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THE EFFECT OF SUBSTRATE MATERIAL ON THE QUASI-STATIC MEASUREMENT OF CRITICAL ENERGY RELEASE RATE IN ADHESIVE JOINTS

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Introduction

An engineering approach to fracture load predictions for adhesive joints was presented in Refs. [1] and [2]. The concept of the adhesive sandwich, where the bonded overlap is isolated from the surrounding structure as a free body, makes this approach applicable to a variety of joints including more practical joints like single-lap-shear (SLS) and cracked-lap-shear (CLS) joints. The dependence of the critical energy release rate (G_c) on the mode ratio, known as the fracture envelope, is experimentally determined over a range of mode ratios using quasi-static fracture tests on double-cantilever-beam (DCB) specimens. The joint failure will occur by crack propagation in the bondline whenever the calculated energy release rate (G) in the practical joint exceeds G_c from the fracture envelope at the corresponding mode ratio. The test results showed a good agreement with the model for aluminum adherends.

Recent results of quasi-static fracture tests on DCB specimens made of aluminum and steel revealed that G_c appeared to depend on the substrate material and the thickness of the adherends. Bell and Kinloch [5] found the highest values of G_c associated with joints having stiffer adherends; however, Yan *et al.* [6] reported that G_c was lower for stiffer substrates. These observations were attributed to changes in the stress field ahead of the crack [5] and the degree of triaxiality of the stress state [6].

In this report, G_c was measured on aluminum and steel DCB joints at different mode ratios. The results were consistent with Ref. [6] and the analysis of Ref. [7].

Experiments and Analysis

The DCB specimens were fabricated from aluminum 6061-T651, aluminum 7075-T651 and steel AISI 4140 flat bars (thickness 12.7 mm) bonded with a 0.4 mm thick layer of toughened epoxy adhesive. The aluminum parts were abraded, degreased and then surface pretreated while the steel parts were only abraded and degreased prior to bonding. Cohesive fracture through the adhesive layer was observed in all the cases, so the value of G_c was not affected by interfacial debonding. The adherends remained elastic. The specimens then were tested using the load jig of Ref. [3] at different mode ratios under displacement control. More details on sample preparation and test procedure can be found in Refs. [1] - [4].

The typical R-curves of these DCB samples are shown in Fig. 1. The tests were conducted at a constant crosshead speed (CHS) of 1.5 mm/min where the load was gradually increased to the point of fracture. The maximum difference in measured values of G_c (30%) was observed for these adhesive systems under mode I loading. The slope of the rising part of the R-curve reflects the crack propagation distance required to establish a fully developed damage zone. Hence, the development of the damage zone was faster in the aluminum DCB specimens.

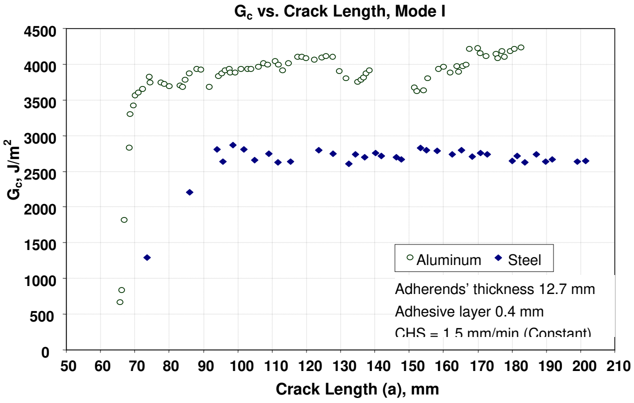

Figure 1. R-curves measured for aluminum and steel DCBs in quasi-static tests.

A second series of G_c measurements were made with DCBs having different adherend materials but the same flexural rigidity. For a phase angle of 16°, the 18 mm thick steel and 12.7 mm thick aluminum specimens were tested at identical strain rates. Figure 2 shows that G_c in this case was independent of material.

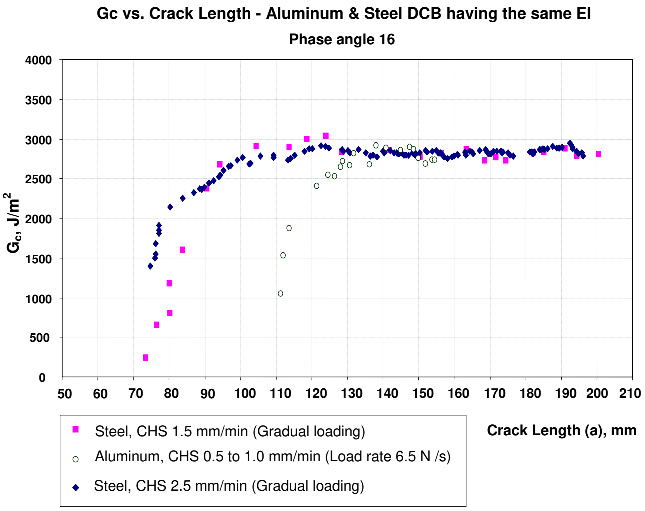

Figure 2. Aluminum and steel DCB tests having similar rigidity tested at similar strain rates.

Strain rate in adhesive layer: It was observed that the crack would grow with different velocities depending on the flexural rigidity of the bonded adherends. To evaluate the difference in strain rate around the crack-tip, aluminum and steel DCB specimens having the flexural rigidities of 12,200 and 35,000 N.m, respectively, were modeled using finite element analysis (FEA). A typical result is shown in Fig. 3 for the phase angle of 0° (mode I) and 51° with a crosshead speed of 1.5 mm/min. In this case, the adhesive layer of the stiffer steel DCB experiences twice the von-Mises strain rate of the aluminum specimen. Mode I strain rates are greater than those at 51° for both steel and aluminum.

Based on the FEA results, another experiment was conducted to evaluate the effects of different crack velocities on G_c for steel DCB specimens. For some of the tests, the crosshead speed was maintained constant, while for others a variable crosshead speed was applied to keep the load rate constant over a range of crack lengths. The results (Fig. 4) revealed a significant dependency of G_c on the adhesive strain rate.

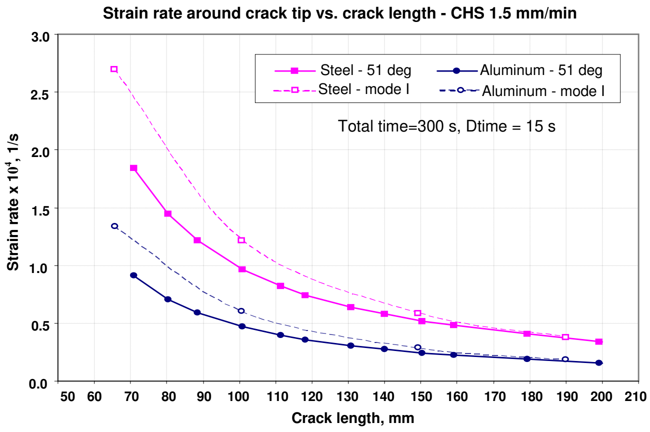

Figure 3. Von-Mises strain rate in the adhesive layer of DCBs under mode I and at a phase angle of 51°.

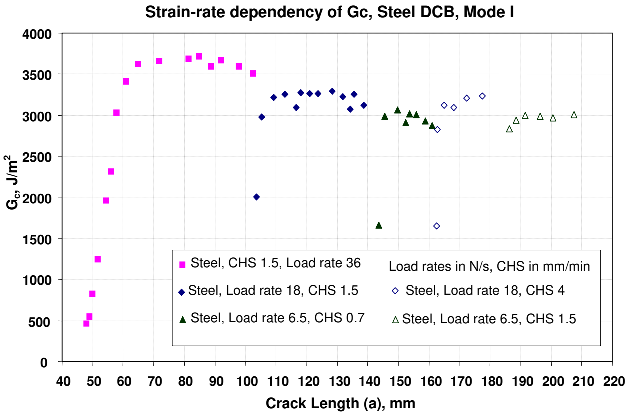

Figure 4. Strain-rate dependency of G_c measured with steel DCBs

Mode ratio: The differences in G_c of aluminum and steel DCBs decreased at higher phase angles (Fig. 5).

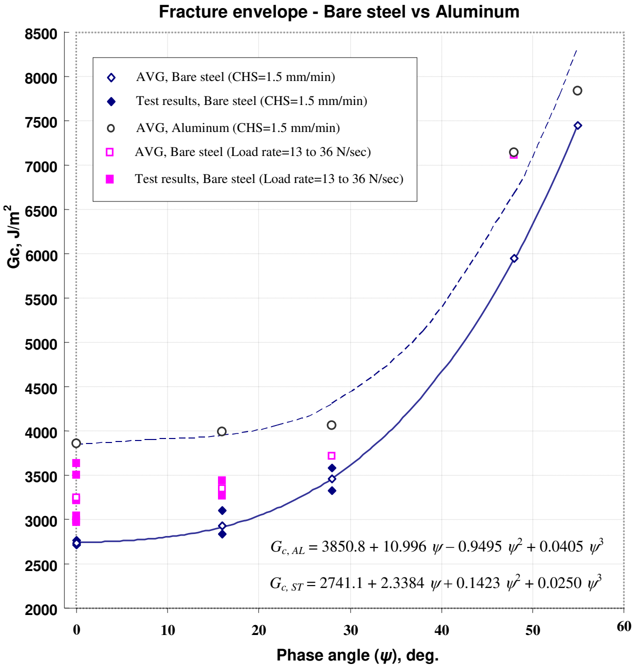

Figure 5. Fracture envelopes obtained from the quasi-static tests on aluminum and steel DCB specimens

Stress field and plastic zone: The stress field and the size of the plastic zone ahead of the crack depend on the joint geometry [5]. The FE models revealed that the stresses in the adhesive layer bounded by the stiffer adherends are more elevated. This could be the cause of the longer damage zone in steel DCB specimens (Fig. 1).

Degree of triaxiality of the stress state: 3D FE models have been constructed to help understand the influence of constraint in the adhesive layer of DCBs made with steel and aluminum.

Conclusion

The adherend thickness and its stiffness affect the stress field, plastic zone, degree of constraint, and strain rate in the adhesive layer of DCBs during fracture tests.

Acknowledgements

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