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

Keywords: Polymer-matrix Composites (PMCs), Thin-ply, Transverse Failure, Debonding, Finite Element Analysis (FEA)

---

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 [15] in an infinite matrix and a cluster of fibers in a homogenized UD [16].

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

Acknowledgements

Luca Di Stasio gratefully acknowledges the support of the European School of Materials (EUSMAT) through the DocMASE Doctoral Programme and the European Commission through the Erasmus Mundus Programme.

References

[1] J. E. Bailey, A. Parvizi, On fibre debonding effects and the mechanism of transverse-ply failure in cross-ply laminates of glass fibre/thermoset composites, Journal of Materials Science 16 (3) (1981) 649–659. `doi:10.1007/bf02402782`.

[2] A. Perlman, G. Sih, Elastostatic problems of curvilinear cracks in bonded dissimilar materials, International Journal of Engineering Science 5 (11) (1967) 845–867. doi:10.1016/0020-7225(67)90009-2.

[3] M. Toya, A crack along the interface of a circular inclusion embedded in an infinite solid, Journal of the Mechanics and Physics of Solids 22 (5) (1974) 325–348. doi:10.1016/0022-5096(74)90002-7.

[4] F. París, J. C. Caño, J. Varna, The fiber-matrix interface crack — a numerical analysis using boundary elements, International Journal of Fracture 82 (1) (1996) 11–29. doi:10.1007/bf00017861.

[5] J. Varna, F. París, J. C.Caño, The effect of crack-face contact on fiber/matrix debonding in transverse tensile loading, Composites Science and Technology 57 (5) (1997) 523–532. doi:10.1016/s0266-3538(96)00175-3.

[6] M. Comninou, The interface crack, Journal of Applied Mechanics 44 (4) (1977) 631. doi:10.1115/1.3424148.

[7] E. Correa, E. Gamstedt, F. París, V. Mantič, Effects of the presence of compression in transverse cyclic loading on fibre–matrix debonding in unidirectional composite plies, Composites Part A: Applied Science and Manufacturing 38 (11) (2007) 2260–2269. doi:10.1016/j.compositesa.2006.11.002.

[8] E. Correa, V. Mantič, F. París, Effect of thermal residual stresses on matrix failure under transverse tension at micromechanical level: A numerical and experimental analysis, Composites Science and Technology 71 (5) (2011) 622–629. doi:10.1016/j.compscitech.2010.12.027.

[9] E. Correa, F. París, V. Mantič, Effect of the presence of a secondary transverse load on the inter-fibre failure under tension, Engineering Fracture Mechanics 103 (2013) 174–189. doi:10.1016/j.engfracmech.2013.02.026.

[10] E. Correa, F. París, V. Mantič, Effect of a secondary transverse load on the inter-fibre failure under compression, Composites Part B: Engineering 65 (2014) 57–68. doi:10.1016/j.compositesb.2014.01.005.

[11] C. Sandino, E. Correa, F. París, Numerical analysis of the influence of a nearby fibre on the interface crack growth in composites under transverse tensile load, Engineering Fracture Mechanics 168 (2016) 58–75. doi:10.1016/j.engfracmech.2016.01.022.

[12] C. Sandino, E. Correa, F. París, Interface crack growth under transverse compression: nearby fibre effect, in: Proceeding of the 18^{th} European Conference on Composite Materials (ECCM-18), 2018.

[13] L. Zhuang, A. Pupurs, J. Varna, R. Talreja, Z. Ayadi, Effects of inter-fiber spacing on fiber-matrix debond crack growth in unidirectional composites under transverse loading, Composites Part A: Applied Science and Manufacturing 109 (2018) 463–471. doi:10.1016/j.compositesa.2018.03.031.

[14] J. Varna, L. Q. Zhuang, A. Pupurs, Z. Ayadi, Growth and interaction of debonds in local clusters of fibers in unidirectional composites during transverse loading, Key Engineering Materials 754 (2017) 63–66. doi:10.4028/www.scientific.net/kem.754.63.

[15] F. París, E. Correa, V. Mantič, Kinking of transversal interface cracks between fiber and matrix, Journal of Applied Mechanics 74 (4) (2007) 703. doi:10.1115/1.2711220.

[16] L. Zhuang, R. Talreja, J. Varna, Transverse crack formation in unidirectional composites by linking of fibre/matrix debond cracks, Composites Part A: Applied Science and Manufacturing 107 (2018) 294–303. doi:10.1016/j.compositesa.2018.01.013.