Introduction

In the previous lecture we have seen some methods to determine the in-plane shear modulus as well as shear strength. Some methods were easy at both experimental as well as analytical level, whereas some were easy on analytical level but difficult at experimental level. These methods have their own pros and cons. In this lecture we will see some more methods to determine the shear properties. Finally we will see methods to determine the flexural properties along with shear properties.

The Lecture Contains

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1. Rail Shear Test:

This is a very popular method used to measure in-plane shear properties. This method is extensively used in aerospace industry. The shear loads are imposed on the edges of the laminate using specialized fixtures. There are two types of such fixtures: Two rail and three rail fixture.
The ASTM D4255 standard covers the specification for two and three rail specimens for both continuous and discontinuous (0° and 90° fibre alignment), symmetric laminates and randomly oriented fibrous laminates.

a. Two Rail Shear Test
:

The two rail shear test fixture along with a laminate to be tested is shown in Figure 8.12. The Figure 8.13 shows the specimen geometry according to ASTM D4255 standard. The two rail shear test fixture has two rigid parallel steel rails for loading purpose. The rails are aligned to the loading direction as shown in Figure 8.12. Thus, it induces the shear load in the specimen which is bolted to these rails. A strain gage is bonded at 45° to the longitudinal axis of the specimen.

The Shear strength is obtained as

$$\tau_{xy}^{ult} = \frac{P_{\max}}{Lh} \qquad (8.28)$$

where, $P_{\max}$ is ultimate failure load, L is the specimen length along the rails and h is the specimen thickness.

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The shear modulus is given as

$$G_{xy} = \frac{\Delta\tau_{xy}}{\Delta\gamma_{xy}} = \frac{\Delta P}{2Lh\Delta\varepsilon_{45}} \qquad (8.29)$$

where, ΔP is the change in applied load and $\Delta\varepsilon_{45}$ is the change in strain for $+45^{\circ}$ or -45° strain gage in the initial linear stress-strain regime. It is suggested that the change in the strain is taken as the average of the change in strains on the both sides of the specimen.

Various modes of failure are seen. The modes are highly dependent upon the microstructure of the material.

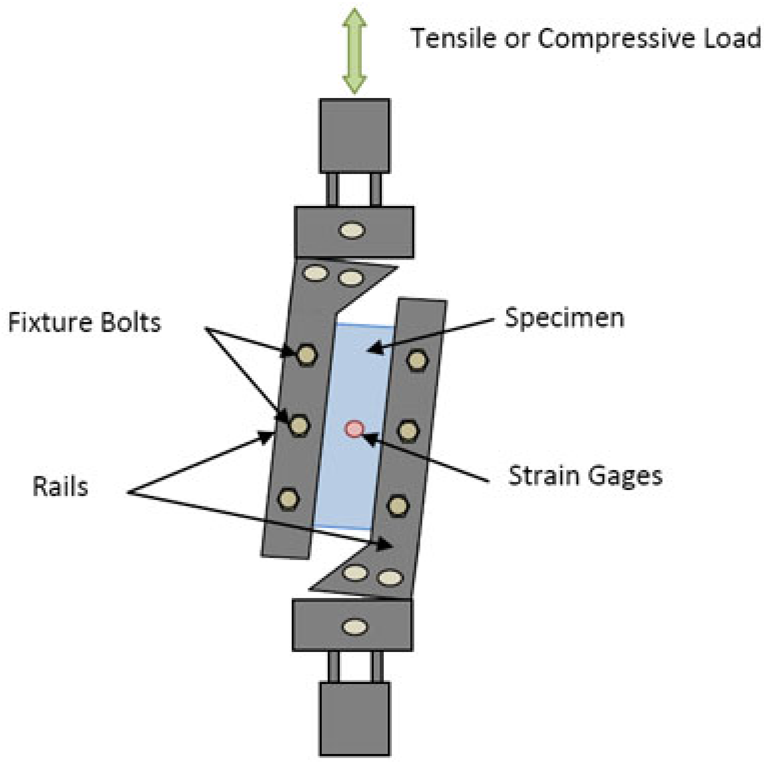

Figure 8.12: Two rail shear fixture for shear testing

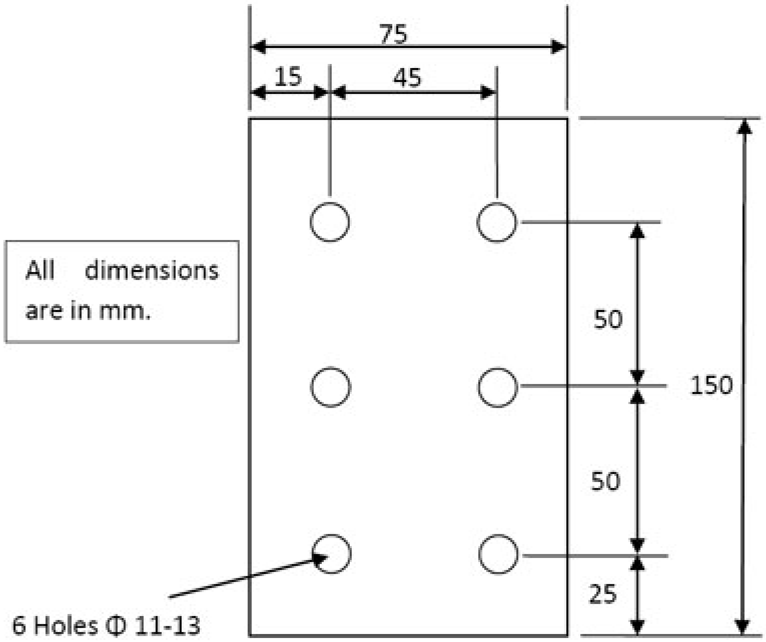

Figure 8.13: Two rail shear test specimen

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b. Three Rail (Symmetric) Shear Test:

The three rail shear test is an improved version of the rail shear test. Using one more rail in two rail shear test fixture it can produce a closer approximation to pure shear. The fixture consists of 3 pairs of rails clamped to the test specimen as shown in Figure 8.14. The outside pairs are attached to a base plate which rests on the test machine. Another pair (third middle) pair of rails is guided through a slot in the top of the base fixture. The middle pair loaded in compression as shown in Figure 8.14. The shear force in laminate is generated via friction between rail and specimen. The strain gages bonded to the specimen at 45° to the specimen's longitudinal axis. The specimen geometry is shown in Figure 8.15.

The shear strength is given as

$$\tau_{xy}^{ult} = \frac{P_{\max}}{2Lh} \tag{8.30}$$

And the shear modulus is given as

$$G_{xy} = \frac{\Delta\tau_{xy}}{\Delta\gamma_{xy}} = \frac{\Delta P}{4Lh\Delta\varepsilon_{45}} \tag{8.31}$$

where, all variables in these two equations are given previously.

It should be noted that the holes in the specimen are slightly oversized than the bolts used for clamping. Further, the bolts are tightened in such a manner to ensure that there is no bearing contact between the bolt and specimen in the loading direction. It is recommended that each bolt is tightened with a 100 Nm torque.

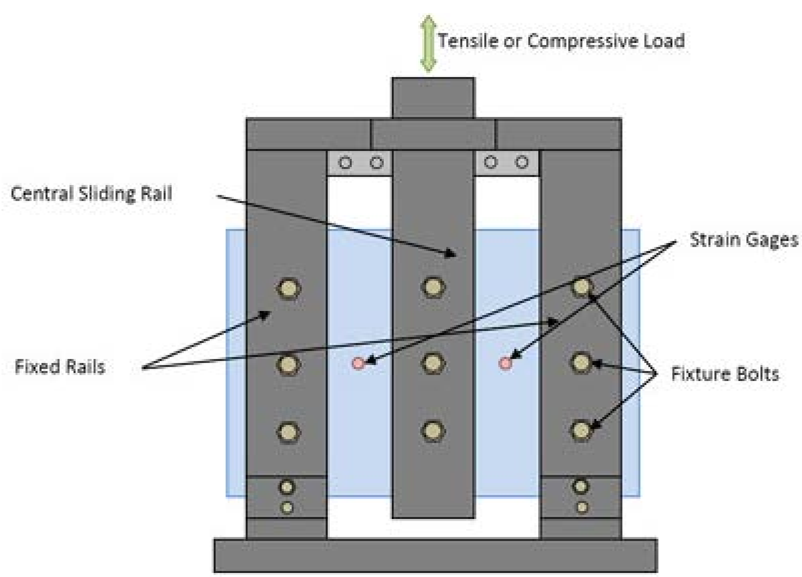

Figure 8.14: Three rail shear fixture for shear testing

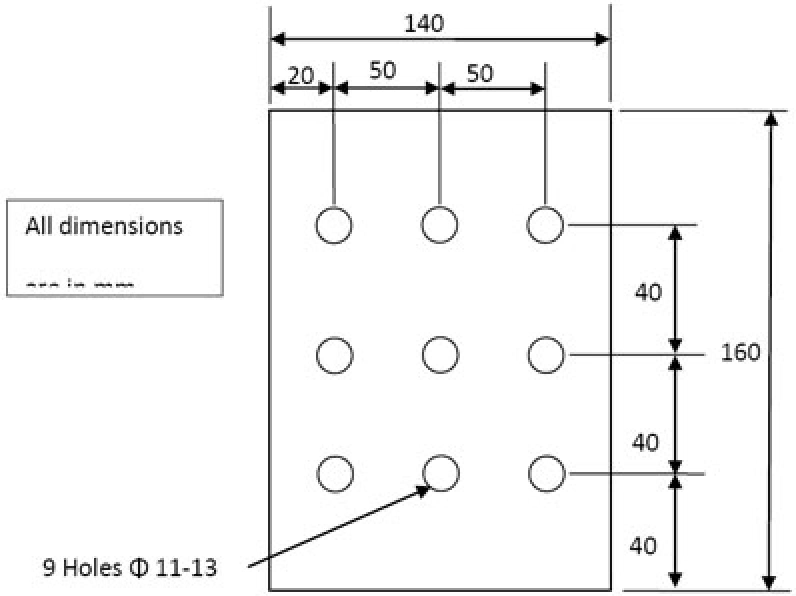

Figure 8.15: Specimen dimensions for three-rail shear test

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2. Picture Frame Test:

The picture frame test is another method for shear testing of composites. This method is mainly used for the shear testing of woven composites.

A picture frame fixture for shear testing is sketched in Figure 8.16. The frame has four legs which are hinged to form a picture frame. Further, there is a rod which runs across one of the diagonal of the frame. It should be noted that this rod is not in the plane of the frame but runs behind the frame. The lower end of the rod is hinged with the common hinge of the two legs meeting in that corner. The other opposite corner hinge is resting in the slot provided in the rod. Further, at the lower end the rod is again hinged to individual legs of the frame. The lower end of the rod is fixed in jaws of the loading machine. Thus, when the load is applied through the upper end of the rod, it pushes these two legs apart and deforms the frame. These two legs in turn push their adjacent legs making their common hinge to slide in the slot of the rod. The plate deforms into a diamond shape. The woven composite is clamped to the frame with the help of clamping plates.

The pre-treatment of specimen is essential in this testing. The pre-treatment is given in the following paragraphs.

The specimen is pre-sheared several times before experiment, so as to make the yarns, as well as their intervals, more uniform hence obtaining a more consistent geometry of the whole fabric. When clamped into the fixture, the specimen is kept exactly loose in order to avoid pre-tension in both two directions of yarn. Beforehand, several marks are drawn on the contacting point of fixture and specimen; then after the test, it can be ensured by observation that the marks are still contacted; therefore, there is no slippage between the specimen and the clamping plates.

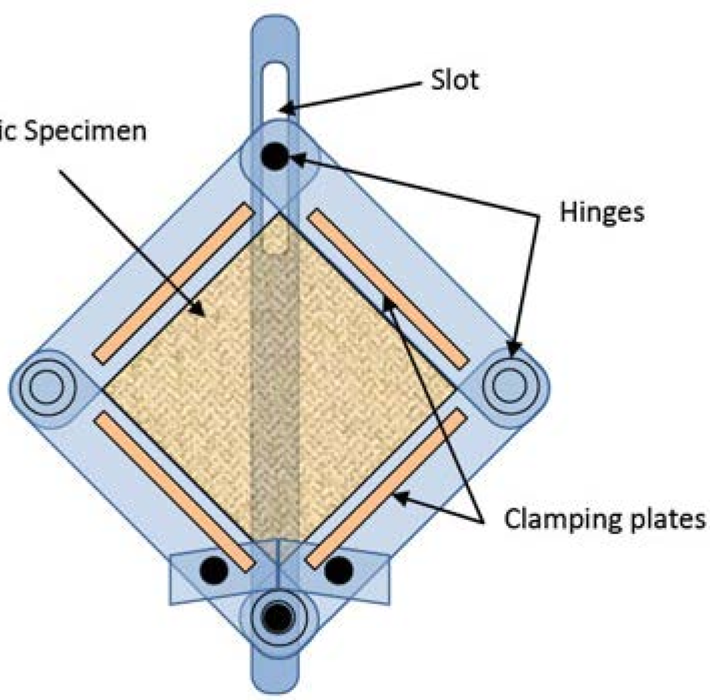

Figure 8.16: Picture frame test fixture

Flexural Tests:

The flexural tests are conducted to determine the mechanical properties of resin and laminated fiber composite materials. Further, these tests are used to determine the interlaminar shear strength of a laminate, shear modulus, shear strength, tensile and compression moduli along with flexural and shear stiffness. These tests are not only used for composites but also for sandwich beams.

These tests are simple one. Further, they need simple instrumentation and equipment required. These tests conducted on beams of uniform cross section. These beam specimens do not require the end tabs.
There are two methods to carry out these tests. The beam is a flat rectangular specimen and is simply supported close to its ends. In the first method the beam is centrally loaded. Thus gives three point bending. Since there are three important points (two end supports and one central loading point) along the span of the beam this method is called as *three-point bending* test. In the second method the beam is loaded by two loads placed symmetrically between the supports. In this method there are four important points (two end supports and two loading points) along the span of the beam. Thus, it gives four-point bending. Hence, this method is called *four point bending*. These methods are shown schematically in Figure 8.17(a) and (b), respectively. Also shown in this figure are the shear force diagram (SFD) and bending moment diagrams (BMD) related to the particular loading regimes.

From the shear force and bending moment diagrams it is clear that there is a stress concentration at the point of loading. However, for four point bending there is uniform bending moment and both shear force and interlaminar shear stress are zero between the loading points. Thus, it leads to the pure bending loading. Such a state of stress is desirable in testing.

The properties are assumed to be uniform through the thickness as composite as it is a unidirectional composite or isotropic material. For such a material the normal stress varies linearly across the thickness. The maximum in compression is on one side and an equal maximum in tension on other side of the thickness and passes through zero at the mid-plane. The maximum normal stress is given as

$$|\sigma_C| = |\sigma_T| = \frac{6M}{bh^2} \tag{8.32}$$

where, M is the bending moment, b is width and h is the thickness of the specimen. Further, σ_C and σ_T denote compressive and tensile normal stresses, respectively.

The shear stress varies parabolic through the thickness with maximum at mid plane and zero at the outer surface. The maximum shear stress at the mid plane is given as

$$\tau = \frac{3Fs}{2bh} \tag{8.33}$$

where Fs is the shear force on the specimen cross section. The normal stress and shear force variation through the thickness is shown in Figure 8.18.

The flexural response of the beam in three or four point bending test is obtained by recording the load applied and the resulting strain. The resulting strains are measured using the strain gages bonded on the beam in the gage length. It is clear from the distribution of the shear force and bending moment that the state of stress in specimens subjected to three and four-point bending tests are somewhat different. Thus, it may lead to differences in the results.

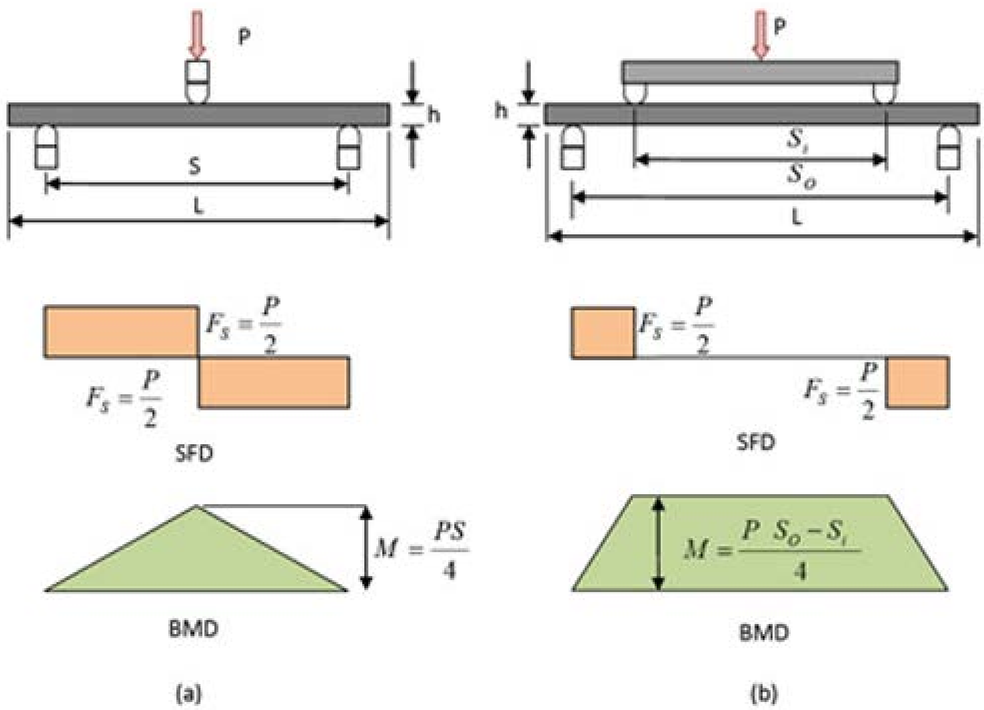

Figure 8.17: Shear force and bending moment diagrams for (a) three point and (b) four point bending test

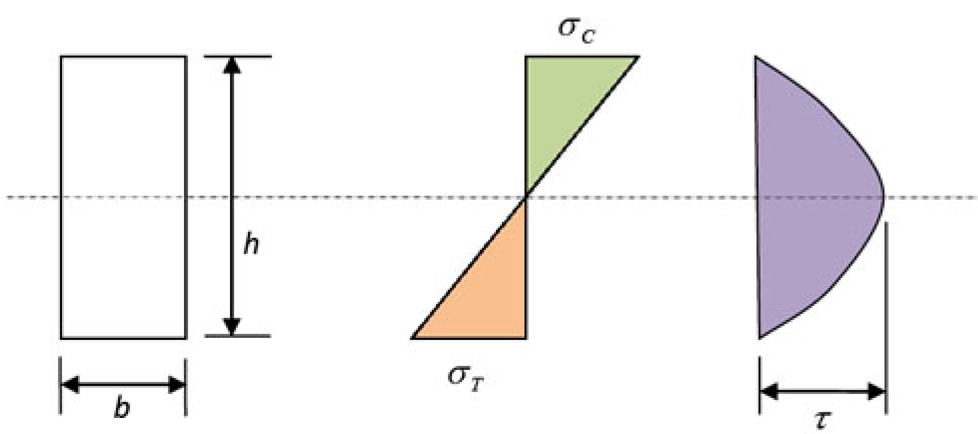

Figure 8.18: Bending and shearing stresses in the thickness direction

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In the following we will see the measurement of flexural modulus and maximum stress on the outer surface of the beam.

***Flexural strength*:** This is the stress on the surface of the specimen at failure, which should be accompanied by the breaking of fibers, rather than inter laminar shear.

In the three point bending method the flexural modulus E_f is given as

$$E_f = \frac{S^3 m}{4b\, h^3} \quad (8.34)$$

where, E_f is flexural modulus, S is the support span, m is the slope of the load-deflection curve, b and h are the width and thickness of the specimen, respectively.

In case of four point bending there are two options according to ASTM D790 standard. In the first option the loading span is one third of the support span. For this case the flexural modulus is given as

$$F_f = 0.21 \frac{S^3 m}{b h^3} \quad (8.35)$$

In the second option the loading span is half of the support span. The flexural modulus for this case is given as

$$F_f = 0.17 \frac{S^3 m}{b h^3} \quad (8.36)$$

where, the parameters in these two equations are as defined earlier.

The maximum stress on outer surface of the beam is given below for all the cases.

$$\begin{aligned} \sigma &= \frac{3PS}{2b\, h^2} \quad \text{3 point bending} \\ \sigma &= \frac{PS}{b\, h^2} \quad \text{4 point bending with loading span equal to one third support span} \\ \sigma &= \frac{3PS}{4b\, h^2} \quad \text{4 point bending with loading span equal to one third support span} \end{aligned} \quad (8.37)$$

It is important to note that the measurement of width and thickness of the beam is important for accurate measurement of flexural modulus and maximum stresses.

For more details on these tests one can refer to ASTM D790-92 and ASTM D790M-93.

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Module 8: Composite Testing

Lecture 39: Shear and Flexural Testing

Home Work:

1. Explain in brief: (a) Two and three rail shear test, (b) picture frame test and (c) three and four point bending test.
2. What are differences between two and three rail shear test? Give their relative advantages and disadvantages.
3. Differentiate between three and four point bending tests along with their pros can cons.

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