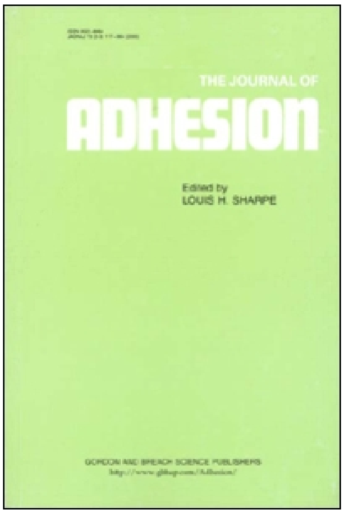

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Shear Stress-Strain Characteristics of Adhesive Layers

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Shear Stress— Strain Characteristics of Adhesive Layers

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Shear behavior data of adhesives are evaluated by a specially constructed torsion device which enables recording of shear moment displacement relationship for thin adhesive layers. Shear strains and stresses were computed from the recorded torsional moment displacement curve by assuming linear shear strain distribution throughout the adhesive thickness and uniform shear strain distribution at the cross-sectional area. The general trend shows an increase of modulus with an increase in thickness up to the bulk material modulus, with very little change in shear strength.

1. INTRODUCTION

The main problem in characterizing an adhesive as a structural material is to determine whether its behavior in a confined state differs from that of its bulk material reference. Solution of this problem is essential for an evaluation of design allowables of bonded joints. It is therefore necessary to carry out elaborate and precise measurements and to develop special testing procedures. In such tests, a crucial problem stems from the fact that the thickness of an adhesive has a major effect on its mechanical performance. This is due to the adherend–adhesive boundary constraints and to the small measurable displacements obtained in commonly used adhesives which are usually very thin The data available,[1–4] which originated in the work of Hughes and Rutherford,[5] is mainly concerned with adhesive behavior under uniaxial tension. It indicates that above thickness of approximately 0.25 mm, adhesive strength and effective modulus decrease whilst the thickness of the adhesive layer increases until it levels off at a value close to that of the bulk material. Below 0.25 mm, a steep increase in adhesive strength and, to a lesser degree, of effective tensile modulus, is evident.

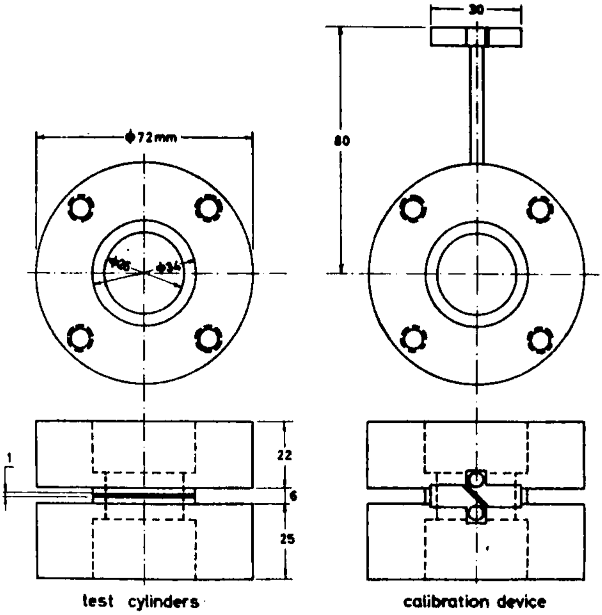
In the case of tensile loading, lateral restraint of the metal adherend reduces longitudinal deformation. The changes in adhesive thickness affect the state of stress and tend to increase stress concentration—thus leading to premature failure.

Although most adhesives are used mainly under shear, very little work has been done on torsional shear behavior.[5, 6] In the present work, torsional shear behavior of adhesives is investigated and shear strength and moduli data of adhesives are evaluating using a specially constructed torsion device which enables the recording of the shear moment-displacement relationship.

2. TESTING PROCEDURE

2.1 Torsion device

The main problem in designing a torsion device is to ensure the state of pure shear in the tested specimen. To this end a special torsion device was constructed consisting of two cylinders made of the adherend material under



test cylinders

calibration device

FIGURE 1 Schema of torsion cylinders.

investigation (see Figure 1). These cylinders are mounted in a loading attachment which transfers the tensile load applied by an Instron Testing Machine to pure torsion in the cylinders (Figure 2). The specimen is a short cylinder with an inside diameter of 26 mm and an outside diameter of 34 mm. The load was recorded by the Instron load cell while the deformation was recorded by mounting an extensometer on the two cylinders. The extensometer monitors the arc of rotation "δ". By geometry, the arc of rotation can be translated into angle of rotation which, by itself, can be translated into the shear angle γ.

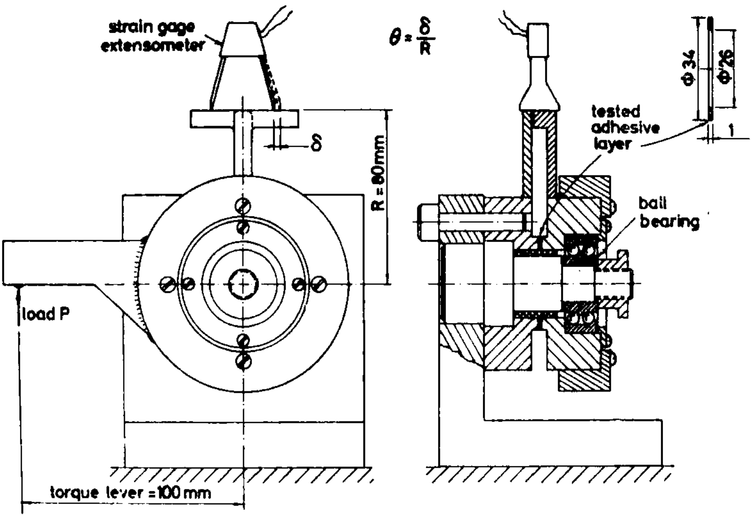


FIGURE 2 Schema of torsion testing device.

As the arc of rotation "δ" is affected by the adherend material as well as the specimen, calibration cylinders, which are a pair of cylinders exactly the same as the testing cylinders but made of one piece of the adherend material under investigation (Figure 1) were used. The mechanism is equivalent to zero adhesive thickness. The arc of rotation of these cylinders is recorded and used as the zero level rotation for the torsion device.

2.2 Method

The material tested in this work was epoxy composed of Shell Resin 828 and General Mills Versamid V-140 in the ratio of 2:1. The two adherend cylinders were aligned on a special fixture at a controlled spacing which ranged from 0.1 to 2.0 mm. The resin was then cast in the spaces and cured for 24 hours at room temperature followed by post curing of 6 hours at 80°C.

After curing, the shear specimens were installed in the torsion device which was mounted on the Instron Tester.

2.3 Specimen preparation

Two types of adherend surfaces were used. For the detection of moduli changes due to varied thickness, the surface was very slightly roughened with no. 400 emery cloth and then cleaned with methyl ethyl ketone (MEK). To measure the ultimate shear strength of the adhesive and to ensure against premature failure of the specimen at the interface, a sandblasting technique was employed. The surface was cleaned and then blasted by fine sand at 2 atm. pressure for 1 minute, after which the specimen was again cleaned with MEK. This treatment was found to yield good results without destroying the specimen's surface.

3. EXPERIMENTAL RESULTS

Shear strains and stresses were computed from the recorded torsional moment-displacement curve by assuming linear shear–strain distribution at the cross-sectional area. Typical shear stress–strain relationships for different

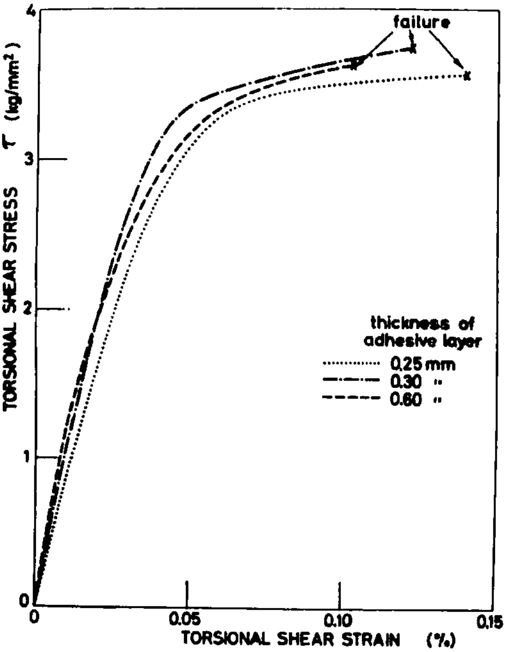


FIGURE 3 Typical shear stress-strain curves for the adhesive layer.

adhesive thicknesses are shown in Figure 3. Two types of experiments were carried out—one for measuring moduli data and the other for ultimate shear strength. Results are shown in Figures 4 and 5 respectively.

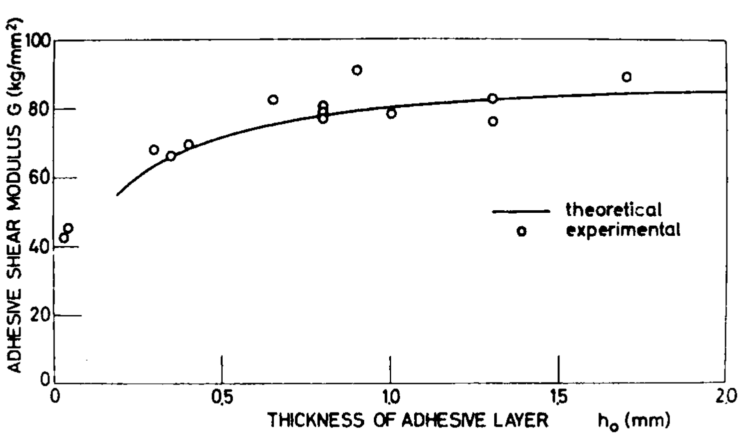


FIGURE 4 The effect of adhesive layer thickness on initial shear modulus.

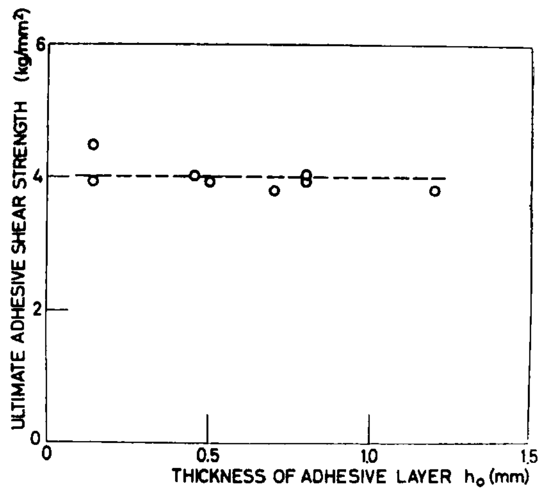


FIGURE 5 The effect of adhesive layer thickness on ultimate shear strength.

In spite of the reasonable scatter of the moduli data, the general trend is clear, i.e., an increase of modulus with an increase in thickness. The higher values of shear modulus are compatible with shear data obtained for the bulk epoxy material. On the other hand, ultimate shear strength was almost unchanged by varying thicknesses.

4. THEORETICAL ANALYSIS

The finding of no change in shear strength despite lower modulus in thin adhesive layers can be explained. It is generally understood that when dealing with cast-in-place adhesives, the layer closest to the adherend surface will have different mechanical properties due to the different adhesive and cohesive force relations. Once this fact is established, the adhesive layer can be divided into three different layers (Figure 6) and the ratio between the material bulk modulus and the measured apparent modulus can be calculated.

Considering only half the specimen thickness, with γ_{ap} the measured shear angle, γ_0 the real material shear angle and γ_i the apparent boundary layer shear angle, let t be the boundary layer thickness and s the shear displacement. Then, from simple geometrical analysis for small deformations:

$$s = \gamma_{ap}\frac{h_0}{2} = \gamma_0\left[\frac{h_0}{2}-t\right]+\gamma_i t \tag{1}$$

from Hooke's law.

$$\gamma = \frac{\tau}{G} \tag{2}$$

Combining (1) and (2) leads to:

$$\frac{\tau}{G_{ap}}\frac{h_0}{2} = \frac{\tau}{G_0}\left[\frac{h_0}{2}-t\right]+\frac{\tau}{G_i}t \tag{3}$$

G_{ap}, G_0 and G_i being the apparent measured modulus, bulk material modulus and boundary layer modulus, respectively,

$$\frac{h_0/2}{G_{ap}} = \frac{h_0/2}{G_0}+t\left[\frac{1}{G_i}-\frac{1}{G_0}\right] \tag{4}$$

$$\frac{h_0[G_0-G_{ap}]}{2G_{ap}} = \frac{t[G_0-G_i]}{G_i} \tag{5}$$

The boundary layer thickness and properties are functions of the adhesive–adherend relations and thus, for the same adhesive and adherend, are constant. The final solution is:

$$\frac{h_0[G_0-G_{ap}]}{2G_{ap}} = \text{const.} \tag{6}$$

or

$$\frac{h_1}{h_2} = \frac{G_{ap1}[G_0-G_{ap2}]}{G_{ap2}[G_0-G_{ap1}]} \quad \text{when} \quad h \to \infty \quad G_{ap2} \to G_0 \tag{7}$$

which should be the case.

This solution is valid only for $h_2 \geqslant t$ and for G_0 which is the initial modulus of the material. When the bulk material torsional modulus and one apparent modulus for a certain thickness are known, the apparent modulus for a certain designed thickness can be computed.

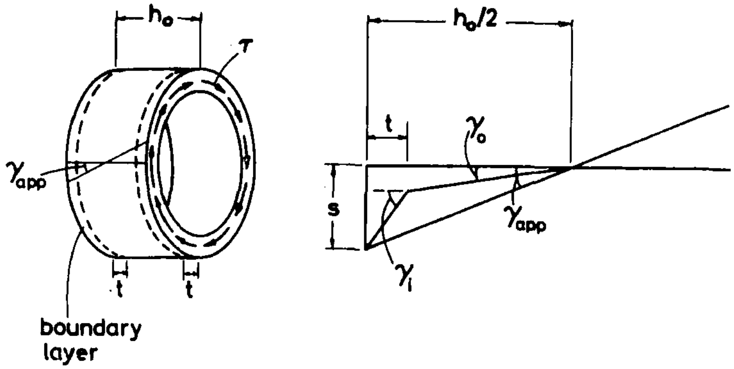


FIGURE 6 Theoretical model analysis.

In Figure 4, Eq. (7) is shown as a theoretical line where agreement is apparent. The same logic applies also to the ultimate shear strength results. As the properties of the boundary layer are unchanged by the specimen's thickness as long as the total thickness is well above t, the strength of the adhesive should also be unchanged, which is the case.

5. SUMMARY

In designing joints and hybrid composites, the basic parameters on adhesive mechanical properties (i.e., ultimate strength and modulus) are essential. It can be concluded from the present study that two different experimental findings are necessary for the evaluation of such parameters:

(a) The evaluation of the bulk properties of the adhesive material;

(b) the evaluation of the properties of the adhesive as a thin layer for a specific adherend-adhesive system.

Based on this data, design parameters for the respective joint system may be evaluated.

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