MIXED MODE I/II EXPERIMENTS USING CTS SPECIMENS AND DEVELOPMENT OF A FRACTURE CRITERIA FOR CFRP LAMINATES

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The main disadvantage of composite materials is their tendency to delaminate. Delamination, or interlaminar separation, is the most predominant and life-limiting failure mechanism in composite structures. Delaminations may develop during manufacturing as a result of non-optimal curing or the introduction of foreign objects. It may also result from impact damage, or from the three-dimensional interlaminar stresses that develop at stress-free edges of discontinuities. Even in the absence of such discontinuities, delamination can result from the applied compressive loading, which may cause local or global buckling and also produce internal transverse tensile and shear stresses that can cause delamination. The main problem of predicting the failure of laminated composite materials is the evaluation of interlaminar fracture toughness properties under mixed mode loading conditions.

In real loading conditions, it is unlikely that pure mode I or mode II conditions will occur. Therefore, it is important to know how the fracture toughness changes as the loading changes from pure mode I to pure mode II loading conditions. Mixed mode I/II tests are characterized by the ratio $G_{\mathrm{I}}/G_{\mathrm{II}}$, which drives the crack. Various mixed mode ratios $G_{\mathrm{I}}/G_{\mathrm{II}}$ can be obtained by using different, such as mixed mode flexure (MMF), end loaded split (ELS), single leg bending (SLB), and crack lap shear (CLS) test specimens. The most recent development is the proposed compound version of the compact tension shear (CTS) specimen which cover all in-plane mixed mode loading conditions starting from the pure mode I through any mixed mode I/II ratio up to the pure mode II loading.

In the present work, a compound version of the CTS specimen is used for the mode I, mixed mode I/II and mode II studies of the interlaminar fracture toughness properties of unidirectionally reinforced carbon/epoxy laminates. The material is assumed to be transversely isotropic. For calculation of the energy release rates G_{I} and G_{II}, a modified integral virtual crack closure method is utilized so that the separated strain energy release rates are obtained by only one calculation for the actual crack length. The finite element model of the specimen consists of quadrilateral plane strain elements with 4 nodal points. The plain strain conditions are used in the finite element analysis.

A mixed mode I/II fracture criterion based on the energy release rates is employed:

$$\left(\frac{G_{\mathrm{I}}}{G_{\mathrm{I}C}}\right)^{m}+\left(\frac{G_{\mathrm{II}}}{G_{\mathrm{II}C}}\right)^{n}=1.$$

By using the mixed mode experimental results, the finite element analysis, and the least squares technique, the critical energy release rates G_{IC} and G_{IIC} are obtained for the fracture criterion. It is found that the best fit criterion for the material investigated is a linear criterion, i.e., with exponents $m = 1$ and $n = 1$.

Reference

1. R. Rikards, F. G. Buchholz, H. Wang, A. K. Bledzki, A. Korjakin, and H. A. Richard, "Investigation of mixed mode I/II interlaminar fracture toughness of laminated composites by using a CTS type specimen," Eng. Fract. Mech., **61**, No. 3/4, 325-342 (1998).