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PII: S0022-5096(15)00019-8
DOI: http://dx.doi.org/10.1016/j.jmps.2015.01.010
Reference: MPS2588

To appear in: *Journal of the Mechanics and Physics of Solids*

Received date: 30 April 2014
Revised date: 27 October 2014
Accepted date: 27 January 2015

Cite this article as: Q.D. Yang, D. Schesser, M. Niess, P. Wright, M. Mavrogordato, I. Sinclair, S.M. Spearing and B.N. Cox, On crack initiation in notched, cross-plied polymer matrix composites, *Journal of the Mechanics and Physics of Solids,* http://dx.doi.org/10.1016/j.jmps.2015.01.010

# On crack initiation in notched, cross-plied polymer matrix composites

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**Abstract** The physics of crack initiation in a polymer matrix composite are investigated by varying the modeling choices made in simulations and comparing the resulting predictions with high-resolution *in situ* images of cracks. Experimental data were acquired using synchrotron-radiation computed tomography (SRCT) at resolution in the order of 1 micrometer, which provides detailed measurement of the location, shape, and size of small cracks, as well as the crack opening and shear displacements. These data prove sufficient to discriminate among competing physical descriptions of crack initiation. Simulations are executed with a high-fidelity formulation, the augmented finite element method (A-FEM), which permits consideration of coupled damage mechanisms, including both discrete cracks and fine-scale continuum damage. The discrete cracks are assumed to be nonlinear fracture events, governed by reasonably general mixed-mode cohesive laws. Crack initiation is described in terms of strength parameters within the cohesive laws, so that the cohesive law provides a unified model for crack initiation and growth. Whereas the cracks investigated are typically 1 mm or less in length, the fine-scale continuum damage refers to irreversible matrix deformation occurring over gauge lengths extending down to the fiber diameter (0.007 mm). We find that the location and far-field stress for crack initiation are predicted accurately only if the variations of local stress within plies and in the presence of stress concentrators (notches, etc.) are explicitly computed and used in initiation criteria; stress redistribution due to matrix nonlinearity that occurs prior to crack initiation is accounted for; and a mixed-mode criterion is used for crack initiation. If these factors are not all considered, which is the case for commonly used failure criteria, predictions of the location and far-field stress for initiation are not accurate.

## 1. Introduction

High-fidelity simulations of damage evolution are approaching realization for a number of material systems, thanks to significant advances in modeling methods and experimental characterization. Nevertheless, significant challenges remain.

One challenge is the difficulty of developing practicable formulations for dealing with materials with complex material heterogeneity and reinforcement architectures. Heterogeneity poses special problems with the accurate prediction of local stress and strain fields, which can vary strongly with local material features. Heterogeneity also complicates the predictions of cracks and localized damage bands, which can appear not only on the material domain boundaries, but also on other surfaces that cannot be specified *a priori* [1-3]. In continuous fiber