Growth of transverse cracks from multiple adjacent debonds: debond-debond interaction between rows of partially debonded fibers in UD composites

Luca Di Stasio[a,b], Janis Varna[b], Zoubir Ayadi[a]

[a] *Université de Lorraine, EEIGM, IJL, 6 Rue Bastien Lepage, F-54010 Nancy, France*
[b] *Luleå University of Technology, University Campus, SE-97187 Luleå, Sweden*

Abstract

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1. Introduction

Transverse cracks (or micro- or matrix cracks) represents one of the very first damage mechanism appearing in a Fiber Reinforced Polymer Composite (FRPC). A full understanding of the factors determining its onset and propagation could lead to structural improvements aimed to delay, suppress and possibly control transverse cracking in order to increase the energy absorbing capabilities of polymer composites. Early mcroscopic observations determined that onset of transverse cracking coincides with the appearance of fiber-matrix interface cracks (also called debonds), which grow along the arc direction of the fiber until a critical size, then kink out of the interface and coalesce with other debonds to form what is macroscopically seen as a transverse crack [1].
Analytical models of a single partially debonded fiber in an infinite matrix were firstly solved by Perlman and Sih [2], who provided the solution in terms of stress and displacement fields, and Toya [3], who analyzed the energy release rate at the crack tip. Numerical treatment of the problem soon followed, in particular with the Boundary Element Method (BEM) solution by Paris et al. [4]. The numerical analysis of the single fiber model allowed first to understand the

importance of crack face contact in the mechanics of fiber-matrix debonding [5], confirming earlier results regarding the straight bi-material interface [6]. Fiber-matrix debonding was thus investigated in models of a single fiber embedded in an effectively infinite matrix under remote tension [4] and remote compression [7]. Residual thermal stresses were also analyzed [8]. The effect of a second nearby fiber was furthermore studied under the effect of different uniaxial and biaxial tensile and compressive loads [9, 10, 11, 12]. Debond growth in a hexagonal cluster of fibers embedded in an effectively homogenized UD composite was investigated by Zhuang et al. [13]. The interaction of two debonds facing each other on two nearby fibers was addressed in [14] for a cluster of fibers immersed in a homogenized UD, while models of kinking were developed for a single fiber in an infinite matrix [15] and a cluster of fibers in a homogenized UD [16].

According to the observations presented in [1], multiple debonds grow at the same time on a series of fibers roughly aligned along the thickness direction of the laminate; they then kink and coalesce to form a transverse crack. If a few studies of kinking [15, 16] and linking of debonds [14] are present in the literature, it seems that no attention has still been paid to the effect on debond growth of the presence of multiple debonds on (vertical or horizontal) rows of fibers, i.e. the stage that precedes kinking, coalescence and the appearance of a macroscopic transverse crack. It is this issue that we want to address in this paper. By means of Representative Volume Elements (RVEs) with symmetry or coupling conditions on all its boundaries, three different configurations of debonds appearing in a UD composite with a regular microstructure under transverse tension are studied: first, the case of multiple vertical (i.e. along the thickness direction) rows of partially debonded fibers; second, the case of multiple horizontal (i.e. along the loading direction) rows of partially debonded fibers; finally, the case of partially debonded fibers appearing after the same number of fully bonded fibers along the vertical and horizontal direction.

2. RVE models & FE discretization

2.1. Models of Representative Volume Element(RVE)

2.2. Finite Element (FE) discretization

3. Results & Discussion

4. Conclusions & Outlook

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