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Mode II fracture testing of composites: a new look at an old problem

B.R.K. Blackman [a,*], A.J. Brunner [b], J.G. Williams [a]

[a] Department of Mechanical Engineering, Imperial College London, South Kensington Campus, London SW7 2BX, UK
[b] Materials and Engineering, Empa, Swiss Federal Laboratories for Materials Testing and Research, CH-8600, Dübendorf, Switzerland

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Abstract

A number of technical issues have slowed the progress towards an agreed mode II test protocol for composite laminates and perhaps the most important of these has concerned the difficulty in measuring crack length during the test. In this paper, we extend a previous analysis which was developed for mode I delamination cases where significant bridging and micro-cracking occurred. The approach utilises an effective crack length and if successful, may eliminate the need to measure this parameter experimentally. To accommodate the new approach, an existing test protocol based on the end-loaded split (ELS) method has been revised and some data measured using the scheme is presented. This includes some initial results measured in a round-robin activity co-ordinated by a technical committee of the European Structural Integrity Society (ESIS). A number of materials are examined with a view to determining the utility of the 'crack length independent' approach.

Keywords: Composite; Mode II; Effective crack length

1. Introduction

Whilst the mode I delamination test method for composites based on the double cantilever beam (DCB) test has progressed to an international standard [1], there has been little progress in recent years towards the goal of a mode II delamination standard. This is perhaps a little surprising following the extensive evaluation of the competing test methods that was conducted in 1997 as part of the collaborative international round-robin co-ordinated by VAMAS (Versailles Project on Advanced Materials and Standards). The round-robin activity set out to evaluate the reproducibility of the end-notched flexure (ENF) test, the stabilised ENF test proposed by the Japanese Industrial Standards (JIS) group and the end-loaded split (ELS) test.

* Corresponding author. Tel.: +44 (0)20 7594 7196; fax: +44 (0)20 7594 7017.
E-mail address: b.blackman@imperial.ac.uk (B.R.K. Blackman).

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At about the time of the round-robin, a fourth test was proposed by Martin and Davidson [2], based on a four-point loaded variant of the ENF test. This test was included in the second phase of the VAMAS round-robin and the main results of this round-robin programme were published in 1999 [3]. The four test methods are shown schematically in Fig. 1.

The original ENF test, which uses three point loading, has the disadvantage that it is unstable, and yields only initiation values of G_{IIC}. For this reason, it is not widely considered as suitable for an international standard, but is being pursued as an initiation test by the American Society for Testing and Materials (ASTM). The stabilised ENF test requires the crack shear displacement to be measured, and this value is then used to control the real-time loading of the test specimen (by feeding the signal into the hydraulic control system of the testing machine). It was considered that this test procedure was probably too complex for an international standard. Thus, the ELS and 4-ENF test remained as possible methods for international standardisation, as both are stable and both may be performed with relatively simple apparatus. Several further studies have been performed using the 4ENF test, for example Schuecker and Davidson [4] investigated the effects of friction in the test, and found this to be somewhat higher than in the 3-point ENF test. These authors also commented in the same article on difficulties in measuring the delamination length. Recent work on the 4-ENF test has focussed more closely on geometrical aspects of the test, and on fixture compliance [5].

The ELS test was used in some early work at Texas A&M University [6] and was later employed by Russell and Street [7]. The European Structural Integrity Society (ESIS), Technical Committee 4 (TC4) on polymers and composites have also used this method extensively and have completed several round-robins using the ELS test method. Two main conclusions were drawn from the earlier studies by ESIS TC4. Firstly, most participating groups had found it very difficult to measure the crack length accurately during mode II delamination. The use of high powered optical microscopes often made matters worse, as the closer one looks, the more damage one can see (and distinguishing between damage and crack growth is not trivial in mode II). Secondly, the clamping of the sample, as required in the ELS test, appeared to introduce variability. If the flexural modulus of the composite specimen was determined via a so-called 'inverse ELS test' (in which the specimen becomes a simple built-in cantilever, with the crack fully held within the clamp), then low values of modulus would always be measured, compared to values obtained via three-point flexural tests e.g. via [8]. Now, the problems associated with defining the mode II delamination length and then measuring it are common to both the 4ENF and the ELS tests however, the problems associated with clamping are specific to the ELS test. Clearly there is a strong rationale to develop a methodology which circumvents the need to measure crack length. Such an approach was recently developed by the present authors [9] for mode I delamination which had particular application when extensive fibre bridging and micro-cracking rendered the definition of crack length difficult. This scheme has been extended to the mode II ELS test and a current ESIS TC4 round-robin is investigating its potential in a new ELS test protocol [10]. In the present work we outline the scheme, describe a method to reduce clamp variability and present some initial test results. The full results of the current round-robin will be published on completion of the programme.

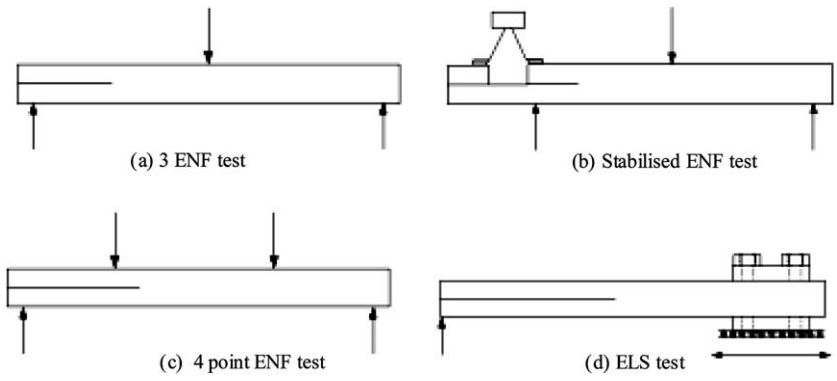

Fig. 1. Schematic diagram of various mode II delamination test methods.