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John Montesano, Brent McCleave, Chandra Veer Singh

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Prediction of ply crack evolution and stiffness degradation in multidirectional symmetric laminates under multiaxial stress states

John Montesano [a, *], Brent McCleave [a], Chandra Veer Singh [b,c]

[a] Dept. of Mechanical & Mechatronics Engineering, University of Waterloo, 200 University Ave. West, Waterloo, Canada N2L 3G1

[b] Dept. of Materials Science and Engineering, University of Toronto, 184 College St., Suite 140, Toronto, Canada, M5S 3E4

[c] Dept. of Mechanical and Industrial Engineering, University of Toronto, 5 King's College Road, Toronto, Canada, M5S 3G8

[*] Corresponding Author: Tel.: +1 (416) 888-4567, ext. 38086, Email: john.montesano@uwaterloo.ca

Abstract

A comprehensive study was performed to assess the influence of microscopic ply crack interactions on crack surface opening (COD) and sliding displacements (CSD) for arbitrary plies in general symmetric multidirectional laminates under multiaxial stresses. Based on a generated database, general unified expressions for determining both CODs and CSDs at various crack densities were developed and used with a multiscale damage-based model to predict stiffness degradation and ply crack evolution for cross-ply, angle-ply and quasi-isotropic laminates. The predicted elastic properties for laminates containing cracks in individual plies, as well as simultaneous cracks in multiple plies, were found to correlate well with data from independent finite element analysis, while crack density predictions were validated with available experimental data. The developed unified expressions have increased the robustness and range of applicability of our damage-based multiscale model. Meanwhile, the ability of the model to predict simultaneous cracking in multiple plies and both intra-ply and inter-ply crack interactions for laminates under combines stresses is regarded as advantageous. The model can be invoked to efficiently predict ply crack evolution in laminates, and when combined with a suitable delamination model may be used as a design tool to assess the long-term durability of critical load-bearing structures.

Keywords: A. Laminates; B. Transverse cracking; C. Micro-mechanics; C. Damage mechanics.

1. Introduction

The optimal use of multidirectional laminates for critical load-bearing structures requires an enhanced understanding of their complex failure processes. In particular, the consideration of subcritical intra-ply