172 Transverse cracking in thin-ply composites: experimental observation techniques

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Introduction

Thin-ply composites have gained a lot of interest in recent years thanks to their enhanced onset of damage, ultimate tensile strength and fatigue life as compared to their traditional counterparts. Regarding the onset of damage under tensile loading, in the transverse plies in particular, the underlying reasons of the enhanced strength and fracture properties were not yet well understood, especially for the thinnest plies available, as has been shown in Amacher et al. [1].
The acoustic emission (AE) measurements performed in this work raised the question of the applicability of the microscopy observations performed at the free edge of the samples for comparison with plane-strain models, and did not provide any information regarding the kind of damage dissipating the energy. Consequently, simultaneous in-situ optical microscopy images taken at the free edge of test samples and AE measurements were performed in this work to study the damage mechanisms of quasi-isotropic ($[45/90/-45/0]_{ns}$) unnotched tensile test samples. Ex-situ micro-tomography was then implemented to assess the damage propagation within the sample, and the acquired data were used to calibrate a pertinent embedded-cell multi-scale FE model [2].

Material and methods

ASTM D3039 compliant tests were performed on 240x24x2.4mm samples using UD prepregs of varying ply thickness (*t* = 268µm, 134µm, 67µm and 34µm) provided by North Thin Ply Technology in Switzerland, made of T800 carbon fibres and TP175 epoxy matrix. A constant specimen thickness was obtained by varying the number of repetition *n* of the sublaminate. The free edges of these samples were polished manually using SiC papers down to a grit size of 3 µm followed by a final polishing using diamond past down to 1 µm. Testing was performed on an MTS 809 servo-hydraulic tensile testing machine, with a single strain gauge used on most specimens and a second one on the opposite face at the start of each test series to ensure proper alignment. The optical microscopy was performed using a VHX-500 video microscope using its motorized head to increase the depth of field, up to an optical magnification of 4x amounting to a digital magnification of 200x, as shown on Fig. 1 in the case of a *t* = 134 µm sample. The AE onset of damage was defined as a cumulative energy threshold of 10^{-15}J as acquired by a Mistras-2001 measurement equipment using a 65dB minimum acquisition threshold and an appropriate Δt front end filter to reject acoustic activity taking place out of the gauge length.

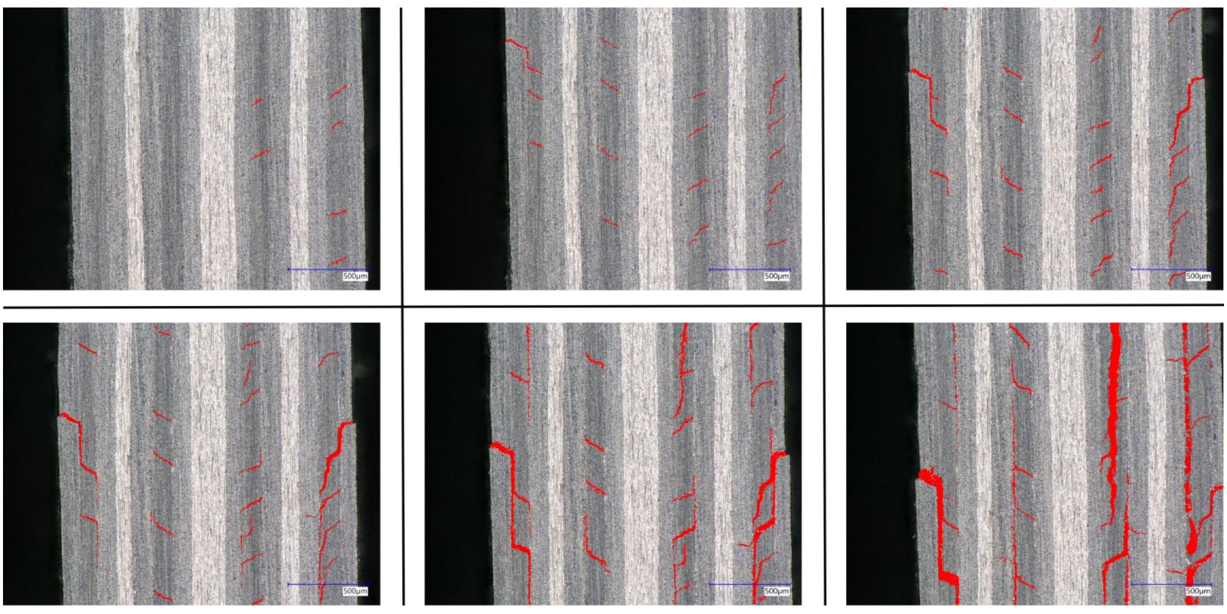

Figure 1 - Damage development at the free edge of a sample with t = 134 µm.

To validate the hypothesis that the AE threshold corresponds to the propagation of transverse free edge cracks into the bulk of the samples, as predicted by the FE model, some additional samples were loaded until pre-defined applied strain levels chosen to bound the AE threshold strain previously recorded for the different ply thicknesses used. These samples were then infiltrated with a ZnI_2-based contrasting agent whilst a 0.1% strain was applied to ensure that existing transverse cracks were re-opened. Subsequent tomography scans were performed on an RX-Solutions Ultratom micro-CT device at a resolution of approximately 7 µm per voxel. The contrasting agent ensured that crack as small as 5% to 10% of the voxel size could be rendered visible [3].

Results

A notable change of damage mechanism can be observed at the free edge for all ply thicknesses. Delamination plays a dominant role (followed by transverse cracking) for thicker plies, whereas with decreasing ply thickness, this mechanism progressively disappears with only transverse cracking remaining. A stress analysis shows that the principal stress at the free edge is in fact normal to the transverse crack direction observed experimentally. Performing a linear regression on the observed crack density, the onset of free edge cracking can be computed for all ply thicknesses and compared with their respective AE onset of damage, as shown on Fig. 2(a). Clearly, free edge damage and AE onset are representative of two different events. Finally, tomography images reveal that the AE onset does indeed correspond to a strong increase in propagated transverse crack density, as shown on Fig. 2(b). Furthermore, it was observed that the transverse cracks returned to their expected normal orientation compared to the loading direction as early as 2mm into the width of the samples.

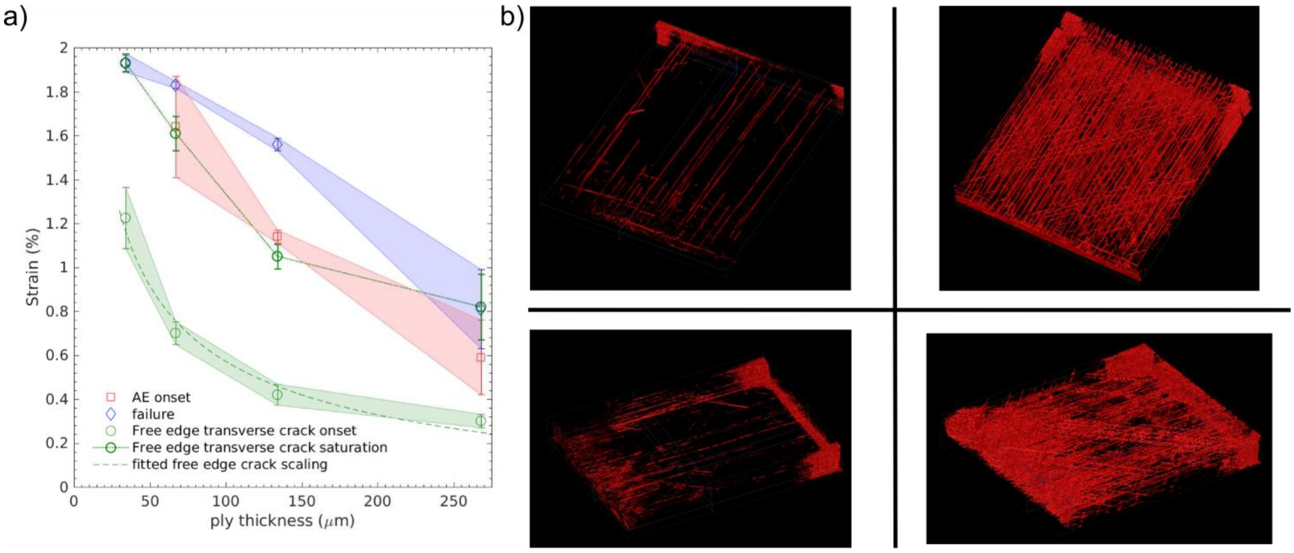

Figure 2 - (a) Comparison between free edge crack onset and AE onset for all ply thicknesses. (b) Tomography images showing the cracks in red, for 134 µm samples (top row) and 67 µm ones (bottom row) before AE onset (left colum) and after it (right column).

Conclusion and future outlook

The use of several observation techniques was key to understand the decoupling between free edge and bulk behaviour. Furthermore, the use of tomography was required to validate the damage mechanisms creating the AE recorded, which on its own was not as conclusive. The multiscale FE model created to reproduce these experiments was successfully implemented and calibrated, allowing several further interesting observations to be performed numerically. This also highlighted the potential of coupling experimental and numerical approaches to understand the challenging underlying phenomena. A development of the radiography and/or tomography technique allowing in-situ observation of full scale samples would be a welcome improvement and provide very valuable further experimental data.

References

[1] R. Amacher. J. Cugnoni, J. Botsis, L. Sorensen, W. Smith, C. Dransfeld, *Thin ply composites :Experimental characterization and modeling of size-effects*. Composites Science and Technology, 101, 2014, pp.121-132.

[2] S. Kohler, R. Amacher, J. Cugnoni, J. Botsis*, Effect of ply thickness and constituents on the transverse crack propagation of thin-ply composites: Damage progression and modelling*, Proceedings of the 18th European Conference on Composite Materials, Athens, 2018.

[3] F. Sket, A. Enfedaque, C. Alton, C. González, J. M. Molina-Aldareguia, and J. Llorca., *Automatic quantification of matrix cracking and fiber rotation by x-ray computed tomography in shear-deformed carbon fiber-reinforced laminates*, Composites Science and Technology, 90:129–138, 2014.