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SIMULATION AND VALIDATION OF DELAMINATION PROPAGATION AND MIGRATION IN COMPOSITE PANELS SUBJECTED TO OUT-OF-PLANE BENDING

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ABSTRACT

Delamination is one of the most critical failure modes of composite materials, and it occurs when the constitutive layers separate due to excessive loads or internal defects. Understanding delamination mechanisms and predicting its onset and propagation are crucial to improving composite design and performance. Moreover, delamination can migrate to different interfaces, which must also be predicted for a safe design. Two different numerical methods are generally employed for delamination predictions: Virtual Crack Closure Technique (VCCT) [2] and Cohesive Zone Modelling (CZM). VCCT has its roots in Linear Elastic Fracture Mechanics [1], and it computes the Strain Energy Release Rate (SERR) at the delamination front, quantifying the energy released during crack formation. Delamination begins when the local SERR exceeds the material's fracture toughness. On the other hand, CZM models the interfacial behaviour between surfaces in contact using a traction-separation law to simulate potential delamination propagation.

This study evaluates the applicability and performance of different simulation approaches to model delamination propagation in a non-standard experimental case study. This case study concerns a quasi-static out-of-plane bending of a Carbon Fibre-Reinforced Polymer (CFRP) panel featuring an initial circular delamination [3]. The specimen is a CFRP panel with an embedded circular Teflon insert in the middle interface to act as a delamination initiator. The experimental results recorded two main phenomena: planar delamination starting from the pre-crack in the middle interface and a delamination migration to a different interface, depicted in Fig. 1a.

To reproduce the experimental results in a numerical model, a total of 12 simulation models were performed, consisting of 4 different delamination modelling techniques and 3 different representations of the experimental structure. We used VCCT (with and without propagation) and CZM applied in the middle interface. Additionally, a simulation was included where both interfaces affected by the delamination (the initial one and the one where the delamination migrated) were considered. Moreover, the 3 different representations were considered by applying different loading conditions. A spring with distinct stiffness was introduced to balance the overprediction of stiffness and non-ideal boundary conditions of the experiment. Fig. 1b shows the model of the experimental structure, where loading and boundary conditions are reported.

The first batch of simulations featured an almost infinite fracture toughness to prevent delamination propagation. In this way, we could assess the SERR distribution at the delamination front using VCCT. The results from different meshing strategies were compared due to the mesh-dependent nature of VCCT, which influences the SERR readings [4]. Cohesive contact was then considered to model delamination growth in the middle interface of the panel. From the comparison between the experimental results and the numerical model (as Fig. 1c and 1d show), we can observe a very similar delamination shape, if compared to the VCCT results. Also, as shown in Fig. 1d, the results proved to be less mesh-dependent. The final batch of simulations featured an additional cohesive interface in the

upper ply with respect to the middle interface to capture the migrated delamination growth. To enable delamination propagation, simulations were performed with actual values of fracture toughness. Two different simulation models were analysed to capture the migration: one model with VCCT applied in the middle interface and a cohesive layer in the migrated interface, and another model with cohesive contact applied in both interfaces. The first simulation successfully captured the delamination migration to the upper interface, but failed to depict the middle interface planar delamination. On the other hand, the second model led to the representation of both the delamination in the middle interface and the migration (shown in Fig. 1e and 1f respectively), replicating the experimental results.

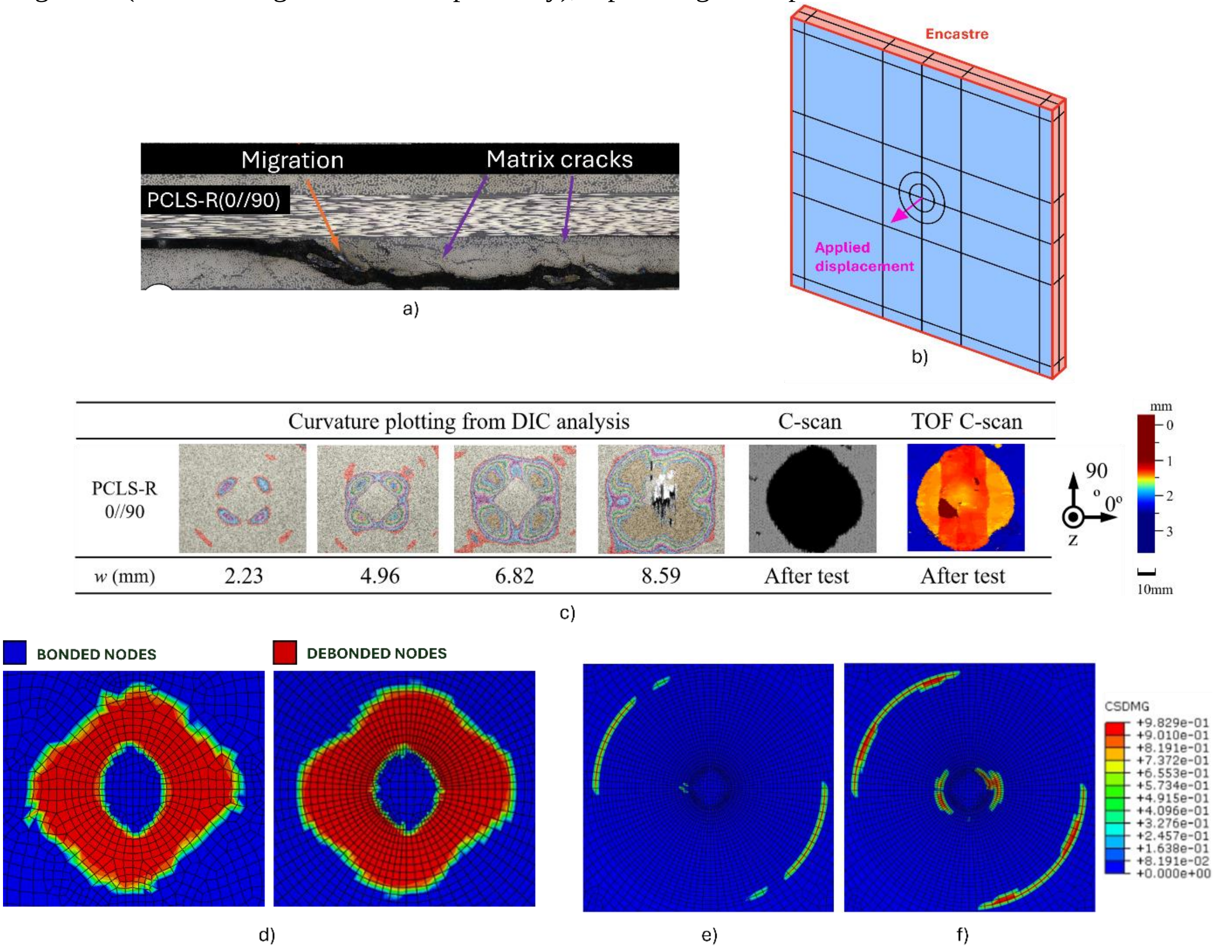

Figure 1: a) Representation of the delamination migration, reprinted from [3], with permission from the author; b) representation of the model, an encastre was applied in the red highlighted region, while the pink arrow indicates the loading condition; c) qualitative representation o the experimental results regarding the shape of the delamination in the middle interface, reprinted from [3], with permission from the author; d) delamination results from different mesh techniques used for simulations with cohesive contact to highlight the mesh independence of the delamination modelling method; e) representation of the delamination through the CSDMG variable, which indicates the damage reported in an interface in the middle interface; f) representation of delamination through the CSDMG variable in the migrated interface.

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