Summary

The International Symposium on Adhesive Bonded Joints: Testing, Analysis, and Design was held in Baltimore, Maryland, on 10–12 September 1986. The symposium was sponsored by ASTM Committee D-14 on Adhesives. Twenty-five papers were presented at the symposium, with over one third of the speakers being from outside the United States. Twenty-one of the papers were passed through the peer review process and appear in this volume. The papers are organized into four sections: Mechanical Testing, Stress Analysis, Failure Mechanisms, and Design and Durability. The papers in each section are briefly summarized below.

Mechanical Testing

This section on testing contains eight papers. *Anderson et al.* presented an improved gripping technique that significantly reduces the data scatter and raises the strength values for tensile button testing. Essentially, the improved technique removes the eccentricity from the load train, which creates a more even stress distribution across the bond area. *Liechti and Hanson* measured crack opening displacements normal to the plane of an interface crack in a blister specimen using optical interferometry. Their test provided a range of mixed-mode fracture conditions free from complicating edge effects and could be used to define the limits of elastic and inelastic behavior. *Weissberg and Arcan* discussed the use of a newly proposed stiff adherend test specimen for adhesively bonded joints. This specimen is reported to produce a state of pure shear but also has the ability to test adhesive systems within a range of controlled mixed-mode loading. Some unique methods to obtain adhesive properties using the double-lap specimen are presented by *Gilibert et al.* They suggest using a series of strain gages, coupled with analysis, to determine the adhesive's mechanical properties.

Jangblad et al. presented a test method to determine the elastic modulus and Poisson's ratio for an adhesive *in situ.* They compared the *in situ* values to bulk specimen values. *Spingarn* used the chevron-notched specimen to determine the Mode I fracture toughness of a nylon-modified epoxy adhesive joint. He also investigated the effects of crack velocity, adhesive thickness, and temperature on the measured toughness values. *Dillard et al.* proposed several new specimen geometries to overcome certain limitations associated with currently available techniques for measuring the fracture toughness of elastomer to rigid adherend bonds. They discussed the blister test, strip blister test, and double cantilever sandwich beam. A new test specimen was introduced by *Groth* that gave a constant value of the stress intensity factor in Mode I under prescribed displacements loading conditions. The specimen is essentially a double-contoured cantilever beam.

Stress Analysis

Four papers are included in this section. *Post et al.* used high sensitivity moiré interferometry to develop displacement contour maps across the adherend and adhesive in a thick adherend joint. They determined the stress and strain distributions along the length of the joint as well as across the adhesive thickness. A detailed elastic finite element analysis of an aluminum double cantilever beam specimen was conducted by *Crews et al.* to determine the effects of adhesive thickness and specimen width on the stress state in the adhesive layer. Estimates for adhesive yielding at the crack tip showed that both the area and height of the plastic zone increased to a peak value for increasing adhesive thicknesses. *Aivazzadeh et al.* presented various special triangular mixed finite elements for the static analysis of adhesive joints. The results obtained from the interface finite elements show that the stress distribution could be evaluated more accurately using these elements. *Gilibert and Rigolot* introduce a new approach for analyzing the stress distribution in double lap joints by using matched asymptotic expansions and conformal mapping. Experimentally they used rather thin joints with electrical strain gages.

Failure Mechanisms

Three papers are contained in this section. *Ripling et al.* use a tapered double cantilever beam specimen to obtain pure Mode I and mixed Mode I-III toughness and debond growth rate properties. They found that different scrim cloth materials can significantly influence the fracture and debond growth behavior for different loading modes. They also found some interesting frequency-humidity effects. *Ziane and Coddet* tested double cantilever beam specimens made of galvanized steel adherends and epoxy adhesives. They showed the independence of the strain energy release rate and of the *R*-curves with respect to debond length. They also used acoustic emission to determine the onset of debonding. The debonding characteristics of woven Kevlar adherends was discussed by *Mall and Johnson.* Their tests, using cracked lap shear specimens, showed that fiber bridging of the Kevlar fabric on the crest of the adherend-adhesive interface significantly increased the fracture toughness of the joint and lowered the cyclic debond growth rate.

Design and Durability

Six papers are contained in the Design and Durability section. *Bigelow* presented design considerations for cracked panels stiffened by bonded stringers. She calculated stress intensity factors for the crack in the panel at various locations and crack lengths relative to the stiffener. Debonding of the adhesive layer is also addressed. *Albrecht and Sahli* showed the advantages that might be realized if steel bridge joints were bonded and bolted rather than bolted alone. The bonding resulted in significantly higher static strength values. They also addressed different preparations of the steel surface for bonding. *Miller et al.* used a tube and socket joint to verify their bonded joint design procedures. They evaluated the adhesive shear behavior and the effects of overlap length and adhesive thickness on tensile failures. Both closed form and finite element analysis were used in this paper.

Krieger presented a summation of his work in creating a valid stress analysis of adhesively bonded structure. The focus was on the design of airframe construction, specifically metal-to-metal bonds. The last two papers address the important issue of environmental effects on adhesive joint behavior. Environmental effects on the fracture of adhesively bonded joints were addressed by *Jurf.* He used the thick adherend specimen to assess the time-temperature-moisture effects. The finite element technique was used to calculate the strain energy release rates. *Pitrone and Brown* experimentally assessed the environmental durability of adhesively bonded joints. They correlated thermal analysis of bulk adhesives, both before and after hygrothermal exposure, with bonded joint mechanical and durability performance.

Summary

It is obvious from the large number of new and unique specimens proposed in this volume that the type of information being sought to understand adhesive joint behavior is not currently covered by today's standard test specimens. Many of the papers discussed sophisticated finite element analysis used to accurately determine stress distributions in the bonded joint and related strain energy release rate data to quantify toughness and correlate debond propagation rates. This type of detailed analysis has only been possible in recent years due to advances in computer technology. This detailed computation of the stress state in the adhesive layer has greatly increased our understanding of the adhesive failure process and will add confidence and reliability to the design process of bonded structures. The need for this type of understanding of bonded joint behavior will become even greater in the future as more advanced aircraft, spacecraft, and missile structures rely on adhesives to join critical components.

In closing, I would like to thank my session chairmen—Dick Everett, Jr., of the Army Aerostructures Laboratory, NASA Langley Research Center; Hal Brinson of Virginia Tech; Ken Liechti of the University of Texas at Austin; Ed Ripling of the Materials Research Laboratory; and Larry Peebles, Jr., of the Office of Naval Research—for their help in planning and conducting the symposium. Grateful appreciation is also extended to the authors, the reviewers, and the ASTM staff, without whom this publication would not have been possible.

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