Accepted Manuscript

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Yuesong Xie, Marisol Koslowski

PII: S1359-835X(16)30346-3
DOI: http://dx.doi.org/10.1016/j.compositesa.2016.10.019
Reference: JCOMA 4456

To appear in: *Composites: Part A*

Received Date: 13 May 2016
Revised Date: 13 July 2016
Accepted Date: 17 October 2016

Please cite this article as: Xie, Y., Koslowski, M., Numerical simulations of inter-laminar fracture in particle-toughened carbon fiber reinforced composites, *Composites: Part A* (2016), doi: http://dx.doi.org/10.1016/j.compositesa.2016.10.019

Numerical simulations of inter-laminar fracture in particle-toughened carbon fiber reinforced composites

Yuesong Xie and Marisol Koslowski
School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907, United States

The most predominant failure mechanism in carbon fiber reinforced composites is delamination. In laminated composites dispersed second phase particles have been added to the interlayer region to reduce delamination. In this work a phase field damage model is used to study Mode I crack propagation in particle-toughened interlayers. The simulations show several damage mechanisms observed in experiments and the processes that produce crack growth. In particular, failure involves multiple micro-cracks forming ahead of the main crack tip that coalesce and lead to crack branching, deflection and the formation of ligaments. Additionally, increasing the particle stiffness and the surface energy of the matrix-particle interface do not lead to an improvement of the interlaminate toughness as the fiber-matrix interface becomes a preferential path for the crack through the nucleation of extended delamination zones ahead of the crack tip.

1 Introduction

Delamination in carbon fiber reinforced polymers (CFRP) is one of the dominating failure mechanisms [1]. In general, microcracks initiate in the resin-rich interlaminar region [2], or at laminate edges [3]; then, the cracks coalesce to form an extended delamination zone. Second phase particles dispersed in the interlaminar region have been identified to suppress or reduce delamination. Experiments show that microcracks interact with particles leading to bridging and a creating a tortuous crack path that helps to increase delamination resistance [4, 5, 6, 7, 8, 9]. Numerical simulations that can predict these mechanisms can be used to advance the design of particle-toughened interlayers by guiding and reducing the number of experiments.

Synchrotron radiation computed tomography (SRCT) and synchrotron radiation computed laminography (SRCL) techniques provide an innovative way to follow crack propagation with resolution of hundreds of nanometers. Borstnar *et al.* [5, 6]