# EFFECTS OF STRAINING RATE ON THE MECHANICAL BEHAVIOR OF ADHESIVE BONDS UNDER SHEAR DEFORMATION

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## INTRODUCTION

The mechanical behavior of adhesive bonds is of interest in a variety of industrial and technological applications, including traditional adhesive bonding, laminated structures and composite materials. The main approach for characterizing the mechanical performance of the bond is based on the bulk form of the material. However, such tests may lead to an early specimen failure due to the presence of high stress concentration. Also, monolithic material testing fails to produce the unique geometrical constraints imposed on the adhesive by relatively rigid adherends; such interaction may greatly alter the performance of the bond as compared to the bulk form, and lead to a considerable deformation in the adhesive prior to failure, particularly for very thin bonds [1]. Gsell et al. [2], in their testing of bulk polymers in shear, were able to eliminate some of these difficulties by localizing the failure with the introduction of a thickness gradient along the direction of maximum shear stress.

This work extends a previous effort for characterizing the mechanical behavior of adhesive bonds into the effect of strain rate [3-5], which plays an important role on the long-term performance of the joint, particularly for polymeric adhesives. In this work, the Napkin Ring Test specimen [6] is used to obtain the stress-strain response of adhesive bonds undergoing simple shear. This specimen has a number of advantages over other forms of adhesive bond tests, including that the state of stress in the joint is nearly pure shear and the variation of shear stress is minimal, irrespective of the deformation level. Also, the deformation in the bond is localized, allowing for very large straining prior to catastrophic fracture.

## APPARATUS AND TESTING

The test specimens were based on the napkin ring configuration; details of fabrication and testing are similar to those described in Ref. 1. As shown in Fig. 1, the specimens are made of two cylindrical rods with edges machined to a ring shape and joined end to end by a thin layer of adhesive. The ring is sufficiently narrow so shear stress variation in the radial direction is small. The adherends were made of 5086 aluminum alloys while the adhesive was a toughened epoxy adhesive (BP-907)[1] having a curing temperature of 180 $^{o}$C. Prior to bonding, the adherend surfaces were cleaned and etched in accordance with the FPL etching procedure [6]. The adhesive thickness was controlled by placing shims over part of the bondline. However, despite great care and in the machining and processing of the test samples, some thickness variations along the bondline occurred. Pending a resolution of this technical aspect, the present work is limited to relatively thick bonds. Torsion tests were

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[1] Certain commercial materials and equipment are identified in this paper in order to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology (NIST) nor does it imply that they are necessarily the best available for the purpose.

carried out with the aid of a servo hydraulic testing machine operated under a controlled shear strain. The latter was measured with the aid of a specially devised apparatus that utilizes a standard extensometer to convert the relative shear displacement across the bond to shear strain. Utilizing this output in a closed-loop computer routine, the actual strain rate in the adhesive could be controlled. The standard uncertainty of the strain measurement lies between 0.03 and 0.05. The standard uncertainty of the stress measurement is 5.0 MPa.

## RESULTS AND DISCUSSION

Tests were carried out on a toughened epoxy adhesive which thickness varies in the range of 50 μm to 150 μm (the standard uncertainty is 5 μm). Because of difficulties in obtaining a uniform bond thickness, the results to be reported are limited to relatively thick bonds, i.e. greater than about 60 μm. The tests were carried out under a constant rate of shear strains of the adhesive bond, with the straining rate varying from nearly quasi-static conditions up to about 0.3/s.

Fig. 2 shows a typical stress strain curve for bonds in the range of 55 μm to 77 μm thick under a constant shear strain rate of 0.29/s. Note that the strain has contributions from both the adherend and the adhesive. However, the adherend contribution, which is linear, can be subtracted off to give the plastic strain in the adhesive. The adhesive response is characterized by a small drop in stress followed by a strain-hardening phase up to complete failure. It is believed that the drop is due to a sudden development and extension of shear bands in the adhesive while the strain hardening is the result of molecular orientation. From such plots, the ultimate strain (the strain at failure) and yield stress of the adhesive can be determined. These quantities are shown in Figs. 3 and 4 as a function of strain rate; as noted in the figures, the adhesive thickness ranges from 55 μm to 77 μm. Fig. 3 suggests that the ultimate shear strain of the adhesive tends to decrease with increasing rate. Most of the decreasing occurs below a strain rate of 0.05/s. For larger rates (beyond a strain rate of .1/s), the deviation in the ultimate shear strain from it's quasi-static value is nearly constant. Fig. 4 shows that over the range of parameters studied, the yield stress of the adhesive changed relatively little. There appears an increase in the yield stress with increasing strain rates below 0.1/s. For larger rates, the yield stress is nearly constant.

Similar results were obtained when testing thicker bonds. Attempts have been made to extend this study to thinner bonds. However, thickness variations in a given sample in these cases precluded making any reliable conclusions to be made.

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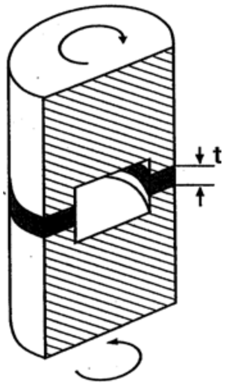

Fig. 1. Sectional view of the Napkin Ring Test specimen; t is the bond thickness

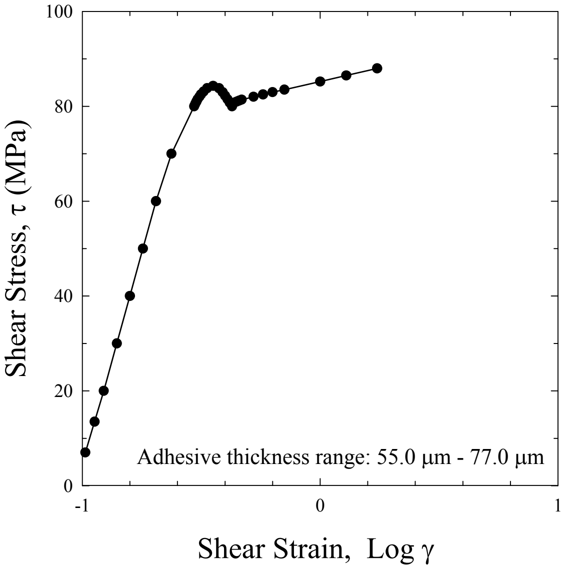

Fig. 2 Stress strain curve under simple shear obtained using the Napkin Ring specimen

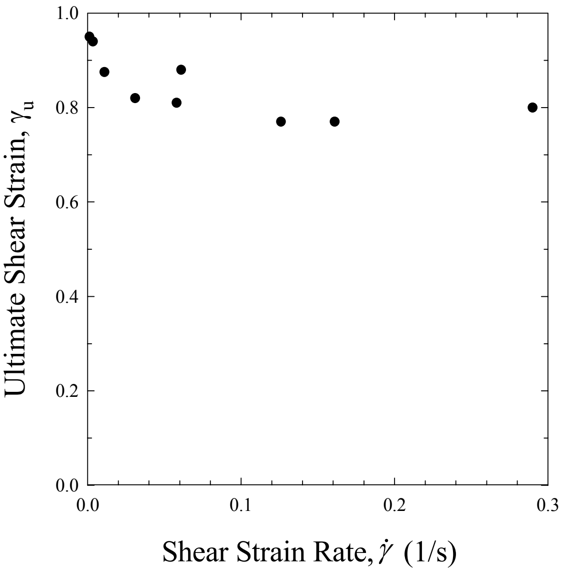

Fig. 3. Ultimate shear strain, $\gamma_u$ vs. shear strain rate, $\dot{\gamma}$ for various bond thicknesses

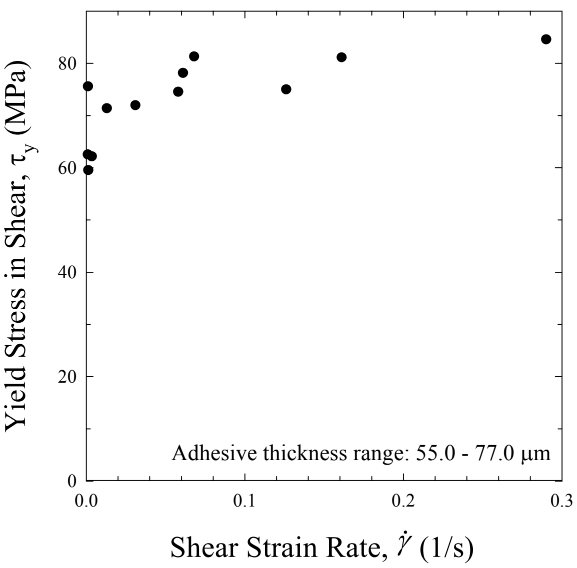

Fig. 4.Yield shear stress, $\tau_Y$ (MPa) vs. shear strain rate, $\dot{\gamma}$ for various bond thicknesses