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YIELD STRENGTH AND STRESS RELAXATION DATA FOR AN ADHESIVE USED IN BUTT JOINT TESTS

T. R. Guess and E. D. Reedy, Jr.
Sandia National Laboratories, Albuquerque NM 87185

ABSTRACT

Mechanical property data are reported for Epon 828/T403, an amine-cured epoxy adhesive. Data include compression modulus, compression yield strength and compression stress relaxation as a function of stress level, strain rate, and temperature and Mode I fracture toughness as a function of temperature. This data was generated to support a study investigating how temperature effects joint strength and the corresponding interface corner fracture toughness for adhesively bonded butt joints.

KEY WORDS: Adhesives, Stress Relaxation, Yield Strength, Fracture Toughness, Butt Joint, Bond Thickness, Temperature

1. INTRODUCTION

Bulk adhesive mechanical property data were measured to aid in the interpretation of tests investigating the effect of bond thickness and residual stress on the tensile strength of butt joints (1). The butt joint specimen is two stainless steel rods bonded together with an amine cured epoxy adhesive (Shell Epon 828 epoxy resin with a Texaco T403 hardener using a 100/36 weight ratio). Some of the butt joint specimens were cured and tested at room temperature to minimize residual stress in the adhesive bond and others were tested at temperatures well below their cure temperatures to introduce residual stress during cooling (2, 3). The measured tensile strength of butt joints cured and tested at room temperature doubles when the bond thickness is reduced by a factor of 8 (from 2.0 mm to 0.25 mm); a failure analysis based on the magnitude of the asymptotic stress state at the adhesive/metal interface corner, in a linear elastic layer, predicts the observed bond thickness effect (2, 3). On the other hand, tests at temperatures well below the cure temperature did not show a decrease in joint strength as expected since the butt joint failure stress should reflect the effect of both the applied load and the residual stress.

The expectation that joint strength will reflect the effect of both applied load and residual stress assumes linear elastic material behavior where residual stress levels do not change with time. To check this assumption, mechanical properties tests were performed on the Epon 828/T403 epoxy adhesive to measure its response at various test temperatures and strain rates. The purpose of this paper is to describe experimental procedures and present results of compression and fracture

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toughness tests on Epon 828/T403 epoxy adhesive. The experimental results suggest that a stress relaxation process may affect residual stress levels in butt joints.

2. EXPERIMENTAL RESULTS

2.1 Compression Tests The Epon 828/T403 epoxy adhesive's initial modulus, yield strength and stress relaxation behavior were measured in compression using cylindrical specimens. Testing procedures followed the guidelines in *ASTM D-695, the Standard Method of Test for Compressive Properties of Rigid Plastics*, using 13.1 mm diameter by 29.2 mm long specimens. Unless indicated otherwise, all tests were performed at room temperature at a strain rate of about 0.0002/s. The compression sample was loaded to yield, and then the test frame's crosshead displacement was fixed for roughly 30 minutes to monitor stress relaxation; apparent yield is defined as the maximum compressive stress attained. The effect of stress level on stress relaxation is illustrated in Figure 1 for two cure conditions. Apparent yield occurs at a stress level of roughly 100 MPa. Considerable stress relaxation can occur when the adhesive is loaded to yield. There is nearly a 40% decrease in the stress level after 30 minutes. Stress relaxation response is similar for the two cure conditions.

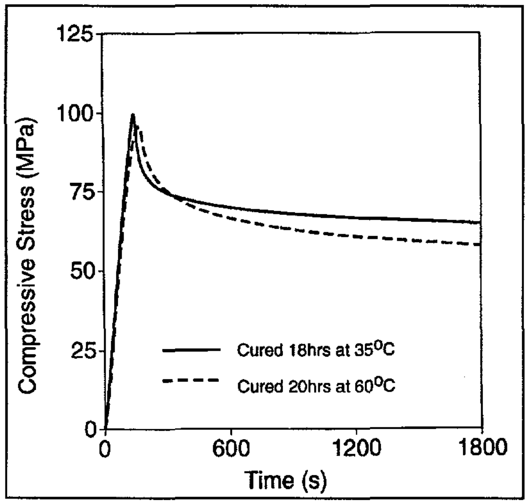

Fig. 1. Room temperature stress relaxation data for an Epon 828/T403 adhesive cured at two different temperatures and loaded to yield at a strain rate of about 0.0002/s prior to fixing the displacement.

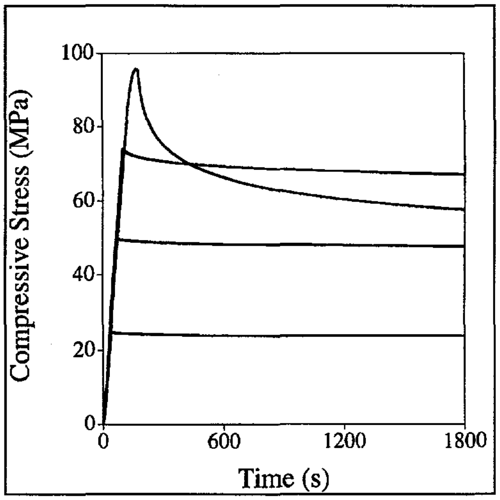

Fig. 2. Room temperature stress relaxation data for an Epon 828/T403 adhesive cured 20 hrs at 60°C. Specimens are loaded to 25%, 50%, 75%, and 100% of yield at a strain rate of about 0.0002/s prior to fixing the displacement.

The effect of stress level on stress relaxation is shown in Figure 2; each sample was loaded to a different level prior to fixing the displacement and monitoring stress relaxation. After 30 minutes, the compressive stress has decayed to 94%, 95%, 90%, and 60% of the initial stress level for samples stressed to 25%, 50%, 75%, and 100% of yield, respectively. The adhesive appears to behave in a linear viscoelastic manner at the two lowest load levels, but exhibits nonlinear, stress level dependent, viscoelasticity when stressed to levels approaching apparent yield. Clearly, significant stress relaxation can occur once the adhesive yields.

The effects of strain rate and test temperatures on apparent yield strength are illustrated in Figures 3 and 4. There is a substantial increase in yield strength with increasing strain rate and decreasing temperature. As the strain rate is increased from 0.00002/s to 0.002/s, the room temperature apparent yield strength increases by 25% from 87 MPa to 109 MPa. As temperature is decreased from room temperature to -60°C, the yield strength, measured at a strain rate of 0.0002/s, increases from 100 MPa to 175 MPa (increases 75%). As shown in Figure 4, considerable stress relaxation can occur in specimens when loaded to yield regardless of the test temperature. Substantial stress relaxation occurs in the yielded adhesive at temperatures as low as -60°C. At this test temperature, the Epon 828/T403 epoxy (cured 18 hours at 35°C) is more than 100°C below its glass transition temperature, yet the stress decreases by 30% over a period of 30 minutes.

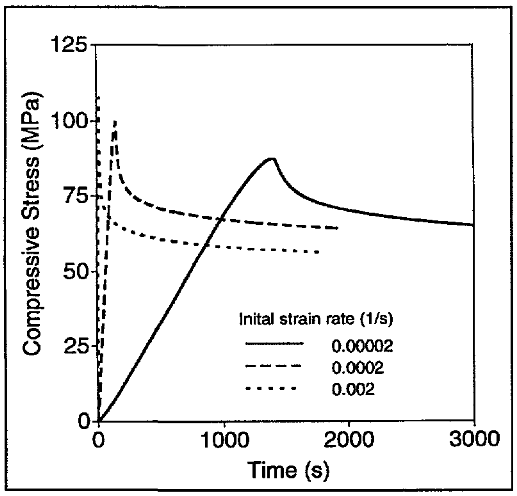

Fig 3. Room temperature stress relaxation data for an Epon 828/T403 adhesive cured 18 hrs at 35°C. Each specimen is loaded to yield at a different strain rate prior to fixing the displacement.

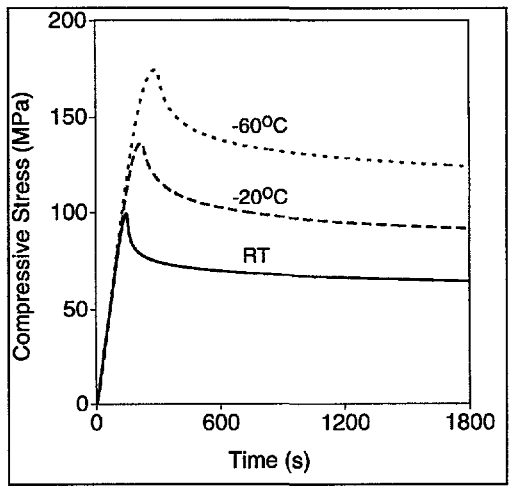

Fig 4. Stress relaxation data for an Epon 828/T403 adhesive cured 18 hrs at 35°C and tested at three temperatures. Each specimen is loaded to yield at a strain rate of about 0.0002/s prior to fixing the displacement.

Young's modulus was measured in each of the stress relaxation tests; results are listed in Table 1.

Table 1. Bulk adhesive properties of Epon 828/T403. All specimens cured at 35°C for 18 hours.

Test Temperature °C	Young's Modulus (GPa)	Apparent Yield Strength (MPa)	K_{IC} (MPa-m$^{1/2}$)	G_{IC} (J/m^2)
20 (RT)	3.66	100	0.81	157
-20	3.86	137	0.94	202
-60	4.00	175	0.96	202

2.2 Fracture Toughness Tests The plane strain fracture toughness of Epon 828/T403 epoxy (cured 18 hours at 35°C) was measured using an edge-cracked, three point bend specimen.

Testing procedures followed the guidelines in *ASTM E-399, the Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials.* A sharp precrack was introduced on one edge of a cast, rectangular bar (100 mm long x 12.7 mm deep by 6.3 mm thick) by clamping the specimen, and then impacting a single-edge razor blade that had been placed against the specimen's edge. The bar was loaded in three-point bend at a rate of 0.02 mm/s and tests were carried out at 20°C, -20°C, and -60°C. The average plane strain fracture toughness, K_{IC}, and the associated critical energy release rate, $G_{IC} = K_{IC}^2/(E/(1-\nu^2))$ values are listed in Table 1.

3. DISCUSSION

Table 1 summarizes bulk adhesive properties for three test temperatures. The adhesive's Young's modulus and yield strength were measured in compression at strain rate of 0.0002/s. The adhesive's yield strength displays a relatively large increase over the 20°C to -60°C temperature range (75%), while Young's modulus shows a much smaller increase (9%). There is a moderate increase in Mode I fracture toughness K_{IC} with decreasing temperature. The critical energy release rate G_{IC} is the only property that does not increase steadily with decreasing temperature.

Reference 1 postulates that the relaxation of residual stress in the region of the interface corner may explain the apparent insensitivity of the measured butt joint strength to residual stress generated by cooling. Detailed finite element calculations indicate that when a butt joint is cooled, a small yield zone develops at the interface corner (4). For the adhesive properties and bond thicknesses used, the yield zone is embedded within the singular interface corner stress field and its length is much less than the bond thickness. In the tested butt joints, fracture always initiated near the interface corner (2, 3). Accordingly, the stress state in the region of the interface corner is presumed to control the fracture process. The test data from the present study indicates that the stresses in the interface corner yield zone, where fracture initiates, will relax if given sufficient time. Residual stress in the tested butt joints is present for hours or days prior to mechanical loading, providing ample time for substantial stress relaxation. Consequently, the interface corner stresses introduced by a subsequent mechanical loading are combined with residual stresses that are much less than those estimated by a linear analysis. This is a plausible explanation for the apparent insensitivity of butt joint strength to residual stresses.

4. SUMMARY

Previous butt joint test data suggested that residual stress has little effect on butt joint strength (2, 3). The possibility that a stress relaxation process affects residual stress levels in butt joints was investigated. In the experimental study reported here, stress relaxation and fracture toughness tests were carried out for the Epon 828/T403 adhesive used in the butt joint tests. This adhesive was found to display a highly nonlinear, stress level dependent, viscoelasticity at stress levels approaching the adhesive's yield strength. Significant stress relaxation was observed at temperatures of more than 100°C below the adhesive's glass transition temperature. These results indicate that the peak stresses in an adhesive joint, in the yield zone at the interface corner where failure initiates, can decay significantly when given sufficient time. Accordingly, the influence of residual stress on butt joint strength can be much less than would be predicted by a linear analysis (1).

5. REFERENCES

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6. ACKNOWLEDGMENT

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