11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Three Dimensional Damage-Mode Based Constitutive Model for Fibre-Reinforced Composites

M. Chatiri[1], A. Matzenmiller[2]

[1] CADFEM GmbH, Grafing b. Munich, Germany, mchatiri@cadfem.de
[2] University of Kassel, Institute of Mechanics, Mönchebergstrasse 7, D-34125, Kassel, Germany, post-structure@.uni-kassel.de

Key Words: *Three dimensional (3D) damage model, Fibre-reinforced composites (FRC), Anisotropic damage, Damage rates equations, Internal variables, Damage mechanics, Damage modes, First-ply failure, Dissipation potential, Puck's criterion, fibre failure (FF) and inter-fibre failure (IFF)*

The presentation outlines a spatial constitutive model for anisotropic damage describing the elastic-brittle behavior of unidirectional fibre-reinforced laminated composites, see [1]. The primary objective of the contribution focuses on the three dimensional relationship between damage of the material and the effective elastic properties for the purpose of stress analysis of composite structures upto complete failure, extended from two dimensional model of Matzenmiller, Lubliner and Taylor [2]. A homogenized continuum is adopted for the constitutive theory of anisotropic damage and elasticity. Damage initiation criteria are based on Puck failure criterion [3] for first ply failure and progressive micro crack propagation is based on the idea of continuum damage evolution. A minimum number of internal variables denoted as damage variables are introduced to describe the evolution of the damage state under loading and as a subsequence the degradation of the material stiffness. Emphasis is placed on a suitable coupling among the rate equations for damage evolution with respect to the various modes upto failure. The failure modes considered in the model proposed are schematically represented in Fig. 1.

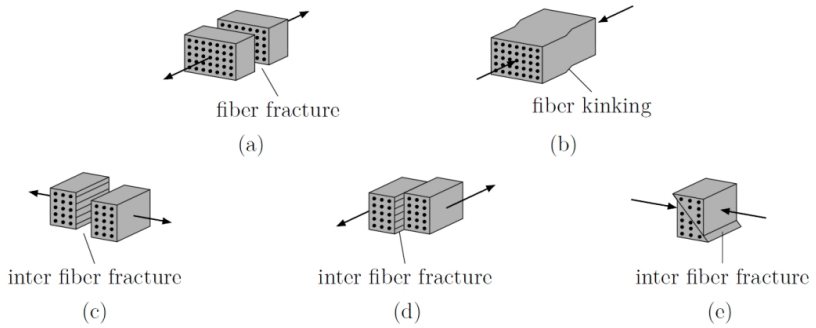

Figure 1: Major failure modes considered in the model

The mechanical failure with progressing damage of laminated FRC materials is outlined. Special emphasis is given to the interaction between fibre damage upto fibre rupture or kinking (see Fig. 1a, 1b) due to fibre stress and matrix damage upto IFF due to transverse (see Fig. 2c, 2e) and shear stresses (see Fig. 2d) on the basis of the elastic response and the ability to transmit stresses in the damage state of the composite. As an outgrowth of various failure mechanisms, also denoted as failure modes for fibre-composites, the loading surfaces in strain

space for UD-laminae complete the anisotropic damage model by identifying them with corresponding failure surfaces in stress space.

A simple algebraic structure of the constitutive tensor for the damaged lamina is proposed depending on the "internal (hidden) variables" in the privilege coordinate system as already proposed in the two dimensional model of Matzenmiller, Lubliner and Taylor [2]. A potential function - denoted as dissipation potential is introduced mainly for convenience which provides the necessary kinetic equations for the internal variables describing the transient state of damage during the entire loading history.

The developed meso-level material model with the 3D Puck failure criteria and anisotropic continuum damage mechanics is very effective in analyzing multi-layered structures having a large number of plies. It describes both onset and progression of damage. It can reproduce the key physical aspects observed in the failure of Fibre-reinforced laminated composites. The failure-model implementation is 3D, and allows non-linearity in-plane shear. Numerical examples for parameter identification, verification and validation describing a constitutive model with failure mechanisms to predict the onset and propagation of intralaminar damage in laminated composites are presented. The schematic sketch in Fig. 2 shows the progressive damage of cross ply laminates. The model is implemented as a user-defined subroutine in LS-DYNA [4] finite element code which is used for impact and crashworthiness analysis of composite structures.

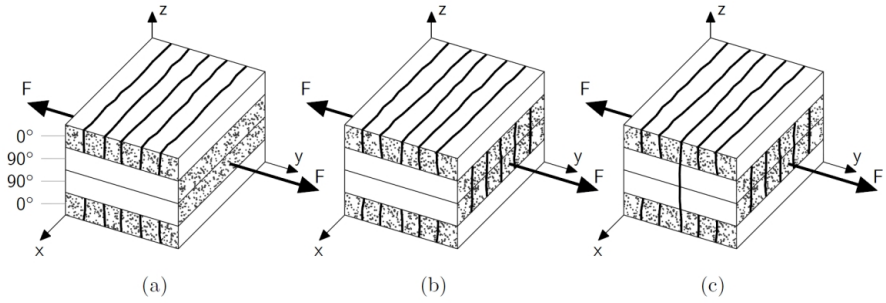

Figure 2: Section of a laminate $[0^\circ/90^\circ/90^\circ/0^\circ]$ under increasing load: (a) first ply failure IFFs in the 0°-laminae, (b) second ply failure IFFs in the 90°-laminae and (c) third ply failure FFs in the 90°-laminae.

REFERENCES

[1] M. Chatiri, A. Matzenmiller, A damage-mode based three dimensional constitutive model for fibre-reinforced composites, Computers, Materials & Continua, Vol. **35**, No. 3, pp. 255-283, 2013.

[2] A. Matzenmiller, J. Lubliner, and R. L. Taylor, A constitutive model for anisotropic damage in fibre composites, Mechanics of Materials, Vol. **20**, pp. 125-152, 1995.

[3] A. Puck, H. Schürmann, Failure analysis of FRP laminates by means of physically based phenomenological models, in Failure Criteria in Fibre Reinforced Polymer Composites: The World-Wide Failure Exercise, P. D. Hinton, A. S. Kaddour, and M. L. Soden, Eds. Elsevier: Oxford, pp. 832-876, 2004.

[4] J. O. Hallquist, LS-Dyna Keyword Manual Version 971, Livermore Software Technology Corporation, Livermore, California, 2013.