Failure analysis of composite materials via micromechanics modelling and deep neural networks

Lei Wan[1*], Zahur Ullah[1] and Brian G. Falzon[1,2]

[1] The Advanced Composites Research Group, Queen's University Belfast, Ashby Building, Stranmillis Road, Belfast, BT9 5AH, UK
[2] Royal Melbourne Institute of Technology, 124 La Trobe St, Melbourne VIC 3000, Australia
E-mail: Lei Wan (l.wan@qub.ac.uk), Brian G. Falzon (brian.falzon@rmit.edu.au), Zahur Ullah (Z.Ullah@qub.ac.uk)

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Carbon Fibre Reinforced Polymer (CFRP) composites are currently being utilised in many engineering applications due to their excellent design flexibility and high specific strength and stiffness. However, the failure of composites is difficult to predict due to the complex coupling effects of different damage modes under combined stress states. Failure criteria play a vital role in the design of composite structures. The lack of comprehensive experimental data for the validation of computational failure models, especially for composite structures subjected to multiaxial loadings, has led to highly conservative designs.

Numerical modelling is widely used in industry to accelerate composite design and aid failure prediction, using a suite of computational tools including the finite element method, the phase field approach, discrete element method, or peridynamics. Currently, micromechanics-based 3D Representative Volume Elements (RVEs) are widely used to analyse the microscale failure mechanisms of composite materials which lead to macroscale (structural) failure. In this paper, high-fidelity finite element-based 3D RVE models were developed to analyse the failure mechanisms of IM7/8552 CFRP unidirectional (UD) composites subjected to biaxial loading conditions via periodic boundary conditions. The Drucker-Prager plastic damage constitutive model, and cohesive zone model, were utilised to simulate the mechanical response of the matrix and fibre-matrix interface respectively. Fibres were assumed to be transversely isotropic, elastic and brittle, where fibre failure was predicted by the maximum principal stress criterion. After validation of the RVE models with experimental tests under biaxial loading conditions, numerical simulations of other biaxial cases were conducted. Due to the transverse isotropy of the cross section of UD lamina, nine out of fifteen loading stress combinations were selected. For the generation of failure points, defining a failure envelope, an average of ten loading cases were considered for each selected biaxial stress combination. In order to generate enough data from the obtained numerical results, probabilistic failure distributions were attributed to the data points. Normal and Weibull distributions were used to describe the scattering of biaxial data with failure probabilities deduced from off-axial experiments and the mean failure surface determined using a univariate spline function. Because of the limitation of available experimental data, obtained failure envelopes were assumed to be self-similar which meant the failure envelope contracted or expanded with different failure probabilities and shared the same scattering factors with the ones from the experiments. A database, containing half a million samples was collected, and each sample had six stress components as input and provided a probabilistic failure output. A deep neural network with four hidden layers was used to construct the failure criterion for the lamina. The number of neurons in each layer was 128 after parametric study. Good agreement between the true values and predicted values was achieved.

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