Characterization of the transverse fracture properties of pultruded GFRP materials in tension

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ABSTRACT

The limited experimental research on the translaminar and intralaminar fracture behaviour of pultruded GFRP profiles [1, 2] has hindered an accurate numerical simulation of damage propagation in this material and thus its applicability in civil engineering. In face of these limitations, experimental fracture tests have been conducted on a variety of pultruded materials to better understand their transverse tensile fracture behaviour. The tested materials, from various suppliers, comprise different fibre layups, elastic properties and ultimate strengths, and can be divided into three main fibre layup categories, as a function of their transverse reinforcements: (i) randomly oriented fibres, consisting of continuous filament mats (CFM); (ii) woven [0, 90] layers; and (iii) quasi-isotropic layups, including ±45º and 90º oriented fibres. The wide compact tension (WCT) test configuration was selected to study the fracture behaviour of these materials, as it does not require the application of significant loads (under 10 kN) and it enables significant crack propagation lengths (over 40 mm) prior to ultimate failure. Specimens were prepared with different initial notch lengths, allowing to assess the specimen geometry dependency. The WCT tests were developed with two main objectives: (i) to determine the transverse tensile critical energy release rate (G_c) of a given pultruded GFRP material; and (ii) to establish the cohesive law of that material at the laminate level. The second objective was based on previous studies [3, 4] that showed that G_c by itself is insufficient to accurately simulate damage propagation for different test configurations, when using finite element (FE) models. This highlights the importance of determining the laminate level cohesive law, so that the experimentally determined fracture properties can be applied to other loading cases and/or different structural problems. The critical energy release rate was determined through several data reduction methods, including FE based J-integral, compliance calibration (CC) and modified compliance calibration (MCC), whereas the laminate level cohesive law was determined as a function of energy release rate and crack tip opening displacements (CTOD). Through this methodology, a significant variation of fracture properties was obtained for the various fibre layups: CFM reinforced materials presented the lowest G_c results, ranging from 6 to 11 N/mm, which is in line with previous research for comparable materials [1, 2]; whereas most cross-ply and quasi-isotropic layups presented higher G_c results, ranging from 13 to 30 N/mm; one quasi-isotropic material exhibited significantly higher results, in the order of 150 N/mm. Visually based data reduction methods provided similar G_c results, whereas MCC based methods retrieved significantly lower G_c values. Exponential-type cohesive laws were successfully determined for the laminate level, showing significant differences across different fibre layups, in agreement with the G_c results. These experimental results were further validated through the development of FE models, taking into account the aforementioned fracture properties. Numerical and experimental results were then compared in terms of ultimate failure loads, damage propagation patterns and softening slopes.

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