Accepted Manuscript

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Author: L. Távara V. Mantic

PII: S0093-6413(17)30128-3
DOI: http://dx.doi.org/doi:10.1016/j.mechrescom.2017.07.005
Reference: MRC 3190

To appear in:

Received date: 8-3-2017
Revised date: 12-7-2017
Accepted date: 12-7-2017

Please cite this article as: L. Távara, V. Mantič, Crack paths formed by multiple debonds in LFRP composites, *<![CDATA[Mechanics Research Communications]]>* (2017), http://dx.doi.org/10.1016/j.mechrescom.2017.07.005

Crack paths formed by multiple debonds in LFRP composites

L. Távara*, V. Mantič

Grupo de Elasticidad y Resistencia de Materiales, Escuela Técnica Superior de Ingeniería, Universidad de Sevilla,
Camino de los Descubrimientos s/n, 41092 Sevilla, Spain

Abstract

Onset and growth of debonds at fibre–matrix interfaces in a bundle of fibres subjected to transverse loads are studied numerically. In particular, the crack path formed by debonded neighbour fibres is analysed. The Linear Elastic–Brittle Interface Model (LEBIM) is used to model the fibre–matrix interface behaviour. This simple model of a Long Fibre Reinfoced Polymer (LFRP) composite includes ten parallel fibres embedded in a matrix cell whose external dimensions are much larger than the fibre radius. The advantage of the present LEBIM formulation of the so-called matrix cracking lies in its ability to make quantitative predictions about the concurrent fibre–matrix debond onset and mixed–mode interface crack growth in a fibre bundle. The numerical analysis predicts failure loads producing the first and subsequent debond onsets, leading to a crack path. A discussion on the position where debond occurs is also included. Finally, the effect of the load biaxiality on the crack path is studied in detail.

Keywords:
Fibre–matrix debonding, interface fracture toughness, interfacial strength, failure criterion, inter–fibre failure

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1. Introduction

At the microscale, when analyzing the interactions between fibres and matrix, the role of interfaces and interphases [1, 2] is well recognized. It is well known that the interfaces between the constituents of composite materials play a significant role in failure mechanisms [3, 4, 5, 6, 7, 8].

The inter–fibre failure (also called matrix failure or matrix cracking) was studied experimentally, numerically and semi-analytically for a single fibre configuration under biaxial transverse loads in [4, 8, 9, 10, 11, 12, 13]. The influence of a neighbour fibre on the inter-fibre failure was studied on [13, 14, 15]. Numerical results obtained showed that the distance between two neighbour fibres and the position of a second fibre, in reference to the direction of the external load, has a great influence on the interface crack behaviour. In [16, 17], a proper random distributions of fibres are proved to be necessary for modelling debond initiation, growth and subsequent matrix cracking. The cohesive zone model was used to study the interface crack behaviour in a multifibre model in [18, 19]. Random fibre distributions, including an elastic-plastic behaviour and damage of the matrix, were used to study a 0°/90° laminate configuration in [20, 21]. A related problem of crack patterns in epoxy plates with randomly distributed circular holes was studied in [22]. Recently in [23], the concurrent onset and growth of debonds in a fibre bundle embedded in an infinite matrix subjected to far field biaxial transverse loads was studied by means of the collocational Boundary Element Method (BEM) and Linear Elastic – (perfectly) Brittle Interface Model (LEBIM). This procedure proved to be an efficient, robust and reliable tool also in [7, 8]. In these studies by the present authors, failure curves, in which both tensile and compressive loads are considered, were obtained for a single fibre model and a ten-fibre model.

Although, as shown above, the fibre-matrix interface debond problem has been studied by many researchers, there are still some open questions, e.g., regarding crack path. In the present work, a ten-fibre bundle, with a random distribution of fibres obtained from a micrograph of a unidirectional lamina [23], subjected to several transverse biaxial loads is modelled. Twelve different geometrical configurations obtained by rotating the fibre bundle are used to study the crack path that may be formed by multiple interfacial debonds. The numerical results also include a study of the positions where the first debond occurs in the fibre-matrix system, which may have a great influence on the final macro–crack path position, shape and orientation.

2. Ten-fibre problem

2.1. Description of the problem

In order to model an actual composite configuration several options may be considered. In the present study the option considering a bundle of fibers embedded in a large matrix is considered. Another common option is the use of periodic boundary conditions, see [16] and references therein. A discussion on other feasible options can be found in [23].

A bundle of ten fibres with radius a is numerically solved herein. The position of the fibres corresponds to a randomly selected portion from an actual glass fibre composite micrograph [23], see Figure 1 therein. Figure 1 shows the actual proportions of the configuration under study. A plane strain state is

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*Corresponding author. Tel.:+34 954487299; Fax: +34 954461637
Email address: `ltavara@us.es` (L. Távara)