Introduction

The measurement of shear properties in composites is a very difficult and challenging task. It is very difficult to measure the transverse shear properties like G_{23} and corresponding shear strength. Measurement of in-plane shear properties is also equally difficult. In the present chapter we will see some of the methods used to measure the in-plane shear modulus G_{12}.

The Lecture Contains

- Shear Testing
- Tensile Test
- Shear Of an Off-Axis Lamina
- Thin Walled Tube in Torsion
- Iosipescu Shear Test
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Shear Testing

Here we will see measurement of in-plane shear modulus G_{12} only. The methods are listed below:

1. Tension of a $[\pm 45]_s$ laminate
2. Tension of an off-axis lamina
3. Torsion of a unidirectional tube
4. Iosipescu shear of unidirectional laminae and cross ply laminates
5. Rail shear of unidirectional laminae
6. Picture frame test

1. $[\pm 45]_s$ Tensile Test:

A tension test on $[\pm 45]_s$ laminate is popularly used test for the measurement of in-plane shear modulus G_{12}. The more details of this test are available in ATSM standard D3518/D3518/M–91. According to ASTM standard the method uses a 250 mm long rectangular specimen with width 25 mm and thickness 2 mm. Further, it is recommended that for materials constructed with layers thicker than 0.125mm, the laminate should consist of 16 layers, that is, $[\pm 45]_{4s}$.The specimen is shown in Figure 8.8. The dimensions in this figure are in mm.

When a $[\pm 45]_{4s}$ is subjected to axial tensile stress $\bar{\sigma}_{xx}$ then stresses in principal material coordinates developed in each of the $+45^{\circ}$ and -45° lamina are given as

$$\begin{aligned}\sigma_{11} &= B\bar{\sigma}_{xx}\\ \sigma_{22} &= (1-B)\bar{\sigma}_{xx}\\ \tau_{12} &= \frac{-1}{2mn}[B(1-2m^2)+m^2]\bar{\sigma}_{xx}\end{aligned} \tag{8.14}$$

where,

$$B=\left[\frac{m^2(2m^2-1)+4m^2n^2\frac{G_{12}}{E_2}\left(\frac{E_2}{E_1}v_{12}+1\right)}{4m^2n^2\frac{G_{12}}{E_2}\left(\frac{E_2}{E_1}+2\frac{E_2}{E_1}v_{12}+1\right)+(2m^2-1)(m^2-n^2)}\right] \tag{8.15}$$

and other quantities as defined in earlier chapters. For a special case with $\theta = 45^{\circ}$ we get the shear stress as

$$\tau_{12} = (\pm\theta) = \mp\frac{\bar{\sigma}_{xx}}{2} \tag{8.16}$$

Thus, from this equation one can see that the shear stress in principal material directions is statically determinate, that is, it is independent of material properties of the specimen and only depends upon the magnitude of the applied stress. The magnitude of this stress is half of the applied stress.

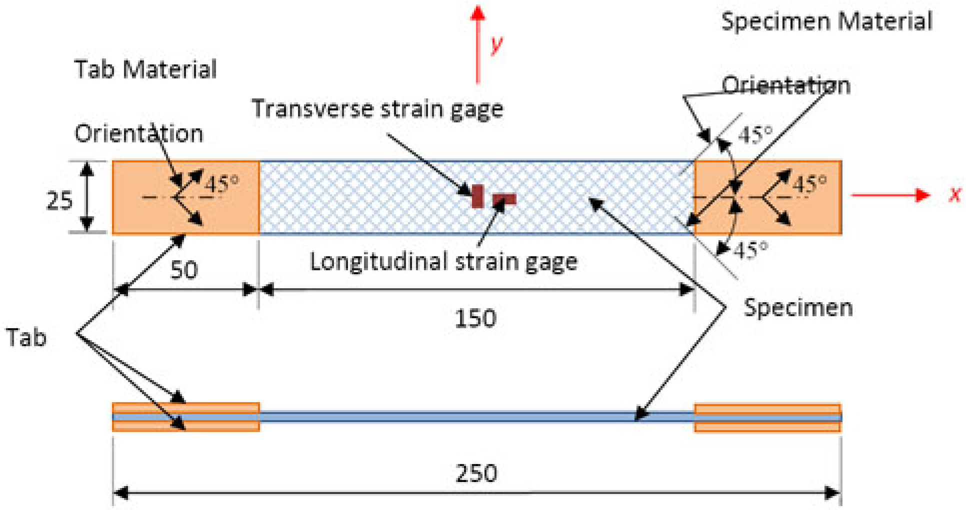

Figure 8.8: Specimen geometry and strain gage positioning for $[\pm 45]_{4s}$ tensile testing

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From the knowledge of linear elastic behaviour of the orthotropic materials it is clear that the shear response is uncoupled from the normal response. Hence, in-plane shear modulus G_{12} can be determined directly from a tensile test on a $[\pm 45]_{4s}$ laminate.

Now the shear strain γ_{12} in principal material coordinates can be found by transformation of the measured axial and transverse strains ε_{xx} and ε_{yy}. It should be noted that the shear strain γ_{xy} is zero for orthotropic laminates under tension and γ_{12} is independent of γ_{xy} for $\theta = \pm 45^{\circ}$ (see the strain transformation relations). Thus, from the strain transformation relations, we can get the shear strain in principal material directions as

$$\gamma_{12} = -\left(\varepsilon_{xx} - \varepsilon_{yy}\right) \tag{8.17}$$

Thus, from the definition of the shear modulus we get

$$G_{12} = \frac{\bar{\sigma}_{xx}}{2\left(\varepsilon_{xx} - \varepsilon_{yy}\right)} \tag{8.18}$$

The above equation can be rearranged in the following manner to express the shear modulus in terms of effective properties of $[\pm 45]_{4s}$ laminate.

$$G_{12} = \frac{\dfrac{\bar{\sigma}_{xx}}{\varepsilon_{xx}}}{2\left(\dfrac{\varepsilon_{xx}}{\varepsilon_{xx}} - \dfrac{\varepsilon_{yy}}{\varepsilon_{xx}}\right)} = \frac{E_x}{2\left(1 + v_{xy}\right)} \tag{8.19}$$

Here, E_x is the effective modulus of the $[\pm 45]_{4s}$ laminate.

The measurement of in-plane shear modulus from shear stress-strain curve is done as follows. The shear stress-strain curve for $\pm 45^{\circ}$ specimen is obtained first. A typical shear stress-strain curve for such a specimen is shown in Figure 8.9. The shear modulus is obtained from the initial slope of the this curve in the range of 0.1-0.5% strain as

$$G_{12} = \frac{\tau_{12}^{'} - \tau_{12}^{'}}{\gamma_{12}^{'} - \gamma_{12}^{'}} \qquad (8.20)$$

The tensile test on $\pm 45^{\circ}$ specimen provides an acceptable method for the measurement of in-plane shear modulus. However, one should be careful while interpreting the ultimate shear strength and strain. It should be noted that the laminae are subjected to a biaxial state of stress and not a pure shear. The normal stresses act along the shear planes causing the onset of mixed mode fracture. Other kind of failure like multiple ply cracking, fibre rotation and edge or internal delaminations occur prior to final failure. Therefore, the true failure is very difficult to determine. The shear strength is specified by different standards corresponding either to the ultimate load generated during the test or to a specified strain level. It is recommended in ISO standard that the test be terminated at $\gamma_{12} = 5\%$. The shear strength is taken as the peak load at or before 5% strain.

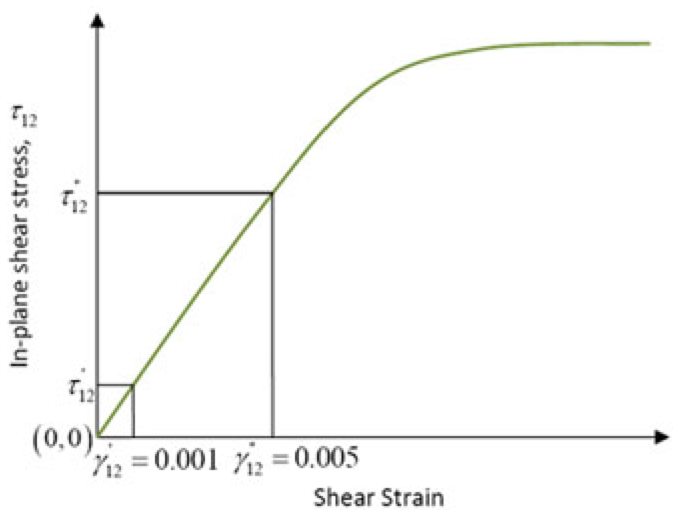

Figure 8.9: Typical shear stress-strain curve for specimen

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2. Shear Of an Off-Axis Lamina:

In similar way to the tensile testing of a $[\pm 45]_{4s}$ laminate one can use a unidirectional off-axis tensile coupon to determine the shear response of a composite in the principal material coordinates. A tensile test on 10° off-axis lamina is a commonly used. Specimen has same geometry as in Figure 8.9. The state of stress in principal material coordinate directions can be obtained from transformation relations. Since, the shear response in the principal material coordinates is uncoupled from the normal response we can write the shear modulus as

$$G_{12} = \frac{\tau_{12}}{\gamma_{12}} \tag{8.21}$$

The shear stress in the principal material directions due to axial tensile stress can be given using transformation relations as

$$\bar{\tau}_{12} = -mn\bar{\sigma}_{xx} \tag{8.22}$$

The shear strain is measured from the strains $\varepsilon_{xx}, \varepsilon_{yy}$ and γ_{xy} with the help of strain transformation relations. Then the apparent shear modulus $\bar{G}_{12}$ can be given as

$$\bar{G}_{12} = \frac{-mn\bar{\sigma}_{xx}}{\gamma_{12}} \tag{8.23}$$

3. Thin Walled Tube in Torsion:

In this method a direct shear stress is applied to a thin walled tube by pure torsion applied along the longitudinal axis of the tube. The thin tube is an ideal specimen for testing composite laminae in shear as it can provide a uniform state of pure shear stress. Due to small thickness of the tube the shear gradient in the thickness direction can be neglected. The specimen should have a gauge length to diameter (L/D) ratio >1, and a wall thickness to diameter ratio (t/D) of 0.02, or less.

Figure 8.10: Shear test by torsion of tube

The in-plane average shear stress $\bar{\tau}_{xy}(\bar{\tau}_{x\theta})$ in a thin walled unidirectional tube $(0^{\circ} \text{or } 90^{\circ})$ under pure torsional loading, is related to torque T by

$$\bar{\tau}_{xy} = \frac{2TD_o}{\Pi(D_o^4 - D_i^4)} \tag{8.24}$$

where, D_o is the outer diameter and D_i is the inner diameter of the tube.

The shear strain is measured by means of two bonded triaxial strain gauges (0°/45°/90°). The strain gauges are bonded diametrically opposite each other, at the centre of the specimen. The strain gauges have a gauge length of 6 mm. The longitudinal and transverse strain gauges are monitored to ensure there are no significant bending forces applied to the specimen during the test set-up and no bending loads present during the test. The shear strain is determined from the average of shear strains measured using the $\pm 45^{\circ}$ strain gauges. The shear modulus is then given as

$$G_{xy} = \frac{\Delta\tau_{xy}}{\Delta\gamma_{xy}} = \frac{\Delta\tau_{xy}}{\Delta(\varepsilon_{45} - \varepsilon_{-45})} \tag{8.25}$$

where ε_{45} and ε_{-45} denote the strain measured by $+45^{\circ}$ and -45° and strain gages. It should be noted that above equation indicates that the shear modulus is obtained from the initial slope of the shear stress strain curve in some range.

More details on this test can be seen in ASTM D5448/D5448M-93.

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4. Iosipescu Shear Test:

This test was developed by Iosipescu in 1967. The original test was designed for a round specimen with a V-notch groove for shear testing of metals. This was extended to flat composite laminates by Bergner et al. The flat specimen has two identical V notches symmetrically placed about the center line at mid length. When the specimen is loaded in shear, a region of nearly uniform, pure shear stress is present in the test section (between the notches). The actual stress distribution is a function of the material properties and fiber orientation. In general, laminae with 0° and 90° orientation are used for this test.

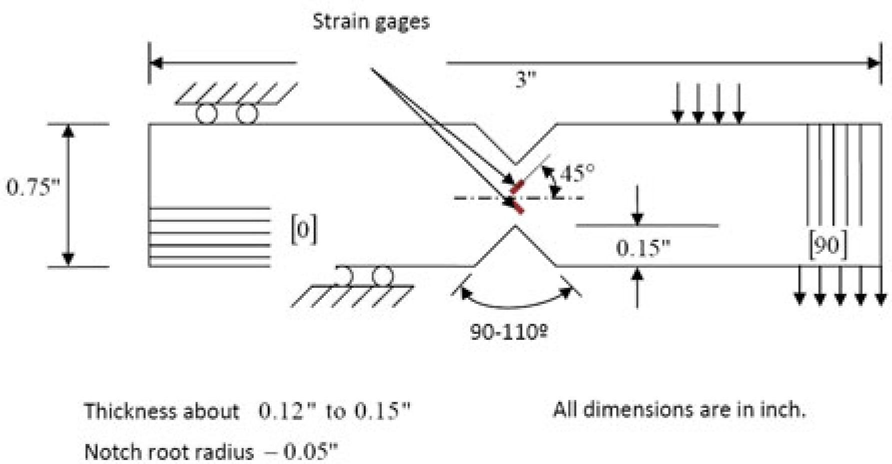

Figure 8.11: Iosipescu shear test

The two bi-axial strain gages, one on each face, in the area between the notches are bonded. The strain gauges should have a gauge length of 1 mm or 2 mm, to keep within the region of uniform stress, and are aligned at ±45° to the longitudinal axis of the specimen.

The average shear strength is given as

$$\tau_{xy}^{ult} = \frac{P_{\max}}{wh} \tag{8.26}$$

and the average shear modulus is given as

$$G_{xy} = \frac{\Delta\tau_{xy}}{\Delta\gamma_{xy}} = \frac{\Delta P}{wh\Delta(\varepsilon_{45} - \varepsilon_{-45})} \tag{8.27}$$

where $P_{\max}$ is ultimate failure load, w is the distance between the notches, h is the specimen thickness, ΔP is the change in applied load and $\Delta\varepsilon_{45}$ and $\Delta\varepsilon_{-45}$ are the corresponding changes in normal strain in $+45^{\circ}$ and -45° and strain gages. Again, it should be noted that the shear modulus is obtained as initial slope in some range of strain.

More details on this test can be seen in ASTM D5379.

Module 8: Composite Testing

Lecture 38: Shear Testing

Home Work:

1. Explain in brief the tension test on $[\pm 45]_s$ and off-axis lamina to determine the shear properties.
2. What is Iosipescu shear test?
3. Write short note on measurement of shear modulus by torsion of a thin walled tube.

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