Lecture 41- Polymer testing-06

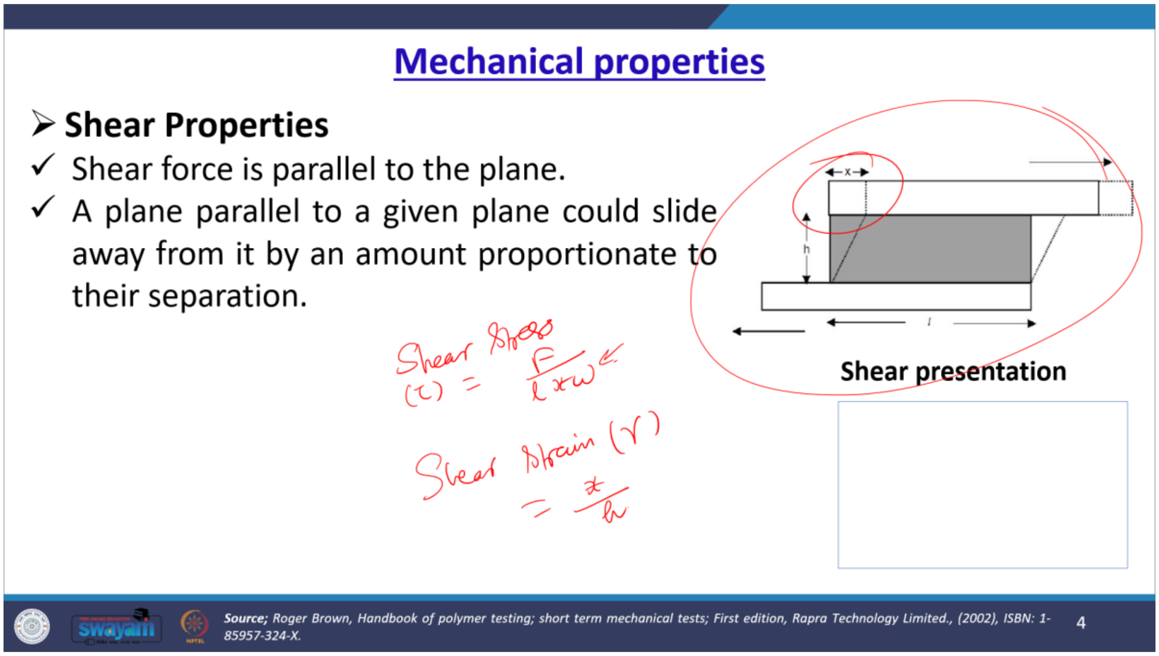
Hello friends, welcome to the segment on polymer testing, where we delve into mechanical properties such as shear and flexural characteristics. In our previous lectures, we explored various mechanical properties like hardness, tensile strength, and compression. However, in this session, our focus will be on shear properties, including tests like the lap or sandwich test. We'll also delve into standard test methods for evaluating these properties. Additionally, we'll cover flexural properties, including stress-strain tests under different loading conditions such as 3-point and 4-point loading, as well as the cantilever test. Throughout, we'll reference relevant standards to ensure a comprehensive understanding.

When discussing shear properties, it's essential to understand that shear force typically acts parallel to a given plane. This concept is illustrated by the shear presentation, where a plane parallel to a given surface can be displaced by an amount proportional to the separation. Mathematically, shear stress (τ) can be represented as

$$Shear\ stress\ (\tau) = \frac{F}{lxw}$$

the force (F) applied divided by the product of the length (l) and width (w) of the material. Similarly, shear strain (γ) is represented by the ratio of displacement (x) to the height (h) of the material. These equations provide quantitative measures of the material's response to shear forces and strains.

$$Shear\ Strain\ (\gamma) = \frac{x}{h}$$



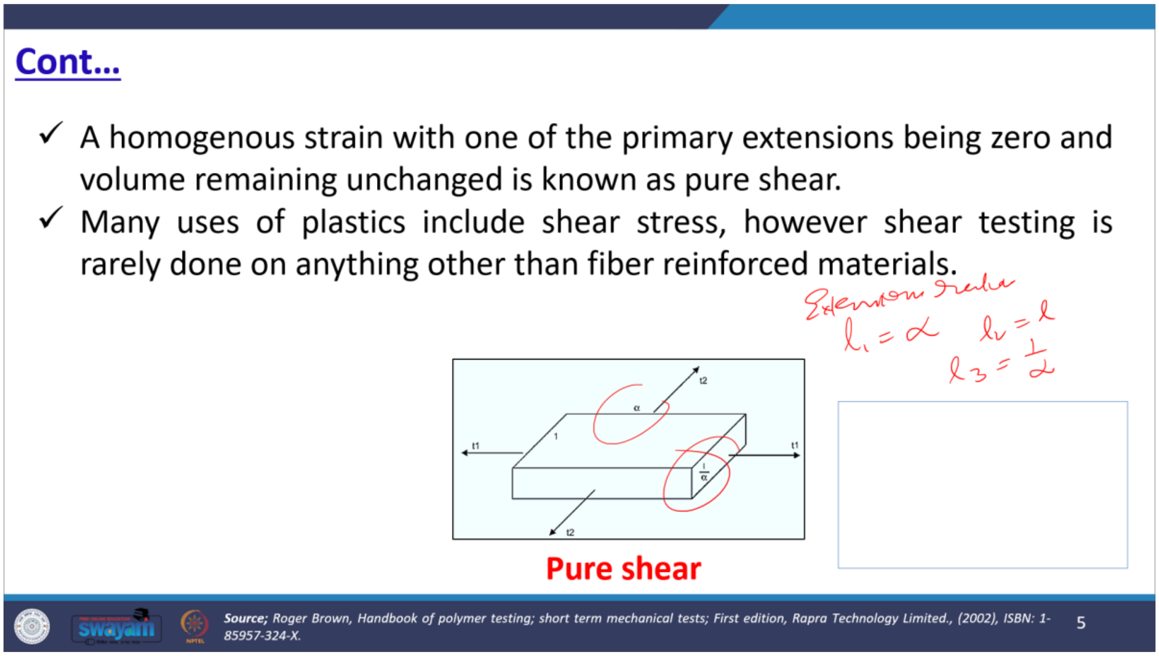
In polymer testing, understanding pure shear is crucial, where a homogeneous strain results in no primary extension and the volume of the material remains unchanged. This phenomenon is fundamental in evaluating shear properties. Despite its significance, shear testing is predominantly conducted on fiber-reinforced materials due to their specific applications and structural requirements.

Extension ratios, denoted by α and β, often play a pivotal role in shear analysis. These ratios represent the lengths l_1 and l_2 along different axes relative to a reference length l_3. The relationship between these ratios provides valuable insights into the material's response to shear stress.

$$l_1 = \alpha$$

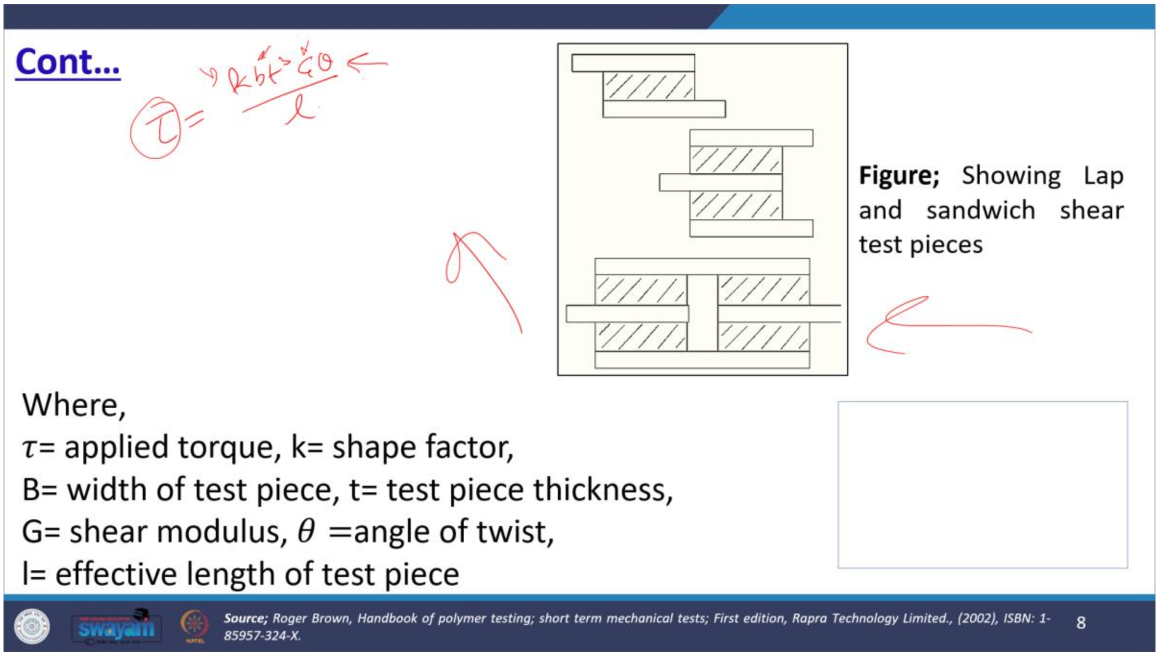
$$l_2 = \beta$$

$$l_3 = \frac{1}{\alpha}$$



In polymer testing, when examining the stress-strain relationship, particular attention is given to the shear modulus, especially in cases where the relationship remains almost linear at small strains. This modulus provides valuable insights into the material's response to shear stress and is typically determined under such conditions.

Shear stresses can arise from various loading systems, including lap, shear, punch shear, torsion, and four-point loading. While the lap or sandwich test is commonly employed for dynamic testing of rubber and foam materials, it is not standardized for quasi-static tests on plastics due to challenges related to gluing test pieces together. In the lap or sandwich test, the design may consist of one, two, or four elements, with the four-element configuration being the most stable.



In the lap or sandwich test configuration, careful consideration is given to the thickness of the elements to minimize bending strain while maintaining a controlled thickness-to-area ratio. This balance ensures that bending effects are kept to a minimum level, thus maintaining the integrity of the test results. The mathematical representation of shear stress (τ) in this setup is given by the equation:

$$\tau = \frac{kbt^3 G\theta}{l}$$

Where,

τ= applied torque, k= shape factor,

B= width of test piece, t= test piece thickness,

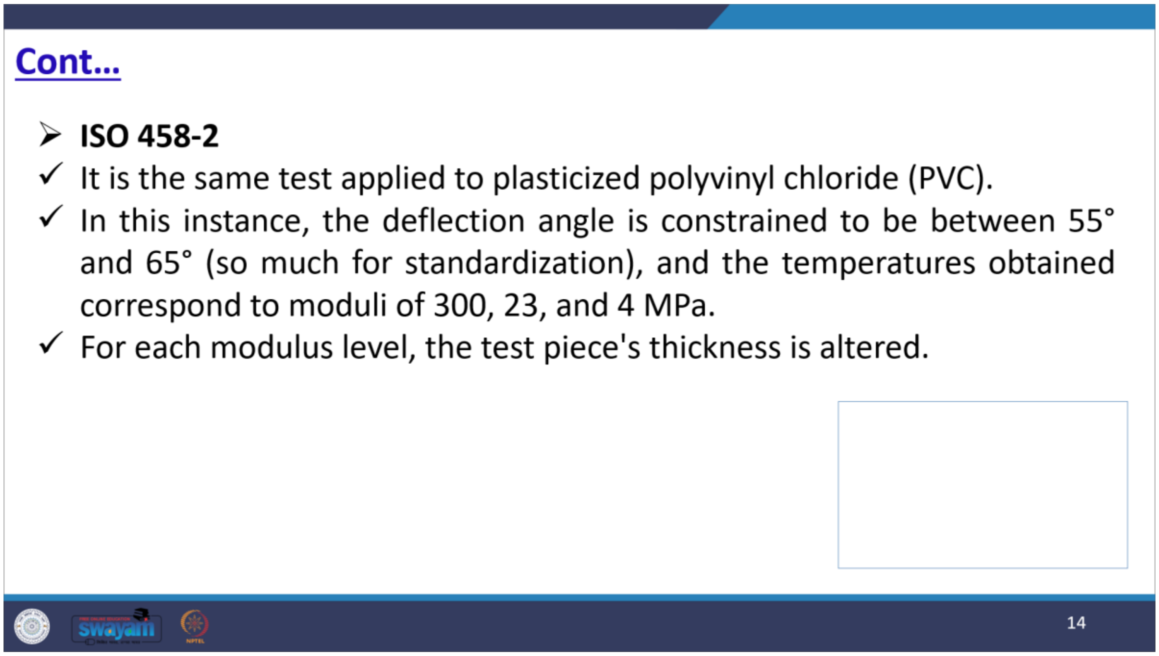
G= shear modulus, θ =angle of twist,

l= effective length of test piece

In practice, measuring plastic shear strength often involves punch or shear geometry. While shear modulus can be evaluated through torsion, it is primarily utilized to assess the stiffness of materials such as rubber, flexible polymers, and coated fabrics, particularly in evaluating their performance at low temperatures.

In tensile testing, if the orientation of the reinforcement is properly arranged relative to the direction of straining, shear can also be induced in directionally reinforced materials.

Universal test machines, commonly referred to as UTM, are equipped with appropriate jigs and grips to mount and strain the test piece, facilitating shear tests using sandwich-type geometry, punch shear tests, and tests where shear is induced from tensile straining. Strain can be detected in a manner similar to compression testing, either through transducers or by measuring cross-head movement.

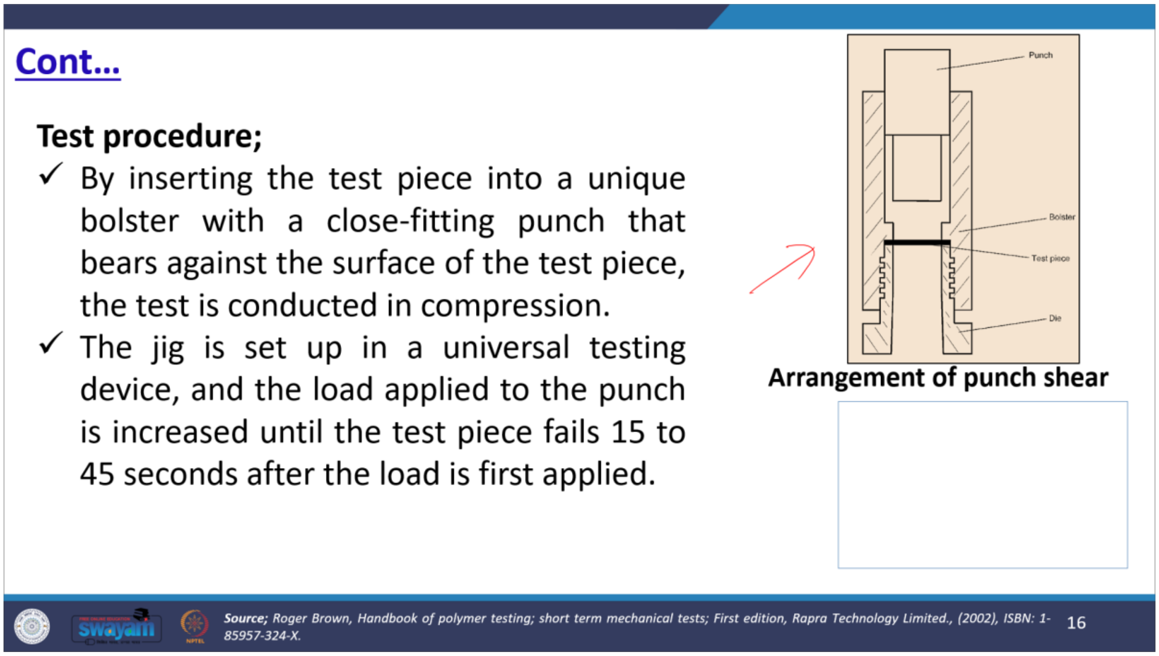


Several tests are attributed to shear testing, including the ISO 458-1 torsional method, particularly intended for testing stiffness in torsion at various temperatures, especially below 0 °C, though not polymer-specific. Utilizing pulleys and weights to apply torque to the strip test piece, the Clash and Burge apparatus is employed to measure shear. To accommodate materials with varying stiffness, a wide tolerance of test piece thickness between 1 and 5 mm is allowed, with higher thicknesses recommended for more flexible materials. Test pieces and grips are submerged in a suitable liquid contained in a Dewar flask to regulate temperature. Dry ice is utilized to cool the flask, ensuring temperatures drop below the desired level before gradually warming up with intermittent heating.

In ISO 458-1, after a conditioning period of 180 seconds, torque is applied to produce an angular deflection between 10° and 100° for method A, and between 50° and 60° for method B, acknowledging the non-linear reaction commonly observed with strain. An arbitrary interval of 5 seconds is standardized to counteract the effect of creep, after which the angle of deflection is measured. Measurements are then made at progressively higher temperatures, and the torsional modulus is determined accordingly.

ISO 458-2 applies the same test to plasticized polyvinyl chloride (PVC), with the deflection angle constrained between 55° and 65°. Temperatures obtained correspond to moduli of 300, 23, and 4 MPa, with the test piece thickness altered for each modulus level.

BS 2782 methods 340A and B address the evaluation of punch shear strength for sheet and molding materials, respectively. Molded discs measuring 25.3 ± 0.1 mm in diameter and 1.6 ± 0.1 mm in thickness are used as test items for method 340A, while method B involves measuring the thickness of the sheet being tested, up to a maximum of 6.35 mm, using a rectangular bar test piece with dimensions of length 32 mm and width of 6.4 ± 0.2 mm.



Let us talk about the test procedure. Now by inserting the test piece into a unique bolster with a close fitting punch that bears against the surface of the test piece and the test is conducted on compression. The jig is set up in a universal testing device and the load applied to the punch is increased until the test piece fails 15 to 45 second after the load is first applied. So the expression provide the formulas for calculating the strength of for method A and B.

So

$$S = \frac{F}{\pi DT}$$

or

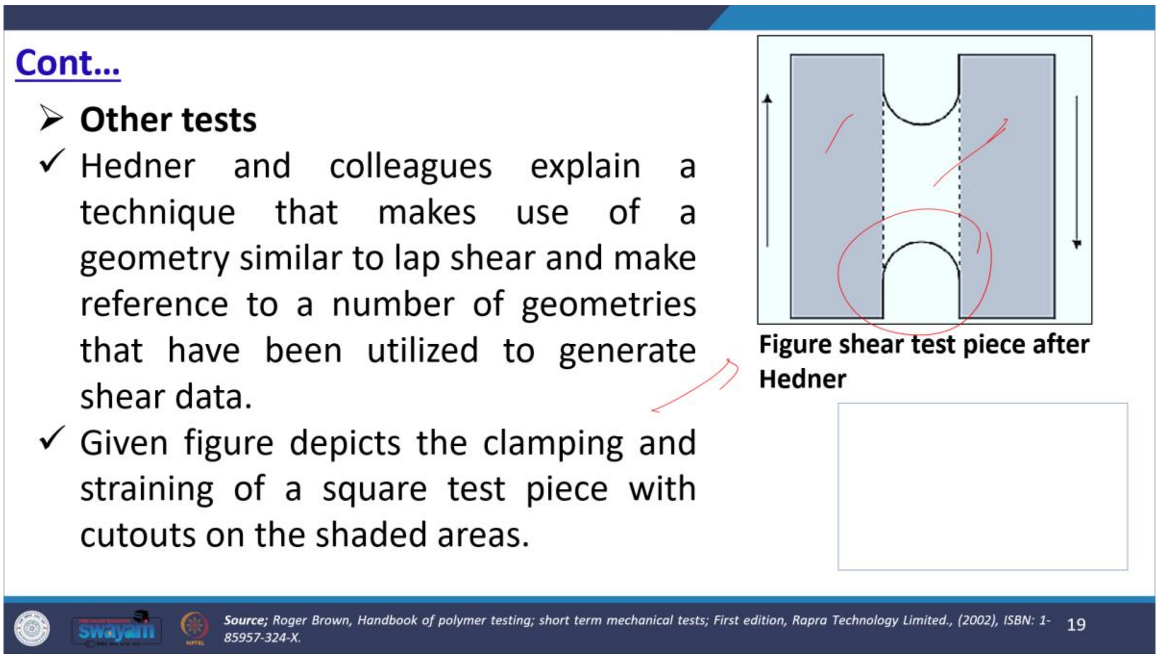
$$S = \frac{F}{2.096BT}$$

Where S stands for shear strength, F for force at break, D for punch diameter, B for mean test piece width, and T for mean test piece thickness.

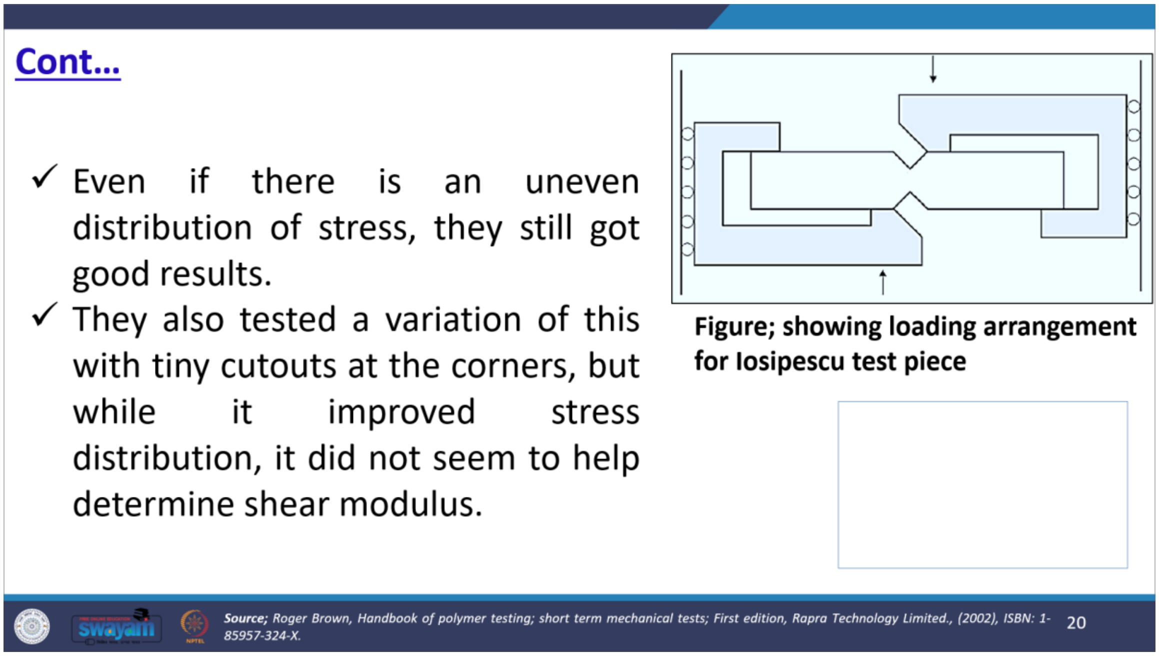
ASTM D732:

Now they follow the same procedure as per the which we have mentioned in method A. The only distinction is that the test piece diameter is 50 mm and its thickness ranges from 0.125 mm to 12.5 mm. Now to find a guide pin on the punch, the test piece is centrally drilled.

It cautions against the interpreting the shear strength calculation based on the shear area showing that the test strength is inversely related to the thickness. Let us talk about the other tests. The Hedner and colleagues they explained a technique that makes use of a geometry similar to the lap shear and make reference to a number of geometries that have been utilized to generate the shear data. This is the figure that shear test pin after the the Hedner. Now this particular figure depicts the clamping and straining of a square test piece with cutouts on the shaded area.



Even if there is an uneven distribution of stress, they still got good results. Now they also tested a variation of this with the tiny cutouts at the corner, but while it is improved the stress distribution, it did not see to help determine the shear modulus. Unexpectedly, there is a pure shear and homogeneous tension across the test piece between the notches.



The two element strain gauge that is glued to one face of the test is used to measure the strain. It is easy to determine the shear stress by this particular formula that is

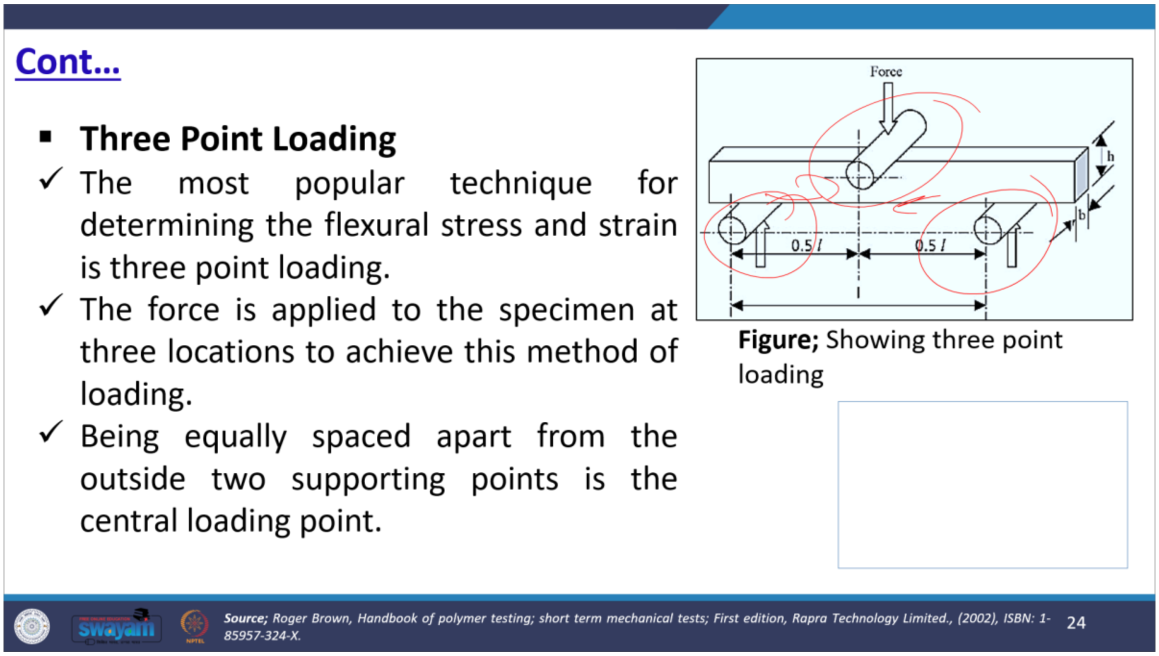
$$\tau = \frac{P}{A}$$

Now where A, this is the cross sectional area between the notches and P is the applied force.

Let us talk about the flexural stress strain, the flexural test. Now a material's short term flexural properties, they are virtually as a frequent measures as it is a tensile one. The majority of the component, they are loaded in a variety of ways and bending or flexing frequently happens either on the purpose or by accident. Flexural test also do not have the same gripping shoes that can rise in tensile testing and a strip testing item is simpler to make than a dumbbell.

Now when we talk about the flexural stress and strain test by measuring both the forces needed to bend a material and the displacement that the material experiences as a result of the applied force at a constant deformation rate, flexural stress strain characteristics may be determined. Now in flexural, the test component experiences a maximum tensile force on one side that the transition to a compressive force on the opposite side and there are three possible loading modes. One is the three point, four point and a simple cantilever.

Let us talk about the three point loading. The most popular technique, here you can see the three point loading.



The most popular technique for determining the flexural stress and strain is three point loading. The force is applied to the specimen at three locations to achieve this method of loading. Now being equally spaced, you see that these are the equally spaced apart from the outside two supporting point is the central loading point. In actual use, the specimen is often supported by the two outer rods while being administered force through the middle loading rods. It will be equipped with the displacement measuring device and a force transducer.

For rectangular bars, the force and displacement must be transformed into the stress strain characteristics. So, the modulus can be calculated from the things like

$$E_f = \frac{l^3}{4bh^3}\, Slope$$

where the slope is the force deflection curve between the reference strain and that is based on ISO 178 that is 0.05% and 0.25%

Now this particular formula

$$\sigma_F = \frac{3Fl}{2bh^2}\left(1 + \frac{4s^2}{l^2}\right)$$

Now this particular formula provides a more precise expression for the stress that accounts for horizontal component of the flexural moment. Since “s” is frequently significantly less than “l”, the second term in this particular bracket adds relatively little stress to the modulus and can be disregarded. So, the expression for the stress modulus for a circular rod, this can be written as

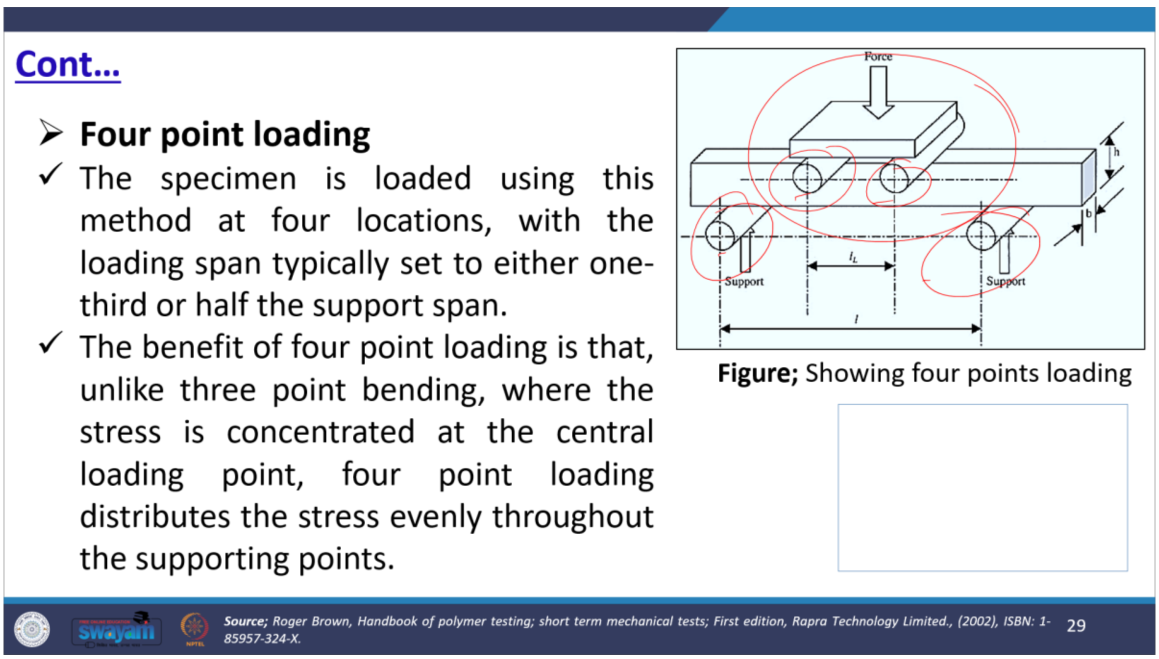
$$\sigma_F = \frac{8Fl}{\pi D^3}$$

And another formula in respect to

$$E_f = \frac{4l^3}{3\pi D^4}\, Slope$$

where D is the diameter of rod.

Let us talk about the 4-point loading. Now this is you can say the typical figure. These are the 4 points. So, the specimen is loaded using this particular method at 4 locations which we have described 1, 2, 3 and 4.



Now with this with the loading span typically set to either one third or half the support span. The benefit of 4 point loading is that unlike 3 point bending where the stress is concentrated at the central loading point, 4 point loading distributes the stress evenly throughout the supporting point. In actual use, the specimen typically rests on the 2 outside loading rods and the force is applied via the 2 middle loading rods, each of which will be equipped with the force transducer and a means of detecting displacement. The uses of the entire inner or outer span, the definition of the major deflection and whether f is a total force or detecting on the support all affects the relationship for the stress and strain in a rectangular bar subjected to the 4 point bending. Now let us talk about the different equations which we can take from ASTM D 6272.

The ($3l_L = l$) for a load span that is one third of the support span.

$$flexural\ stress\ (\sigma_f) = Fl/bh^2$$

and

$$flexural\ strain(\epsilon_f) = 4.7\ hs/l^2$$

Now if the load span is 2 $l_L = l$ then the support is span is also equivalent to 2 $l_L = l$.

l(Support span); The distance in millimeters (mm) between the centers of the two outside supporting rods on the beam.

l_L (Loading span); The distance (mm) between the two loading rods' centers

s; Deflection of the specimen at mid span (mm)

σ_f ;Flexural stress (Nmm^{-2})

ε_f ;Flexural strain

h; thickness of the beam (mm)

b; width of the beam (mm)

F; Force (N)

Let us talk about the cantilever test. A simple cantilever test is carried out by the different specification and a simple cantilever that is loaded at one end and secured at the other with the test piece. Now this is only common way in the form of a straightforward test where the stress was applied by the hanging beam, but it is now very uncommon. For a rectangular beam the stress and modulus they are given by

$$\sigma_f = \frac{6FL}{Bh^2}$$

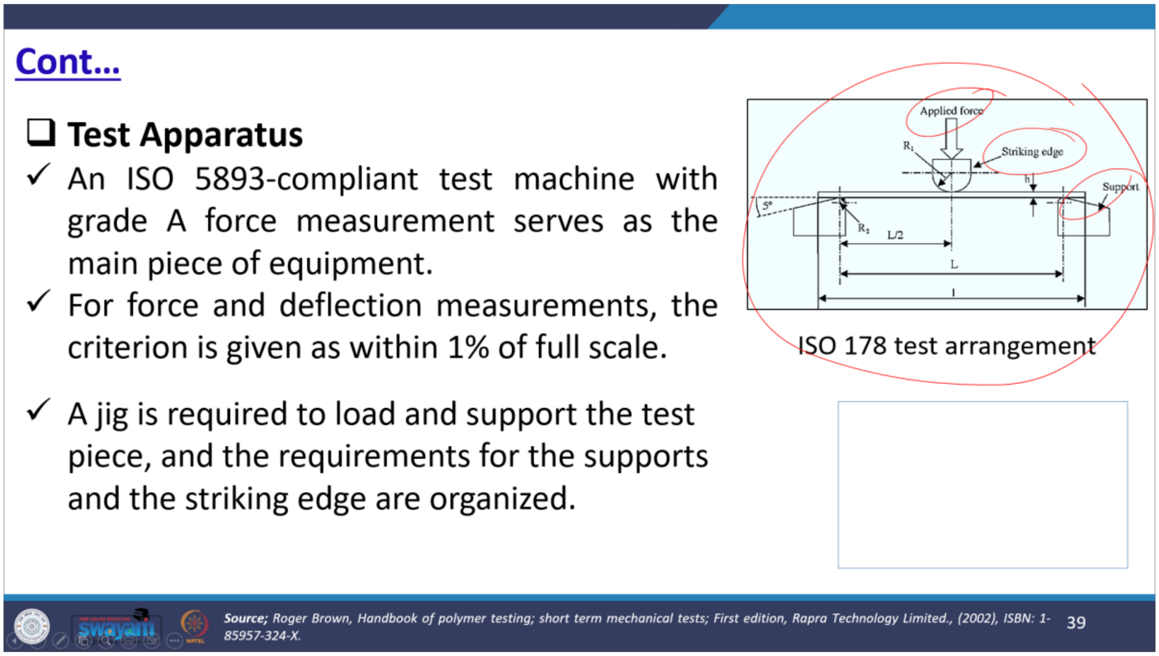
$$\epsilon_f = \frac{4FL^3}{bh^2S}$$

Now the standard method that is given by the ISO 178, it is the international standard for flexural properties. Although it is rumored that 4 point bending is being considered for some textile fibre reinforced polymers, this considered the 3 point bending test.

Let us talk about the ASTM standard, the ASTM D790. This despite not being officially equal to ISO pretty much follows the same principle. Now an appendix with advice on how to handle the toe compensation is a bonus feature. The ester-sustain curve exhibits an artefact that at this particular point because the test system has taken up the slack. In addition, a 4 point loading method using a configuration where the loading span is half the support span is described in ASTM D6272.

Now this ASTM D747, it involves clamping a strip of a material in a vice and applying force through a pivot point where the test piece free length begins at the end of the vice. The stiffness and thus the materials modulus decrease as the bend angle increases. So rather than making absolute finding, the test is more suited for calculating relative modulus. Let us talk about the ISO 178. It covers many material which are like rigid thermoplastic sheets, extrusion and moulding materials including reinforced or filled compounds in addition to unfilled varieties.

The thermosetting material includes the reinforced and unreinforced composites, laminates and thermosetting sheets, fibre reinforced thermosets, thermoplastic composites as milled fibers, matt, woven roving’s, woven fabrics, chopped strands, etc. Now the thermotropic liquid crystal polymers, normally rigid cellular materials and a sandwich structure made of cellular material, they are not appropriate application for the approach. The tensile test can be used to compare most of the flexural definition. This is given by the standard.



Now this is the typical ISO 178 test arrangement. There is a shrinking edge, applied force and support. So the ISO 5893 compliant test machine with the grade A force measurement serves as a main piece of equipment. For force and deflection measurement, the criteria is given as within 1% of full scale. A jig is required to load and support the test piece and the requirement for the support and the striking edge are organized.

Now here this, there are recommended values for the speed of testing is given like speed millimeters per minute and tolerance percentage.

Recommended values for the speed of testing	
Speed (mm/min)	Tolerance (%)
1	±20
2	±20
3	±20
10	±20
20	±10

50	±10
100	±10
200	±10
500	±10

The striking edge's radius R1 and the supports' radius R2 are as follows:

R1 = 5.0 mm ± 0.1 mm

R2 = 2.0 mm ± 0.2 mm (thicknesses of test specimen ≤ 3 mm), and

R2 = 5.0 mm ± 0.1 mm (thicknesses of the test specimen > 3 mm)

The span L should be adjustable.

The dimension and span of the test piece must also be measured and these measurement require a sufficient micrometers and Vermeer caliper or in kilo.

Now let us talk about the test pieces

According to ISO 178, each direction must be evaluated with a minimum of five test pieces.

The strip with the following measurements is the preferred test piece:

Length (l) = 80.0±2.0

Width (b) = 10.0 ±0.2

Thickness (h) = 4.0±0.2

The middle third of the specimen length's thickness cannot vary by more than 2%. A deviation of more than 3% is not permitted in the width of the middle third of the specimen length. The specimen needs to have an unrounded, rectangular cross section.

The following restrictions apply if the selected test piece cannot be used:

The ratio of length to thickness must be 20 (l/h = 20 ± 1).

The following Table outlines the specifications for the specimen's breadth.

Values for the width b in relation to the thickness h		
Nominal thickness 'h'	**Width b ±0.5 (mm)**	
	Moulding and extrusion compounds, thermoplastic and thermosetting sheets	**Textile and long-fiber reinforced plastics materials**
1<h≤ 3	25	15
3<h≤ 5	10	15
5<h≤ 10	15	15
10<h≤ 20	20	30
20<h≤ 35	35	50
35<h≤ 50	50	80

The material with the very coarse filler and the minimum width this shall be 20 mm to 50 mm.

Now when we talk about the procedure: Without a material specification, the test speed is chosen to produce a strain rate that is as close as feasible to 1% per minute, or 2 mm/min for the standard test piece. Although the flexural stress is estimated, one must assume that it may be at break, conventional deflection, or something else entirely. Similar to tensile testing, the definition of modulus uses strains of 0.05% and 0.25% as the limiting values within which it is calculated. The precision of the test component and the test equipment are severely constrained as a result. For the typical test piece, 0.05% strain results in a 0.08 mm deflection of the outer surface from the original position. This does not sufficiently account for test jig backlash, test piece irregularity, or misalignment of any of the three loading bars. Modulus may be determined at other stresses or the secant modulus may be measured, however this is not stated.

So dear friends in this particular segment we discussed about the test protocols for flexural stress strain things and for your convenience we have listed four different references which you can utilise as per your requirement. Thank you very much.