Mechanical Behaviour of Materials
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Lecture - 03
Strength of Materials - A short overview part - I

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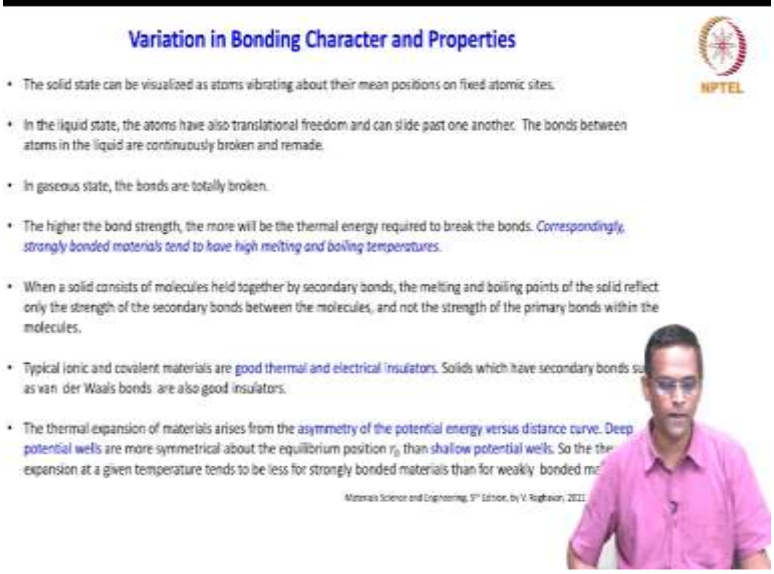

Hello, I am Professor Sankaran in the department of metallurgical and materials engineering. We are going to just look at the some of the salient features of bonding character. So, one of the primary aspect is the solid state can be visualized as atoms vibrating about their mean positions on fixed atomic sites. And in a liquid state, atoms have also translational freedom, important and that can slide past on another. The bonds between the atoms in the liquid are continuously broken and remade, this all we know.

In gaseous state bonds are totally broken, the higher the bond strength the more will be the thermal energy required to break the bonds. Correspondingly strongly bonded materials tend to have high melting point and boiling temperatures. So, this is something which we also looked at the correlation with the potential well diagram. When you have the steeper potential well diagram, it has got something to do with advance strength as well as melting point.

So, we will again acknowledge this idea, as we just move on wherever we try to connect with the atomic basis of the properties, we will be able to connect this idea or carry this along. So, when a solid consists of molecules held together by secondary bonds, the melting and boiling points of the solid reflect only the strength of the secondary bonds between the molecules and not the strength of primary bonds within the molecules.

You see, as we just move along, we will see that the external forces are in this case we are talking about boiling point and that is the thermal energy or even when you say force it is a mechanical energy. So, how these bonds respond to the external forces so, that is the ultimate point we will reach. So, how these primary bonds and secondary bond respond or resist to the external load that determines the physical property primarily and then mechanical property as well.

So, the typical ionic and covalent materials have a good thermal and electrical resistivity. And solids which have secondary bonds such as van der Waals bonds are also good insulators, this is true because most of the ceramic material they are all mostly covalently bonded ionic bonding are mixed of these 2 characters together like intermetallics and so on. So, the thermal expansion of materials arises from the asymmetry of the potential energy versus distance curve.

Deep potential wells are more symmetrical about their equilibrium positions r_0 than the shallow potential wells. So, thermal expansion at a given temperature tends to be less for strongly bonded materials than for weakly bonded materials. So, this aspect we will look at it in much more detail in the coming lectures. So, the thermal expansion of material arises from asymmetry of potential energy well that we have already discussed yesterday by looking at the geometry of this nature of the curve.

So, we will connect them by giving examples in the coming lectures. So, these are some of the important salient features about bond characters and properties.

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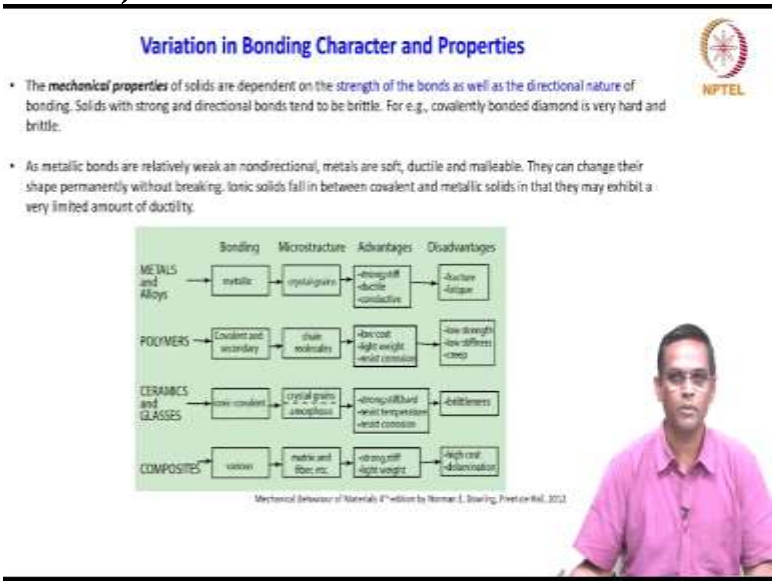

So, finally what we are trying to say is the mechanical properties of solids are dependent on strength of bonds as well as directional nature of bonding. Solids with the strong and directional bonds tend to be brittle for example covalently bonded diamond is very hard and brittle. So, having connecting with all the physical properties, we are now saying that mechanical behaviour of materials also strongly dependent on the type of bond and its nature and also directionality and so on so forth.

So, I was just mentioning in the initial part of the bonding not necessarily know all covalently bonded materials will be hard because, but there is not another requirement. So, the covalently bonded materials will also have a uniform surroundings as in the case of diamond, even in polymers, you have a covalent bond but then the first line of you know resistance is not the primary bond covalent is there, but there it is a van der Waals forces which takes the initial load.

So, the response of the material is quite different as compared to diamond type of materials where you have a covalent bond is you know uniformly are surrounded by all the neighbouring atoms have this same covalent bond. So, it is so, hard and strong and mechanically it is brittle in fracture. So, as metallic bonds are relatively weak and non directional metals are soft, ductile and malleable. They can change their shape permanently without breaking.

Ionic solids fall in between covalent and metallic solids in that they may exhibit a very limited amount of ductility. So, you have one extreme metallic bond and the other extreme is called covalent bond, ionic bond comes in between in terms of their mechanical strength and their physical properties. So, now we will see some of the examples suppose, if you take metals and alloys and they exhibit a metallic kind of bonding and most of them are poly crystalline.So, the crystal grains, they consist of the microstructure consists of crystal grains and advantages they are very strong, stiff, ductile and conductive. Disadvantages they may not have very good fracture and fatigue properties that could be any limitation. And if you take polymers, they are all covalently bonded as well as secondary bonds. The microstructure will show that these materials consist of chain molecules.

Or the microstructure completely contains molecular chain folded into some crystalline form or entangled form or you know tangled form and so on. Advantages in terms of utility, low cost, light weight and very importantly corrosion resistant. So, disadvantages from the engineering point of view a low strength, low stiffness do not have good creep properties. We will see we will understand why these things are so, as we proceed further.

If you take ceramics and glasses, they are having ionic bond or covalent bond or both. They could be poly crystalline nature or there could be semi crystalline or amorphous in nature. Both state of microstructure is possible, that could be completely amorphous or semi crystalline and so, on. Advantages they are strong, stiff, hard, resistant to temperature the very important property and resistance to corrosion is again very important property, very attractive property from the engineering point of view, disadvantages they are highly brittle.

And finally, composites, a bonding could be of various combination in nature because a composite can be a made up of any two or three material together, each one may have a different more bonding it could be covalent and ionic or for example, if you take fiber reinforced plastics, plastic could be you know having bonding of overland and second bonds and your reinforcement could be ceramic or it could be metal or it would be fibre depending upon what type of reinforcement on wish to add.

So, the bonding is various type of bonding possible microstructure either there is a two constituents major constituents here, one is matrix and that is reinforcement. So, matrix can have one microstructure and fiber or reinforcement will have some other microstructure and so on. The advantages, they are very strong, stiff and lightweight and very importantly, disadvantages are very high cost and they may lose their togetherness by delamination. The fiber will pull off, you know could be delaminated from the matrix, these are the properties which will deteriorate the mechanical area and so on.

So, you see that this table clearly demonstrates that there is a strong connection between the chemical bond of a material and what kind of mechanical property they exhibit, there is a strong connection. So, that is the reason we are looking at chemical bonding much more closely.

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So, the next important subject I want to just go and review like chemical bonding though we all know that similar thing subject is strength of materials. So, we will just review this before we proceed further. What is strength of materials? The subject deals with the relation between internal forces, deformation and the external loads. So, assuming the members are in equilibrium that is static equilibrium.

The equation from the static equilibrium are applied to forces, acting on some part of the body, in order to obtain a relationship between external forces acting on the member and the internal forces resisting the action of external loads. you see, we want to have some design criteria. So, let us assume that you know I would take a material which is assumed to be in an equilibrium, in the strength of material concept the static equilibrium equations are applied.

So, when the external force act on the body then the internal forces will resist them so, the basically this resistance of internal force is now termed as a stress. The resistance to external force in terms of internal resistance for example, here we talked about primary bond secondary bond and so on. So, all these bonds will resist the external force so, that external force will be resistance by internal force. So, which is termed as stress and then we need to look at the stress distribution in the body whether it is acting in a point or it is where all it is distributed. But the very important point is you just look at it. so, the internal forces that are resisting forces are usually expressed by stress acting over a certain area. The stress distribution is arrived at by observing and measuring the strain distribution. So, this is important so, we are not going to measure the stress directly because stress cannot be physically measured. So, we are looking for a strain distribution and we will measure the strain distribution. By what? The strain distribution, we will just look at it how we are going to measure the strain through some displacements, how from the displacement how experimently, you will be able to measure the strain, that we can see. The important assumptions in strength of materials, are that the body which is being analysed is continuous, homogeneous and isotropic.

So, we should know the meaning of these three words. A continuous body is a one which does not contain whites or empty spaces of any kind. A body is homogeneous if it has identical properties at all points. A body is considered isotropic with respect to some property, when that property does not vary with direction or orientation, directional nature. So, what strength of material, try to do is it makes some assumptions basically like the material is continuous homogeneous and isotropic and so on.

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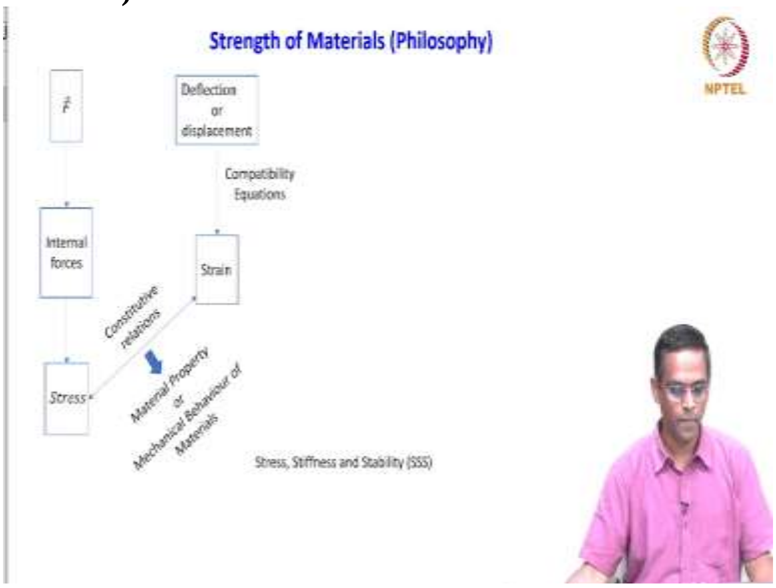

And then it tried to apply the static equilibrium equations, where body is subjected to an external force and the resistance from the body, the internal force is being measured as stress. But then as I just said stress cannot be experimentally and physically measure so, we look at the deflection or displacement then we measured the strain and we have the constitutive relations between stress and strain.

The most popular one, all of us know is Hooke’s law, stress it has. It states that you know stress will have a linear relationship with strain and so on. So, they are called constitutive relations, from this constitutive relations, we try to calculate the stress and then from the stress we can try to calculate the load and dimension of the member and which will be based upon the material property or mechanical behaviour of materials.

So, this is the in a nutshell strength of material philosophy try to give. So, it is very useful so, as a design engineer, if you want to select a material if this properties are given are these relations are given or something is known. So, you will be able to calculate the loads and the dimensions of the material depending upon the specific applications. So, that is philosophy of strength of materials.

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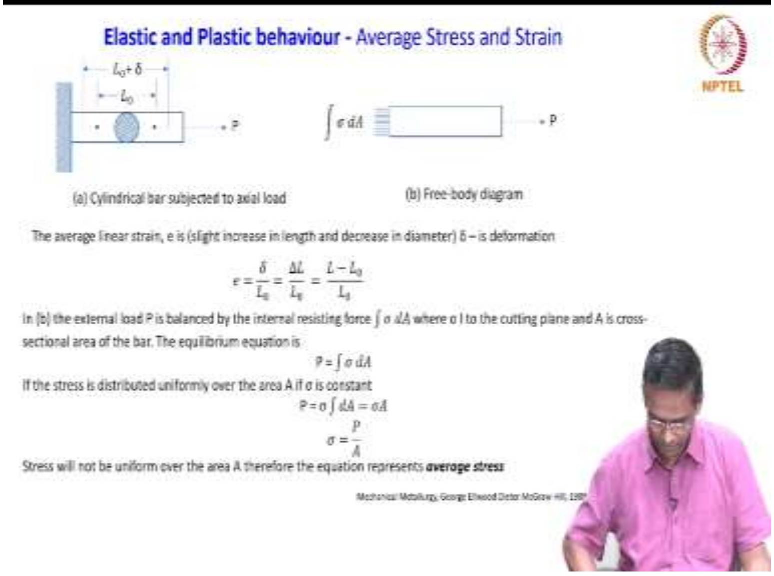

So, with this background, we will just try to move further we will look at again elementary properties, elastic and plastic behaviour. So, what is shown in this figure is a cylindrical bar which is fixed at one end and which is subjected to an axial load in this direction that is a P actual load P and you can see that there are two points which is referring L_0 showing the initial position then after you pull this bar to some extent. Then these two points move to the new positions which is the distance between the two new points will be $L_{0+\delta}$. So, what is delta? Delta is the deformation so, you should also think about suppose if you try to pull this rod in this direction then the length increases also a corresponding a diametrical reduction is also expected. So, that is a kind of configuration we are now trying to look at and describe.

So, the word average linear strain e is measured here and delta is a deformation as a slight increase in the length and a decrease in the diameter that is what I am trying to show here. So, it can be written like this, the average linear strain is equal to deformation delta divided by original length L_0 or change in length by original length can be written as L - L_0 / L_0, that is linear average strain.

$$e = \frac{\delta}{L_0} = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

And what is shown in this diagram (b) is a free body diagram, where again the member is being pulled in this direction P and against its internal forces, shown this kind of small lines and this is an external load P that is what is written here. The external load P is balanced by the internal resisting force, this force which can be an integral of the internal force resisting force times the area so, area is dA this particular area. So, the equilibrium equation for this particular free body diagram is.

$$P = \int \sigma dA$$

And if the stress is distributed uniformly over the area A, if σ is constant then we can say

$$P = \int \sigma dA = \sigma A$$

So, this is how the stress is being defined and very important thing is the stress will not be uniform over the area A therefore, the equation represent average stress. So, this is what you have to be careful so, here also we just used the word average strain, here is average stress.

So that means, when you take a body or a member which, is being pulled in one direction or subjected to an external load we strength of materials concept or continuum assumes that every point of the body undergoes a similar or every point of the body experiences similar load or similar force. But that need not be the case in reality so, there could be some part will be undergo more stress than the other. So, see we do not have that you know clarity there so, that is why it is called average stress.

It is not, you know the stress is not going to be uniform all over the body, or even the strain is not going to be uniform that is why, it is called average strain average stress so, this we have to keep in mind.

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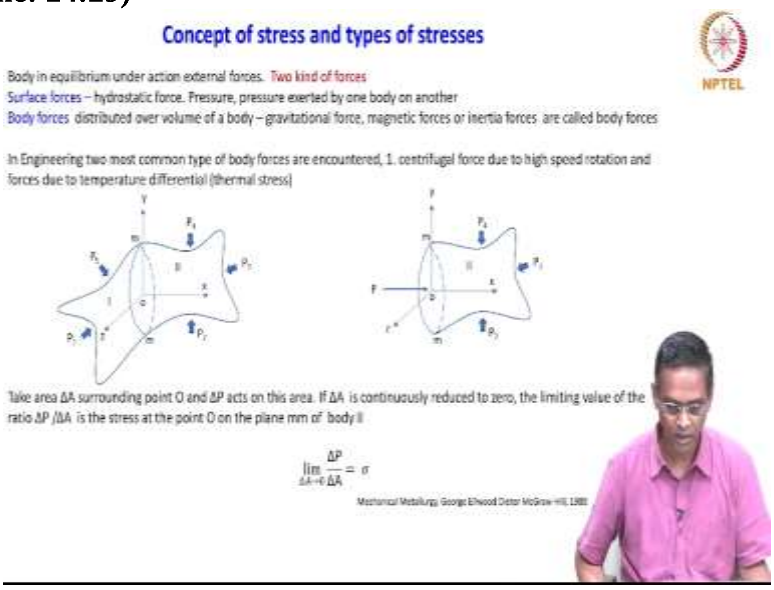

So, when we talk about body in equilibrium under the action of external force, there are two kinds of forces one is surface forces. What is surface forces? Hydrostatic force, pressure, pressure exerted by one body on another. So, we are seeing that external force on a body. So, what kind of force so, that could be two forces one is surface forces, what is the other one other one is a body forces.

What are body forces? A body forces which is distributed over a volume of a body, make a note of it this is over a volume of the body something like a gravitational force, magnetic forces or inertia forces, they are all called body forces. So, in engineering two most common type of body forces are encountered, one is centrifugal force due to high speed rotation and the forces due to temperature differential that is thermal stress. These are all two most common type of body forces which is encountered in the engineering applications.

So, now we will se,e how to look at the concept of stress at a point as per the strength of material concepts. So, look at this diagram which is a body which is assumed to be in equilibrium, is subjected to external pressures P_1, P_2, P_3, P_4, P_5 and then we are interested in looking at the stress at the point O in the plane mm. So, are you can say that this plane mm is bisecting these two parts, part one and part two and this is a x, y, z coordinate.

So, as per the strength of material description, so, what we can do this we will cut this plane, I mean cut this body into two and then what it means is the part two comes off from this and then we are interested in measuring the stress at a point O which is taken from the whole body like this. What it means is, you know the removed portion of the body is replaced by the resisting force or external load at this point or this area.

Or otherwise whatever the forces which were there, when these two parts were together, it is assumed to be still there and we are interested in looking at the stress at a point O. So, take area ΔA surrounding point O and ΔP acts on this area because of this external load if Δ is continuously reduced to 0, the limiting value of ΔP/ΔA is the stress at the point O on the plane mm on the body second .

$$\lim_{\Delta A \to 0} \frac{\Delta P}{\Delta A} = \sigma$$

This limiting value is nothing but a sigma that is stress at a point according to strength of material concepts. So, that is one way of looking at the stress at a point how to visualize or how to grasp the idea.

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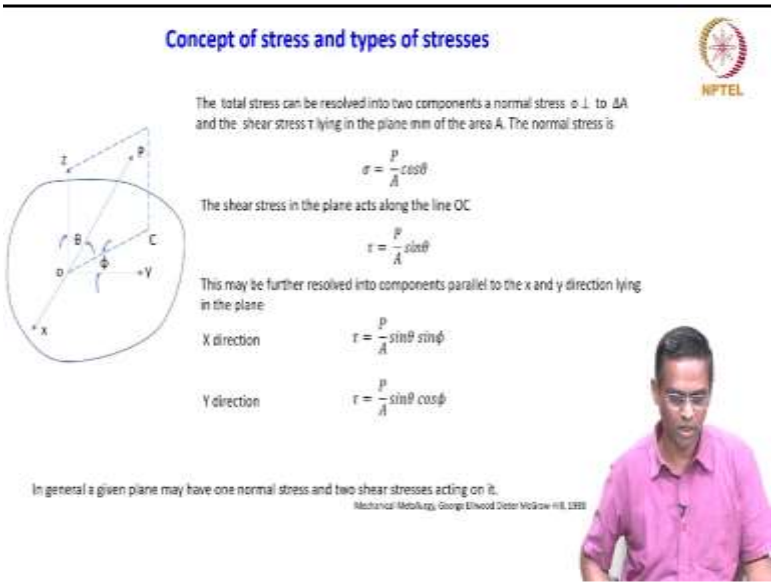

So, what are the types of stresses we know? Like if you look at this diagram, so, you can just assume that this is the same cross section mm in the previous diagram. So, the σ what we refer is a total stress that can be always resolved into two components that is the normal stress sigma which is perpendicular to the area of cross section or the area of interest where we define the O the origin of the point and the shear stress 'τ' lying in the plane mm of the area A.

So, what is the same coordinate is given here, assume this plane is mm and this is the OP is similar direction of the load what is given. So, you can see that this plane OP these lying in O Z and C this kind of a plane. This vector basically and we will now say that sigma the normal stress is $\sigma = \frac{P}{A}\cos\theta$. So, this is the P and this θ is the angle between these two. So, we are looking at a normal stress that means it is a normal to this plane. So, it will have this θ component so that is why it is P/A cosθ.

And the shear stress will be in the plane x along OC, so, this is the angle between y and this plane that is "ϕ".

$$\tau = \frac{P}{A}\sin\theta$$

this "θ" and we are looking at the shear and it may be further resolved into two parallel I mean two components, parallel to X and Y direction lying in the plane. So, the shear stress can be further divided into two that is because of this projection. So, P/A sinθ is shear stress and P/A sinθ sinϕ is the shear stress acting in X direction and P/A sineθ cosϕ is in Y direction.

So, this is just a very convenient way of resolving this, the stresses and this is the way to look at it. So, when we have a total stress, you should remember that it is always convenient to resolve them into shear stress and normal stress. So, this is a convention which is being followed so, I thought first I will introduce this then before we get into this next one.