A multi-scale experimental assessment of the effects of crack propagation speed on mode I fracture properties of composite laminates

Alexis Stanek*†[1,2], Jean-Benoit Kopp[1,2], and Christophe Bois[1,2]

[1]Institut de Mécanique et d'Ingénierie – Univ. Bordeaux, CNRS, Bordeaux INP, I2M, UMR 5295, F-33400, Talence, France – France

[2]Institut de Mécanique et d'Ingénierie – Arts et Metiers Institute of Technology, CNRS, Bordeaux INP, I2M, UMR 5295, F-33400 Talence, France – France

Abstract

This work was motivated by the need for an accurate assessment of fracture properties of composite laminates over a wide range of crack propagation speeds. A review of the literature indeed reveals that rate-dependent fracture properties of composites have to be considered in order to accurately predict the behaviour of composite structures numerically (1), (2). However, composite materials can be manufactured with various processes and their specific microstructures play an important role in their multiscale damage mechanisms and, consequently, on their macroscopic responses (3), (4). Therefore, the microstructure's contribution needs to be accounted for in the comprehensive understanding of delamination in composite. Furthermore, the intrinsic nature of composite laminates makes them sensitive to manufacturing defects or impact damage (5), while their modularity makes them the perfect candidates for the design of "smart materials" with embedded sensors for structural health monitoring applications for example (6). These material discontinuities (damage, void, sewing yarns, embedded sensors) can locally influence the microstructure, further reinforcing the need for a comprehensive understanding of composite fracture properties as these discontinuities are likely to influence the crack propagation rate and therefore the material and structural responses. Such conclusions have already been drawn in the adhesive field, and it was proven that artificially generated defects along the crack propagation path can change the crack propagation speeds and the overall fracture scenario (7). As such, with the effect of the microstructure and its properties in mind, one is allowed to question the actual meaning of fracture standardized tests on composite laminates.

This communication, in response to these challenges, describes the experimental methods developed for the estimation of mode I fracture energies of composite laminates under different crack propagation rates. As such, specific mode I tests fixtures, based on Arcan fixtures (8) and meant to promote instabilities and rapid crack propagation, have been developed and compared to traditional DCB fixtures. In situ observations with an optical microscope mounted on a high-speed camera during crack propagation at speeds ranging from 10 m/s to 1000 m/s have been carried out. A multi-scale approach was used in an attempt to correlate the in-situ observations at small space-time scales to the macroscopic response of the specimens. Post mortem fractographic analyses, using both optical microscopy and SEM

*Speaker

†Corresponding author: alexis.stanek@ensam.eu

methods, were also conducted to reveal the evolution of damage at the microscopic scale with regards to crack propagation speed. Preliminary results indicate a decrease of fracture energies in mode I with increasing crack propagation speeds. These results are supported by the in-situ and post mortem analyses of the fracture process zone and consequent damages. These findings provide critical insights into the fracture properties of composites, further reinforcing the importance of considering microstructural effects in fracture analysis of composite structures.

References

(1) M. May, " Measuring the rate-dependent mode I fracture toughness of composites – A review ", *Composites Part A: Applied Science and Manufacturing*, vol. 81, p. 1-12, févr. 2016, doi: 10.1016/j.compositesa.2015.10.033.

(2) M. May, " Numerical evaluation of cohesive zone models for modeling impact induced delamination in composite materials ", *Composite Structures*, vol. 133, p. 16-21, déc. 2015, doi: 10.1016/j.compstruct.2015.07.032.

(3) T. Osada, A. Nakai, et H. Hamada, " Initial fracture behavior of satin woven fabric composites ", *Composite Structures*, vol. 61, no 4, p. 333-339, sept. 2003, doi: 10.1016/S0263-8223(03)00058-8.

(4) *J.G Funk et J.W Deaton, Langley Research Center, Hampton, Virignia, nov. 1989. "Interlaminar fracture toughness of woven graphite/Epoxy composites", NASA technical paper 2950*

(5) S. Abrate, " Impact on laminated composite materials ", vol. 44, no 4, 1991.

(6) H. Rocha, C. Semprimoschnig, et J. P. Nunes, " Sensors for process and structural health monitoring of aerospace composites: A review ", *Engineering Structures*, vol. 237, p. 112231, juin 2021, doi: 10.1016/j.engstruct.2021.112231.

(7) M. Taleb Ali, J. Jumel, et M. E. R. Shanahan, " Effect of adhesion defects on crack propagation in double cantilever beam test ", *International Journal of Adhesion and Adhesives*, vol. 84, p. 420-430, août 2018, doi: 10.1016/j.ijadhadh.2018.05.008.
(8) M. Arcan, Z. Hashin, et A. Voloshin, " A method to produce uniform plane-stress states with applications to fiber-reinforced materials ".