Tensile Testing of Adhesive Butt-joint Specimens

Introduction

Finite Element Analysis (FEA) is a powerful tool in the design of adhesively bonded joints. In conjunction with a suitable criterion for the failure of the adhesive, an analysis can be used to indicate when a joint will fail under different loading conditions such as impact, creep or fatigue. Since adhesives are generally tough materials, they can sustain large strains before failure and, under these conditions, relationships between stress and strain are highly non-linear.

The large strain properties of rubber-toughened adhesives can be modelled as elastic-plastic materials using material models such as the linear and exponent forms of the Drucker-Prager model which are implemented in FEA packages such as ABAQUS [1]. The results of tests carried out on adhesive samples in tension and shear allow the calculation of the Drucker-Prager parameters. However, identification of the most appropriate form of plastic yield function requires knowledge of the influence of hydrostatic stress on yield behaviour. The stress state in the adhesive in a butt-joint specimen loaded in tension contains a high component of hydrostatic stress. Accurate data from this test are particularly important to enable the applicability of different yield criteria for the adhesive to be assessed [2,3].

Details of the preparation of butt-joint samples are presented in this measurement note. The butt-joint test method is also described, including details of test machine set-up, grip alignment process and extensometer assembly. This is an improved test method giving reliable and repeatable test results.

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May 2001

Butt-Joint Sample Geometry

The butt-joint specimen consists of two hardened steel rods bonded together at end faces using adhesive. Two different rod geometries have been used within work at NPL (Figure 1). For flexible adhesives, the rods are 25 mm diameter along their whole length. When using toughened glassy adhesives, rods with a reduced diameter section at the bonding faces are used. These rods are 25 mm diameter in the grip region, but this is reduced to 20 mm in the bonded region. The butt-joint adherends also have a small radius on the edges of the bonded faces. A v-shaped groove with a depth of 1.0 mm has been machined in the surface of each adherend at a distance of 2.75 mm from the face to be bonded. These served to locate an extensometer consisting of an assembly of displacement transducers.

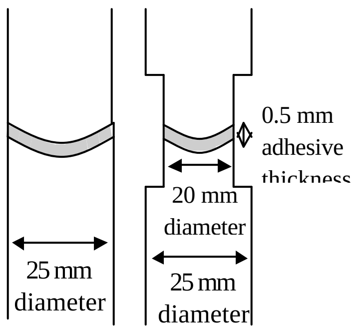

Figure 1. Butt-joint specimen geometries

Butt-Joint Sample Preparation

All specimen preparation methods should take into account the hazardous nature of the adhesives. COSHH procedures should be followed to minimise operator exposure.

Each butt-joint specimen is prepared using an alignment jig illustrated in Figure 2. The jig has a recessed v-shaped channel running down the vertical face that ensures that the adherends are accurately coaxial during the bonding and curing process. The end faces of the adherends should be grit blasted and acetone wiped prior to bonding to promote adhesion. The v-shaped grooves in the adherends should be protected from excess adhesive using masking tape. Next the butt-joint adherends are fitted into the v-shaped channel in the alignment jig. Using a 50 mm gauge block the base of the lower adherend is positioned 50 mm above the base of the alignment jig. The upper adherend is positioned such that the end faces to be bonded are in contact. The clamps should be tightened on both adherends to ensure alignment.
The adhesive is dispensed onto a piece of PTFE sheet. The lower adherend is removed from the jig and adhesive is applied to the bonding area with a spatula, spreading the adhesive carefully to displace air that may become entrapped in the adhesive. The lower adherend is repositioned in the jig, with the adhesive just touching the upper adherend. Gauge blocks are used to gradually raise the height of the lower adherend. After each increase in height the clamps are re-tightened to ensure continued alignment and excess adhesive is removed from the adherend edges using a spatula. This process is continued until the lower adherend reaches a final height of 49.5 mm, giving an adhesive thickness of 0.5 mm. The masking tape can then be removed from the grooves.

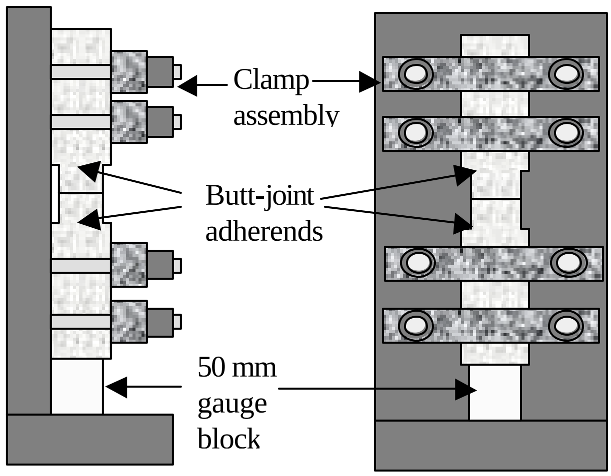

Figure 2. Alignment jig set-up for sample preparation

Curing the adhesive

Data from bulk adhesive specimens [4,5] are used to obtain material parameters for the elastic-plastic models. These models are then used to predict the behaviour of joint specimens. It is therefore important that the adhesive in the butt-joint specimen should be cured to give the same state of cure achieved in the bulk adhesive specimens.

For adhesives cured at elevated temperatures, differences in the effective thermal mass of the alignment jig from the bulk mould may lead to differences in the thermal histories of the adhesives. A thermocouple embedded in the adhesive can be used to monitor the adhesive temperature during cure. Due to the mass of the alignment jig, the joint specimens heat slower than the bulk adhesive sheets. For this reason the total cure time for butt-joints specimens includes a significant warm-up period that must be included in the cure schedule.

An improved butt-joint test method

The following test machine set-up has a high degree of rigidity in the load train, which produces reliable and repeatable butt-joint tests. This set-up was developed to overcome initial problems with specimen bending encountered during testing due to the use of universal joints.

The butt-joint specimen is gripped by a pair of K-BRISTOL ERIKSON collet grips of 25 mm diameter. An Instron alignment fixture is fixed between the load cell and the cross-head of the test machine by means of a pre-tensioned bolt. Figure 3 shows a typical arrangement. With the alignment fixture in this position the load cell and upper grip can be aligned with the lower grip.

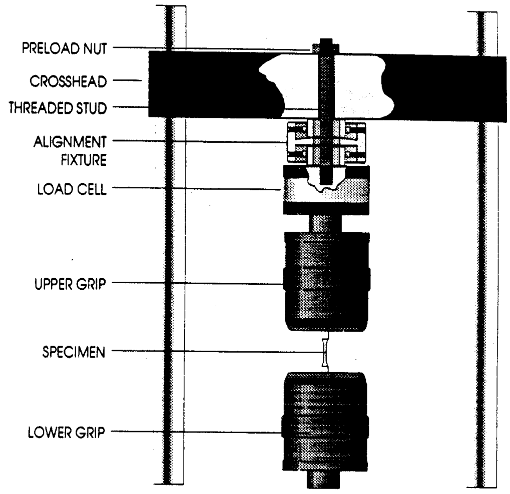

Figure 3. Standard arrangement for installation of the alignment fixture.

Coarse alignment is achieved by setting the adjustment screws of the alignment fixture to the mid position and clamping the fixture to the cross-head with a dummy specimen in place. The dummy specimen consists of a 25 mm diameter steel bar.

The dummy specimen is then replaced by a steel cylindrical dumbbell specimen. This dumbbell specimen has eight strain gauges attached; four equally spaced around the circumference towards the top of the waisted region, the other four in identical positions towards the bottom of the waisted region. The gauges are wired as two full bridges. Instron ALIGNPRO software resolves the strains into angular and concentric misalignment. The adjustment screws on the alignment fixture are used in turn to minimise the misalignments. The dumbbell specimen is removed leaving the collet grips aligned and testing of butt-joint specimens may then proceed. This procedure cannot compensate for any specimen misalignment hence the importance of accurate preparation.

An extensometer consisting of an assembly of displacement transducers is used to determine the axial deformation around the adhesive bond in response to an applied load. The extensometer consists of two rings with knife-edges on their inner surfaces. Each ring locates in one of the grooves in a bonded specimen. One of the rings supports three precision inductive displacement transducers that are equally spaced around the ring. The core of each transducer is supported by an elastic suspension that permits friction-free movement of the core and supplies a restoring force to any displacement. The core of each transducer contacts the surface of the second ring. The transducers record the combined axial deformation of the adhesive and the distortion of the region of the adherend between each bond face and the corresponding v-groove.

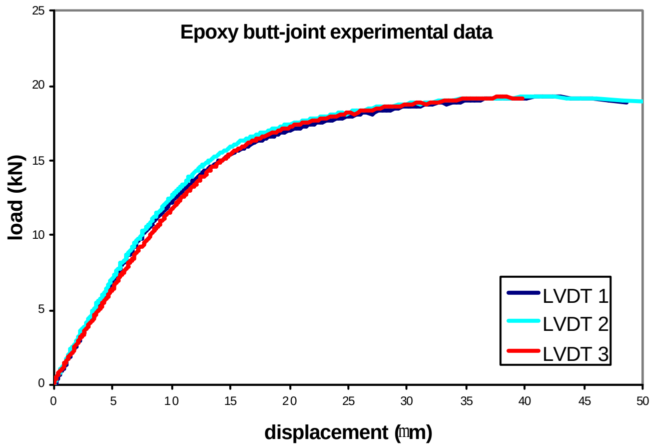

Figure 4. Typical plot of load versus displacement transducer output for the butt-joint test.

Typical butt-joint experimental data obtained using this method are shown in Figure 4. The displacement output shows a consistent axial extension across all three transducers. This means no specimen bending is occurring during testing

The butt-joint specimens are tested at a speed that gives a similar strain rate to that obtained in the bulk adhesive specimen tests. This ensures the validity of comparing the butt-joint data with FE predictions obtained using material parameters calculated from bulk data.

Concluding remarks

- Specimens should be prepared carefully, using the methods described, to ensure alignment of the butt-joint adherends.
- To enable comparisons with FE predictions, cure schedules should be used which reproduce the thermal history experienced by the bulk adhesive sheets
- The large strain properties of rubber-toughened adhesives can be modelled as elastic-plastic materials. Accurate data from the butt-joint test are particularly important to enable the applicability of different yield criteria for the adhesive to be assessed. The new test arrangement employed has led to greatly improved accuracy and repeatability of butt-joint test data.

Acknowledgements

This measurement note was prepared as part of a project on the *Performance of Adhesive Joints*, a programme of underpinning research financed by the DTI. The assistance of Alan Pearce is greatly appreciated.

References

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