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A new jig for mode II interlaminar fracture testing of composite materials under quasi-static and moderately high rates of loading

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Abstract

While it is still debated whether a pure mode II interlaminar fracture can physically exist in composites, several test methods have been proposed for its characterization. Lack of agreement between the results obtained with different test configurations has been attributed to the use of inconsistent data reduction schemes or inadequate correction factors used to correct for, e.g. the large deformations occurring with some tough modern materials.

Aim of this work was to design a new jig that could provide an as pure as possible mode II crack initiation in unidirectional composites materials, that would allow a direct determination of fracture toughness, i.e. requiring almost no assumption for data reduction nor side effects correction and could be amenable to being used under impact as well as quasi-static loading conditions.

The geometry of the system was designed in order to obtain great compactness, i.e. reduced masses and contained volume, making it usable with drop-weight testing machines, but at the same time enough stiffness to prevent flexural moments from closing or opening the crack faces, so granting the purity of the wanted mode, mode II, of loading. The compactness of the jig plus specimen system and the rigid confinement to which the composite specimen is subjected also grant that quite small displacements and overall deformations are reached at fracture.

A *static finite element* analysis was conducted to optimize the jig geometry and is discussed here. Preliminary numerical and experimental results obtained with moderately high rate tests are also presented. The method employed for data reduction is based on the experimental calibration of the compliance and it is quite straightforward.

Keywords: Mode II; Interlaminar fracture; Impact testing

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1. Introduction and motivation of the work

Whether a pure mode II fracture, which should consist of a relative sliding of planes, does really occur in long fibre composite laminates at the microscopic scale is still matter of debate [1]. The micro-mechanics of crack initiation and propagation in this kind of heterogeneous materials has been studied for quite some time and a few theories have been proposed to explain the phenomenology of fracture in these materials. Some authors particularly stress the role of resin toughness and processes taking place in the resin-rich interlaminar region to explain characteristic aspect of fracture surfaces (see for example [2]), others tend to give an important responsibility to shear stresses at the matrix fibre interface (see for example [3]). From the first mechanism it would couched that it is impossible to test a material specimen in mode II since failure will be always dominated by mode I properties.

As long as these processes are not fully understood the dispute about the existence of mode II interlaminar fracture toughness as a true material property will not be resolved and mode II testing will remain controversial.

It is worth noting, that also the conventional mode I tests on such heterogeneous materials involve a variety of local loading modes at the microscopic scale [4], but this does not prevent these tests to produce useful results for engineering purposes.

Since out-of-plane impact induced delamination on typical structural elements is dominated by anti-symmetric loadings,[1] it is valuable to have data on macroscopic mode II delamination for damage tolerance assessment and structural calculations, especially at moderately high and high strain rates, since there can be a non-negligible influence of this parameter on toughness, at least for some materials [5,6].

Of the tests developed for the determination of mode II interlaminar fracture toughness (see e.g. [4,7] for reviews) most involve beam-shaped specimens stressed in bending with the crack perpendicular to the direction of the external load.

A few problems aroused with these tests, such as friction between the crack faces and large displacements with the modern, tougher materials.

As to friction, different analyses regarding ENF test do not agree about the relative influence of friction on total energy release rate (ERR), with estimates varying from 3% [8] to 15% [9]. Moreover, the assumption that in ENF tests friction is acting only in a small region near the loading pin [8] does not agree with the numerical analysis performed to validate the MMB test [10] which indicates the presence of compressive stresses in the tip region, even though loading is predominantly mode II.[2]

The scheme usually employed for data reduction is based on the beam theory, which neglects the warping of the cross-section produced by the high shear stresses acting at the apex. In the case of ENF this leads to a difference between beam theory results for ERR and results obtained in other ways (such as finite element analysis or plate theory), even if the compliances theoretically predicted and calculated are in good agreement [11,12].

To skip these difficulties and tackle the problem anew we tried to abandon the beam configuration and to use a test of the "compact shear" kind (some older tests belonging to this family are briefly presented and analyzed in [13]). This has the advantage of being amenable also to be loaded with a drop weight tower, for the convenience of using a single test under a wide range of conditions and specifically in engineering relevant low-velocity impact conditions; a static characterization is nevertheless needed. In this geometry the test specimen is bonded to two metallic loading fixtures, one fixed and the other one subjected to a prescribed rate of loading, thus inducing a shear stress state at the tip of the crack.

The target of developing a test amenable to impact loading requires a great reduction in the size and some simplification in the shape of the loading fixtures with respect to usual "compact shear" tests. To make sure that the system responds in mode II, finite element analyses (FEA) were conducted to select a geometrical configuration that minimizes opening or overlapping of the crack faces, i.e. mode I loading and friction.

[1] This seems to be a common opinion in the literature so we will not give any specific reference; the only objections are advanced in [1].
[2] It is also reported that, under certain conditions, these stresses can be high enough to suppress completely mode I crack opening [10].