Validation numérique et expérimentale de la démarche de conception d'éprouvettes multi-orientation pour test DCB

Numerical and experimental validation of the design of multi-directional laminates for pure mode I DCB tests

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Anisotropic materials, such as fibres-reinforced composite materials, are extensively used in many industrial fields thanks to their mechanical performances: high stiffness-to-weight and strength-to-weight ratios that lead to a substantial weight saving when compared to metallic alloys.
However, despite the composites are already used in different applications, research on the mechanical behaviour of these structures (especially concerning damage tolerance) is still in progress. In this regard, delamination is one of the damage phenomena which require further studies in order to be properly described. Indeed, delamination is often difficult to detect (e.g. as a result of impacts, out-of-plane loads, etc.) and leads to a drastic reduction of mechanical properties of the structure.
Nowadays, delamination is mainly analysed by means of fracture mechanics concepts [1]. In order to characterise delamination behaviour of composites, appropriate tests to determine the critical value of the energy release rate (ERR) have to be performed.
Thanks to important research works [2], delamination tests have been proposed, improved and eventually standardised into norms for pure mode I [3], mode II [4] and mixed mode I-II [5]. For mode III some promising tests have been proposed [6], but no standard still exists.
However, available standards [3-5] show a consistent limitation: they only apply to the case of 0° unidirectional specimens. In real-world engineering applications, on the contrary, multi-directional laminates are used and delamination may appear and propagate in any interface between two adjacent layers. Consequently, effective ERR characterisation techniques for delamination propagating in multi-directional interfaces are still undefined and they would represent a major improvement for the design and certification of laminated composite structures.

The works presented in literature have shed some light on the major problems and challenges to be faced in order to develop proper delamination tests useful for ERR characterisation.

According to [7] and the relevant literature on the subject, open problems which affect the value of the measured ERR can be listed as follows: 1) the presence of additional energy dissipation mechanisms activated during delamination, 2) the presence of residual stresses in the specimen, 3) the mode mixity at the delamination front, 4) the ERR distribution along delamination front. Therefore, the state of the art on this research topic has shown the importance of an appropriate design of the multi-directional stacking sequence for delamination testing.

In the present work, the approach used to design a special class of multi-directional stacking sequences for delamination tests is presented. Quasi-Trivial (QT) orthotropic and quasi-homogenous sequences (i.e. uncoupled and with identical membrane and bending normalised stiffness) found in [8] are utilised to design both legs of a pre-cracked double cantilever beam specimen. Additionally, the two lay-ups of the specimen legs are carefully designed in order to show the same macroscopic elastic properties and to satisfy the superposition rules presented in [8]. Thus, also the global sequence of the specimen, resulting from the superposition of the two arms is a QT quasi-homogeneous one. The stacks obtained show important elastic properties: null membrane-bending coupling matrix and null bending-twisting coupling for both legs and for the total sequence. This result allows eliminating all issues related to thermal residual stresses within the laminate, which can affect the ERR measurements. In addition, the sequences characterising each leg can be different and thus allow obtaining any desired delamination interface at the specimen middle-plane (i.e. $0°/\vartheta$, $\vartheta/-\vartheta$, ϑ/φ interfaces). These stacks are labelled as *Fully Uncoupled Multi-Directional* (FUMD) sequences and they might be of major interest in the research work finalised at defining a standard for multi-directional interlaminar fracture toughness tests.

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