Interlaminar Fracture Toughness of Graphite/Epoxy Composite Under Mixed-mode Deformations

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ABSTRACT—An antisymmetric test fixture is employed to investigate interlaminar fracture behavior in graphite/epoxy composite material under mixed-mode deformations. Finite correction factors for the graphite/epoxy fracture specimen with various crack lengths are used to determine the interlaminar fracture toughness by finite-element stress analysis. Interlaminar fracture characteristics of graphite/epoxy composite material under mode-I, mode-II and mixed-mode deformations are evaluated experimentally. A mixed-mode fracture criterion is also investigated to obtain information on mixed-mode interlaminar fracture behavior of graphite/epoxy composite material.

Introduction

Interlaminar fracture toughness of composite materials is one of the important properties for design since interlaminar fracture is the primary damage mode and is often observed in laminated composite materials. To identify fracture phenomena due to interlaminar defects, interlaminar fracture toughness, which is characterized by stress-intensity factors at fracture or energy release rates at fracture, is investigated. For a given interlaminar flaw, interlaminar crack propagation may be developed under mode-I, mode-II and/or mixed-mode deformations. Extensive research has been conducted on the mode-I and mode-II interlaminar fracture behavior of composite materials. A double-cantilever-beam (DCB) specimen has been utilized for mode-I interlaminar fracture tests. For mode-II interlaminar fracture tests, an end-notched-flexure (ENF) specimen has been employed. Although several testing methods for a mixed-mode fracture have been proposed in the literature, each method has limitations and advantages in determining interlaminar fracture toughness of laminated composite materials. Most of the mixed-mode tests suggested to date have been performed by using an off-axis unidirectional coupon specimen with a crack parallel to fiber direction. This type of specimen is suitable only for intralaminar fracture toughness and suffers from some limitations. To increase the ratio of mode II to mode I, it require very small angles between the loading and fiber direction. A cracked-lap-shear (CLS) specimen has been adopted for mixed-mode interlaminar fracture test. This type of specimen gives only a fixed contribution to the total strain energy release rate from mode-I component. Therefore, other testing methods of a mixed-mode fracture are still tried in efforts to develop a reliable method for interlaminar fracture under mixed-mode deformations. Recently, a newly developed fracture specimen was suggested for measuring the mode-II fracture toughness of isotropic materials. It is a modification of an antisymmetric test specimen for the measurement of the shear property. It was further adopted to the study of interlaminar fracture behavior in composite materials. Jurf and Pipesi investigated interlaminar fracture characteristics for AS1/3501-6 graphite/epoxy composite material under mode-I, mode-II and mixed-mode deformations. They conducted the mixed-mode fracture tests for only two loading angles to examine a mixed-mode fracture criterion. It was not clear whether finite correction factors for the composite fracture specimens were used to evaluate the interlaminar fracture toughness of graphite/epoxy composite materials. As the use of finite correction factors for isotropic fracture specimen may lead to incorrect interlaminar fracture toughness for orthotropic materials, accurate finite correction factors for fracture specimens should be used to evaluate interlaminar fracture toughness of graphite/epoxy composite materials.

The aim of the present study is to investigate the interlaminar fracture behavior of graphite/epoxy composite material under mixed-mode deformations. As shown in Fig. 1, an edge-cracked fracture specimen of graphite/epoxy composite material is used in these experiments. Since finite correction factors for orthotropic composite fracture specimen are not available in the literature, finite correction factors for an edge-cracked specimen, which are used to determine stress-intensity factors at fracture, are determined for various crack lengths. Interlaminar fracture toughness is evaluated by measuring stress-intensity factors at fracture under various loading angles. The mixed-mode interlaminar fracture criterion is also investigated to obtain information on mixed-mode fracture behavior of graphite/epoxy composite material.

Numerical Analysis for Finite Correction Factors

To assess interlaminar fracture toughness of laminated composite materials experimentally, it is necessary to deter-