



Low-stress creep deformation in two opto-electronic glass-epoxy joints: Part II – Joint measurements and FEA

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ABSTRACT

The creep deformation of two glass-epoxy adhesive joints, representative of joint designs used in opto-electronic devices, was measured at various temperatures and relatively low stress levels using a novel, ultra-sensitive method employing optical interference fringes. The adhesive creep models obtained in Part I were then used as the constitutive equations in finite element models of the joints with the objective of assessing the accuracy of the predictions of creep deformation at the low stresses typical of opto-electronic applications. Good agreement was obtained for both adhesives; however, the higher modulus adhesive was more complicated, exhibiting highly non-linear creep behavior as the stress levels approached zero. The lower modulus adhesive was shown to be linearly viscoelastic over the entire range of stresses encountered in the opto-electronic joints.

1. Introduction

As described in Part I [1], adhesives are often used in opto-electronic assemblies to joint glass components to various other materials. Residual curing stress and stresses due to gravity, vibration and changes in temperature, although relatively small, can produce sufficient creep deformation to misalign optical elements and cause degradation in performance. Creep deformation in these opto-electronic assemblies is usually modelled using finite element analysis (FEA), but the accuracy of these predictions of creep deformation in opto-electronic adhesive joints at very low stress levels has not been adequately assessed.

This requires both adhesive creep constitutive models fitted to data measured at relatively low stress, and the verification of FE model accuracy for opto-electronic adhesive joints on the scale of the stresses and deformations expected in service applications.

The measurement of creep within an adhesive joint is challenging, particularly at low stress, because adhesive layers are usually thin and therefore deformations are small. There are a variety of established methods for monitoring deformation in adhesive joints [2]; however, these are only appropriate for dealing with relatively large deformations and loads. Wu et al. [3] used infrared crack opening interferometry to monitor the minute adhesive deformations in the vicinity of a crack tip growing within an adhesive layer between polished silicon adherends. In the present work, a similar interferometric approach was used to measure creep deformation in glass-epoxy joints designed to model joints in opto-electronic devices.

The objective of the present study was to assess the accuracy of finite element models in predicting creep deformation at very low stress levels in adhesive joints representing those found in opto-electronic devices. Extremely small creep deformations in two epoxy adhesives were measured using an optical interference-fringe approach in two types of glass-epoxy joints subject to relatively low stress. These measurements were then compared with the predictions of finite element models using the creep constitutive models derived from bulk tensile creep tests on the two epoxies from Part I [1].

2. Methods and materials

2.1. Adhesives

The same two epoxy adhesives tested in Part I were used to assemble two different glass joints. Epoxy A had a relatively high modulus and epoxy B was much more flexible. Their properties are given in Table 1 of Part I [1].

2.2. Opto-electronic joints

2.2.1. Measurement methodology

The creep displacements in the two opto-electronic glass-epoxy joints were measured using interferometry to record the minute changes in the inclination of optical flats incorporated into the joint design. As shown in Fig. 1, the distance, L , containing n dark fringes, is

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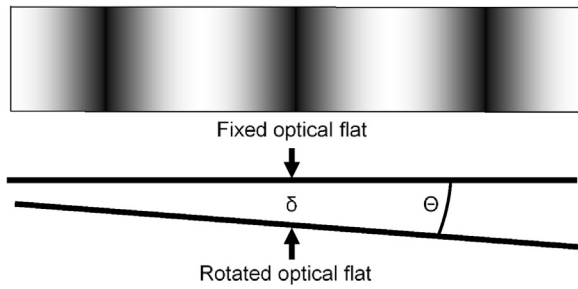


Fig. 1. Optical fringes used to measure the small rotation, θ , due to creep of the adhesive used to bond a glass beam.

related to the angle between the flats, θ , as:

$$\tan \theta = \frac{n\lambda}{2L} \quad (1)$$

where λ is the wavelength of the monochromatic light used in the measurement (Born and Wolf [4]). In the present case, $\lambda = 560$ nm so that the difference in the separation, δ , between the glass surfaces occurring between adjacent dark fringes was 280 nm or $\lambda/2$.

2.2.2. Opto-electronic test specimens

Creep deformation was measured in two types of model opto-electronic joints: one imposing a largely tensile load on the adhesive (type T), and another representing a predominately shear loading (type S). Both specimen types used a rectangular glass beam ($44 \times 15 \times 9$ mm) with a 1.59 mm thick Invar loading plate bonded to it using a high strength adhesive (Loctite 3621, Henkel, Dusseldorf, Germany). The upper surfaces of the beam were specified to be flat within 0.025 mm and were optically polished.

In the type T specimens shown in Fig. 2 this rectangular glass beam was bonded to a rectangular glass substrate ($35 \times 20 \times 7$ mm) using either epoxy A or B. This specimen was designed to test the out-of-plane tensile behavior of the epoxies, similar to a double cantilevered beam (DCB) adhesive joint specimen. Type T specimens were constructed using nominal adhesive joint thicknesses of 100 and 500 μ m. The rotation angle of the upper glass beam was measured by generating interference fringes between its top surface and a glass reference flat fixed just above it in the loading jig.

The type S specimens, shown in Fig. 3, applied a shear stress to either epoxy A or B that joined a cylindrical glass substrate (10 mm in diameter, 15 mm in length) to the rear face of the rectangular glass beam. Type S specimens were designed for a nominal adhesive layer

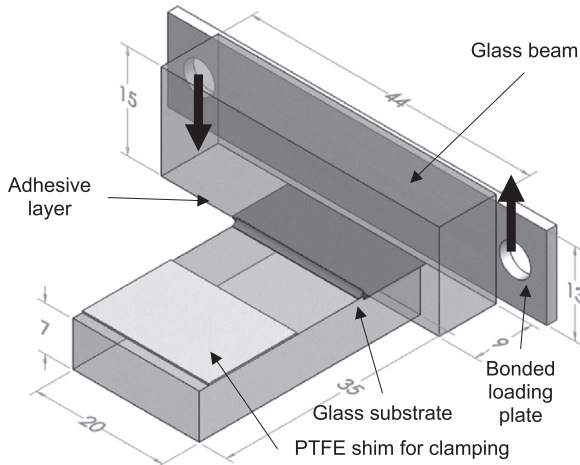


Fig. 2. Type T opto-electronic test specimen (dimensions in mm). Glass substrate was clamped over PTFE shim and force couple applied to loading plate with load jig.

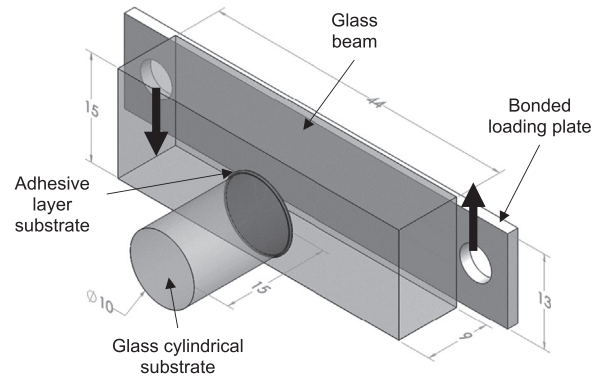


Fig. 3. Type S opto-electronic test specimen (dimensions in mm). Glass cylindrical substrate was clamped and force couple applied to loading plate with load jig.

thickness of 82.5 μ m. Again, the rotation angle of the upper glass beam was measured by generating interference fringes between its top surface and a glass reference flat fixed just above it in the loading jig.

An assembly jig was used to position the glass pieces accurately during bonding and control the bondline thickness. A shown in Fig. 4 the base of the jig consisted of an aluminum block ($60 \times 55 \times 13$ mm) that was polished on one side. Socket head screws were used as stops to position the substrates of each specimen type. Additional upright positioning stops, used for the loaded beam, were attached to the sides of the base using flathead screws and were used to position the loaded beams laterally. The stops could be reconfigured to handle both specimen types. A pair of precision-machined invar spacers was used to control the bondline thickness; 7.498 mm spacers were used for type T specimens and 15.09 mm spacers were used for type S specimens.

Prior to assembly, the bonding surfaces of all components were cleaned with isopropyl alcohol. To manufacture type T specimens with a 500 μ m adhesive layer thickness, the assembly jig was configured as shown in Fig. 4a and the substrate shown in Fig. 2 was placed against the screw heads. An additional 400 μ m spacer was placed underneath the rectangular substrate to manufacture 100 μ m joints. The invar spacers were then placed on both sides of the joint region and epoxy (0.375 mL for 500 μ m joints, 0.125 mL for 100 μ m joints) was poured onto the joint region on the upper surface of the substrate. The loaded beam was then lowered onto the spacers and pushed against the upright stops. Excess adhesive squeezed from the joint was removed using a micro-spatula.

To manufacture type S specimens, the assembly jig was configured as shown in Fig. 4b. The glass rod was placed on the base and was pushed against the two screw heads as shown. Epoxy was then deposited onto the top surface of the glass rod and the invar spacers were placed on either side. The loaded beam was then lowered onto the spacers and pressed against the upright stops. A micro-spatula was used to remove excess adhesive from the edges of the joint.

For epoxy A specimens, the epoxy was degassed for 5 min after being poured onto the bond region and before the joint was closed. Specimens were then cured in a preheated oven at 120°C for 90 min including the oven heat-up time, after which the oven was turned off and the door left slightly open to allow slow cooling of the specimen. After creep testing, the adhesive joint fillet was ground away, and the adhesive layer thickness was verified under a microscope. Epoxy B specimens were cured in a preheated oven at 85°C for 35 min including specimen heat-up time. The oven temperature control was then set to 120°C and after 45 min, including heat-up time, the heater was turned off and the oven door left slightly open to allow the specimen to cool slowly. Cure schedules were verified using a type T specimen with an embedded thermocouple for both adhesives. After testing, the adhesive joint fillets were cut away and the joint adhesive thickness was verified using a microscope.

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