DCB TEST FOR THE INTERLAMINAR FRACTURE TOUGHNESS OF COMPOSITES

Anthony J. Paris[1] and **Joshua D. Gunderson[2]**

(1) Mechanical Engineering, University of Alaska Anchorage, Anchorage, AK 99508
(2) Mechanical and Biomedical Engineering, Boise State University, Boise, ID 83725

Introduction

The most widely used method of determining mode I interlaminar fracture toughness of a composite material is the double cantilever beam (DCB) test [1-4]. The method is based in linear-elastic fracture mechanics theory [5-9] and calculates G_I using the crack length as well as the applied load, load point displacement, and initial specimen width.
Rice [10] exhibited the *J*-integral. Begley and Landes [11] demonstrated an experimental method to evaluate J_I and discussed both numerical and analytical solutions to the *J*-integral. It has been shown that the *J*-integral and the use of the critical value J_{IC} as a fracture criterion are broadly applicable to geometric and material nonlinear behavior.
An analytical closed form solution of the *J*-integral for the DCB test with small displacements and rotations was presented by Paris et al. [12], where it was shown to require only two parameters, the applied load and the beam angle, in addition to the initial specimen width. Nilsson [13] presented a *J*-integral analysis of the DCB test that is applicable to a more -generalized loading condition. Gunderson et al. [14] showed that for small displacements and rotations of the loading points the *J*-integral produces experimental results similar to the Griffith method. Motivation for using the *J*-integral for the DCB test comes from the problematic cost, accuracy, and rate of acquisition inherent in crack length measurement, as well as the desire to use a more robust method based in elastic-plastic fracture mechanics theory. The present work will apply the large displacement J_I theory and verify the theory experimentally.

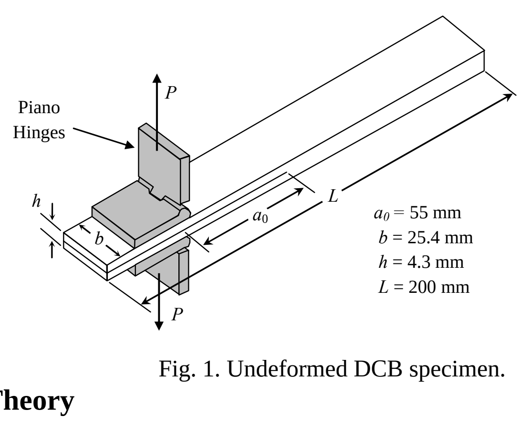

Fig. 1. Undeformed DCB specimen.

Theory

Fig. 1 shows the undeformed DCB specimen where a_0 is the original crack length, b is the specimen width, h is the thickness of the specimen, L is total length, and P is the applied load. Fig. 2 shows the deformed DCB specimen with the test parameters including the applied load P, the load point displacement δ and the opening angle θ.

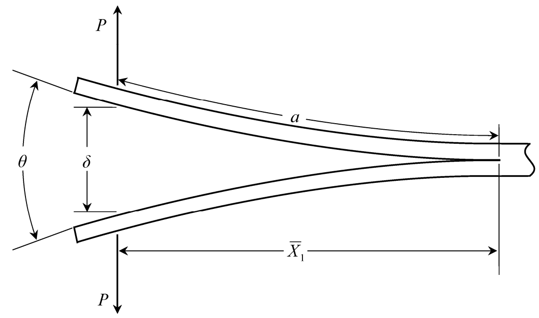

Fig. 2. Deformed DCB specimen.

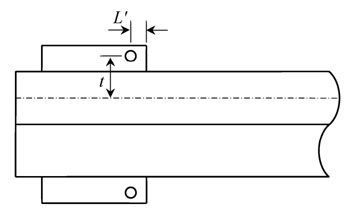

Fig. 3. End block correction factor parameters.

Energy Release Rate G. The recommended large displacement energy release rate G equation [1] is

$$G_I = \frac{3P\delta}{2b\left(a+\left|\Delta_{\mathrm{cor}}\right|\right)}\frac{F}{N},$$

where the compliance offset Δ_{cor} is found by plotting the delamination length vs. the cube root of compliance C, where $C^{1/3} = \left(\delta/PN\right)^{1/3}$, and finding the value at which a least squares fit line intersects the ordinate. Fig. 3 shows the geometry of DCB end blocks, where L' is the distance in the axial direction from the center of the loading pin to edge of the loading block and t is distance in the transverse direction from the beam middle surface to the center of the loading pin. The two correction factors are

$$F = 1-\frac{3}{10}\left(\frac{\delta}{a}\right)^2-\frac{3}{2}\left(\frac{\delta t}{a^2}\right)$$

$$N = 1-\left(\frac{L'}{a}\right)^3-\frac{9}{8}\left[1-\left(\frac{L'}{a}\right)^2\right]\left(\frac{\delta t}{a^2}\right)-\frac{9}{35}\left(\frac{\delta}{a}\right)^2.$$

An alternate method for calculating G_I is the compliance method [1, 4] which yields

$$G = \frac{P^2}{2b}\frac{\mathrm{d}C}{\mathrm{d}a}, \quad \text{where the compliance } C = \delta/P.$$

J-integral. The *J*-integral [10, 11], when applied to the large displacement DCB specimen [12-14], yields

$$J_I = \frac{2P}{b}\sin(\theta/2).$$

Experiment

The object of the experiment was to compare G_{IC} and J_{IC} results for five identical specimens where displacements are considered large. The specimens were prepared in accordance with the specifications in the standard (ASTM D5528-01). The composite material was LTM24ST on 7725 glass manufactured using an autoclave process with a curing temperature of 79.4 °C. DCB specimens were tested in tension at a rate of 5 mm/min, transducers measured the beam angle, applied load, and load point displacement, and digital video recorded crack length.

Results

Fig. 4 shows G and J vs. delamination length for specimen 5. The average values of G_{IC} and J_{IC} were $0.740\,\mathrm{kJ/m^2} \pm 0.0358\,\mathrm{kJ/m^2}$ and $0.743\,\mathrm{kJ/m^2} \pm 0.0367\,\mathrm{kJ/m^2}$. The average difference between G_{IC} and J_{IC} was $0.45\% \pm 0.645\%$. No significant r-curve effect was observed. The results for both G_{IC} and J_{IC} agree well with the compliance method. It was found for the series of tests that the average value of G_{IC} was $0.696\,\mathrm{kJ/m^2} \pm 0.0285\,\mathrm{kJ/m^2}$ and for J_{IC} was $0.706\,\mathrm{kJ/m^2} \pm 0.0253\,\mathrm{kJ/m^2}$. The average difference between G_{IC} and J_{IC} was $1.44\% \pm 0.679\%$. These standard deviations compare favorably with those given in the standard [1] as being typical. Furthermore, these values indicate that the variance between specimens, while relatively small, is still greater than the variance between G_{IC} and J_{IC}.

Conclusions

A large displacement DCB interlaminar fracture toughness test using the J-integral was developed and compared with the ASTM standard method. The J-integral method removes the need to acquire visual measurements of the delamination length and avoids problems associated with locating the crack tip and crack tunneling. Also avoided are the correction factors which account for deviation from linear beam theory including geometric nonlinearity associated with large deformation and root rotation. As a corollary, costly equipment such as a traveling microscope and the software required to automate it are replaced with inexpensive transducers. The J-integral large displacement DCB method allows for an instantaneous calculation of J_I applicable to a variety of material systems and is able to accommodate significant plasticity at the crack tip provided that a contour may pass through material experiencing only elastic deformation. Perhaps most importantly, the method reduces the time and cost of interlaminar fracture toughness testing while the five tests carried out in the present work show no significant difference between the results.

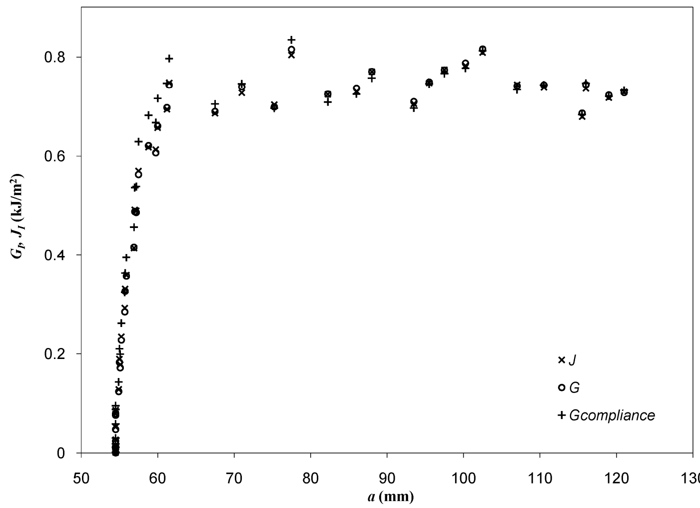

Fig.4. G and J vs. delamination length for specimen 5.

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