Comparison of methods for determining mode I interlaminar fracture toughness in composite laminates

Georgios Kotsinis[1], Leo Škec[2], Lucas Binsfeld[3], Anastasios P. Vassilopoulos[4], Theodoros Loutas[5], Panayiotis Tsokanas[6], Yentl Swolfs[7]

[1] Luxembourg Institute of Science and Technology, Luxembourg, Luxembourg. georgios.kotsinis@list.lu
[2] Faculty of Civil Engineering, University of Rijeka, Rijeka, Croatia, Croatia. leo.skec@uniri.hr
[3] Luxembourg Institute of Science and Technology, Luxembourg, Luxembourg. lucas.binsfeld@list.lu
[4] Composite Mechanics Group (GR-MeC), Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, Switzerland. anastasios.vassilopoulos@epfl.ch
[5] Department of Mechanical Engineering and Aeronautics, University of Patras, Patras, Greece, Greece. thloutas@upatras.gr
[6] Department of Materials Engineering, KU Leuven, Leuven, Belgium, Belgium. panayiotis.tsokanas@kuleuven.be
[7] Department of Materials Engineering, KU Leuven, Leuven, Belgium, Belgium.

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Abstract

Interlaminar cracking is a critical failure mechanism in layered materials, including fibre-reinforced composite laminates and adhesively bonded joints. In composite structures, in particular, interlaminar cracks (delaminations) can initiate during manufacturing or service and may propagate under relatively low loads, leading to severe reductions in stiffness, strength, and structural integrity. As a result, reliable determination of the interlaminar fracture toughness is essential for both material characterisation and structural design. The double cantilever beam (DCB) test is the most common configuration for mode I fracture characterisation. However, a large number of data-reduction methods exist to extract the energy release rate (ERR) from DCB experiments, often based on different theoretical assumptions and levels of approximation. This diversity makes it difficult to assess the reliability, applicability, and limitations of each method, particularly when phenomena such as fibre bridging are present. In this work, a comprehensive collection, classification, and implementation of established data-reduction methods for the determination of mode I interlaminar fracture toughness is presented. The methods are grouped into six broad categories, including classical beam-theory-based approaches, standardised methods, J-integral-based techniques, models accounting for shear deformation and crack-root rotation, cohesive-interface models, and approaches that avoid direct crack-length measurement. For each category, the underlying assumptions and governing expressions are briefly discussed. The different methods are systematically applied to the analysis of experimental DCB data obtained from glass-fibre-reinforced polymer composite laminates. Digital image correlation (DIC) is employed to measure full-field displacements and to compute the J-integral, providing an independent and physically grounded reference for comparison. Particular attention is given to cases where fibre bridging is prominent, as this mechanism challenges several classical assumptions underlying standard data-reduction schemes. The results reveal significant differences in the fracture toughness values obtained from different methods, especially in the presence of fibre bridging and non-ideal boundary conditions. Some approaches are shown to be more robust and less sensitive to experimental uncertainties, while others may systematically overestimate or underestimate the ERR. The study highlights which methods are best suited for specific experimental conditions and identifies key trade-offs between simplicity, accuracy, and physical fidelity. Overall, this work provides a unified mechanics-based framework for comparing mode I fracture toughness determination methods and offers practical guidance for researchers and engineers seeking reliable and consistent fracture characterisation of composite laminates.

Keywords:

Mode I interlaminar fracture toughness Data reduction method Composite laminate Digital image correlation