8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

A THREE-DIMENSIONAL DAMAGE MODEL FOR COMPOSITE LAMINATES

*** Pedro P. Camanho[1], Pere Maimí[2] and Joan A. Mayugo[3]**

[1] DEMEGI, FEUP, Universidade do Porto, Portugal
Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
pcamanho@fe.up.pt
www.fe.up.pt

[2] AMADE, Universitat de Girona, Spain
Campus Montilivi, 17071 Girona, Spain
pere.maimi@udg.es
www.udg.es

[3] AMADE, Universitat de Girona, Spain
Campus Montilivi, 17071 Girona, Spain
ja.mayugo@udg.es
www.udg.es

Key Words: *Composite Materials, Fracture, Damage.*

ABSTRACT

One of the most significant barriers to the increased use of composite materials is the inability to predict accurately structural failure, especially when both delamination and intraply failure mechanisms, such as matrix cracking or fiber failure, contribute to the fracture process.

Delamination is normally simulated using methods based on Linear-Elastic Fracture Mechanics, such as the Virtual Crack Closure Technique [1], or using cohesive formulations [2]. The onset of intralaminar failure mechanisms is normally predicted using ply-based failure criteria [3]. Generally, failure criteria alone are unable to predict the collapse of composite structures. To predict failure initiation, propagation and final collapse it is necessary to combine the ply-based failure criteria with appropriate damage models.

There are several relevant structural applications of laminated composites where both delamination and ply failure mechanisms are relevant, interacting, energy dissipation mechanisms. For example, in composites subjected to low velocity impact, in skin-stiffener terminations or in ply-scaled notched laminates. Therefore, the objective of this work is to formulate a fully three-dimensional damage model at the sub-ply level that is able to represent both interlaminar and intralaminar failure mechanisms without previous knowledge of the orientation of the failure planes. The composite material is taken as a transversely isotropic material and, to accurately predict the crack closure effect under load reversal cycles, the proposed constitutive model is defined in a coordinate frame where the shear strain ε_{23} is equal to zero.

The proposed constitutive model is implemented in ABAQUS [4] non-linear finite element code as a user-written UMAT subroutine. The model is validated by comparing the numerical predictions with the experimental data obtained by Varna in $[\pm\theta/90_4]_s$ glass-epoxy laminates [5]. Figure 1 shows the predicted accumulation of transverse matrix cracks in a $[0_2/90_4]_s$ laminate loaded in tension, and Figure 2 compares the predicted and experimentally measured reduction in the laminate's Young modulus and Poisson ratio as a function of the applied strain

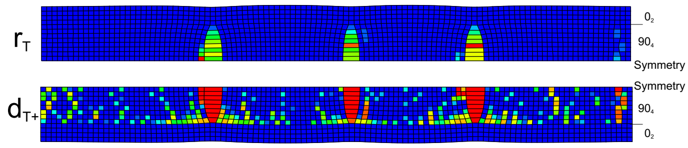

Figure 1: Internal variable r_T and transverse tension damage variable (d_{T+}) for a $[0_2/90_4]_s$ laminate. Mean laminate deformation of ε_{xx}=0.01. Deformed scale: 10x.

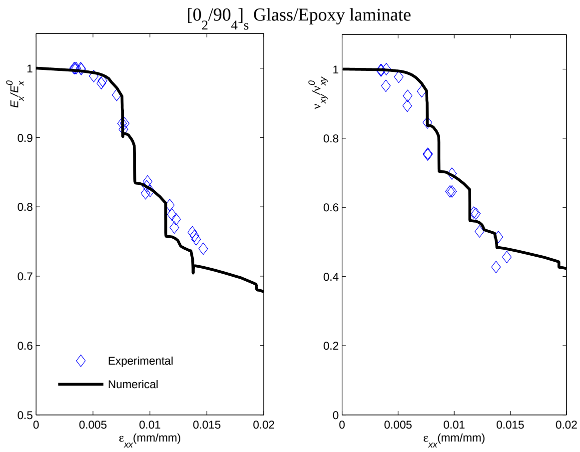

Figure 2: E_x and ν_{xy} as functions of the applied strain for a $[0_2/90_4]$ laminate. Experimental results from Varna *et al.* [5].

The results indicate that the model is able to capture the effect of the transverse matrix cracks in the residual strength and stiffness of composite laminates. Furthermore, the model simulates the interaction between transverse matrix cracks and delamination that occurs at high values of the applied strain.

REFERENCES

[1] R. Krueger, I. Paris, T.K. O'Brien, P.J. Minguet. "Comparison of 2D finite element modeling assumptions with results from 3D analysis for composite skin-stiffener debonding". *Composite Structures.*, Vol. **57**, 161–168, 2002.

[2] A. Turon, P.P. Camanho, J. Costa, C.G. Dávila. "A damage model for the simulation of delamination in advanced composites under variable-mode loading". *Mechanics of Materials.*, Vol. **38**, 1072–1089, 2006.

[3] C.G. Dávila, P.P. Camanho, C.A. Rose. "Failure criteria for FRP laminates". *Journal of Composite Materials.*, Vol. **39**, 323–345, 2005.

[4] ABAQUS 6.5 User's Manual, ABAQUS Inc., Pawtucket, RI, U.S.A. 2005.

[5] J. Varna, R. Joffe, R. Talreja. "Mixed micromechanics and continuum damage mechanincs approach to transverse cracking in $[S, 90_n]_s$ laminates". *Mechanics of Composite Materials.*, Vol. **37**, 115–126, 2001.