Non - Metallic Materials
Prof. Subhasish Basu Majumder
Department of Materials Science Centre
Indian Institute of Technology, Kharagpur

Module – 04
Mechanical properties of non – metallic and composite materials
Lecture – 18
Mechanical properties of non-metallic materials, stress–strain response, elastic, and plastic deformation

Welcome to my course, Non Metallic Materials and today we are in module 4 Mechanical properties of non metallic and composite materials and this is lecture number 18, where I will be discussing on the mechanical property of the non metallic materials, their stress strain behavior as well as elastic and characteristics of plastic deformation. So, we will continue with that.

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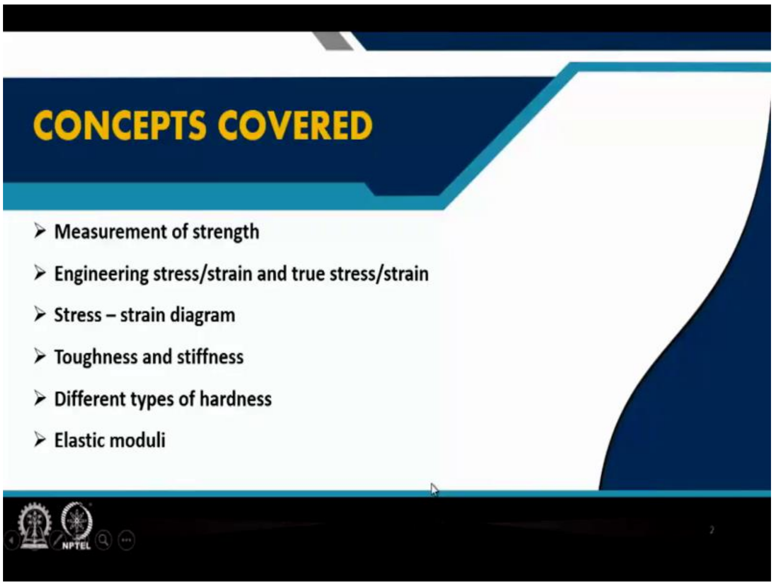

Now, if you see this the concept that I would like to cover in this particular lecture is there are different types of strength that is measured for this material. So, what are the origins of different types of strength, so that we will be taking first. Then engineering stress strain and true stress strain kind of behavior that will be clarified. And then I will show stress strain diagram for various classes of material, including metal, ceramic, polymer, then elastomer.

You already know part of my polymer lectures, you know what is elastomer, what is a polymeric material, what is a brittle solid like glass. So, how their stress strain diagram varies and then we will talk about the toughness and stiffness of this material and also different types of hardness that you come across. And finally, various types of elastic moduli will be introduced in the course and this knowledge will be used in our forthcoming lectures, this foundation will be used.

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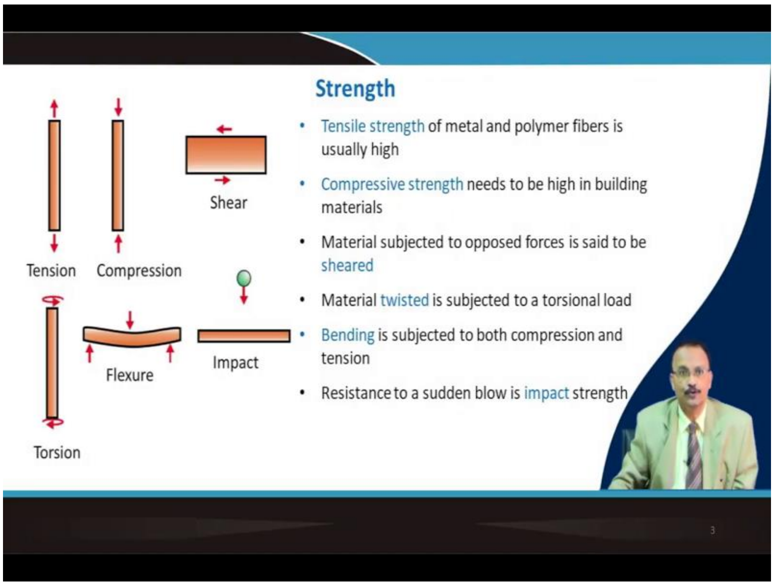

So, if you see a metal and polymer basically, they are under tension. So, this tensile strength of metal and polymer fiber in particular that usually they are quite high. Then, compressive strength is measured under compression and for building materials for example, a cementitious concrete beam or reinforced cement concrete beam you need very high compressive strength that is one of the primary requirement. Now, the material if they are subjected to this opposed force then you talk about the shear strength.

So, this is called shearing. Also, when the material is twisted then we are interested in this torsional load. So, this is the twisting, it is in one direction, this one is in other direction. So, this is the twisting, the torsional thing that is also important for this non metallic material.

For some class of material particularly ceramics what we are interested in this kind of bending kind of configuration where this top surface for example, is under compression and the bottom surface is under tension and there is a neutral plane somewhere in between.

So, this is actually a complex kind of loading both tension and compression is affected here. And finally, impact force which is. So, important when you design a baseball bat or a cricket bat then suddenly, the force is coming and hitting the object. So, the impact strength of this material could be very high.

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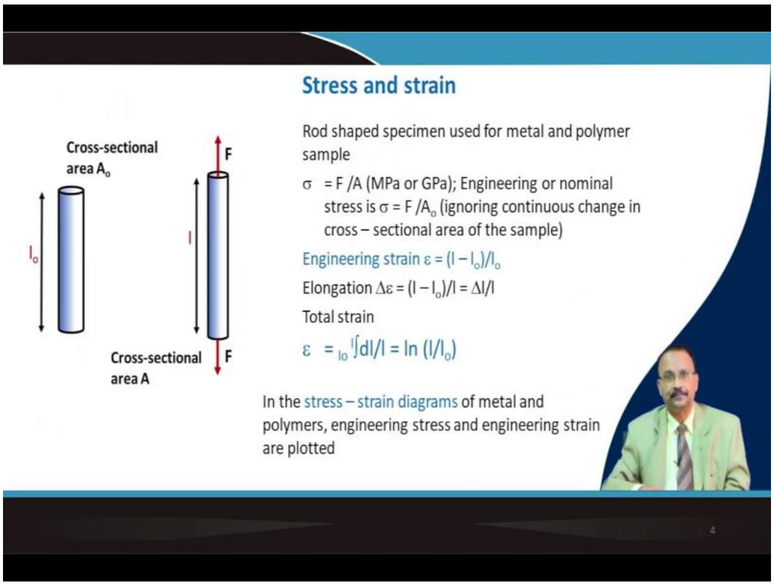

So, when we talk about the stress strain kind of behavior as you can see here that we have a rod which is having a finite length say l_0 and then you apply a tensile load then it will get elongated, when you apply a force which is under tension and of course, the cross sectional area that will get reduced. So, progressively it will get reduced and in case of metal it will form a nick and then the nick will be elongated.

So, in the first instance if you just do not consider this reduction of this area then you are talking about engineered or nominal stress value. So, it is simply F /A and usually this a is the initial cross sectional area. So, ignoring the continuous change in the cross sectional area of the sample particularly which is relevant for the metallic sample.

In case of ceramic it does not mean much, because there is no such dramatic reduction of the cross sectional area. So, it suddenly it fails. So, that is your engineering strain which is the length change l minus l_0 by original length. So, the elongation part is the change in the dimension. This is l minus l_0 by l. So, this is basically $\Delta l/l$.

So, the total strain if you want to calculate then you will have to integrate this d l by l part from initial length to final length and eventually, you will get l n l by l 0, where l is the final length and l 0 is the initial length. So, in the stress strain diagram of metal and polymer engineering stress and engineering strain usually we plot it, not the true strain or true stress in that respect.

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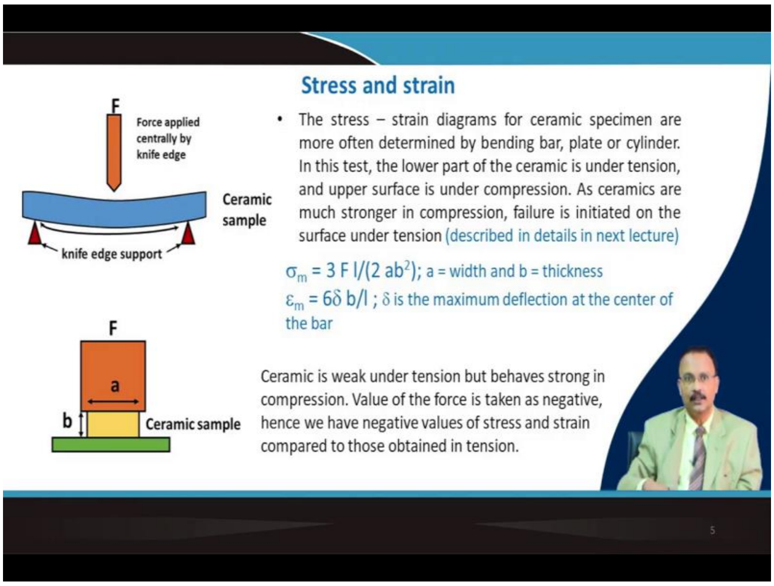

In case of ceramic as I told that it is actually measured in a flexural configuration. So, a beam of ceramic material it is placed on this two support and it is a knife edge support and you apply a load exactly at the midpoint. There are different configurations. This is as you can see it is a three point configuration. You can also uniformly apply load one here and one here and support is something like this, whatever you have. So, then it is a 4.0 loading. Particularly, it is important for ceramic material.

So, the outer surface will be under tension. So, ceramics are weak in tension. So, the outer surface if the crack generates here, it can lead to the failure. So, usually the sample is in the form of a bar, it can be a rod, it can be plate. So, as I mentioned that this outer part will be under tension and the inner part will be under compression, this surface will be under compression.

So, if you this maximum stress that you are applying, this you can approximately it can be estimated also, it can be derived from the movement of inertia calculations. But this equation is valid where F is the applied load l is this span between these two knife edge and a and b are the width and thickness of the beam in question and if you want to estimate the strain particularly at the midpoint, this is given by this relation and delta here is the maximum deflection at the center of this bar.

So, this is extensively used in ceramic material. You can also test it under compression and ceramics are weak in tension. So, this surface will fail first and strong in compression. So, we will just understand that why it is strong in compression in my next lecture. So, value of the force is taken negative as compared to the value that you take in the tensile test. So, that is a convention.

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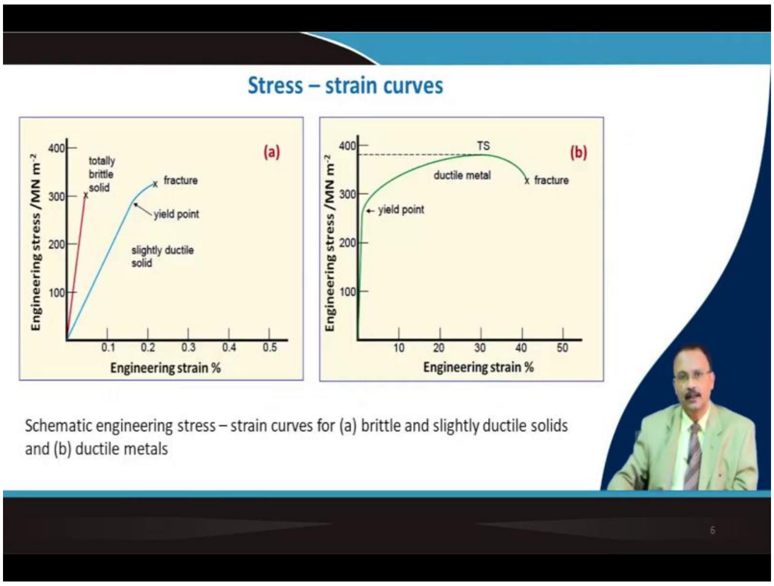

Now, if you see a typical brittle material, you apply a stress and estimate the strain at very small strain level this will suddenly fail. So, usually this stress strain curve is a straight line and this slope is elastic modulus. In certain case you have a straight curve like this and then the slope changes not very significantly, but a little bit change is there before it gets fracture.

So, when this straight line portion is taken up by this non-linear portion so that point is known as yield point and we call this kind of feature is a slightly ductile solid. It is not fully brittle, this one is fully brittle and in this case as you can see the elastic modulus the slope is less. So, elastic modulus is lower than this, but it has a little bit of ductility in it. In case of pure metal this part is very sharp.

As you can see it goes very sharply, this slope is very large and then beyond the yield point there are lot of plastic deformation before finally, it fracture. So, the ultimate strength that you are getting it is the ultimate tensile strength TS is the tensile strength of the material. This is the elastic to plastic conversion and this is the yield point, yield point and the stress corresponding to that is the yield stress.

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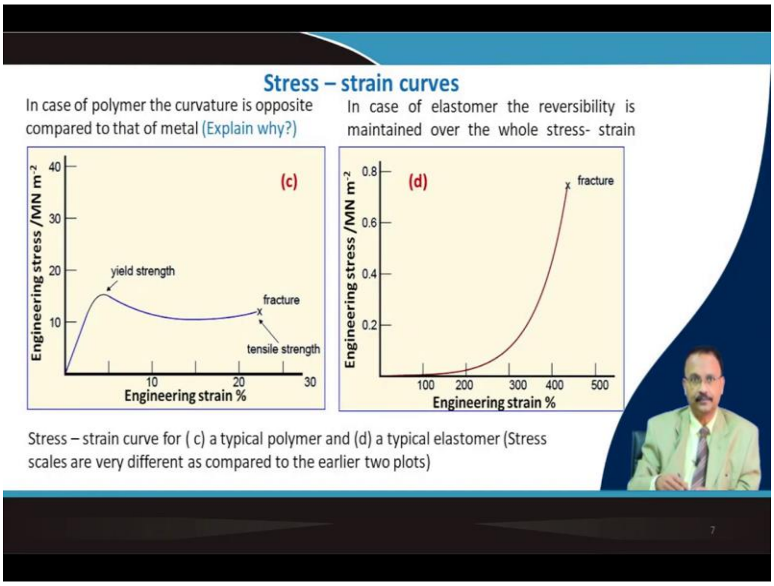

In case of polymeric material as you can see the slope is not very steep and also the values if you compare the last two slides and these two slides the scale is dramatically different, is a softer material.

So, it cannot withstand much load thereby, the stress, it cannot withstand it and if you compare it with metal, the polymeric material also undergo lot of ductile behavior, plastic behavior it is there, but the slope you can see the slope is in the diverse direction. I leave it on you to explain it that why in case of metal you have convex kind of behavior and in case of polymer you have a concave kind of behavior.

Otherwise, you have a yield strength which is defined here, which is marked here and fracture takes place here. Before fracture there are lot of plastic deformation in this type of material. You can just have practical experience, if you are carrying something in a poly bag then before it gets torn up then there is a lot of elongation and then it fails something similar to that. You are under a tensile load when you are carrying something and it gets elongated reasonable amount of elongation before it finally, fails.

In case of elastomeric material which is a rubbery material, you can see that this slope is almost negligible, but look at the strain the strain is 300 to 400 percent before it fails and this is completely reversible. It goes like this and comes back like this. So, elastomer is having the reversibility maintained over the whole range of stress strain curve, but not like this, this is not recoverable in case of elastomer. It is recoverable, this strain is completely recoverable.

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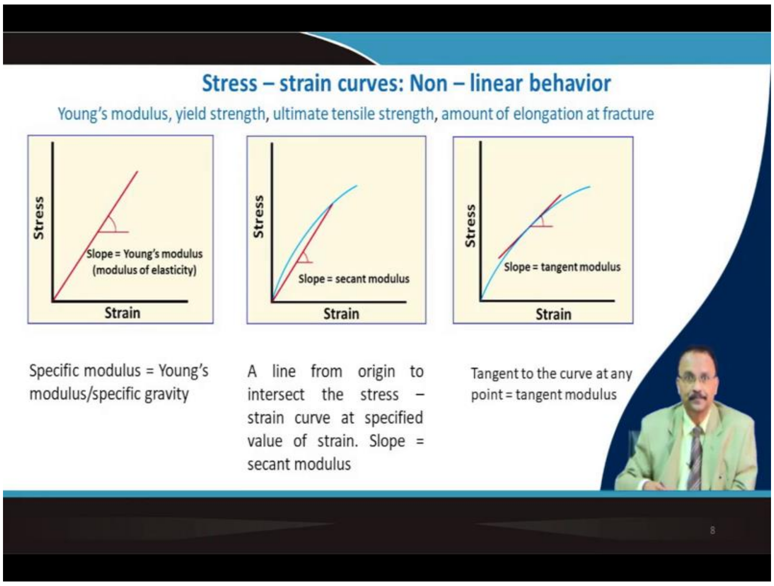

So, sometimes this straight line behavior it is not very prominent. In case of elastic solid it is very prominent you can very easily estimate the slope, you can estimate the elastic moduli, but sometimes there is a non-linear behavior like this. So, in case of the non-linear behavior the moduli you can define either it is a second modulus we call or we call it is a tangent modulus.

This two special terminology is used. In case of second modulus what you do from the origin you draw a straight line and wherever it cuts this so that intersection of the stress strain curve at a specified value of strain that slope is a your second modulus.

So, slope of this linear line is your second modulus. In case of your tangent modulus then each point you can draw a tangent and slope actually changes in this point. So, tangent to the curve at any point that is actually defined as a tangent modulus.

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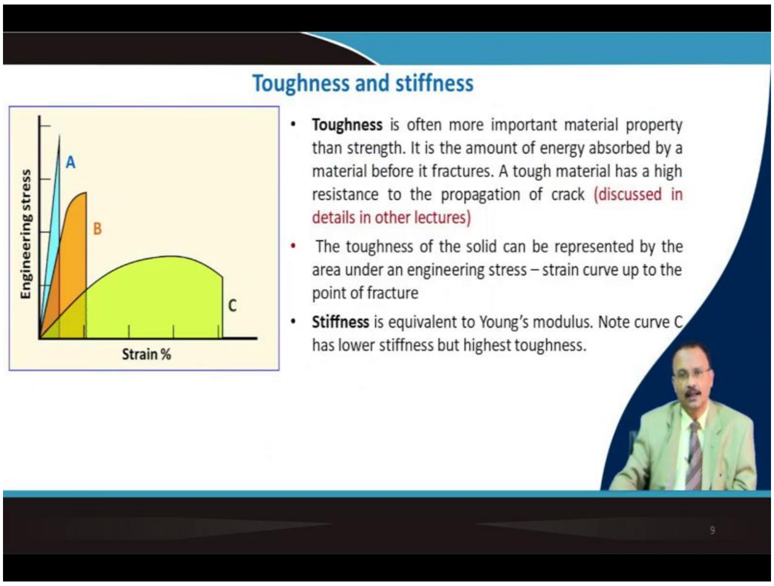

Now, you have this three different types of situation; in first case it is a brittle material so it is very steep and then suddenly it fails. In the second case it is not that slip not that steep, but a little bit angle is less, the slope is less and little bit ductility is there. Here, in this case the slope is very small and lot of ductility is there. So, the toughness that is defined and which is an important property, it is not only strength which is important, but toughness is also equally in fact, more important than the strength one can say.

So, it is actually the energy absorbed by a material before it fractures so, that is toughness. So, the tough material has a high resistance to the propagation of the crack and this I will discuss in my next lecture in little bit more details. So, the toughness of the solid can be represented by the area underneath this curve. So, from here to here you take what is the total area and as you can see that here the area is far larger.

So, toughness is much higher here, as compared to the brittle material, but the elastic modulus may be quite high here. So, this two things actually does not match well; a material may be more tough, but its elastic modulus may not be that high and the slope is the Young's modulus and the stiffness I will again talk about it the stiffness. So, this stiffness is more or less equivalent to your Young's modulus, we will see that later.

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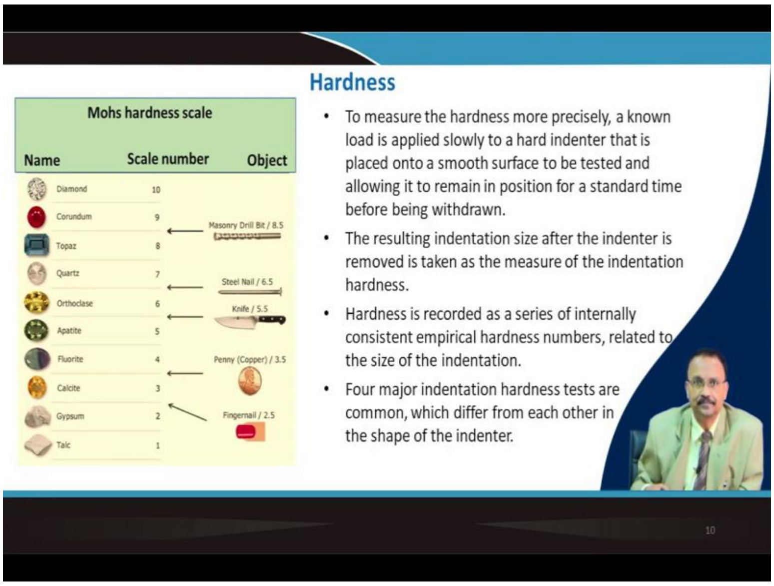

Another important property is the hardness and I guess you are familiar with the Moh hardness scale depending on different types of gem. Diamond is the hardest material and talc is the softest material and in one scale was designed from 1 to 10 to define the hardness of this material, but in case of in any engineering material to measure the hardness more precisely you cannot define just by this scratching and by this Moh's scale.

So, usually the hardness is measured. So, in that case very slowly a hard indenter is placed on a smooth surface, smooth polished surface of a non metallic material and allow it to remain there for certain amount of time, standard time before it is withdrawn and then this impression that gives you the idea about the hardness.

So, this is a empirical hardness number it is related to the type of indentation experiment that you are doing and there are four different types of indenter used and based on that you have four different types of hardness.

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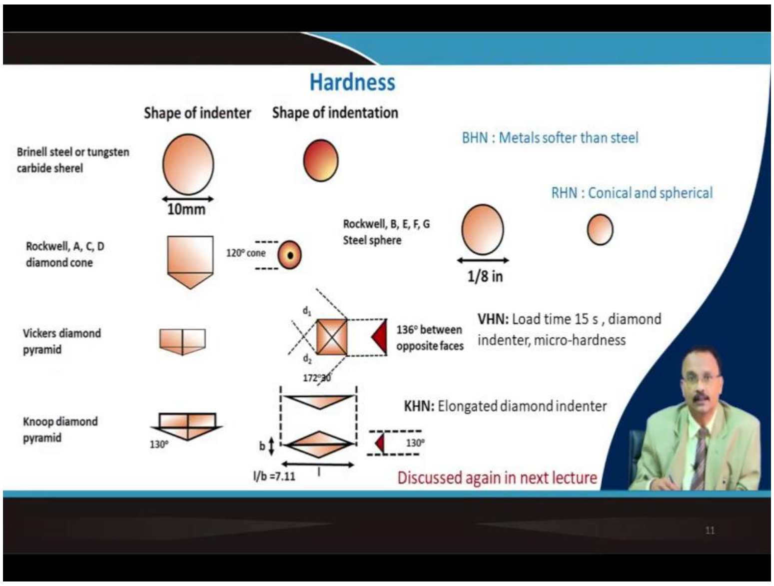

The first one is the Brinell hardness where you can see, it was developed in 1900 so some 120 years back. So, this is a spherical ball and this impression of this ball is measured. So, this is a Brinell hardness.

So, metal and softer then steel, those metal that is usually tested by this Brinell hardness, then you used two types of the Rockwell hardness test and the difference is the type of the indenter as you can see for A type, C type or D type a diamond kind of thing is used and in case of B E F and G type hardness you have a spherical type of indenter is used, then one can test also the Vickers hardness, Vickers hardness or the Knoop diamond pyramid hardness test.

So, this type of diamond indenter made out of the diamond tip material relatively smaller load is used for 15 second and this type of measurement particularly this two measurements we called that this is a micro hardness measurement and I will again come back to my next lecture and illustrate it more, illustrate this concept more when we will talk about the hardness measurement in brittle material and how one can correlate it with the fracture toughness value. So, again we will take it up.

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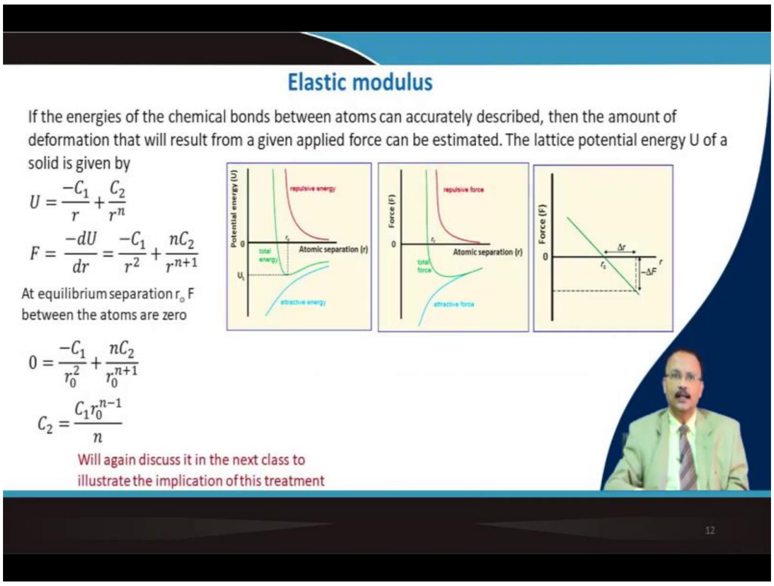

So, now if you see from the first principle you consider in a lattice, there are two atoms. They are specifically in a crystal lattice depending on the crystal structure they are arranged. So, you would like to calculate the potential energy of between this two atom to define that what is their equilibrium position of the equilibrium position of their, equilibrium position in their crystal structure.

So, this potential energy curve they have basically two component; one is a repulsive component, because when it comes very close proximity then the electron cloud there interfere and they try to repel and when they go far distance then the attraction is more.

So, you have one attractive component which is negative and you have a repulsive component which is positive and then finally, you get this kind of potential energy curve and this you can work it out for in fact, in one of the assignment problem I have given that you can from the estimated value of this r, the distance between this two atom in question you can calculate its attractive potential following this relation, you can calculate the repulsive potential and then in fact, you can draw this kind of potential energy curve with a well a potential well.

Now, this potential well has various significance if it is very sharp then it will indicate that a lot of energy will be required to separate them out and as a result the melting point of those particular oxide material will be reasonably high and also the elastic modulus which is also related to some kind of cohesiveness between these two atom that will also be very high and not only that the symmetry of this kind of potential will take you, with eventually tell you that whether they are transparent sorry, thermally thermal expansion coefficient of this material you can have a fairly good idea.

If it is very symmetric then thermal expansion is low, if it is non symmetric then you can see that this is the minimum energy position for a particular temperature and in between this and this it can assume any position. So, if it is non symmetric then it will go like this. So, it will have a large thermal expansion coefficient certain assignment problem will clarify the idea.

Now, you can calculate the force also if it is the differentiation of this potential energy with the inter atomic distance and you get this kind of relation and at the equilibrium your force is basically 0 and this part I will also take it up when I will talk about the fracture, because the concept of the potential energy, derivation of the potential energy to derive the restoring force and how it controls the strength of the material, the fracture of the material that again I will come back in my other lectures.

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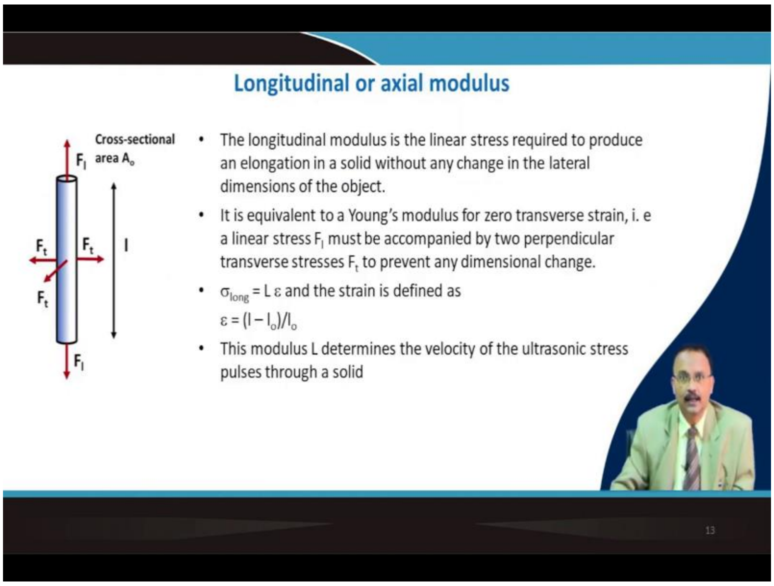

So, we can now talk about different types of modulus; the first one is longitudinal or axial modulus and this is a bit special if you apply a tensile load here, you see that then this will be contracted and so, you have a restoring force so that it do not allow it to contract in that way. So, that eventually will give you the longitudinal or axial modulus. So, this is demarked by l.

So, basically this stress, longitudinal stress is this coefficient into strain under the elastic limit following the Hooke's law and strain you can calculate $(l - l_0)/ l_0$. So, that is engineering strain. So, this type of modulus and the restoring force as I said that is also operative.

So, it is equivalent to Young's modulus for 0 transverse strain that is a linear stress must be accompanied by two perpendicular transverse stresses to prevent any dimensional change. So, this modulus determines the velocity of the ultrasonic stresses, stress pulses through a solid. So, that is why it is significant.

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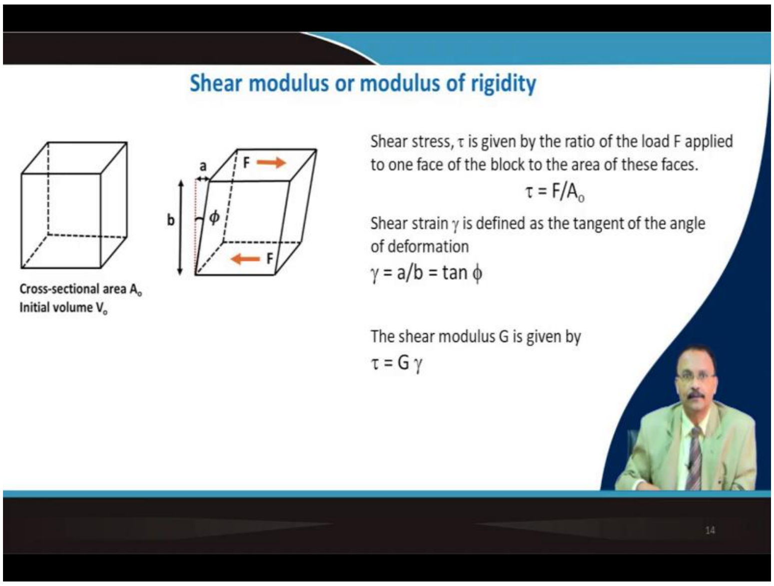

Shear modulus is basically related to two opposite kind of force. So, shear stress is given by the ratio of the load that you are applying to one face of this kind of block to the area of this spaces. So, the area is taken at A_0. So, your shear stress is F $/A_0$ at one of the faces and shear strain is defined by the tangent of the angle of deformation. You see that when you apply this kind of stress so this angle changes.

So, this angle is tan ϕ which is defined by a/b according to this geometry. So, it also follows this Hooke's kind of behavior. So, shear stress is proportional to shear strain and the modulus is known as modulus of rigidity or it is basically shear modulus.

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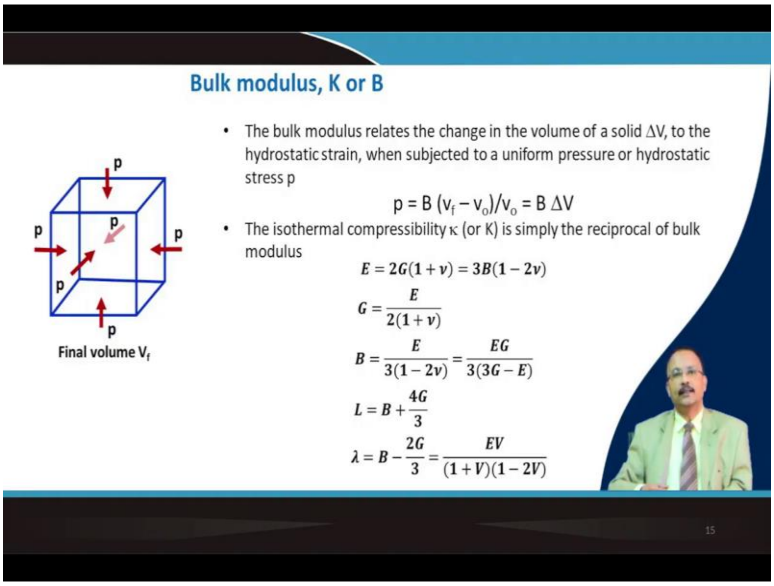

Then also you can estimate what we call the bulk modulus and this bulk modulus they basically relates the change in the volume of a solid. So, it is the change in volume of the solid with the application of a hydrostatic pressure.

So, the pressure is being applied from all possible angle of this all possible phases of this cubical cube type of sample and final volume is say it is V_f and original volume it is V_0. So, the change in volume is $(V_f - V_0)/V_0$. So, the hydrostatic force which is p that is related to a bulk modulus and the volumetric change. So, $p = B\,\Delta V$.

So, you can defined the bulk modulus by this concept. Now, you see that all this modulus whatever I described like elastic modulus, then shear modulus, bulk modulus, the longitudinal modulus, they are interrelated to each other and what I did not describe the concept of Poisson ratio that whenever you apply a tensile load then there is not like your longitudinal modulus, but actually it will reduce its dimension.

So, it is the lateral deformation by longitudinal deformation that ratio gives the Poisson ratio. So, Poisson ratio the new is defined so that is there in longitudinal thing it is hindered forcefully, but in case of the actual tensile loaded sample the Poisson ratio plays an important role.

So, if you know this modulus individually then these relations, all this relation you can work out from first principle. For example, it is possible for you to derive a relation between elastic modulus and shear modulus and as you can see the Poisson ratio is involved in it and bulk modulus is also involved in it.

So, I am leaving it here on you to work it out based from only from the first principle understanding the nature of this modulus. Go ahead and estimate this relation, I mean try to derive this relation and in one of the assignments also I have set one problem based on it, the relation between the shear modulus and elastic modulus and like the following the same thing you can you can estimate the other relations as well as I have shown in this new graph.

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So, these are the reading material, study material particularly from the book by Tilley understanding the solids. You will have to read chapter number 10 and Barsoum book, chapter number 11. It is relevant there are two excellent text books, also I have mentioned.

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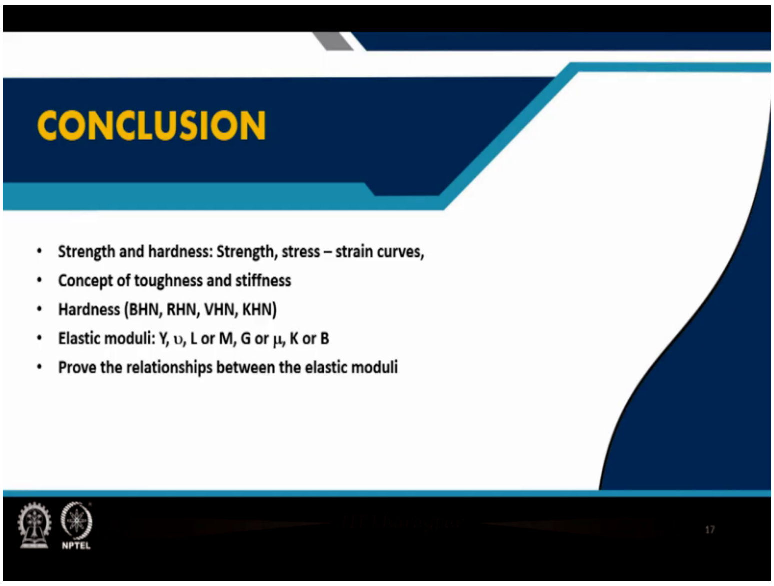

So, in this particular lecture I talked about the strength and hardness concept and stress strain diagram in a very general way, concept of toughness and stiffness that was elucidated, hardness of different types I just introduced, elastic modulus starting from Young's modulus, Poisson ratio, bulk modulus, shear modulus they are explained and the interrelation between the elastic modulus are highlighted.

Thank you so much for your attention.