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

EXPERIMENTAL VALIDATION FOR A NUMERICAL MODEL OF TRANSVERSE DAMAGE IN COMPOSITE MATERIALS

D.J. Mortell[1], D.A. Tanner[2] and C.T. McCarthy[3]

[1] Department of Mechanical, Aeronautical and Biomedical Engineering, University of Limerick, Ireland, Daniel.Mortell@ul.ie
[2] Department of Design and Manufacturing Technology, University of Limerick, Limerick, Ireland. David.Tanner@ul.ie
[3] Department of Mechanical, Aeronautical and Biomedical Engineering, University of Limerick, Ireland, Conor.McCarthy@ul.ie

Key Words: *SEM, Microstructure, Virtual Experiment Method, Transverse Damage*

Delamination is one of the most frequently encountered modes of failure in composite materials. Matrix cracking and transverse crack growth initiate delamination, indicating the important interaction and coupling of these failure modes [1-3]. Experimental validation of numerical models for failure initiating from micro-crack growth is important for defining design criteria for composite structures. Virtual testing of actual composite microstructures for validating an existing two-dimensional micromechanical model of transverse damage behaviour developed by Vaughan & McCarthy [4] will be presented in this paper. The advantages of virtual experiments include reducing the need for costly manufacture and expensive testing associated with composite materials [5]. Previous research carried out by Vaughan & McCarthy, and similar work by González & Llorca [6] involved numerical analysis of generic microstructures which were generated from a statistical model of fibre distribution [7]. Using a real microstructure will allow the failure seen in numerical analysis to be compared with experimental failure.

In-situ scanning electron microscope (SEM) testing was performed on specimens of carbon fibre reinforced polymer (HTA/6376). Similar in-situ testing of composite materials for comparison with numerical models was conducted by Zhang et al. [5]. The first step in this analysis is to generate a real microstructure model from an existing composite material specimen. Using a light microscope, images of the initial microstructure can be produced prior to testing. The images are then analysed with an image processing tool. The shape of the fibres from the images are detected using a combination of phase coding, two-stage, edge detection and "threshold" [6] methods to determine the centre-point coordinates and radii. An example of this can be seen in Figure 1 for a portion of 90° plies in a specimen of unidirectional ply.

Figure 1: *(A) Original image of microstructure from light microscope. (B) Sample of analysed image with fibres automatically located for input into finite element analysis software.*

Once the location and dimensions of the fibres in the microstructure have been determined from the first step, this information is applied in the numerical model for transverse damage produced by Vaughan & McCarthy. Due to the nature of the virtual experiment, the microstructure model generated from the real specimen will not be applied periodically as real composite microstructures are not periodic. Instead the representative volume element is surrounded by a homogenised region representing the surrounding 90˚degree plies, and subjected to the appropriate loading. This method is justified by the type of mechanical loading used.

Three-point flexural loading is used to induce maximum normal and shear stresses at the centre of the span length and encourage failure at this location. Therefore, only the microstructure in this region needs to be analysed to create the geometry for the numerical model, as this is the primary location of failure during mechanical testing.

Once the numerical analysis has been performed, the results are then compared with those of the experimental tests. The SEM records real-time video which can be reviewed after mechanical testing has been completed, and includes the corresponding load and displacement information. The very slow displacement rate (0.033mm/min) of the micromechanical tester allows for very thorough analysis of the SEM footage, for tracking the initiation and propagation of damage in the transverse plies. Significant correlation between the failure observed in the numerical models and the experimental results would suggest that this particular numerical model and the method used to represent the microstructure is appropriate for use in virtual testing composite materials under similar loading conditions.

REFERENCES

[1] Adolfsson, E., & Gudmundson, P. 1997. Thermoelastic properties in combined bending and extension of thin composite laminates with transverse matrix cracks. *International Journal of Solids and Structures,* 34**,** 2035-2060.

[2] Sun, Y., *et al.* 1995. "In-situ SEM study of micromechanical behaviour in crack tip damage zone of polymer matrix composite", paper presented at *ICCM-10,* Whistler, Canada, August. Vancouver: The Tenth International Conference on Composite Materials Society, pp. I - 343 & I - 344.

[3] Liu, S. 1993. Delamination and matrix cracking of cross-ply laminates due to a spherical indenter. *Composite Structures,* 25**,** 257-265.

[4] Vaughan, T. J. & McCarthy, C. T. 2011. Micromechanical modelling of the transverse damage behaviour in fibre reinforced composites. *Composites Science and Technology,* 71**,** 388-396.

[5] Zhang, B., Yang, Z., Sun, X. & Tang, Z. 2010. A virtual experimental approach to estimate composite mechanical properties: Modeling with an explicit finite element method. *Computational Materials Science,* 49**,** 645-651.

[6] González, C. & Llorca, J. 2007. Mechanical behavior of unidirectional fiber-reinforced polymers under transverse compression: Microscopic mechanisms and modeling. *Composites Science and Technology,* 67**,** 2795-2806.

[7] Vaughan, T. J. & McCarthy, C. T. 2010. A combined experimental–numerical approach for generating statistically equivalent fibre distributions for high strength laminated composite materials. *Composites Science and Technology,* 70**,** 291-297.