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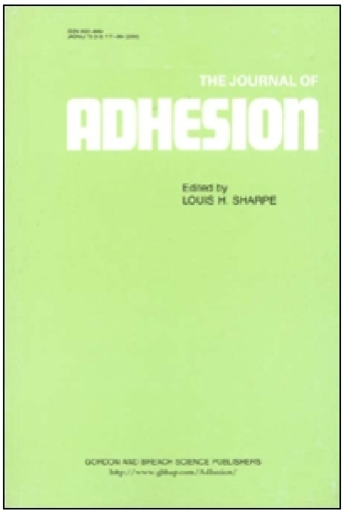

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A Novel Technique for Evaluating the Work of Adhesion

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NOTE

A Novel Technique for Evaluating the Work of Adhesion

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INTRODUCTION

One of the basic problems which one encounters in bonding dissimilar materials such as glass and polymers is the development of internal stresses. These stresses arise primarily as a result of the difference in their thermal coefficients of expansion. Other stresses may also occur due to the processing history of the polymer, swelling of the polymer due to the absorption of gases in the environment or internal reaction products, and/or the loss of absorption of solvent from the adhesive. As a result, it is obvious that techniques designed to evaluate adhesion must evaluate the effects of these intrinsic stresses without modification by the external imposed stresses of the test. For example, Ahagon and Gent evaluate a work of detachment from the time average of the 180° peel force per unit width of the detaching layer.[1] However, Gent and Hamed have recently shown that this mode of peeling involves deformation of the detaching layer due to bending.[2] Similar problems are encountered in other techniques used to measure adhesion.

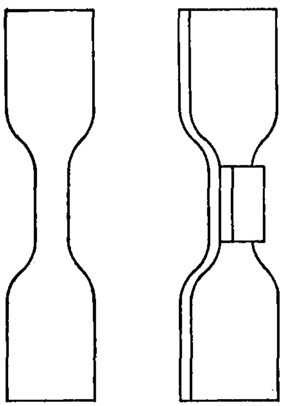
In the course of recent work in our laboratory, it occurred to us that a simple modification of the 0° peel test could provide an evaluation of the work of adhesion which appears to have been overlooked by previous investigators. Our preliminary studies indicate that a well defined work of adhesion based on a quasithermo dynamic approach can be measured and that it is related to the amount of deformation which occurs in the interfacial region and to the failure which takes place during detachment.

THEORETICAL

Consider as shown in Figures 1a and 1b two dumbbell shaped samples. Their dimensions and physical properties are identical except that the sample in Figure 1b has adhesively bonded to either one or both of its surfaces a second material. The total area of contact is defined to be A. If the sample in Figure 1a is deformed uniaxially along the major axis at a temperature T and a rate R, to failure, a typical force-time curve can be determined. The work done in a time interval dt is

$$dW = \sum_{i=1} fi\,dli \tag{1}$$

where fi is the force and dli is the displacement in dt along the ith direction. The total work, W_T, done after a time t, can be found by simple integration.



1a 1b

FIGURE 1 Sample geometries used in studies.

If one repeats this experiment with the sample shown in Figure 1b, then the force-time curve will exhibit a different behavior which will depend on the bonded material, the adhesive, the level of adhesion, the geometry of the composite, and the properties of the dumbbell. In systems where the modulus of the bonded material is much greater than the dumbbell material, then as the deformation of the dumbbell is increased, a time, t_1, will be reached where detachment from the bonded material will being. If the test is allowed to continue, the area of detachment of the bonded material exists. At this time, t_2, the force on the dumbbell will be the same as that on the sample used in the first experiment, if the strain ellipsoids are the same, i.e., the strain

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ellipsoid is a measure of the dimensional changes which occur as a result of the deformation.†

If the test is run until failure of the debonded sample, t_3, a super position of these two force-time curves between t_2 and t_3 will exist, if the strain ellipsoids become the same. The work $W(t_2)$ done in this second experiment over time interval $0 < t < t$ will consist of terms which reflect the mode of deformation of the dumbbell, the interface, the bonded material and thermal conduction losses.[3] This work is

$$W(t_2) = W_0(t_2) + W_A \tag{2}$$

where $W_0(t_2)$ is the work done in the same time interval by the dumbbell in the absence of the bonded material and W_A is the work of adhesion. A similar equation can be written for the time interval $\int_0^{t3}$

$$W(t_3) = W_0(t_2) + W_A + W_0(t_2 - t_3) \tag{3}$$

W_A can thus be obtained as

$$W_A = W(t_2) - W_0(t_2) \tag{4}$$

It should be noted that this procedure could in principle be used to evaluate, W_A, at any time, t, during the experiment after detachment has started. However, the inhomogeneous deformation which occurs during debonding complicates the procedure except after complete debonding has occurred, and superposition of the force-time curves is obtained.

EXPERIMENTAL

The materials used in these experiments were: a double strength window glass, a block copolymer of bisphenol A polycarbonate and polydimethyl siloxane.[4]

The glass surface was cleaned by washing it with Reagent grade isopropal alcohol.

The copolymer was bonded to glass in a MTS press. Test pieces were cut from 12 × 12 inch laminates into the desired form for testing. The force time measurements were made on an Instron tensile testing machine at room temperature.

Typical force-time data for copolymer-glass samples of the type shown in Figures 1a and 1b are presented in Figure 2. It has been found that the complete detachment of the adhered occurs after approximately 1.25 minutes on curve 1b.

† See A. E. H. Love, *Theory of Elasticity*, Dover Publications for a more complete discussion.

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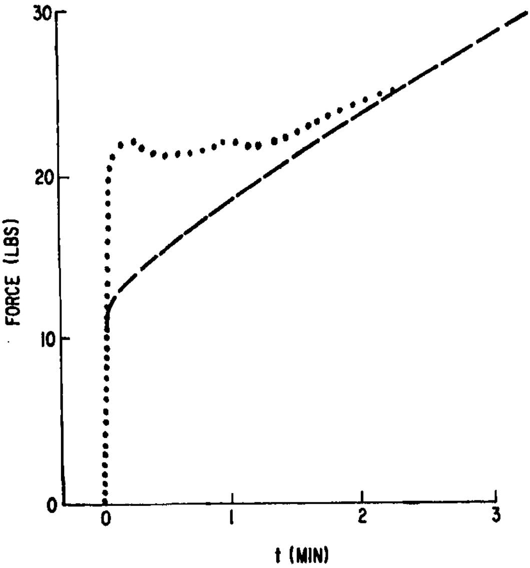

FIGURE 2 Force time-curves for samples of type 1a and b. (The broken dash line is for sample 1a, and the dots are for 1b).

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RESULTS AND DISCUSSION

Plain Strain-Plane Stress Conditions

Different strain histories may occur during the test due to the sample dimensions. In the first case, the width and thickness of the sample are small in comparison to its length. In the second case, the thickness is small in comparison to its width and length. In both cases, a uniaxial force is applied, but as shown by Blatz and Ko the strain ellipsoids are different.[5] These are commonly called plane stress and plane strain, respectively.

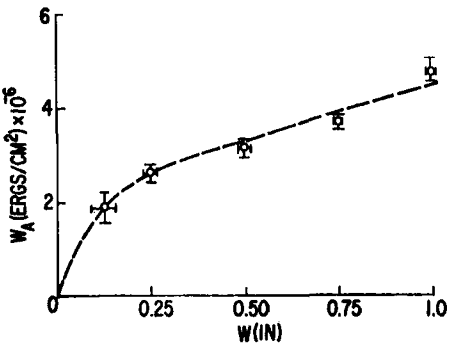

FIGURE 3 Work of adhesion as a function of width.

In order to test for the effect of these conditions, a set of samples where the width was varied from 0.125 to 1 inch at a constant thickness of 50 mils were prepared and tested at a strain rate of 0.5 inch/inch/min. The results of these tests are plotted in Figure 3. The nonlinear behavior suggests that a transition occurs in the vicinity of a width of approximately 0.125 inches. The W_A curve has been extrapolated to zero at zero width on the assumption that as the area goes to zero the work involved in the detachment must also go to zero. A second set of samples which varied in thickness were prepared and tested at constant width and strain rate. These data are plotted in Figure 4. Again, a nonlinear variation in the work of adhesion is noted.

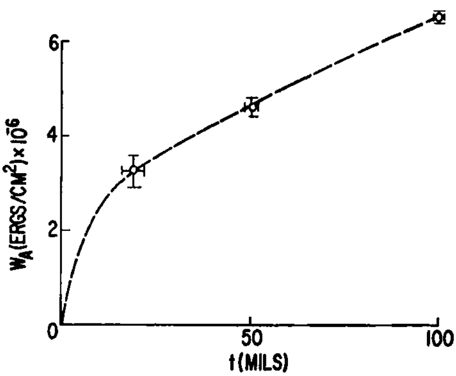

FIGURE 4 Work of adhesion as a function of thickness.

While the data is limited, it does point out the need for precisely defining the test geometry. This is analogous to the problem in determining the work of adhesion of a liquid–liquid boundary from surface and interfacial tension measurements because if the surfaces and interface are planar and the dimensions are finite, then

$$W_A \equiv \gamma_A + \gamma_B - \gamma_{AB}$$

where the γ's are surface tensions and γ_{AB} is the interfacial tension.[6] However, for molecular dimensions, corrections must be made.[7]

These findings raise several important questions of both practical and basic interest. First, if one measures the adhesion of a strip of plastic to a finite planar substrate can these data be extrapolated to small glass fibers in a polymer matrix? Second, can one by experimental and theoretical analysis separate the work of adhesion into terms such as an inter and/or intra molecular surface energy and a bulk strain energy arising from material contiguous to the plane of failure?

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Effect of Strain Rate

W_A reflects not only contributions from failure at the interface, but also the rheological behavior of the materials contiguous to the failure plane. W_A has been evaluated at several strain rates. The results are shown in Figure 5. The data, while limited, indicates that W_A is dependent upon strain rate.

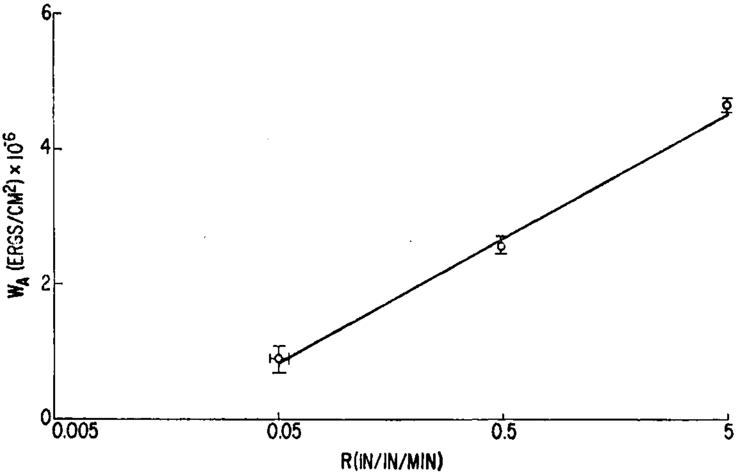

FIGURE 5 Work of adhesion as a function of strain rate where the sample was 0.050 inch thick and 0.50 inch wide.

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Discussion of Technique

It would appear that a simple modification of the 0° peel test can be used to obtain a well defined work of adhesion which reflects the effects of the rheological character of the interface, the geometry of the sample, and the interfacial failure plane. At this point, we believe that a more thorough analysis, both experimentally and theoretically, of this technique would provide a firm foundation for separating these various factors. Even with the limited data offered here, it is clear that the simplicity of the test and the interpretation of the results should aid in advancing our basic understanding of adhesion.

CONCLUSION

It has been shown that a well-defined work of adhesion between a flexible sample bonded to a rigid substrate, can be obtained from a zero degree peel type test. The values of W_A evaluated by this simple technique are shown to be dependent on sample geometry and on the rate of peeling. It is suggested that a similar procedure can be used in other peel tests, e.g. 90° and 180°.

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