Mechanical Behaviour of Materials

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Lecture - 34
Mechanical Testing – II

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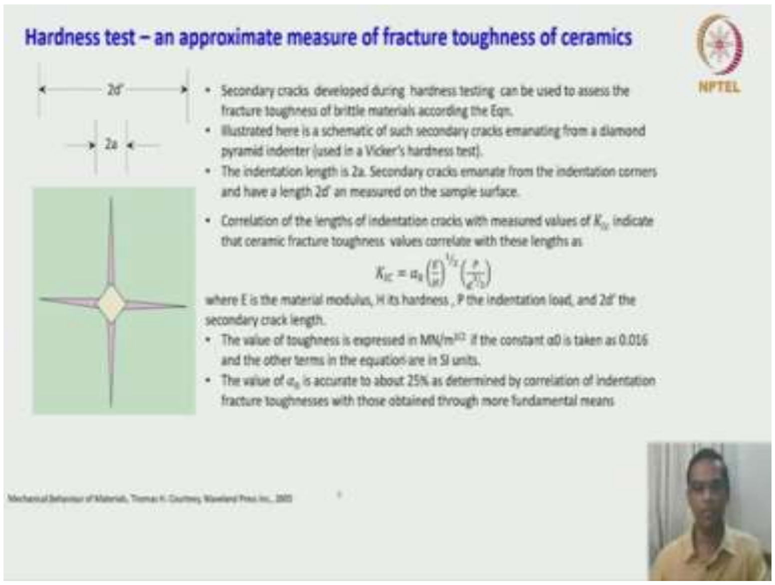

Hello, I am Professor S. Sankaran in the Department of Metallurgical and Materials Engineering. So, now, having described you know very sophisticated oddness methods, how the hardness measure methods or hardness measurement is useful in finding out something else. So, hardness test an approximate measure of fracture toughness of ceramics. So, the fracture toughness is measured by just measuring the hardness in ceramics.

So, we will see in the later that you know ceramics exhibits very poor ductility and the fracture toughness of the ceramics are very poor but improving the fracture toughness of the ceramics itself and technology. So, huge technology and very important we will see when we look at in the fracture mechanics aspects of materials. Here just by measuring the Vickers hardness, which makes the pyramid impression like this. The surface will have this square type this and what is shown in the rose colour is the cracks with just emanates from the sharp edge corners of the intenders, so assume that this ceramic material and this is the Vickers hardness measurement and the cracks develops like this secondary cracks developed during the hardness testing can be used to assess the fracture toughness of brittle materials. So, illustrated here is a schematic of such secondary cracks emanating from the diamond pyramid indenter used in a Vicker's hardness test. So, this is what it is.

So, this distance is 2a and this end to end 2 crack ends or measures 2d ′, the indentation length this 2a basically a diagonal length here, secondary crack emanate from the indentation corners and have the length of 2d′and measured on the sample surface. The correlation of the lengths of indentation cracks with measured values of K_{1C} indicate that ceramic fracture toughness values correlate with this length as,

$$K_{1C} = \alpha_0 \left(\frac{E}{H}\right)^{1/2} \left(\frac{P}{d^{3/2}}\right)$$

Where, E is the material modules, H which its hardness, P the indentation load and 2d′ this secondary crack length. The value of toughness is expressed in $MN/m^{3/2}$, if the constant α_0 is taken as 0.016 and the other terms of the equations are in SI units. The value of α_0 is accurate to about 25% as determined by the correlation of indentation fracture toughness with those obtained through more fundamental means, you see it is right quite interesting.

So, I said that knowing the fracture toughness of the cracks in ceramics is very important and it is very technologically also very important. So, measuring this you know, fracture toughness just by means of hardness test is also very handy, though it gives some, you know some not very accurate but approximate value gives, nevertheless it gives an idea about the fracture toughness. So, this is another interesting aspect of measuring hardness in ceramics.

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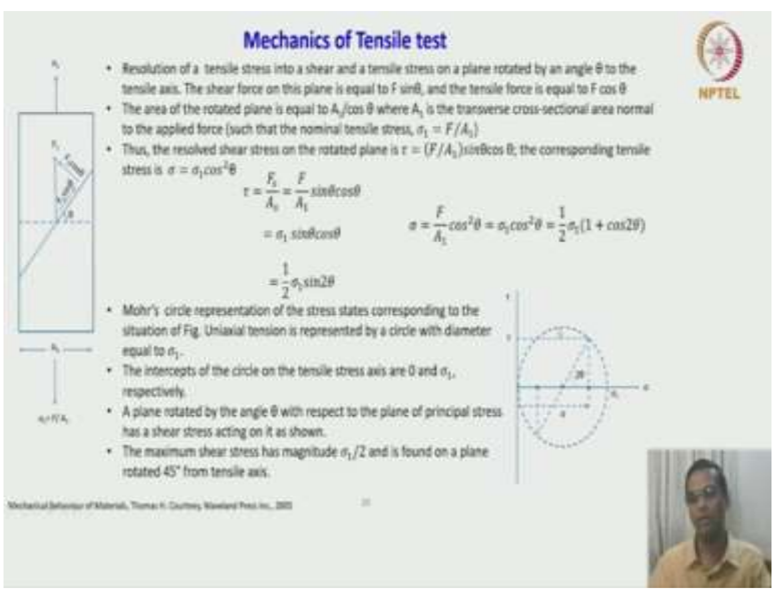

Now, we just move on to the next important mechanical testing or tensile test, before even getting into the results and the description of what kind of data you will get. We will also look at the mechanics aspect of conjecture, since we have spent a lot of time in mechanics aspects, so, it is better to correlate then and there, that helps. So, what is involved in a tensile test? A tensile test normally conducted on a cylindrical bar or a plate with a specific geometry we are not talking about that we are simply taking a rectangular bar or a sheet in 2D, and then subject them to a tensile force like this and the area of the cross section is A_1 and the tensile forces F_1 here. So, the σ_1 is F / A_1. So, that is what it is. The resolution of a tensile stress into a shear and a tensile stress on a plane rotated by an angle θ to the tensile axis. The shear force on this plane is equal to F sinθ and the tensile force is equal to F cosθ. So, how do we understand this, so this is the shear plane which is 45 ˚, this also you understand now, that is the plane where the maximum shear stress acts. So, all the questions slip by I mean deformed by slip under this plane that those details are you know now. So, this is axis course axis, so this isθ, 90˚θ, so, cos (90-θ) is sin θ. so, that is how it becomes the F_1 sin θ. So, this is F_1, so this is F_1 sin θ is becomes this shear force that is what it is so, that sin θ comes from cos(90 - θ)so said. So, F_1 sin θ into shear force and then this one is the tensile force. So, you just look at this direction and then take the force which is coming, acting on this plane is not just F_1, but it is a F_1 times cos θ is the magnitude of the tensile force acting on this. So, that is what it is here. So, we have already since we have already spent a lot of time on you know how to resolve this test and all that. So, this is the one good example application of your knowledge in a simple tensile testing. The area of the rotated plane = A_1 / cos θ.Where A_1 is a transverse cross sectional area normal to the applied force such that the normal tensile stress $\sigma_1 = F / A_1$. Thus is the result shear stress on the rotating plane is $\tau = (F / A_1) \sin\theta\cos\theta$, the corresponding tensile stresses $\sigma = \sigma_1 \cos^2\theta$. So, how do we get this, so, the shear stresses shear force by the shear stress acting on the area, so which is equal to (F / A_1)sin θ cos θ.

$$\tau = \frac{F_s}{A_s} = \frac{F}{A_1} sin\theta \cos\theta$$

$$\tau = \sigma_1 \, sin\theta \cos\theta$$

$$\tau = \frac{1}{2}\sigma_1 \, sin2\theta$$

So, you need to understand that the rotated plane is much larger than this. So, that means a larger by what amount, larger by 1 / cosθ it is larger than by 1 / cosθ. So, that is why it is written like that. So, this can be written like this F / A_1 = σ_1, that is the only principle stress in the tensile stress or tensile test, σ_1 okay. So, which can be rewritten like this $\tau = \frac{1}{2}\sigma_1 \sin 2\theta$.

Why do we write in this form, because, we can represent this whole state of stress in a Mohr's circle which is always plotted with 2θ. this solves procedure also we have seen, so now, we can see the application of that later. So, this is a shear stress and the tensile stresses σ,

$$\sigma = \frac{F}{A_1} Cos^2\theta = \sigma_1 Cos^2\theta = \frac{1}{2}\sigma_1 (1 + Cos\, 2\theta)$$

So, this is in the trigonometry identities. So, we can now, plot this in a Mohr's circle to understand that concept again, this will again give an opportunity to recall what we have already learned. So, what is shown here it is as I told you, this is the only principle stress in our tensile test is σ_1. So, which is which will form a say around this will make a circle. So, that becomes a diameter σ_1 is become a diameter of Mohr's circle.

And then, so, this is what is written here, a Mohr's circle representation of the stress state corresponding to the situation in the figure one, uniaxial tension is representation by the circle with a diameter equal to σ_1 what I just said. The intercepts of the circle on the tensile stress axis are 0 and σ_1. So, this is 0 and σ_1, this is two intercepts of the circle. A plane rotated by the angle θ with respect to the plane of the principal stress has a shear stress acting on it as shown. So, here this is θ. So, in Mohr's circle we brought it as 2θ. So, 2θ wherever it intersects it; gives a corresponding tensile stress and a shear stress. So, whatever we are now, showing as a resolved shear stress and tensile stress also can be obtained by simply plotting on the Mohr's circle here. So, this is corresponding shear stress and this is corresponding tensile stress. So, the maximum shear stress as the magnitude of σ_1 / 2 and it is found on the plane rotated 45 degree from the tensile axis. So, this also we known, so that will come here. So, the 2 θ will become what 90. So, θ will become 45. So, that is also we known.

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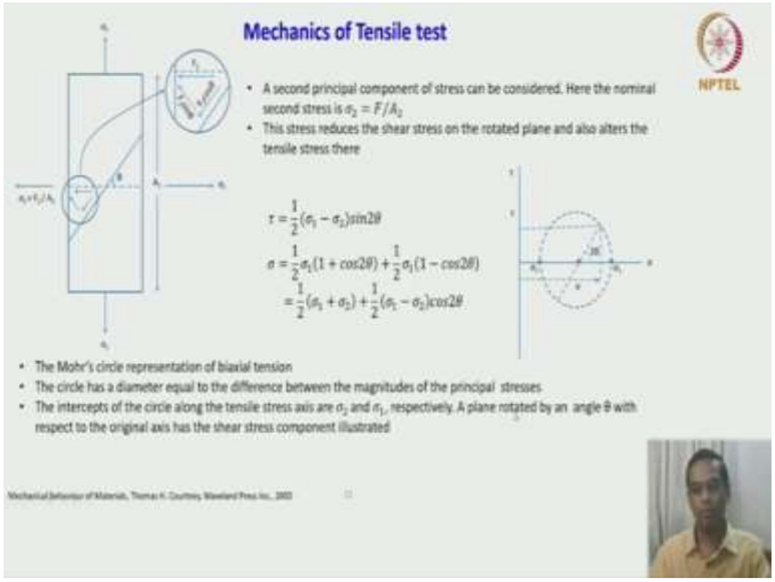

So, the next one is what will happen to subject the specimen by biaxial tension. Another simple interesting problem, suppose a second principal component of the stress can be considered, here the nominal second stress is σ_2 is = F / A_2. So, here we are talking about this a σ_1 and this is σ_2 in this direction. So, same figure, but then you see that the stress resolution takes place here, which is shown here you can see that this is F_2 because this direction and then this is the normal force and the shear force and the normal force is given like this.

So, here the shear force is $F_2 \cos\theta$ and normal force is $F_2 \sin\theta$ which is already we have seen, but this stress reduces the shear stress on the rotated plane and also alters the tensile stress there. So, very important point we are talking about a biaxial tension. So, these the secondary principal component of the stress going to reduce the shear stress, what is the already there in the uniaxial tensile test. So, here the maximum shear I mean the shear stress is given by the difference in the two principle stress times the sin2θ.

$$\tau = \frac{1}{2}(\sigma_1 - \sigma_2)sin2\theta$$

So, we can just again we can write the tensile stress which is equal to

$$\sigma = \frac{1}{2}\sigma_1 (1 + Cos\ 2\theta) + \frac{1}{2}\sigma_1 (1 - Cos\ 2\theta)$$

$$\sigma = \frac{1}{2}(\sigma_1 + \sigma_2) + \frac{1}{2}(\sigma_1 - \sigma_2)Cos\ 2\theta$$

So, we can write it like this. So, this is a combination of two principal stresses plus the difference in the principal stresses times the cos2 θ that is your tensile stress. So, we can plot them again on the Mohr's circle here what we are seeing? Here we are talking about two principal stresses σ_1 and σ_2 the difference between the σ_1 and two forms the diameter of the Mohr's circle.

So, that is $\sigma_1 - \sigma_2$ is this. So, this is what written the circle has a diameter equal to the difference between the magnitude of the principal stresses, the intercepts of circle around the tensile stress axis or σ_2 and σ_1 and here a plane rotated by an angle θ with respect to the original axis has the shear stress component illustrated. So, see rest all the same we know that this is 2 θ, so this is σ and this is shear.

The maximum shear stress again found on a plane rotated by 45˚, however in this case the maximum shear is $(\sigma_1 - \sigma_2)/2$, this is important there it was $\sigma_1 / 2$ maximum, but here it is not $\sigma_1 / 2$ it was rather $(\sigma_1 - \sigma_2)/2$. So, this is another way of looking at this. Now, we will go to engineering stress strain curve.

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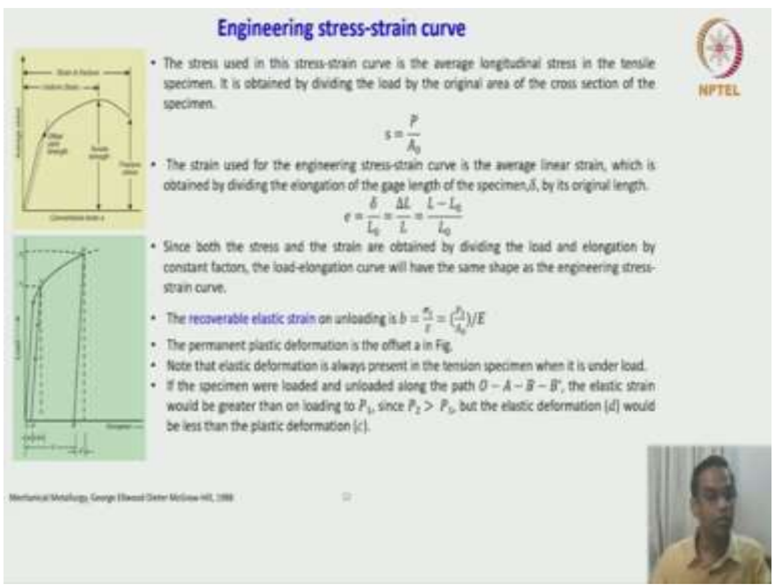

So, normally in any textbook, the engineering stress strain is illustrated like this. So, what is plotted here is an average stress versus conventional strain. So, you can see that the average stress goes like this and reaches a maximum and it comes down, the stress used in this sustained curve is the average longitudinal stress in the tensile specimen. This is obtained by the load by the original area of cross section of displacement.

So, this important whenever we talk about engineering stress, we divide the load by the original area of cross section. So, what are the descriptors here, so we are showing something since this curve is continuous. So, to find out the yield strength there is something called offset yield strength is defined, we will see it how exactly we can do that and there is something called uniform strain which goes up to the maximum and the strain to fracture up to the fracture point and then you have offset yield strength, tensile strength and the fracture stress.

So, many parameters are already this I mean denoted on this stress strain plot. So, we will thoroughly look at all of them one by one very slowly okay. So, the engineering stress is represented by s in this textbook. So, I have followed this reference mostly for this section, which is in detail the engineering stress is given by s is equal to load divided by original area. The strain use for the engineering stress strain curve is the average linear strain.

So, if you recall when we introduce the stress strain in the elasticity, there also I use the same terminology average strain and average stress. So, you know, you have to now, see that we are now talking about a bulk property. So, you have to connect what is the strict definition of strain and stress, but we are here we are talking about average stress on average strain which is obtained by dividing the elongation of the gauge length of the specimen which is Δ by its original length.

So, $E = \Delta / L_0$, which is equal to $\Delta L / L$, which is equal to $(L - L_0)/ L_0$. Since, both the stress and the strain are obtained by dividing the load and the elongation by constant factors, the load elongation term will have same shape as the engineering stress strain curve. So, this is so what is shown here is another interesting idea you have to keep in mind there is something called you know the recoverable elastic strain, we have to understand what is this recoverable elastic strain.

So, look at this diagram little carefully. Now, this is a load versus elongation plot, first the specimen is loaded from 0,A and then it is unloaded it just crosses the yield point and then got unloaded to the point A′, then what happens? So, corresponding to this point A the strain is somewhere supposed to be here, but what is that we are landing we are landing at A_1. So, this OA′, is the permanent strain.

But A′ to this point that is b it measures as a b is a recoverable elastic strain on loading which is b is measured as σ_1 / E which is nothing but $(P_1 / A_0)/ E$. So, this is recoverable. The permanent plastic deformation is offset A this is offset a which is shown here. So, there is permanent deformation plastic definition b is the recoverable elastic strain.

So, what is important here, point is note that elastic deformation is always presented the tension specimen when it is under load okay. If the specimen were loaded and unloaded along the path O-A-B-B′, so we are going further away with the higher loads. The elastic strain would be greater than on loading to P_1, since P_2 is greater than P_1, but the elastic deformation (d) would be less than the plastic deformation (c), very important.

So, now, we are now crossing this point A continuously going all the way up to B and unloading loading and reaches point B′, then you just compare what is the elastic strain would be greater than on loading to P_1. So, elastic strain will be greater but the elastic deformation (d) is much less than the plastic deformation. So, you see earlier the difference is not much A B but as you go higher loads, the d becomes the elastic recoverable strain elastic strain is much smaller as compared to the plastic deformation (c).

So, this point we have to keep in mind we will see how all this small certain differences will help us in understanding the material behaviour especially when we go to different type of loading combinations of loading, cyclic loading all this small factors will contribute in understand.