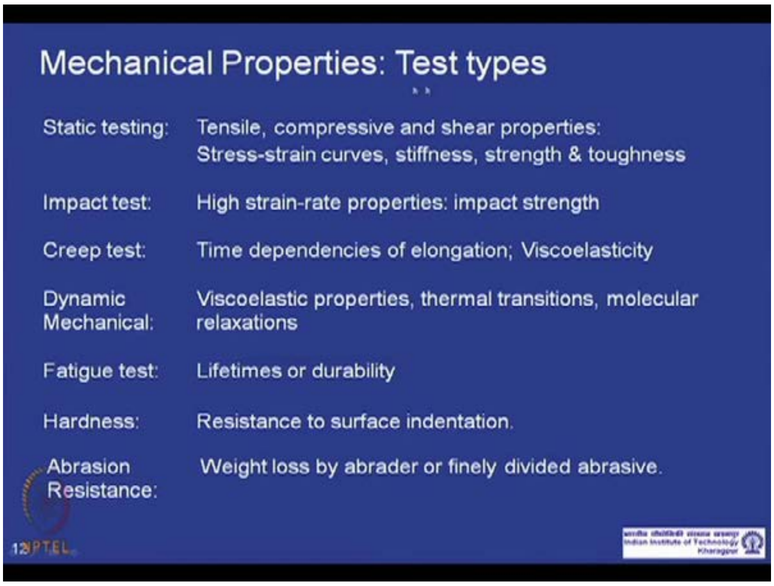

So, you test the mechanical properties, the different types of test can be conducted, static states test like a tensile compressive shear properties, which gives stress and curves, stiffness and strength and toughness of polymeric material. We impact test, which is basically high strength test done it very fast fast by by applying stress in a fast rate and it can give the impact strength, the resistance of about plastic material to a impact can be given by impact stress and time dependence (( )) of polymer material can be done from a creep test.

Similarly, the other test like dynamic mechanical test, fatigue test, hardness, abrasion resistance and these are all, within what this test mean are written here. You can just read fatigue test is for determining the lifetime or durability, hardness is the resistance to surface indentation, abrasion resistance is the weightless by a fine or abrader or the finely divided abrasive particle. But, for these lecture, we will mainly talk about first two test, which are used very often and rest of the test will not be covered because the, because of lack of time, this will not be covered in this lecture.

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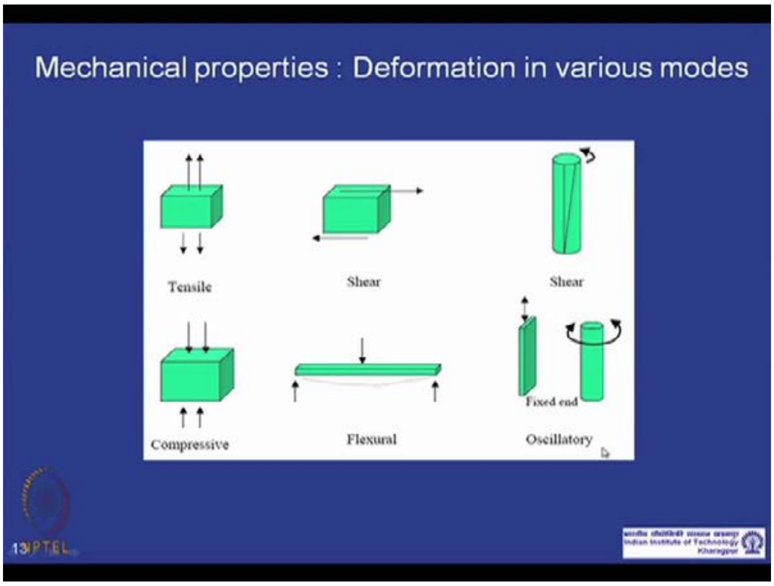

We talking about deformation of polymer material, that this deformation can be bring about in a polymer material in different ways. Like tensile, you can pull a polymer specimen, you can compress them, which gives us a compressive deformation. You can shear then and you can shear in rotational way as well, you can bend them, bend a polymer by applying stress in in the middle of the polymer where, the two sides are supported.

You can apply this stress or or so that, there is this deformation happen oscillatory, that stress can be applied or the deformation can happen in a tensile way or a shear shear manner. So, that is that is the way, oscillation oscillatory deformation is done so, basically it you must know this basic deformation modes to understand the subsequent test and polymer mechanical properties.

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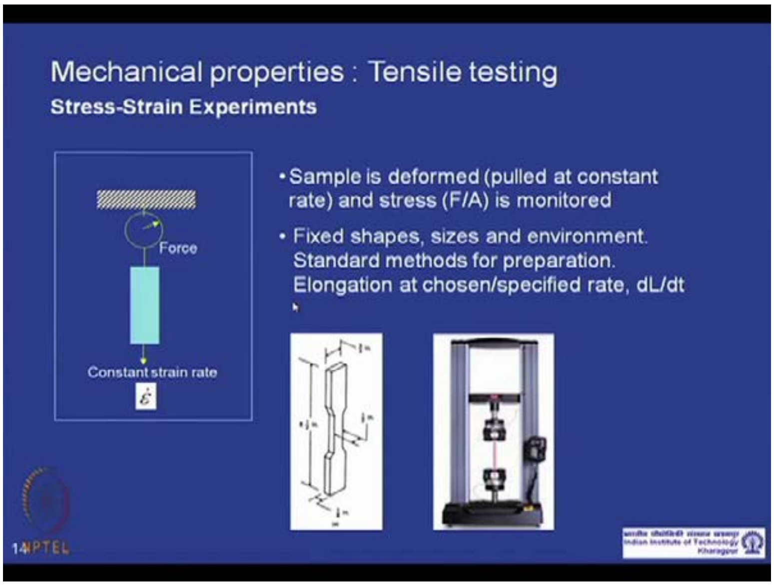

So, let us talk about tensile testing, what is done, you take a specimen something like this geometry, which is like a tumbleset geometry or we call dog bone geometry in a crude way. And then, fix this two side and pull them applied force from both the sides, sample is deform, the deformation is done in the constant rate and the amount of stress is required for keeping that constant rate of deformation is monitored. So, stress is plotted against time or stress now remember, in this test and all subsequent polymer property testing, you must…

Because, this test is very much dependent on the size, shape of the specimen and the environment, what you when you are doing the test like temperature and relative humidity of the environment. So, you must there are agencies which give like ASTM and ISO International Standard Organization or ASTM American in Standard Organization where basically, they give specific conditions, specific size of the and shape of the polymer specimen and the conditions.

So, we must when we testing, we must keep those condition intact to get the report is full or repeatable polymer property measurements. So, this is done with a fix shape, this tensile test is done with a fix shape, size and environment to condition and elongation at at a chosen or specified rate d L by dt.

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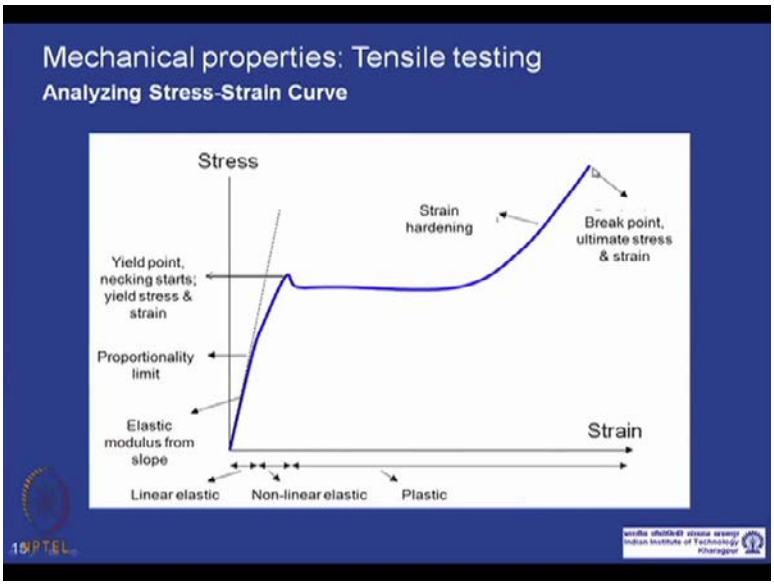

So, what is the typical stress strain curve look like, we can analyze a stress strain curve so, stress is plotted against strain and these curves basically shows, what are the possible effect or possible deformation in a sample. This is this does not happen for all the sample but, this is shown here to so that, you know all the different terms and related to this tensile testing. So, as you know, the first part is linear up to this point so, this part is elastic and you from this slope, you can get the elastic modulus of the material.

This is the proportional to the limit and this is the point where, yield happened yield means, sneaking happens in the sample. So, beyond this stress, beyond this strain, the polymer start deforming permanently so, up to this, is an elastic linear elastic limit and up to from here to here, it is nonlinear elastic limit. So, you can if you deform up to this point and then, remove the stress, it will come back to the original state. But, beyond this yielding point, it will not come back to the original state so, permanent deformation happens so, this is a plastic.

So, from this point to the further onwards, is a plastic deformation happening, below this elastic deformation is happening, this is called yield point. So, the corresponding stress is the yield stress and corresponding strain is the yield strain and on subsequent applying subsequent stress, subsequent straining, sometimes at the end, the stress might go a further thus because, strain hardening technique takes place, the chains are already stretched.

So, for further stretching of the chains become difficult, polymer chains becomes difficult so, if you have more stress to give a given strain and this has strain hardening this is because, strain called strain hardening and this slopes sometimes can get give us the strain hardening modulus. And this is the point where, polymer breaks, polymer fails, the basically failed apart and this is the corresponding stress is called the ultimate stress and the strain is the ultimate strain, which is the strain or elongation at at break.

So, please do remember all this terminologies, this yield point, this is final break point so, elongation at the break, ultimate strain and this slope, the initial slope gives us the elastic modulus.

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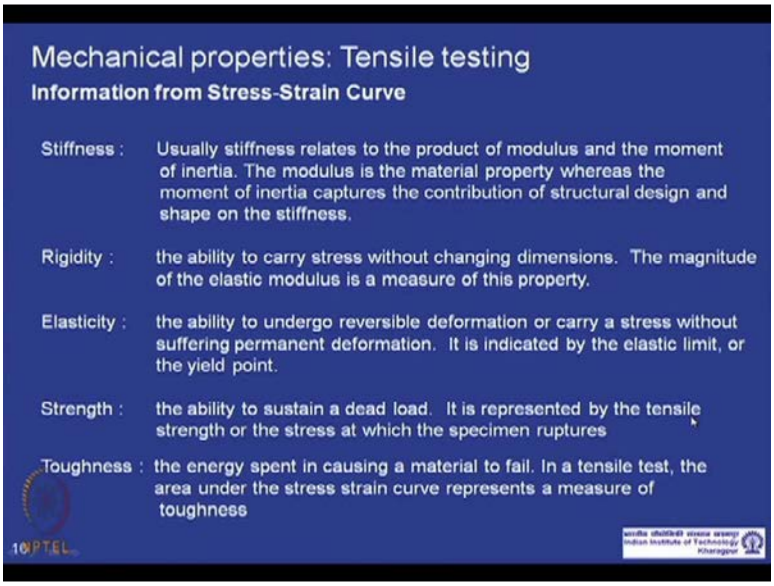

Some terms related to tensile testing, stiffness usually stiffness related to the product of the modulus and the movement of inertia. So, basically, if you have a specimen, you try to bend them and if you resist, you feel resistance to bending you call this, the material is stiff. So, that is depends upon the movement of inertia, which is given by the shape and geometry of the specimen. And if you compare between difference material and out of same sample specimen then, higher the modulus obviously, higher will be the stiffness, higher will be the resistance to bend.

So, this modulus is the material property whereas, the movement of inertia captures the contributed of structure design and the shape on the stiffness . So, if you compare same structural design and the shape materials, the higher the elastic modulus or with the stiffness, rigidity is the ability to carry stress without changing dimension, basically. Similar to stiffness, and the magnitude of the elastic modulus is a measure of rigidity, elasticity is the ability to undergo reversible deformation.

Means, where that, after the stress is released, it should come back to the original state that is, what mean by the reversible deformation. And or carry a stress without suffering permanent deformation and it is indicated by the elastic limit or the yield point, beyond yield point the elasticity the sample actually undergoes permanent deformation. Strength, is the load, is the sustain it is the ability to sustain dead load so, basically ultimate strain is the stress it it can capture or it can hold before it breaks and yield stress, yield strength is basically the stress, you it can it can take up before it yields.

And toughness is basically, the energy spent, the entire energy is spent for causing the material fail, is basically the the area under those stressed in curve in case of a tensile testing.

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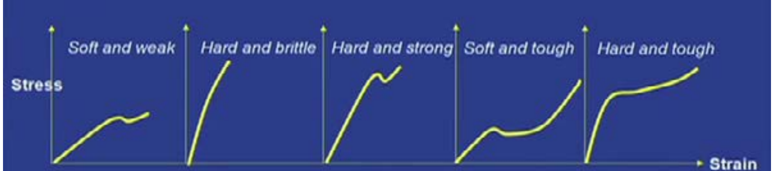

Material Stress-Strain Behavior	Elastic modulus	Yield Point	Tensile Strength	Elongation at Break
• Soft and weak (polymer gels)	Low	Low	Low	Moderate
• Hard and brittle (PS)	High	Practically non-existant	High	Low
• Hard and strong (PVC)	High	High	High	Moderate
• Soft and tough (rubbers)	Low	Low	Moderate	High
• Hard and tough (cellulose acetate, nylon)	High	High	High	High

I just showed one example in in last page of one type of stressed in curve is basically capture everything, all the possible deformation of terminologies. But, in typically, one particular polymer can have one type of this deformation behavior for example, polymer gels have this type of soft and weak stressed in behavior, this is hard and brittle. So, it breaks at a low strain elongation value similar, this is hard and strong, this is strong and tough and this is hard and tough and example of these are given in this table.

So, hard means higher elastic modulus where, soft means low elastic modulus and weak can brittle is basically given by the elongational breaks. So, higher high elongation means toughness value is high so, these are different types of stress tensile possible for different polymers, the examples are given here.

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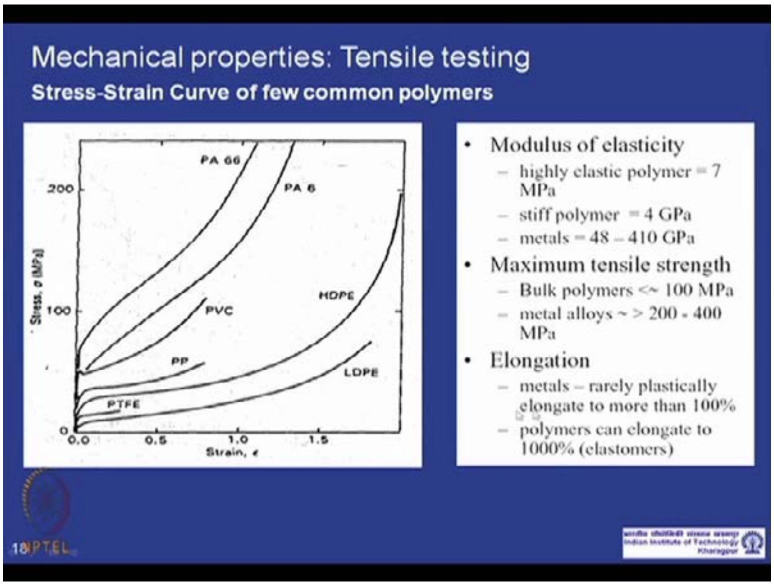

Some more examples with the names of the polymers this nylon, PVC, HDPE, LDPE now, just to compare the values of the polymers with metals. For example, with highly elastic polymers like rubbers, they have low modulus 7 mainly about 7 MPa, stiff polymers which have higher modulus about 4 GPa and metals is is much higher, if you compare a polymer and metal, metal is much more higher modulus. So, where in the applications, where you require very high loading high loading applications where basically, the part has to hold a very high load.

Basically, polymer does not does not fair well in those applications so, metal is the choice of material in those applications. Tensile strains for bulk bulk polymers are less than about 100 MPa whereas, metals and ions, they are quiet high. Elongation is where, polymers win over metals, the polymers can elongate in case of a elongation typically, polymers elongate much more than the metals.

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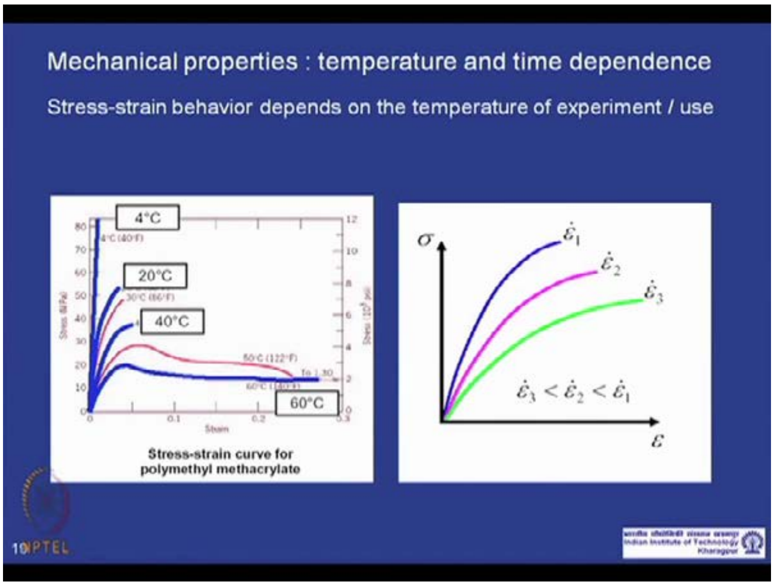

Now, the stress strain curve we a talked about and the modulus or the stiffness and the rigidity and your elongation at break, all those parameters or properties can actually depend both on the temperature and the time. The strain rate physically, how fast you applying the stress or how fast you straining the polymeric material for example, this is a stress strain curve for poly methyl methacrylate. And as you can see the stress strain behavior changes at a lower temperature, it becomes hard and brittle.

Whereas, at higher temperature, it become soft and a and a along with a ductile, which means it the the sample can be elongated, is more tough in that that sense. Similarly, if you change the strain rate, strain rates means the the the d L by a L value, the fast you are the fast you are changing this applying strain, see your (( )) the first deformation will change the stress strain behavior. If the that the strain rate is higher, it will become closer to is become to hard and brittle and if you do the deformations, it is slow phase then, it will become more soft and ductile or tough in nature.

So, basically you must know that, the mechanical properties of polymers this for examples stress strain curve and other mechanical properties always as well, very much depended on the temperature of the experiments. So, and and finally, where this material is applied so, definitely if you measure a modules or stiffness at say 40 degree centigrade and find your material is sustaining the load. You probably may not used that at higher temperature like 80 degree you might see failure, because of decrease in the modules of the material.

So that, you must know that, all the mechanical properties depends on depend on the temperature of the experiment or the application and and the how fast the deformation is taking place, how how fast the load is applied.

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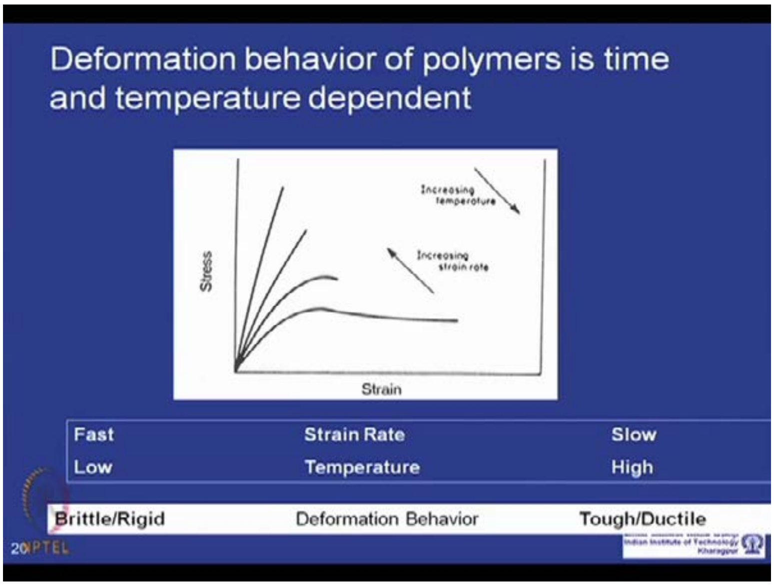

So, just again showing the same thing, with increasing temperature, the sample become stuff and ductile. With reducing temperature, becomes brittle and rigid whereas, applying high strain rate, makes the sample brittle and rigid, very slow strain rate mix the sample tough and ductile.

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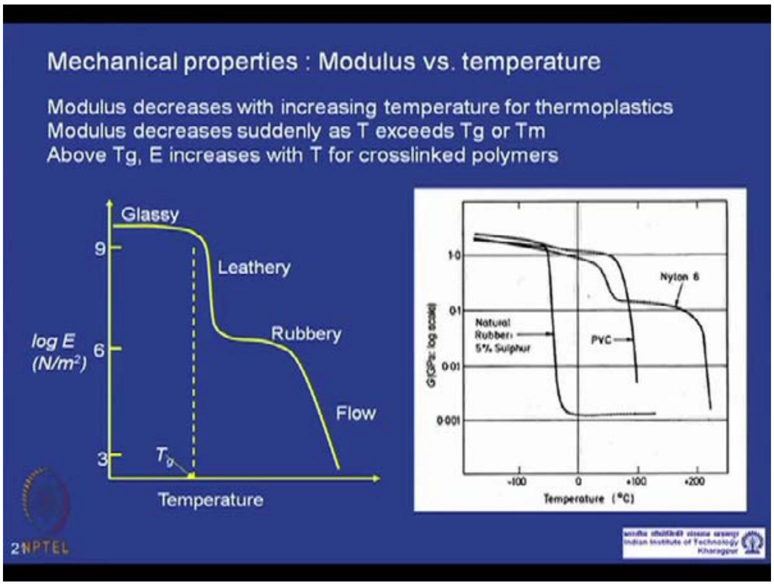

The modulus which means, the stiffness or rigidity, very much depends on the temperature, as I said so, this is the example, how the modules changes with temperature. As we know that, the polymers have undergo glass transition and melting transition at at a adiabatic temperature for example, if you pure amorphous material undergo go glass transition T g whereas, semi crystallized polymers undergo both glass transition and a melting at T g and T m subsequently.

So, the so, the modulus also changes with temperature generally, molecular modulus decreases with increasing temperature of the thermoplastics and at T g and T m, the modulus decreases suddenly at T x added T g and T m. And with increasing crystalinity, in case of semi semi crystallized polymers, with increasing crystalinity modulus goes up and also for the cross link polymer with increasing degree of the cross linking, the modulus goes up.

So, with different so, this is a plot of lock elastic modulus with temperature, which shows that, different regions of polymer elasticity. Whereas, below T g, it is glassy, which have higher elastic modulus and more it is more of a elastic behavior is like a elastic behavior then, immediately after the T g it is becomes soft but, because of high viscosity thus, the polymer chains steel cannot move fast each other very easily. And that is robbery here, leathery state and on further reading, it reaches the viscosity comes down and polymer chains can move fast each other quite easily and that state is robbery.

And this we talking about a amorphous material and at the highly temperature is, it behaves like a polymer liquid. So, is basically flow state, this example of real polymers, nylon 6 is semi crystalline polymer, is basically drops after T g, it drops very fast and then, after T m this is T m and after T m, it is becomes polymer that, if the elastic modules becomes very low after T m. So, this is T g here, drop in modulus and T m, drastic drastic drop in modulus in case of a semi crystalline polymer.

This is a pure amorphous polymers so, the drop in elastic modulus or modulus after T g and this is a rubber with cross linking. So, it drops after T g but, because of the cross linking, if the presence of the cross linking, the elastic modulus or modulus does not drop significantly after after a value.

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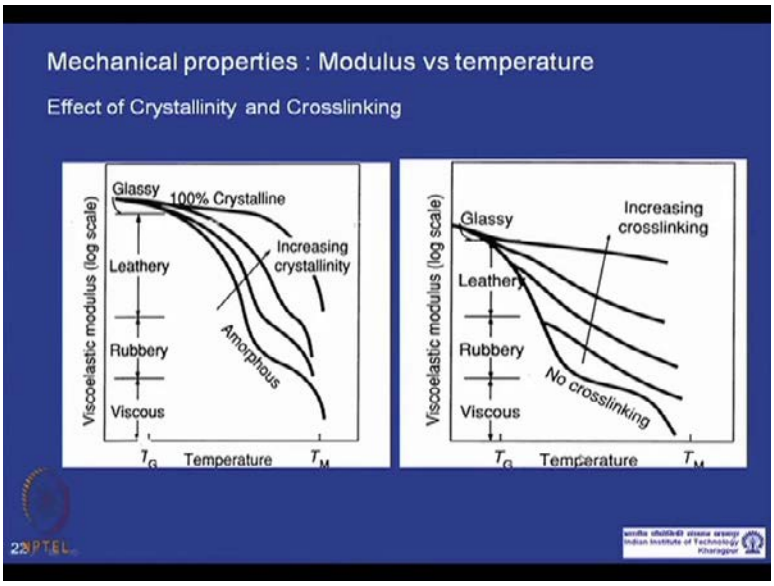

So, this is what I was discussing in in just a minute that, with a for a semi crystalline polymer with increasing crystalinity at the modules goes up elastic modules goes up. Where, in case of cross linking, material with cross linking, the the material the less modulus can goes up further with cross linking. So, this is the way, you can basically change, if your semi crystalline material, you can increase the crystalinity to increase the load bearing capacity of the material. And you can also crosslink to increase the load bearing capacity, even at the higher temperature but then, cross link brings other problem like a possibility with it.

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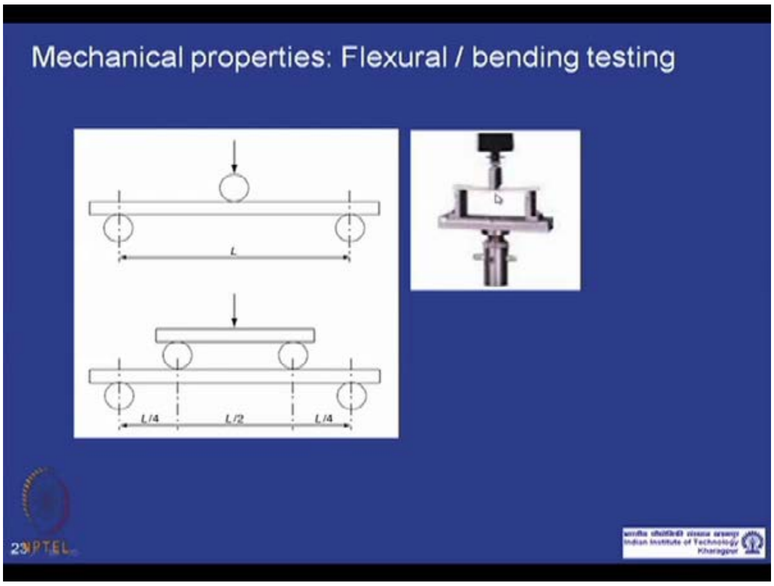

This is another mechanical property testing, we just discuss all last few minutes about tensile basically, the stresses is applied in a longitudinal direction. Here, in case of flexible or bending testing is basically bending mode where, the stress applied. It could be three point bending test or four point bending test, is like stresses or strain is applied in bending direction so, higher the modulus as bending will be lower.

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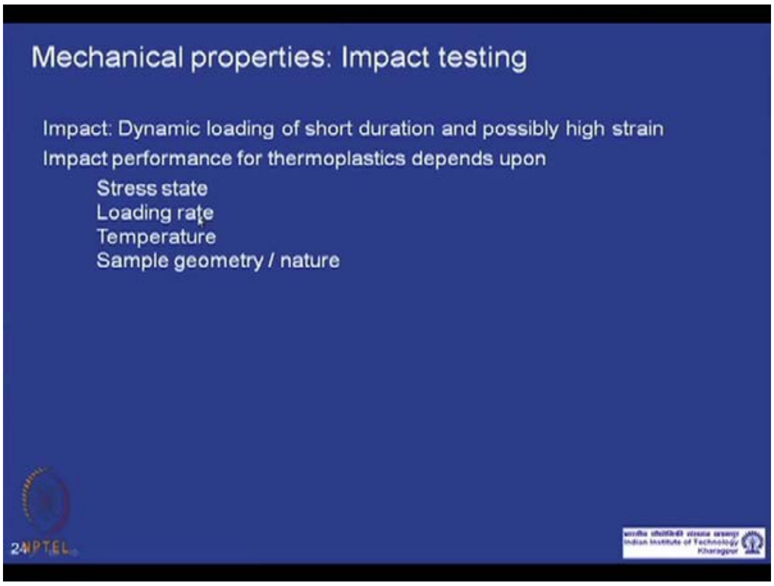

We can we just talk about impact testing, impact basically is a dynamic loading at short duration. You know we we know about impact like, if you have just a glass then, if you hammer it, it breaks which means, the glass has a very low impact property. Glass like we talk about glass then, if you keep a glass and you can put a load on it, it does not break. So, the modulus of glass is high because, the strain rate or the the stresses are applied is not in a higher rate you know, very fast rate.

But, when you impact, apply a hammer on that, you are applying the stress in a much faster rate so, a strain in the material at the very faster rate and the material performs poorly, the glass perform poorly. So, the impact behavior of glass is basically poor so, the glass impact behavior and modulus does not always match with each other. The testing itself is different modulus, we talk about the slow deformation that, we do deformation as we apply strain in a much slower rate compared to a impact testing.

So, impact testing is a dynamical load of short duration and very high strain and at high very high strain rate. And the performance of thermoplastic or plastic material depends upon the stress rate obviously, the higher you know it depends up on how we are applying the stress, loading rate, what is the amount of force, temperature and sample geometry and nature of the sample of course.

There are different types of impact test available, which you know the you have to if you are applying a designing any you have made a polymer and you want to test, you have molded it and you want to test impact properties then, you need to know the target application. Depending upon the target application, you choose the type of impact test should be done on that sample. So, different types of test possible namely, Charpy, Notched Izod, Falling dart, tensile and and drop test and they are basically different and different types of test.

Charpy test is is shown here schematically, you have sample, the sample is clamped both the sides and there is a notched in the other side and you hammer it and find out the energy require to break the material. In case of Notched Izod test, you clamp this specimen upto the notch, this both side and hammer on the top part. So, this material, this specimen breaks from the notch and the amount of energy require will to break this material will be the Notched Izod impact energy.

Sometimes, the test is done without the notch where, we say just Izod testing or notched izod impact testing. In case of tensile testing, the tensile bar, a dog bone type specimen or a dumbbell type specimen is fixed one side and another side with a pendulum is is hit the hammered from both the side. So, actually the deformation or the strain happen in a tensile way, in a longitudinal way, uniaxial if this uniaxial to...

So, the only difference between this and a tensile stress strain test that, here the strain is applied or the stress is applied much higher rate. So, the amount of energy required to break this bar is called impact strain. Another testing where, a load is just applied of actually, allowed to drop from a height on a circular disk and it can break this material or it can make a hole, just hole depending upon the energy. And the amount of energy required to break this material is again is impact energy for this plate.

And drop test is basically, take the specimen and drop from a certain height, which is very complex complex phenomena. Now, we know different test impact test, tensile test, now we need to find out, what is the relations between the polymer structure and and the properties. Now, as I said that, temperature is a very important thing so, we can compare for a same same polymer, same chemical nature at a same temperature, elastic modulus will increase with crystallinity.

As we have seen earlier that, for a particular semi crystalline polymer at a, if we want to increase the elastic modulus at a particular temperature, you increase the crystallinity. Or we can if it is not a homo polymer, it is a blend of different phase, there is a basically there could be two, one a soft or rubbery phase and a hard or elastic phase. Basically, with increase the soft disperse phase, the modulus increases. If there is a orientation, the chains if the chains are already oriented little bit obviously, if you want to deform further, you have to you have to stretch the polymer chains further.

Which means, what I am telling that, this is the original state now, if I already have stretched and aligned oriented little bit then obviously, aligning from or stretching reforming from this state will be much easier compared to aligning from or deforming longitudinally form this state. So, orientation increases modulus and for a semi crystalline polymer, if we increase a some glassy additives like glass fibers in the amorphous region then, basically the elastic modulus goes up.

Flexible modulus increase with elastic modulus generally, generally flexible modulus and elastic modulus go hand in hand. So, with increase in elastic modulus of a plastic material, flexible modulus or bending modulus also go up. Yield strength that is, the stress where, yielding starts or permanent deformation starts and again with yield strength decrease, if we add some plasticizer or a solvent molecule obviously, the yielding yield stress comes down.

It increases elastic modulus, it increases with crystallinity of a semi crystalline polymer and if we add this glassy additives like glass fiber then, yield state increases. Elongational break decreases with increasing molecular weight and elongational break decreases with increases short change branching density of the polymer. And basically, we relate brittleness of a polymer with elongational break basically, when something elongate more we say, this less brittle and if does not elongate, we call that it is a brittle material.

In general, if we talk about different polymers, if you want to compare the mechanical properties of different polymer in general what happen. If you have steep polymer back bone obviously, stretching it further or deforming it further is always difficult. So, yield strength and the elastic modulus is becomes higher, if it is a flexible back bone obviously, reforming deformation is much easier so, modulus comes modulus come down.

Similarly, if it is stiff then, you cannot deform it you know, you cannot strain it much longer which means, the elongational break for a stiff polymer is low. Whereas, a flexible polymer will have very you know much higher elongational break, in terms of impact properties again, a stiff polymeric back bone, if you apply impact apply impact then, with a short time, the polymer cannot rearrange and absorb that energy. So, it breaks. it is become brittle whereas, if you have flexible polymer chain obviously, it can absorb that energy and change it conformation.

So, in general, if you want to summarize, flexible back bone, lower modulus and strength, chain stiffness would have back bone or bulky side group increases the modulus and strength, and chain stiffness lower the impact strength and elongation would break. Now, with this, I stop for this lecture, I will just continue the mechanical property in the next lecture with little more discussion. And we will talk about some other, we will start discussion about some other properties in next lecture as well.