THE INFLUENCE OF EMBEDDED OPTICAL FIBERS ON THE INTERLAMINA FRACTURE TOUGHNESS OF COMPOSITE MATERIALS

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INTRODUCTION

Smart Structure Technology involving structurally integrated fiber optic reticulate sensor (SIFORS) systems could make obsolete the catastropic failures that have plagued aircraft, trains, cars ......to date, [1]. The introduction of structurally integrated fiber optic damage assessment systems would permit structural integrity of a component to be monitored throughout its life. During manufacture and installation these built-in sensors would check for flaws or mishandling and therefore provide quality control. Internal damage generated by: impacts, manufacturing flaws, excessive loading or fatigue could be detected and assessed and growth of these damage zones also monitored.

Fracture of optical fibers embedded within composite materials, with the attendant disruption in their transmitted light, represents the simplest technique for damage detection. We have recently laid much of the ground work for the development of this fiber optic damage assessment technology, [2,3].

An important issue in the development of this technology concerns the influence of the optical fibers on the properties of the structures within which they are imbedded. In particular, how do they affect the interlamina fracture toughness . This question is addressed in this paper. We have also attempted to answer the question: do embedded optical fibers act as crack initiators or terminators. These results will shortly be published.

EXPERIMENTAL TECHNIQUE

Delamination of composite laminates can involve three modes of fracture. In reality, however, Mode I is the most important, see figure 1, and this initial study of the influence of the embedded optical fibers on the toughness of the composite material was restricted to Mode I fracture.

This investigation used the standard double cantilever beam (DCB) for evaluating the materials toughness against Mode I failure. The specimens were made of Kevlar/epoxy [Fiberite HY-E17714AA/4560 unidirectional prepreg tape] and consisted

Review of Progress in Quantitative Nondestructive Evaluation, Vol. 9
Edited by D.O. Thompson and D.E. Chimenti
Plenum Press, New York, 1990

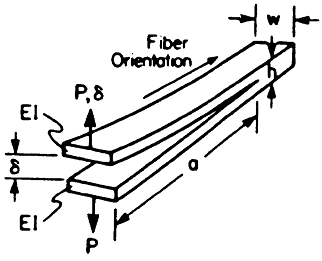

Figure 1. Schematic of Mode I delamination test (Ref. 4).

of 2.5 cm by 25 cm coupons with a folded layer of thin aluminium film included at one end to initiate a delamination.

Two groups of specimen were prepared in configurations $[0_8/0_8]$ and $[0_2/90/0_5/90/0_5/90/0_2]$. A number of the samples had optical fibers imbedded in either the 0, 45 or 90 degree orientation between the mid plane 0 plies of the $[0_8/0_8]$ configuration as indicated by the position of the curly brackets: $[0_8\{x\}0_8]$ where x can be either 0, 45 or 90 degrees.

In a similar manner a number of the samples of the other configuration had optical fibers imbedded between the mid plane [...0/90...] plies with the same three possible orientations, these can be designated $[0_2/90/0_5\{x\}90/0_5/90/0_2]$ where x is again either 0, 45 or 90 degrees. For both configurations the samples, with the imbedded optical fibers and the control samples without optical fibers, were cut from the same plate in order to avoid variability associated with curing differences.

The compliance "C", defined by the relation:

$$C = \partial/P \tag{1}$$

where "∂" is the displacement (or separation) of the cantilever beams and "P" is the applied load. From elastic beam theory the compliance of the DCB specimen is obtained is given by the expression:

$$C = 2a^3/[3EI] \tag{2}$$

where "a" is the crack length and "EI" is the flexural rigidity of each beam of the specimen. "E" being Young's Modulus and "I" the moment of inertia of each beam. The energy release rate, [4], can be written in the form:

$$G = \{P^2/2w\}[dC/da] \tag{3}$$

where "P" is the applied load and "w" is the width of the specimen. Equations (1) and (2) give:

$$G = P^2a^2 / [wEI] \tag{4}$$

and the critical energy release rate, "G_c", is defined as the energy release rate corresponding to the critical value of the applied load, ($P = P_c$) for a crack length of 100 mm and can be written in the form:

$$G_c = P_c(a=100mm)^2(a=100mm)^2/[wEI] \tag{5}$$

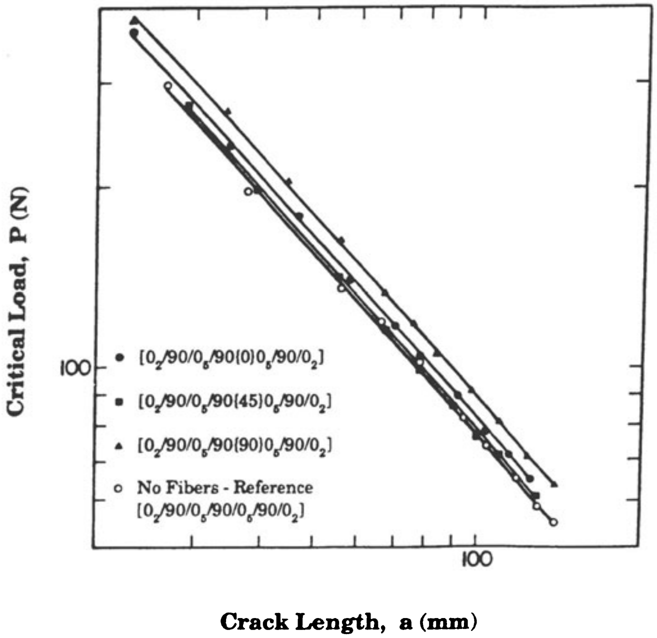

Figure 2(a) Variation of the Critical Load versus Crack Length for $[O_2/90/O_5\{x\}90/O_5/90/O_2]$ Kevlar/Epoxy Composite, with x = 0, 45 or 90 degrees.

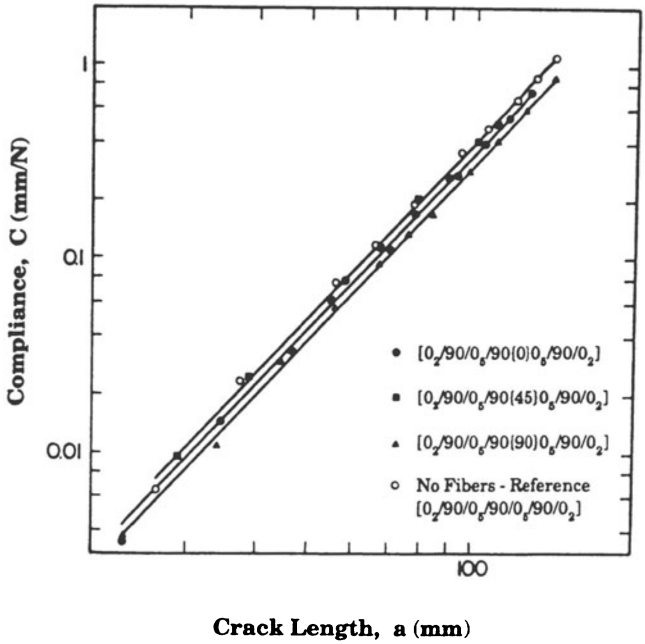

Figure 2(b) Variation of the Compliance versus Crack Length for $[O_2/90/O_5\{x\}90/O_5/90/O_2]$ Kevlar/Epoxy Composite, with x = 0, 45 or 90 degrees.

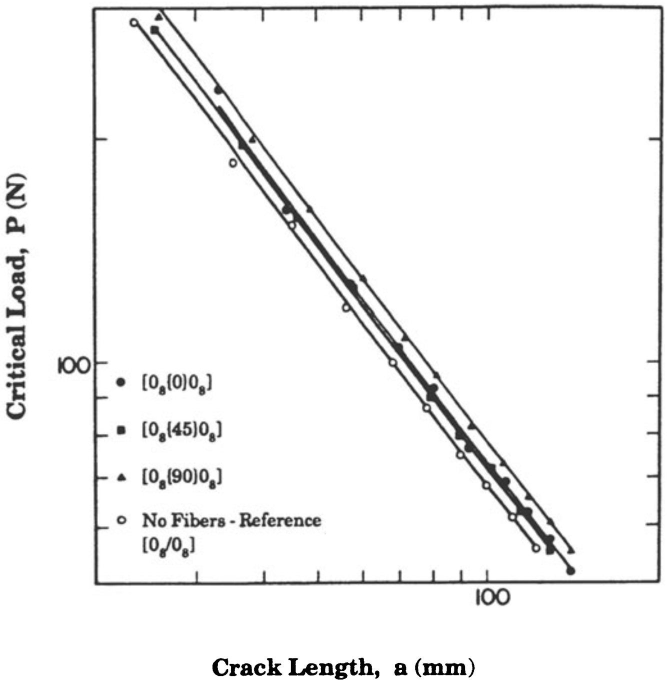

Figure 3(a) Variation of the Critical Load versus Crack Length for [O8{x}O8] Kevlar/Epoxy Composite, with x = 0, 45 or 90 degrees.

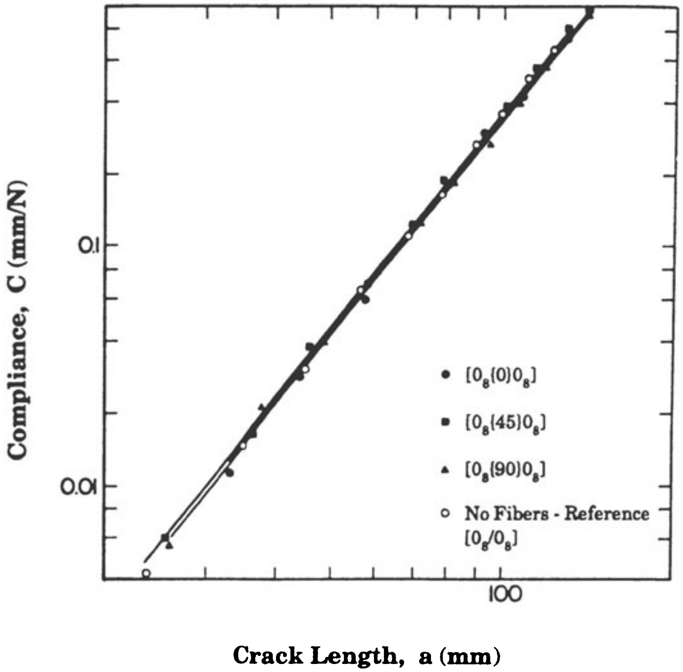

Figure 3(b) Variation of the Compliance versus Crack Length for [O8{x}O8] Kevlar/Epoxy Composite, with x = 0, 45 or 90 degrees.

Table 1. Critical Energy Release Rate, G_c (100 mm), for Kevlar/Epoxy panel samples with and without Embedded Optical Fibers.

Composite Sample Configuration	**Critical Energy Release Rate, G_c**
Reference Sample with No Optical Fibers $[0_8/0_8]$	1.09 (KJ/m^2)
$[0_8\{0\}0_8]$	1.12 (KJ/m^2)
$[0_8\{45\}0_8]$	1.14 (KJ/m^2)
$[0_8\{90\}0_8]$	1.24 (KJ/m^2)
Reference Sample with No Optical Fibers $[0_2/90/0_5/90/0_5/90/0_2]$	1.43 (KJ/m^2)
$[0_2/90/0_5\{0\}90/0_5/90/0_2]$	1.44 (KJ/m^2)
$[0_2/90/0_5\{45\}90/0_5/90/0_2]$	1.46 (KJ/m^2)
$[0_2/90/0_5\{90\}90/0_5/90/0_2]$	1.48 (KJ/m^2)

During the tests the displacement "∂" was measured at the loading line by means of an extensometer and the crack length "a" was measured from the loading line to the current crack tip by means of a precision dial calliper. The load was applied by an Tinius-Olsen machine with a direct reading of the load. The values of "P_c" for a crack length of 100 mm were derived by extrapolation.

EXPERIMENTAL RESULTS

The variation of the compliance "C" with the crack length "a" and the variation in the critical load "P_c" with the crack length "a" for both $[0_2/90/0_5\{x\}90/0_5/90/0_2]$ and $[0_8\{x\}0_8]$ configurations are presented as figures 2 and 3, respectively .

The values for the critical energy release rate, "G_c" obtained in the manner described above are presented in Table 1, for the different configurations and optical fiber orientations. It can be seen that the critical energy release rates was never reduced by the presence of imbedded optical fibers.

Indeed, in the case of 90 degree optical fiber orientation in the $[0_8/0_8]$ Kevlar/epoxy layup, i.e., $[0_8\{90\}0_8]$ the "G_c" was increased by nearly 15%. Since the critical energy release rate is a material property which reflects the ability of a material to resist crack propagation, these results strongly suggest that the presence of imbedded optical fibers actually toughen the composite material against Mode I delamination propagation.

CONCLUSIONS

An initial investigation of the influence of embedded optical fibers upon the damage resistance of Kevlar/epoxy has been undertaken. Measurements of the critical energy release rate in double cantilever beam experiments clearly indicate an increase in the material's resistance to Mode I delaminations when the optical fibers are placed in the same plane as the disbonding front. In effect the presence of embedded optical fibers appear to enhance the interlamina fracture toughness of the composite.

Although much work remains to be done, especially in terms of checking the influence of the embedded optical fibers upon the fatigue characteristics of the material, the present results are encouraging as no detrimental effects are apparent for Kevlar/epoxy.

ACKNOWLEDGEMENTS

This work was supported by the Natural Science and Engineering Research Council of Canada and the Ontario Laser and Lightwave Research Centre.

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