

THE EFFECT OF ADHEREND STIFFNESS ON ADHESIVE BEHAVIOR

by

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INTRODUCTION

Many of the studies undertaken to improve adhesively bonded joints have focussed on modifying the polymeric adhesive itself or on changing the surface of the adherend, but none has been aimed at investigating the relative effects of material properties such as stiffness on the durability of the bonded structure. The reason for this apparent oversight is the difficulty of measuring factors that affect joint durability, such as load-bearing capacity and fracture toughness, especially in a way that correlates with joint performance.

We have obtained experimental results which suggest that the stiffness of an adherend may actually affect the load-bearing and fracture behavior of the adhesive in a bonded structure. We subject our samples to the standard single-specimen, unload compliance procedure commonly used in J integral testing, and analyze the data by an energy separation technique [1,2] that clearly distinguishes crack growth energies and allows calculation of a parameter, I, which is a distinct and sensitive measure of the plastic component of fracture resistance.

RESULTS

Table 1 shows some of our results for the elastic energy release rate G and the plastic energy dissipation rate, I, during fracture tests on neat adhesive and bonded aluminum (6061-T6) compact tension specimens; J is included for comparison and was calculated as defined by ASTM E 1152 [3]. All values listed (average of three tests) are for a crack extension of 0.030 in. (7.6mm). G and I were determined by the energy separation method except in the case of brittle fracture, where G was calculated from

$$G_q = K_q^2 / E(1-\nu^2)$$

where K_q is the stress intensity factor as calculated from ASTM E 399 [4]. Test results on the different neat adhesives varied widely, displaying considerable differences in load magnitudes at crack initiation as well as in plastic deformation.

Fracture characterization data indicate that, in general, bonded specimens are more stable and tougher than neat specimens. Figure 1 shows load versus load-line displacement plots for 1/2T CT plan neat and bonded test specimens identical in size, type, and adhesive. As can be seen, the stiffer bonded specimen undergoes considerably less load-line displacement than the neat specimen, and withstands over 3 times the load at crack initiation. Additionally, crack growth is considerably more stable for the bonded specimen; the bulk specimen in this case is completely brittle.

The value of G for bonded specimens is similar to, but slightly lower than, that for the neat specimens. Bondline failure is nearly always cohesive; when the bondline fails at the adhesive-adherend interface, the value of G drops substantially. I for the bonded specimens is routinely higher, consistent with their more stable crack growth.

DISCUSSION

The most probable explanation for the differences in behavior observed is the substantial difference in the stiffness of the two types of specimens. The aluminum adherends, which are quite stiff relative to the bondline adhesive, allow a more uniform rotation of the specimen during loading, and thus, a more uniform distribution of stress over the entire bondline. As a result, the concentration of stress at the crack tip is reduced, allowing the specimen to sustain a higher load. On the other hand, the more flexible neat specimen, as demonstrated by its greater load-line displacement, tends to "peel" apart; stresses are thus concentrated nearer the crack tip, which allows a smaller load to initiate crack growth. Greater material stiffness would thus appear to benefit a bonded joint by conferring higher load capacities without loss of fracture resistance.

CONCLUSIONS

Our bonded adhesive specimens sustained more than three times the load at crack initiation of our neat adhesive specimens, and consistently exhibited greater crack growth stability, even when the neat specimens showed brittle behavior. The energy separation method described here allows G to be measured directly from the test record, yielding values which correlate well with current theory. The parameter I , as derived with the energy separation method, provides a distinct and sensitive measure of the plastic component of fracture resistance.

REFERENCES

1. Mecklenburg, M.F., J. Joyce, and P. Albrecht, "Separation of Energies in Elastic-Plastic Fracture," to be published in ASTM STP, American Society for Testing and Materials.
2. Arah, C.O., J. Vogin, D. McNamara, J. Ahearn, A. Berrier, and G. Davis, "Moisture-Resistant Low-Temperature-Curing Adhesives," in Proc. 5th Joint Military-Government-Industry Symp. on Structural Adhesive Bonding, Picatinny Arsenal (ADPA, Washington DC, 1987), pp. 440-458.
3. ASTM E1152-87, American Society for Testing and Materials, Philadelphia, PA., 1987.
4. ASTM E399-83, American Society of Testing and Materials, Philadelphia, PA, 1983.

ACKNOWLEDGEMENT

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Table 1. Fracture Toughness Results on Neat Adhesive and Bonded Aluminum Compact Tension Specimen

Adhesive	G (in-lb/in ²)	I (in-lb/in ²)	J (in-lb/in ²)	Peak Load (lb)
1	3.7 (4.2) ^a	4.2 (19.8)	4.7 (4.5)	32 (149)
3	8.3 (8.3)	5.8 (12.4)	10.9 (7.1)	34 (138)
5	3.5 (3.5)	18.7 (11.9)	8.8 ^b (3.0)	14 (75)
14	11.0 (3.8)	0 (1.2)	11.0 ^b (2.1)	36 (131)
96	7.2 (4.0)	0 (2.7)	7.2 ^b (4.1)	31 (111)
98	7.9 (7.9)	0 (0)	7.9 ^b (7.9)	35 (111)
100	10.4 (8.2)	27.7 (40.0)	18.0 (11.0)	58 (214)

^a Values in parentheses are for bonded aluminum specimens

^b Specimen showed totally brittle behavior; G = J.

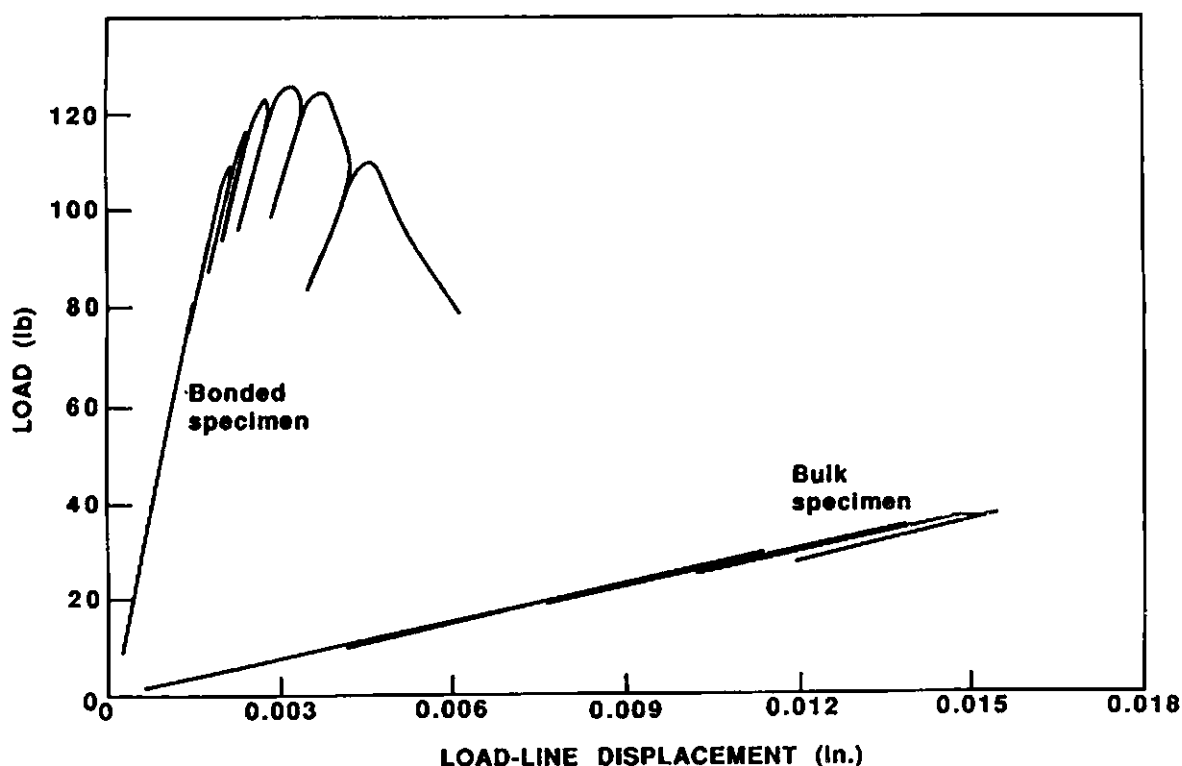


Figure 1. Comparison of the load versus load-line displacement records for bonded and neat adhesive 14 specimens.

1989 Feb 18-21 Heaster, Savannah 458/Ni.
1990 Feb 17-20 Belmont, Clearwater, Fla.
Adhesion Society (12th): 1989: Hilton Head Island, South 285 deluxe
Carolina, 65 traditional

ABSTRACTS:
TWELFTH ANNUAL MEETING
OF THE
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MARRIOTT'S HILTON HEAD RESORT
HILTON HEAD ISLAND, SOUTH CAROLINA
FEBRUARY 20-22, 1989

WEDNESDAY, FEBRUARY 22, 1989

SESSION: MECHANICS OF ADHESIVE BONDS

THIS SESSION IS DEDICATED TO THE MEMORY OF
DR. GARRON P. ANDERSON

SESSION CHAIRPERSON: DR. DON HUNSTON, NATIONAL INSTITUTE
OF STANDARDS AND TECHNOLOGY

8:15 AM Comments and Dedication

8:30 AM "Properties of the Interaction Region Between
Adherend and Adhesive - Degree of Adhesion"
A. H. Cardon
Free University of Brussels

9:00 AM "The Effect of Adherend Stiffness on Adhesive
Behavior"
C. O. Arah, D. K. McNamara, H. M. Hand, Martin
Marietta
M. F. Mecklenburg, The Smithsonian Institution

9:30 AM "Bonding and Debonding Processes in the Tack of
Pressure Sensitive Adhesives"
T. Tsukatani, Y. Hatano and H. Mizumachi
The University of Tokyo

10:00 AM "The Use of Imbedded Kynar Piezoelectric Film
to Measure Peel Stresses in Adhesive Joints"
G. L. Anderson, A. Raheem, A. Riad, R. C.
Robertson and D. A. Dillard
Virginia Polytechnic and State University

10:30 AM "Computational Chemistry: Adhesion of Aldehyde
Resins to Cellulose Crystal Surfaces"
W. E. Johns and A. K. Dunker
Washington State University

11:00 AM "Buckling Instability During 180° Peel
Adhesion"
G. Hamed and T. Tsauer
The University of Akron