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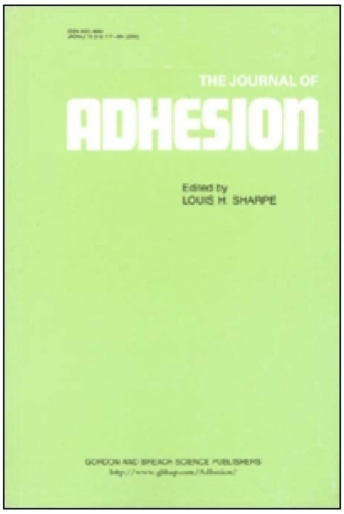

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Failure of Adhesive Bonds at Constant Strain Rates

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Failure of Adhesive Bonds at Constant Strain Rates

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Shear strengths of adhesive bonds using AF126 and two thicknesses of aluminum were measured at constant rate of crosshead separation. It was found that the shear strength could be related to temperature and strain rate or failure time over the range of deformation rates used.

INTRODUCTION

Recently, there has been some interest[1,2] in the failure of adhesive bonds under various loading conditions. Using some constant strain rate shear strength determinations on an AF126 adhesive, this paper shows that the strength of such a bond, under conditions where cohesive failure occurs, can be related to temperature and strain rate or failure time.

EXPERIMENTAL

Materials

2024–T3 aluminum panels 4″ x 13″ x $\frac{1}{8}$″
2024–T3 aluminum panels 4″ x 12″ x $\frac{1}{16}$″

AF126–3, a thermosetting, nonvolatile modified epoxy film adhesive designed for structural bonding of metals.

Adherend preparation

The aluminum panels were washed with acetone followed by degreasing in hot vapors of stabilized perchloroethylene. The area to be bonded was then etched for five minutes at 150°F in FPL etch solution in accordance with MIL-A-9067C, then washed with tap water at 140°F followed by deionized water rinse. The panels were dried in a forced-air circulating oven at 140°F for one hour.

Specimen preparation

One group of panels was prepared using the $\frac{1}{16}''$ thick aluminum. A second group was prepared using the $\frac{1}{8}''$ thick adherends.

A single layer of the film adhesive was placed at the edge of one panel; a second panel was placed over the adhesive and held in place to provide a $\frac{1}{2}''$ overlap. The assembly was placed in a hydraulic press at room temperature and 50 psi pressure. The temperature was raised to 250°F at a rate of approximately 8°F/min. The pressure and temperature were maintained for one hour. The assembly was then cooled under pressure.

One inch wide specimens were cut from the panels using a band saw. The pieces from each end of the panels were discarded.

Testing

The testing temperatures were maintained using liquid carbon dioxide and electric heaters, as required, with a standard test cabinet. The load was applied using a 60,000 pound capacity Baldwin testing machine operating at a constant rate of crosshead separation. Rates of 0.105, 0.8, and 2 inches/minute were used. Failure times were measured by use of a stop watch. Five specimens were tested at each condition. The temperatures used were 193°, 233°, 273°, 296°, 323° and 343°K.

RESULTS AND DISCUSSION

In this work crosshead separation rates of 0.105 to 2 inches/minute were used. Over this rather limited range we are interested in the relations between shear strength, temperature, crosshead separation and failure time for a commercial epoxy-aluminum system. Although such a study will obviously not verify any of the phenomenological theories, such theories should be useful in establishing the relationships that are sought.

If the deformation (ε) is constant at a given temperature, the rate of crosshead separation (C) should be simply related to failure time (t_f).

$$Ct_f = \varepsilon \tag{1}$$

A somewhat more convenient representation can be given by rearranging Eq. (1) and taking logarithms:

$$\log C = \log \varepsilon + \log (1/t_f). \tag{2}$$

Equation (2) shows that a plot of $\log C$ verses $\log (1/t_f)$ drawn with a slope = 1 will yield (ε) at $\log (1/t_f) = 0$. Figure 1 illustrates this for the $\frac{1}{8}''$ thick adherend data.

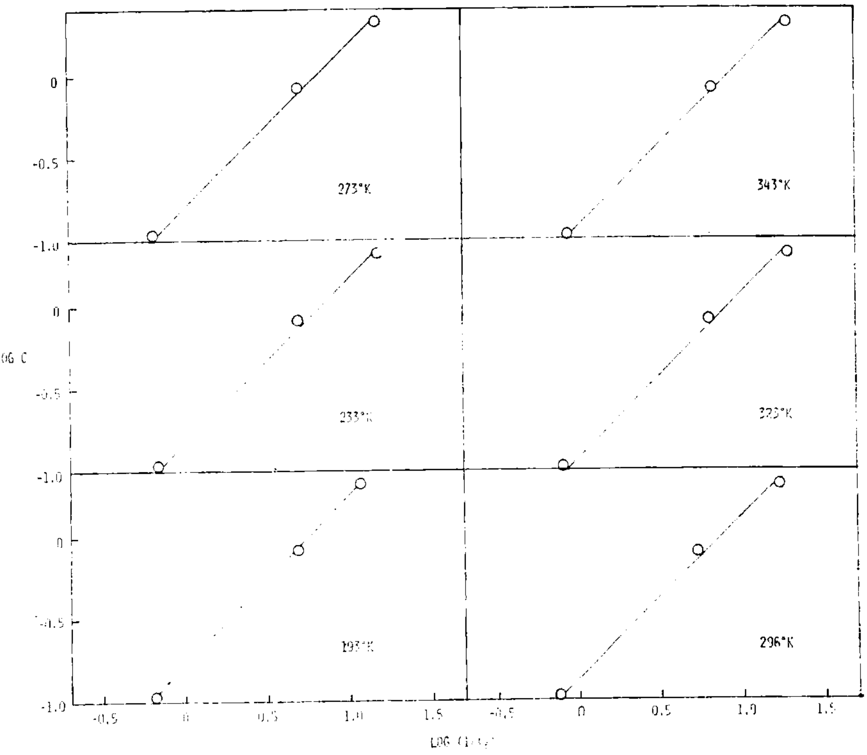

FIGURE 1 Log C versus $\log (1/t_f)$ for AF126 adhesive with $\frac{1}{8}''$ aluminum adherends.

It is interesting to note that there appears to be a small, but noticeable, variation of deformation with temperature for samples using $\frac{1}{8}''$ aluminum adherends. For the case of $\frac{1}{16}''$ aluminum adherends, the deformation does not appear to vary with temperature, at least beyond the experimental error.

The deformation as calculated from the C and t_f values includes grip slippage, deformation in the machine as well as deformation in the adhesive and adherends. The $\frac{1}{16}''$ aluminum adherends deformed visibly during testing, while the $\frac{1}{8}''$ aluminum adherends did not. The observed differences are probably due to the difference in the response of the aluminum.

Linearity between mechanical strength of polymers and the logarithm of the failure time has been observed in many cases. Eqs. (1) and (2) suggest that a similar relation between strength and rate of crosshead separation may be applicable. Such a relation has also been proposed by Cherry and Holmes[3] for a polyethylene-stainless steel adhesive system. Figure 2 shows the S versus log C plots for the $\frac{1}{8}''$ aluminum adherend data. Similar results were obtained using the $\frac{1}{16}''$ adherend data.

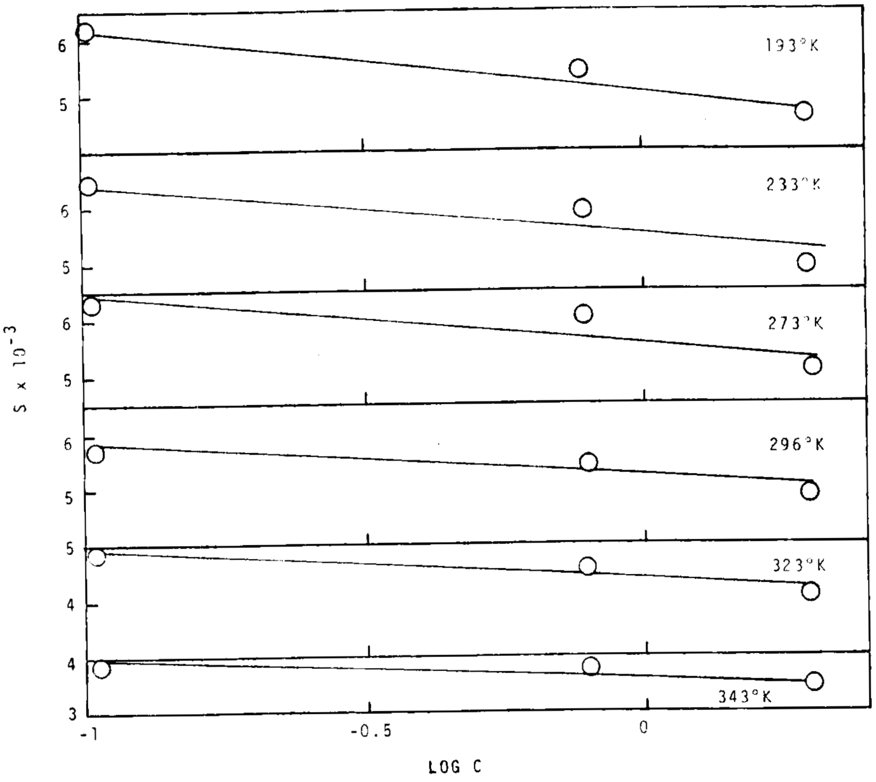

FIGURE 2 S versus Log C for AF126 adhesive with $\frac{1}{8}''$ aluminum adherends.

Equation (2) and Figure 1 suggest that S should also be linear with

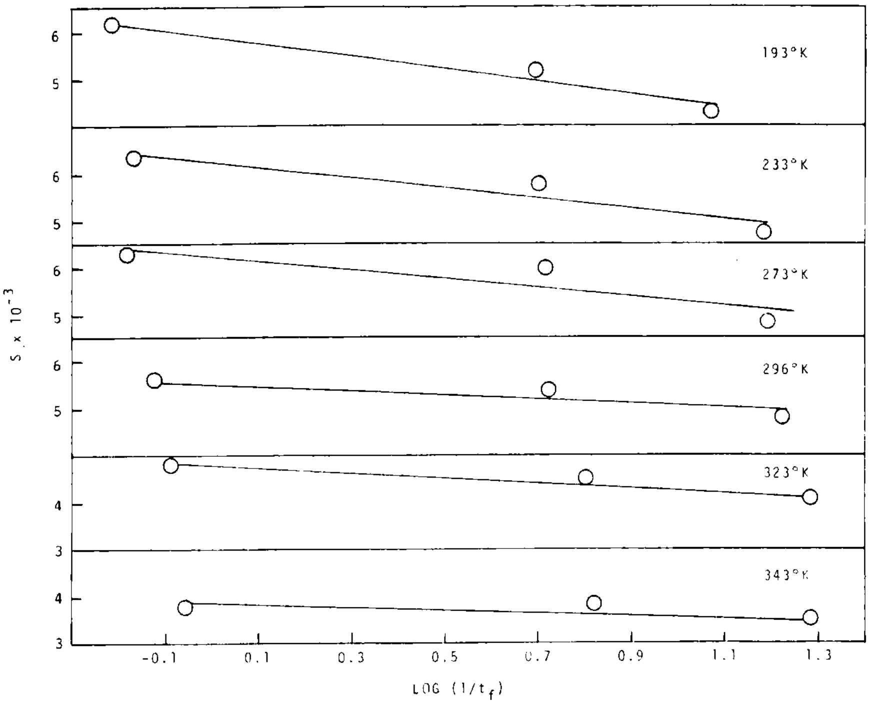

FIGURE 3 S versus $\log(1/t_f)$ for AF126 adhesive with ⅛″ aluminum adherends.

$\log(1/t_f)$, i.e. the deformation appears to be constant. Figure 3 shows that the plots are reasonably linear.

The volume of elements that respond in failure (β) may be obtained from the slope of the S versus $\log C$ plot[3].

$$S = (2kT/\beta)\ln C + (2kT/\beta)\ln(hl/\rho\beta T) + (2RG_e)^{\frac{1}{2}} + 2\varepsilon_0/\beta \qquad (3)$$

l is the diameter of the "dislocation loop", ρ is the density of dislocation lines in unit volume of the medium, $(2RG_e)^{\frac{1}{2}}$ is a critical value of strain at failure, and ε_0 is an activation energy barrier. The last three terms on the right hand side of Eq. (3) are constant at a given temperature. Apparent β values obtained in the present work from the slopes of the lines according to Eq. (3) are shown in Table I. Although numerical values of β for the crosslinked, modified epoxy are considerably lower than those found by Cherry and Holmes[3] for polyethylene, β does increase with temperature as observed by these investigators. Due to reservations about applying Cherry and Holmes'[3] model directly to the epoxide system, quantitative significance probably should not be attached to these results. However, it is encouraging that the trend is in the same direction.

TABLE I

$\beta(\text{Å})^3$ values from slopes of the S vs log C plots.

For $\frac{1}{8}$" aluminum adherends		For $\frac{1}{16}$" aluminum adherends
Temperature	$\beta(\text{Å})^3$	$\beta(\text{Å})^3$
193	1500	4700
233	2350	4900
273	2950	5400
296	4300	8300
323	5600	8000
343	8700	11000

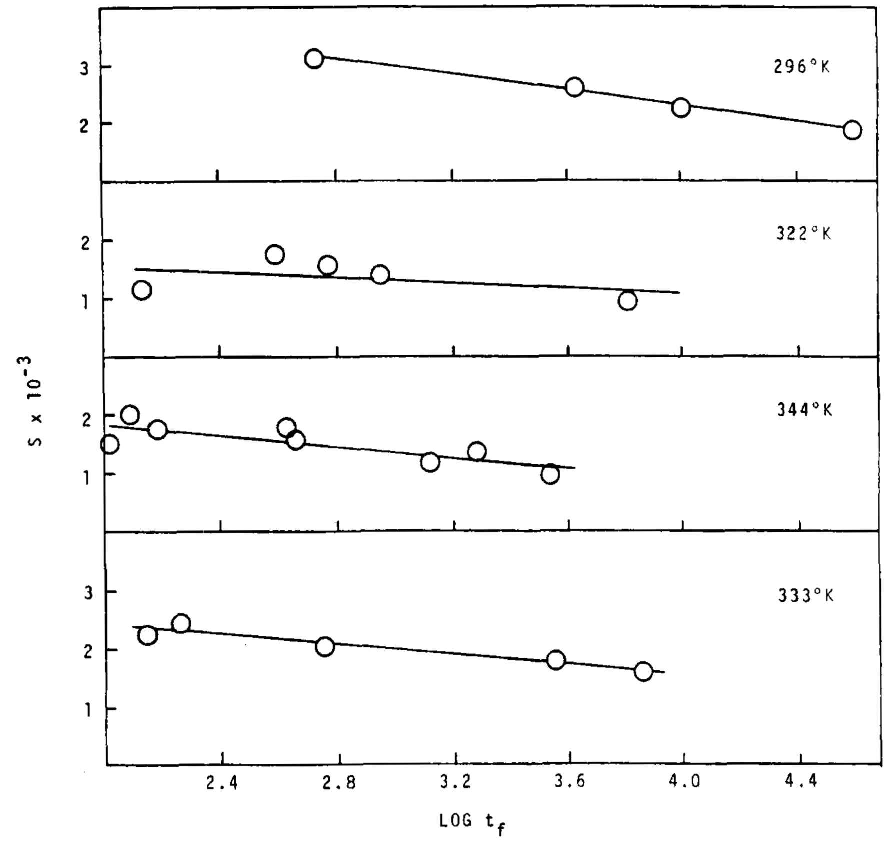

FIGURE 4 S versus Log t_f for AF126 adhesive with $\frac{1}{16}$" aluminum adherends. 90–95% relative humidity.

Some constant stress data using AF126 adhesive with $\frac{1}{16}''$ aluminum panels are available[2]. For this type of loading the linear relation between stress and ln t_f is well established[4]. Once again β is readily accessible from the slope as in the case of constant rate of strain experiments. A comparison should be useful in giving an indication that the same parameters describe the behavior under different types of loading. Unfortunately, a direct comparison is not possible since at the long times of the constant stress experiments, the failure time was rather markedly dependent on humidity[2]. Also, at the much lower loads of the constant stress experiments, there was no noticeable deformation of the $\frac{1}{16}''$ aluminum. Hence, a quantitative comparison of β values for the two cases does not seem to be in order. However, Figure 4 shows the expected linearity, allowing for the usual adhesive scatter, between stress and the logarithm of failure time. This gives some confidence that these relations can describe data obtained by different loading methods. Table II gives apparent β values calculated from the slopes of the lines in Figure 4 for the 90–95% relative humidity data and from similar plots for 50% relative humidity. Qualitatively, the values appear to be in the general range that would be expected from the results described above. However, in each case, there seems to be a rather sharp and unexpected downturn in β (increase in slope) at the highest temperature (344°K). The decrease in β at higher humidity implies that the polymer mobility increases in the presence of absorbed water molecules. This was also observed by Kwei[5] for crosslinked epoxides under constant stress.

TABLE II

β values from constant stress data.

Temperature (°K)	β(Å)^3	
	50% RH	95% RH
296	—	3800
322	9700	5500
333	10000	7000
344	7800	5900

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