A continuum elastic–plastic model for woven-fabric/polymer-matrix composite materials under biaxial stresses

G. Odegard a,1, K. Searles b, M. Kumosa a,*

aCenter for Advanced Materials and Structures, Department of Engineering, University of Denver, 2390 S. York, Denver, CO 80208, USA
bDepartment of Materials Science and Engineering, Oregon Graduate Institute of Science and Technology, PO Box 91000, Portland, OR 97291-1000, USA

Received 13 January 2001; received in revised form 14 August 2001; accepted 25 September 2001

Abstract

In this study a simple continuum model for the macro-mechanical prediction of the elastic–plastic behavior of woven-fabric/polymer-matrix composites has been proposed. This model uses a scalar hardening parameter (which is a function of the current applied stress state) instead of an effective stress-strain relation to determine plastic strain increments. For simplicity, the stresses are expressed as invariants based on the material symmetry. It has been shown, by the use of experimental data for two different woven-fabric/polymer-matrix composite materials, that the newly proposed model accurately describes the non-linear mechanical behavior for different in-plane biaxial stress states ranging from pure shear to pure tension. © 2001 Published by Elsevier Science Ltd. All rights reserved.

Keywords: A. Textile composites; B. Mechanical properties; B. Modeling; B. Plastic deformation

1. Introduction

Woven-fabric composites have received considerable attention in recent years on account of their increased damage tolerance with respect to unidirectional and angle-ply composite laminates and because of the relative ease and low cost of fabrication of composite structures made from woven fabric pre-pregs. A common type of woven-fabric composite used in the aerospace industry is a bi-directional woven carbon-fibre-reinforced polymer (typically epoxy or polyimide). The fabric is woven on a loom and is composed of two sets of interlacing, mutually orthogonal yarns (the longitudinal and widthwise yarns are known as the warp and fill, respectively). The size of each yarn is determined by the number of filaments (or fibers) it contains. The architecture of the fabric is characterized by the interlacing pattern of the warp and weft yarns. The basic geometrical pattern can be characterized by the parameter \( n \) which denotes that the warp yarn is interlaced with every \( n \)th fill yarn, and vice versa. For example, Fig. 1 shows an example of a plain woven architecture \((n=2)\), and Fig. 2 shows the 8 harness-satin (8HS) woven geometry \((n=8)\).

It is well known that woven-fabric/polymer composites exhibit significant non-linear stress/strain behavior when subjected to pure shear or shear-dominated biaxial stresses [1–5]. In many cases, the non-linearity may even be detected upon initial loading of the material and continues until catastrophic failure. This non-linear mechanical response is mostly due to the non-linear constitutive behavior of the polymer matrix, microcracking of the matrix material, fiber/matrix interface debonding, and interlaminar delamination. Typically the interlaminar delamination releases a significant amount of energy upon deformation at higher loads and is responsible for a large, irregular change in the stress/strain curve [4,5]. Fig. 3 shows the side view of an 8HS woven graphite/PMR-15 off-axis tensile coupon that has been tested under a large shear-dominated biaxial load. The bulging is due mostly to delaminations that occur between plies and in the crimp area in between perpendicular yarns that relax when the specimen is unloaded. These delaminations start in regions with high stress concentrations, e.g. near intralaminar matrix...