Materials Science and Engineering
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Lecture – 24
Elastic Behaviour

Hello friends. So, till now, we were discussing I think quite few number of lectures on phase diagram and then we looked at some phase transformation kind of ideas and we looked at some heat treatment procedures ok. So, now, we will be shifting our course to mechanical properties ok, and before coming to mechanical properties or what do we call as mechanical response of material to any mechanical stress or strain ok. So, first thing we want to discuss in this is called elastic behaviour.

So, if you look at any material they will always show you some elastic behaviour and some plastic behaviour. So, first we will look at the elastic behaviour and then we will go further and look at plastic behaviour. So, first we want to note that what do we mean by elastic behaviour of the material, ok. So, before that let us define few terms here one is the normal stress ok. So, you can see that one sample is shown here and we are showing you a cross sectional area here ok.

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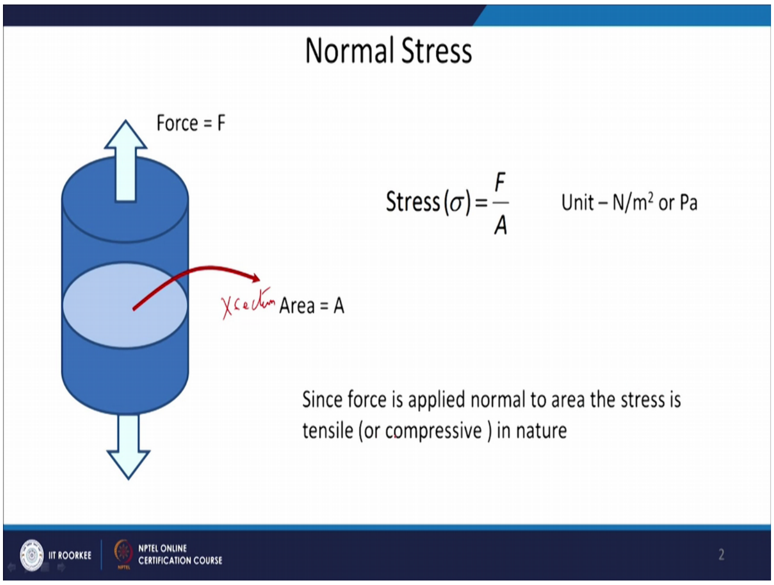

So, this is you can say cross sectional area rather than just area which is given by A, and we are applying one force here on this material which we are saying is F ok.

So, what do we mean by stress the stress will be defined as F force divided by area. So, force per unit area is the stress which is acting on this sample ok. And the unit for that will be Newton per meter square or which is also can be referred as Pascal. And since force is applied normal to the area here the stress is called normal stress and it this can be either tensile. So, tensile means I am elongating the material or it can be compressive in nature in which case I am basically compressing the material or I am shortening the length of the sample ok. So, it can be tensile where you are stretching it and it can be compressive and in both the cases because I am applying the force normal to the area then that is why it is called normal stress.

There is another kind of stress can be possible which in which case we will call it as shear stress.

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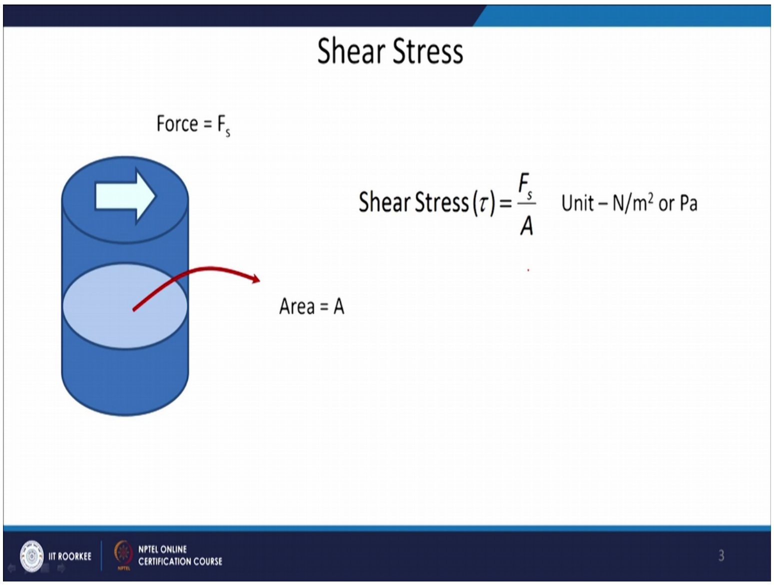

So, now, in this case force is applied parallel to the area ok. So, I am calling it as F s now, because it is parallel to the area. So, again this is my area is defined and I am applying the force parallel to that the shear stress, I am defining by symbol here as tau which is again force per unit area which will give you the shear stress again the units will be same as Newton per meter square or Pascal.

Now, there is another term ok. So, stress can be there and similarly there can be a strain ok. So, what do we mean by strain? Strain is basically change in length divided by initial length ok, any change in the length divided by initial length is equal to strain.

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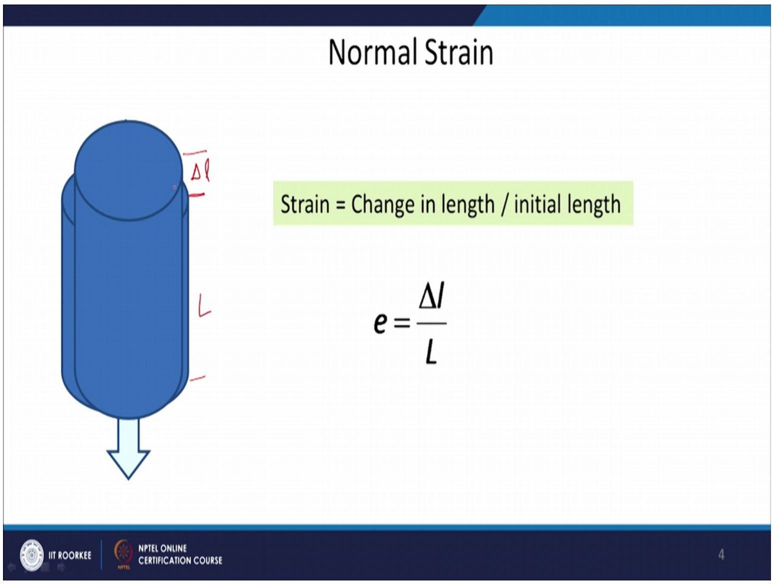

So, basically I when you apply a force like this ok, I am have changed the length. So, initial length let us say for my material was L and change in length is let us say given by delta l ok, then the strain will be change in length which is delta l divided by the initial length that will be equal to the normal strain again because I am measuring the strength on the area which is normal to the stress ok. So, I will call it as normal strain.

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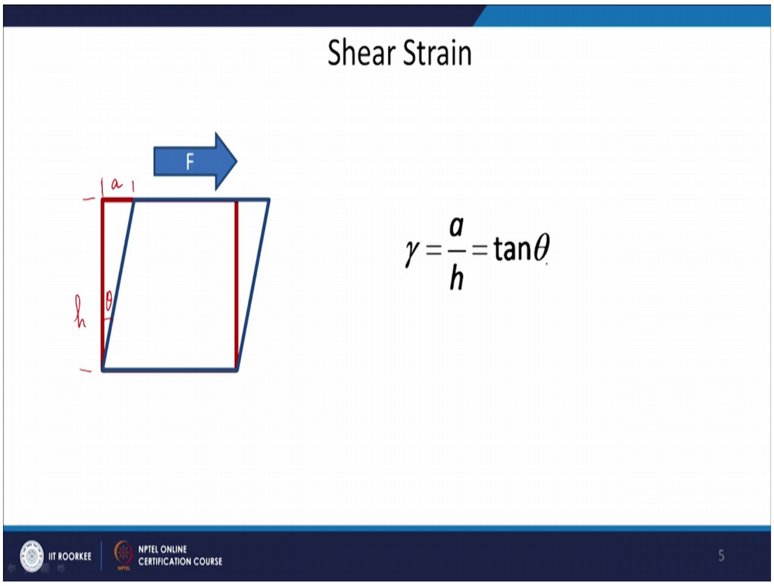

Similarly there can be shear strain which will be because of the force applied to the parallel to the area. So, suppose this is my initial object and I am applying a force here in this direction ok. So, because of that my material is deformed is deformed like this ok. So, let us say my height of this sample was edge and this deformation is let us say a and this new edge is making an angle theta with the old edge ok. Then I can define the shear strain which is I am referring here as gamma that will be the displacement a divided by the perpendicular distance from the fixed end which is h, a by h and that will be; obviously, because this is a perpendicular then this is the base perpendicular upon base then and this is angle theta. So, it will be equal to 10 theta.

So, this is the shear strain because of the shear stress on the material whatever strain is produced called shear strain and that will be equal to a by h equal to 10 theta ok. So, these are definition for stress and definition for strain ok. Very quick definitions we are doing here. For a very detailed definition of stress I would suggest that as a mechanical engineer, engineer student you must be going through a course called strength of materials in that you will see a detailed definition of stress. We are not doing it here for that you go through that particular course ok.

Now, what is elastic behaviour? So, once we have defined stress in the strain. Now, we can look at.

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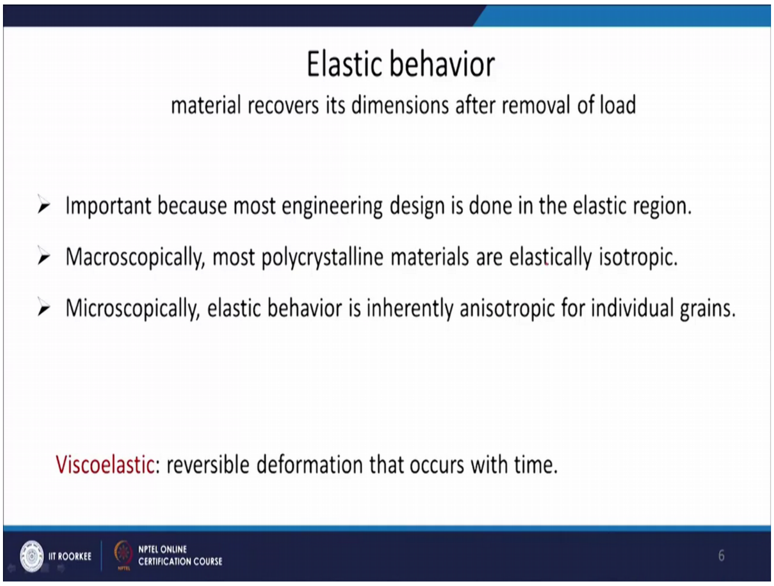

Elastic behaviour of the material it is the material if material recovers its dimension after removal of load ok. So, if I have applied a load and when I remove the load it goes back to its original position ok. One of the very good example of understanding this type of behaviour is you can see in springs ok. So, you take a spring you compress it and when you leave the load it will go back to its origin position for if I stretch it and when I remove the load it will again go back to its original position ok. So, spring is one example very close to this idea of course, there are no there is no spring when we are talking about material ok, but the behaviour is same that when I apply the load it will deform when I remove the load it will come back to its original position.

Why we are understanding of elastic behaviour is important. It is important because most engineering design is done in the elastic region as the mechanical engineer whatever design you are going to do for any structure ok. It has to be done under elastic limit ok; that means, it has to be done where the material show elastic behaviour you cannot cross the yield or you cannot cross the limit where it starts deforming plastically because if it does deform plastically; that means, it the material is failed ok. So, in the strength of material approach again that that will come to understand as a yield criteria. So, for any engineering design it is important that your material should not cross the elastic behaviour of region ok.

Microscopically if you see most poly crystalline material are elastically isotropic. So, we do not have any problem of that they may show an isotropy microscopically it can have an isotropy, but since materials most of the engineering material are polycrystalline, I do not have to worry about that. Then there is another concept called viscoelastic properties of material in which case this reversible deformation that occurs is dependent on time. If it is not a viscoelastic normal elastic behaviour then as soon as I leave the load it will go back to its original position without any time delay ok. But if there is any time delay involved in this and as I told you earlier also that any time factor when it comes it is called visco is a prefix is added. So, if the reversible deformation is time dependent it takes some time to go back to its original position then that is called viscoelastic behaviour.

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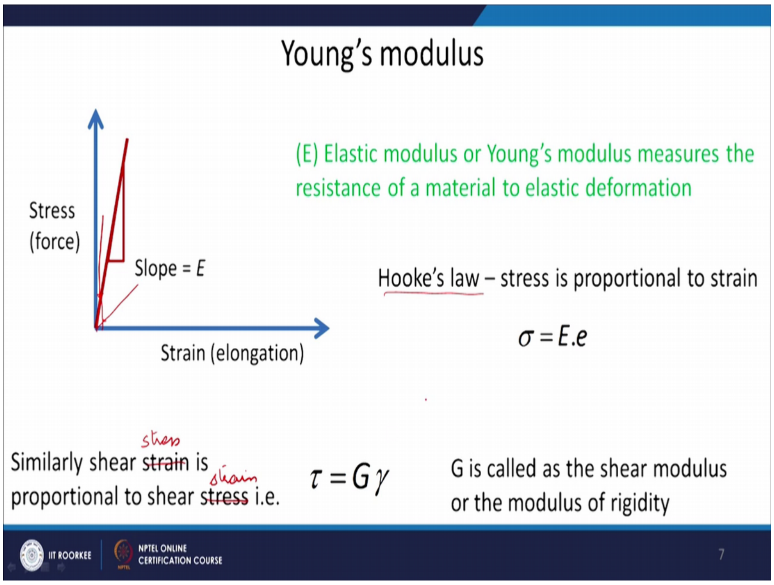

So, this is how elastic behaviour will look like in a typical stress strain curve ok. So, you have stress on the y axis and strain on the x axis.

Please remember when we show something like this we are showing it in because when we do a tensile test what we impose on the material is strain not the stress ok. We force the material to deform and the stress is the response of the material to this elongation or strain ok. In normal lab you practice basically we apply the load and the material responses in form of strain ok. So, there can be different situation in different cases, but when we do a tensile test what we are imposing or what is the independent variable is strain I am deforming my cross head of the machine is moving, and it is deforming the material it is imposing the strain and material is responding in form of stress and that is what is measured using load cell in the machine and that is what is reported ok.

So, basically I on the x axis it can be elongation moment of the cross head or you can convert that into strain because delta l by L. It will also give you force from the machine that can be converted to stress. So, force divided by initial area that will give a stress and the elastic in the elastic part it will have this linear behaviour between the strain and stress. So, stress is linearly dependent on strain ok. And the slope of this linear curve is what we call it elastic modulus or Young's modulus E, ok.

So, slope of the curve will give you E and this linear independent the dependence of stress on strain which is what we call as Hooke's law stress is proportional to strain. So, sigma is equal to E into strain that is what is Hooke's law. What it measures elastic modulus or Young's modulus measures the resistance of a material to elastic deformation as I told you that whatever deformation I am imposing it is resistance. So, if you have high elastic modulus; that means, resistance will be more it will you will require more stress. So, if a material has low elastic modulus the it will be slope will be small. If material has very high elastic modulus the slope will be high. So, resistance will be high for the same amount of deformation ok.

In this case the stress is this much in this case the stress is this much resistance has increased. So, it gives you a resistance to deformation and it is the response of the material in form of stress when you are imposing strain. In case of shear strain also you can do same things similarly shear strain is proportional to shear stress. So, sorry shear stress is proportional to shear strain. So, I will just do some small correction here. So, that tau is equal to G gamma ok. So, here you are getting a new elastic modulus a new elastic constant which is the shear modulus or modulus of rigidity.

So, when I am doing under shear condition then I am going to use the shear modulus when I am doing in a tensile uniaxial tensile or compressive type of experiment then I will be relating the stress with a strain using Young's modulus. So, what type of deformation I am doing I have to choose elastic constant accordingly.

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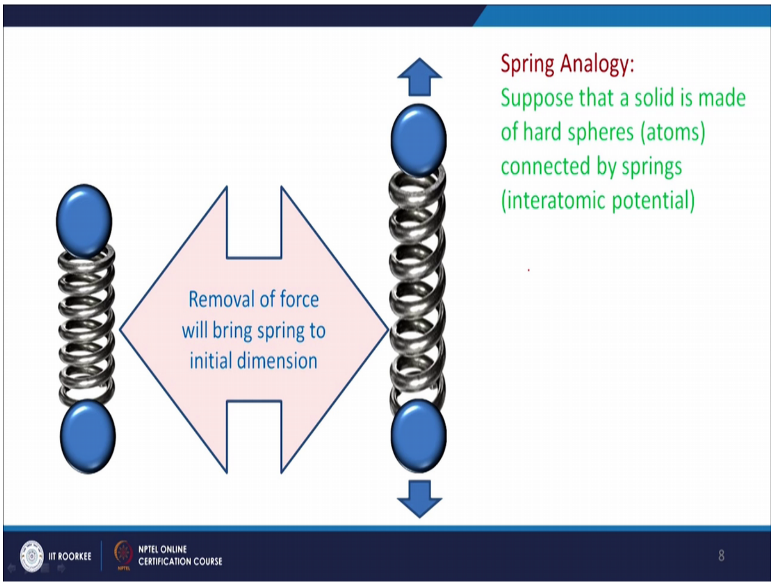

So, this is the spring analogy for elastic deformation as I told you ok, that you have atoms and atoms are basically having bonds between them and then bonds can be considered as spring ok. So, when I am deforming it the spring is getting stretched. So, as soon as I remove the force it will go back to its original position ok. So, removal of force will bring spring to initial dimension. So, I can use a spring analogy to explain this that solid is made of hard sphere which are atom and connected by spring which are inter atomic forces or potential ok. And as soon as I remove the force it will go back to its original position ok.

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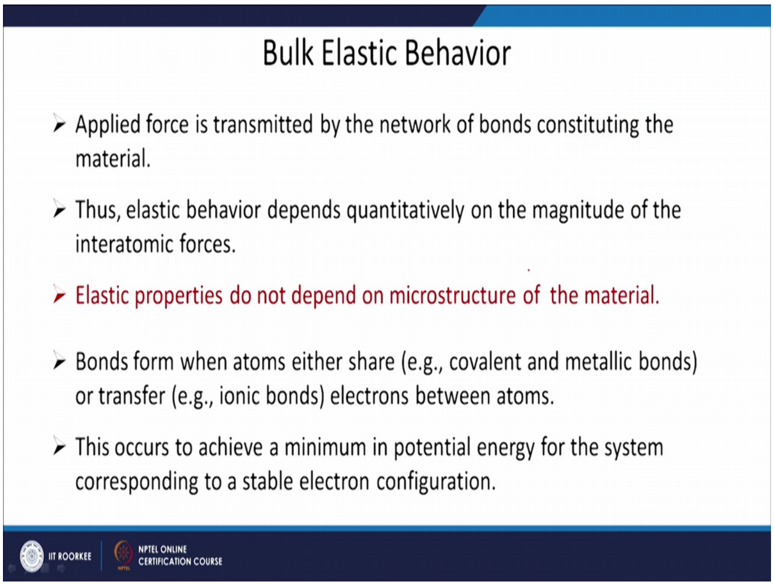

So, basically if you look at elastic behaviour applied for is transmitted by the network of bonds constituting the material of course, there are bonds between the atoms the elastic behaviour depends quantitatively on the magnitude of the inter atomic forces. So, if you have a stronger bond then you will require more force to deform it ok; that means, the elastic Young's modulus of that material will be high. So, if the stronger bonds are there elastic modulus will be high Young's modulus will be high, more inter atomic forces you have more bond strength more Young's modulus.

Elastic properties do not depend on microstructure of the material. This is very important to note that my Young's modulus does not depend on the microstructure of the material. So, you can have fine grain you can of course, grain whatever it is not going to depend on the on the microstructure they lasting modulus ok. It is only dependent on the bond strength and that is not changing.

So, bond force and a term either share example it can be covalent or metallic bonds or it can be ionic bonds ok. So, depending upon different type of bonds you will have different bond strengths and different elastic modulus. Of course, the bond strength bond length should be such that that it is minimizing the potential energy for the system ok. So, let me just bring this aspect out.

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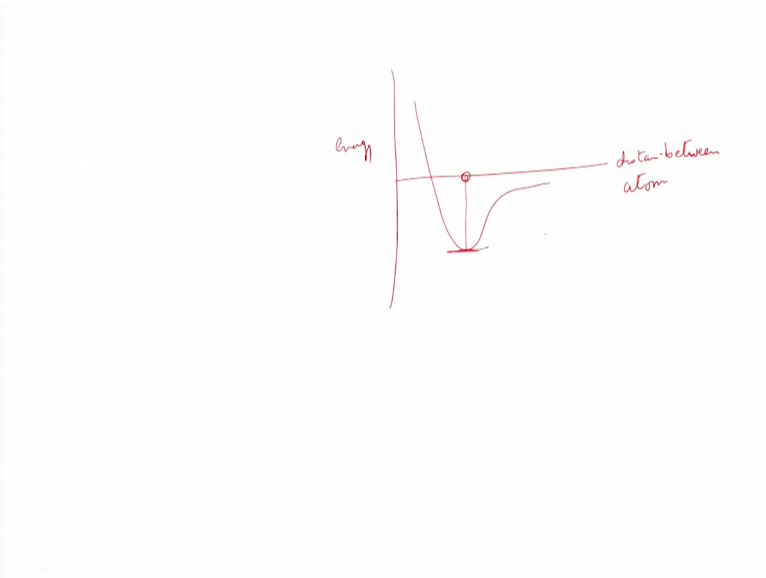

If you see in terms of potential energy the curve for potential energy is something like this is the distance ok. So, it will be something like this, this is the position where you will are going to have minimum energy ok. So, this is this will be the bond length. So, distance between atoms ok. So, this is the distance equilibrium distance if I bring them closer the potential energy will increase if I then take them apart again the potential energy will increase ok. So, as to whether I do stretching or whether I bring them closer in both the cases the potential energy will increase ok, and that is what we do not want and that is what atoms do not want ok. So, as soon as I remove the force it will try to go back to its minimum potential energy configuration which is what is the equilibrium distance between the atoms ok.

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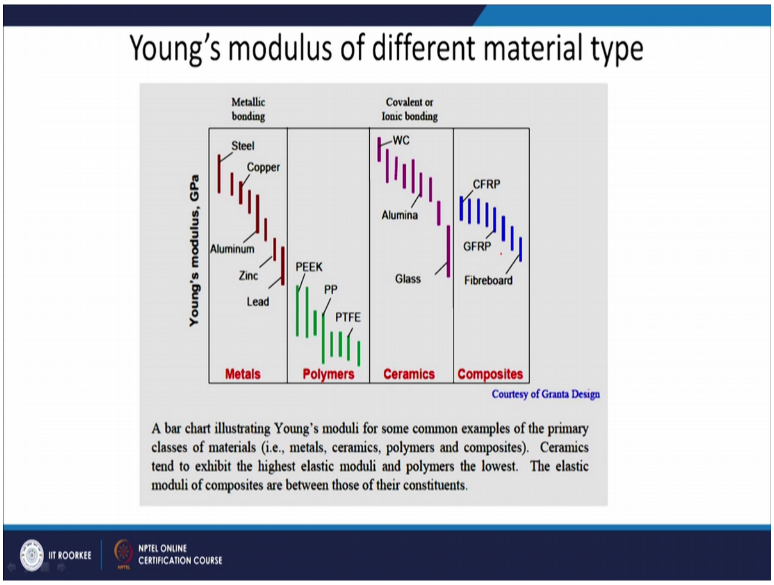

This is what is the driving force for elastic deformation. These are some values of Young's modulus of different material type ok. So, you can see that covalent or ionic bonds are a very strong bond. So, very high elastic modulus and this is for metallic bonds steel has very high long elastic modulus than copper aluminium zinc depending upon their bond strength ok. They will be grouped in different categories here some for polymers also are shown here polymer and composite.

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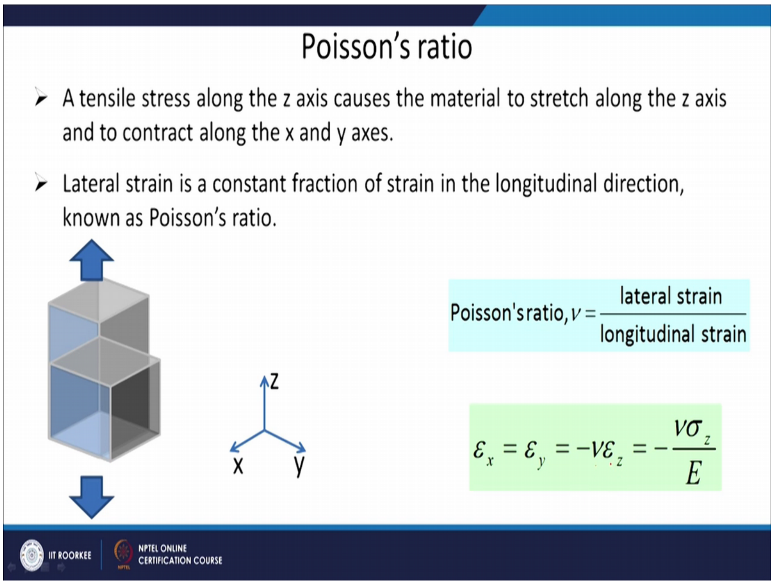

Now, after understanding the elastic deformation and Young's modulus, there is another very important parameter when you are doing deformation and the elastic limit is called Poisson's ratio ok.

What does it mean? That when I am applying a tensile stress for example, in the z axis in this direction. So, when I am elongating in z axis z direction there has to be contraction in the x and y direction ok. So, that is what is there. So, when I am doing a stretching along the z axis there is to be contraction along the x and y axis the lateral strain lateral means this two in x and y direction is a constant friction of strain in the longitudinal direction that is the in the z direction and that is known as Poisson's ratio.

So, suppose this is a cube as shown here and I want to apply a force here in z axis and because of that it will deform elongate in z direction and there will be contraction in x and y direction ok. So, if you measure all these dimensions the strain in the x or y direction divided by the strain in the z direction will give you the Poisson's ratio. So, Poisson's ratio nu is equal to lateral strain about longitudinal strain ok. So, epsilon x in the x direction or epsilon y in the y direction is equal to minus nu of epsilon z ok. Why we are keeping minus sign here is because if strain in the z direction is tensile the strain in x and y direction is there is a contraction ok, there is a negative dilation ok. So, that is why we are using minus here that epsilon s will be equal to minus of nu into epsilon z or epsilon y is equal to minus of nu into epsilon z ok. So, if one is tensile other way has to be compressive and that is why the negative sign.

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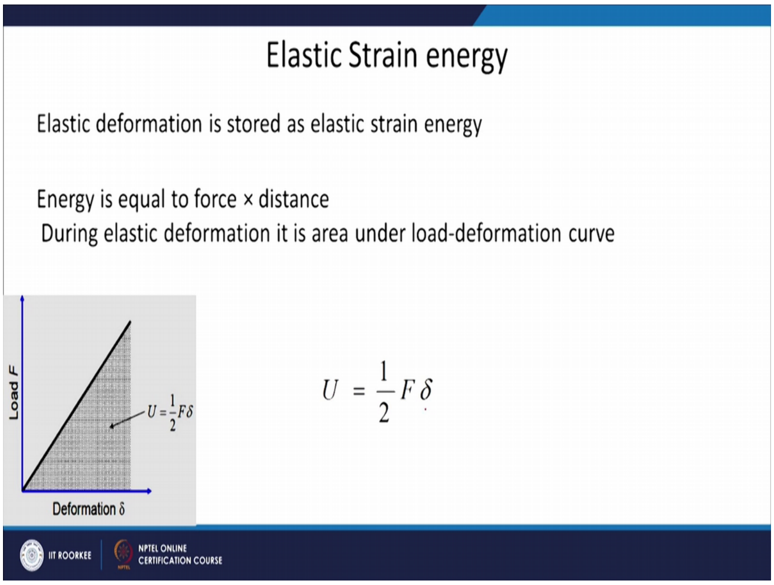

Now, there is another concept called elastic strain energy. As you see that when I am deforming it my potential energy is increasing; that means, I am storing the strain energy in the material, of course, elastic strain energy in this case because we are doing it under elastic limit. So, elastic deformation is stored as elastic strain energy in the material and how what do we mean by energy, energy is equal to force into distance.

So, during elastic deformation it is area under the load deformation curve. So, if I instead of plotting stress versus strain if I plot deformation versus load area under the curve and area under the curve will be equal to half of force into displacement and that will give me the area under the curve. So, this is my elastic strain energy which is stored in the material when I am deforming it.

And when I release the force ok, this strain energy will be recovered and of course, this energy has to go somewhere actually it will go in heating the material ok. So, if I keep on doing suppose this continuously after some time you will see that the material is heated up because this strain energy which is stored will be dissipated in form of heat and slowly you will see that there the temperature of your material is rising if you keep doing this for quite number of time ok.

So, with this we have covered the elastic part of the deformation ok. We are very important for a mechanical engineer and of course, you have a kind of a full course on that in terms of strength of materials course, where the whole treatment is under elastic limit. And actually you under try understand the whole plastic deformation in much detail then what we did here ok. Here we are just kind of trying to understand that when you do a stress and deformation or you plot a stress strain curve there has to be some elastic region and then there has to be some plastic region ok, an elastic you can have certain things which we and try to understand in the present lecture.

Thank you very much.