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THE COHESIVE – SEQUENTIAL STATIC FATIGUE ALGORITHM: A NOVEL APPROACH FOR THE FATIGUE PROPAGATION OF DELAMINATION IN COMPOSITES

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ABSTRACT

One of the most dangerous and common forms of damage in laminated composites is delamination propagation under fatigue loads. Predicting the evolution of delamination defects under fatigue loads is thus of critical importance. The most common modelling techniques used for this purpose are the Virtual Crack Closure Technique (VCCT) and the Cohesive Zone Modelling (CZM) [1].

VCCT, based on linear elastic fracture mechanics, effectively predicts the strain energy release rate G at a crack tip. However, VCCT has notable limitations, including the need for a pre-existing crack, its inability to account for nonlinear behaviours; moreover, its implementation for fatigue analyses is not straightforward nor very efficient. In contrast, CZM can simulate both crack initiation and propagation while being less sensitive to mesh size, enhancing its accuracy. Despite its advantages, CZM often requires specific implementation strategies for fatigue analyses. Most implementations in the literature rely on custom Abaqus subroutines, such as user material (UMAT) [2] or user element (UEL) [3], to model delamination propagation. This is often a cumbersome task, often requiring very specific expertise and additional modelling assumptions.

Martulli and Bernasconi [4] recently introduced an efficient VCCT-based algorithm, called Sequential Static Fatigue (SSF), for simulating delamination propagation. The SSF algorithm, here referred to as V-SSF (for VCCT-SSF), utilizes a Python script to automate multiple Abaqus static simulations, each representing individual fatigue cycles. This method significantly reduced computational time compared to the commercially available reference, while maintaining accuracy, except in cases of highly curved cracks due to VCCT's mesh sensitivity. Building on the advantages of the SSF while addressing VCCT's limitations, this work presents a new cohesive element-based formulation, C-SSF (for CZM-SSF), to model delamination under fatigue loading in laminated composites. The C-SSF method simulates the fatigue loading by launching a set of static simulations rather than a single cyclic one. Moreover, cohesive degradation is done between the simulations using Python, eliminating the need for the custom Abaqus subroutines.

The C-SSF method was validated using experimental data from a Double Cantilever Beam (DCB) sample reported in the literature [5]. As shown in Figure 1-a, the predicted crack propagation rates from the C-SSF algorithm closely matched the experimental results, with slight overprediction likely due to differences between the analytical and numerical distributions of G. The C-SSF algorithm was further tested on a non-standard, DCB-like specimen with experimental data from [6]. The fatigue load was applied in two steps. In the first fatigue step, the predicted forces closely aligned with the experimental results and matched those of the V-SSF method (Figure 1-b). In the second fatigue step with curved delamination fronts, the C-SSF demonstrated superior accuracy avoiding the significant stiffness overprediction observed with the V-SSF (Figure 1-c).

Overall, the C-SSF approach accurately predicts delamination behaviour in composite structures under fatigue loading, consistently delivering more precise and reliable results than the V-SSF method, particularly for large or curved delamination fronts. Compared to the available literature, the C-SSF allows to avoid overly complex subroutine implementations, providing a valid alternative that eliminates the need

for extensive programming. This makes the C-SSF a valuable tool for improving the accuracy of fatigue-induced delamination predictions in composite laminates and similar structures.

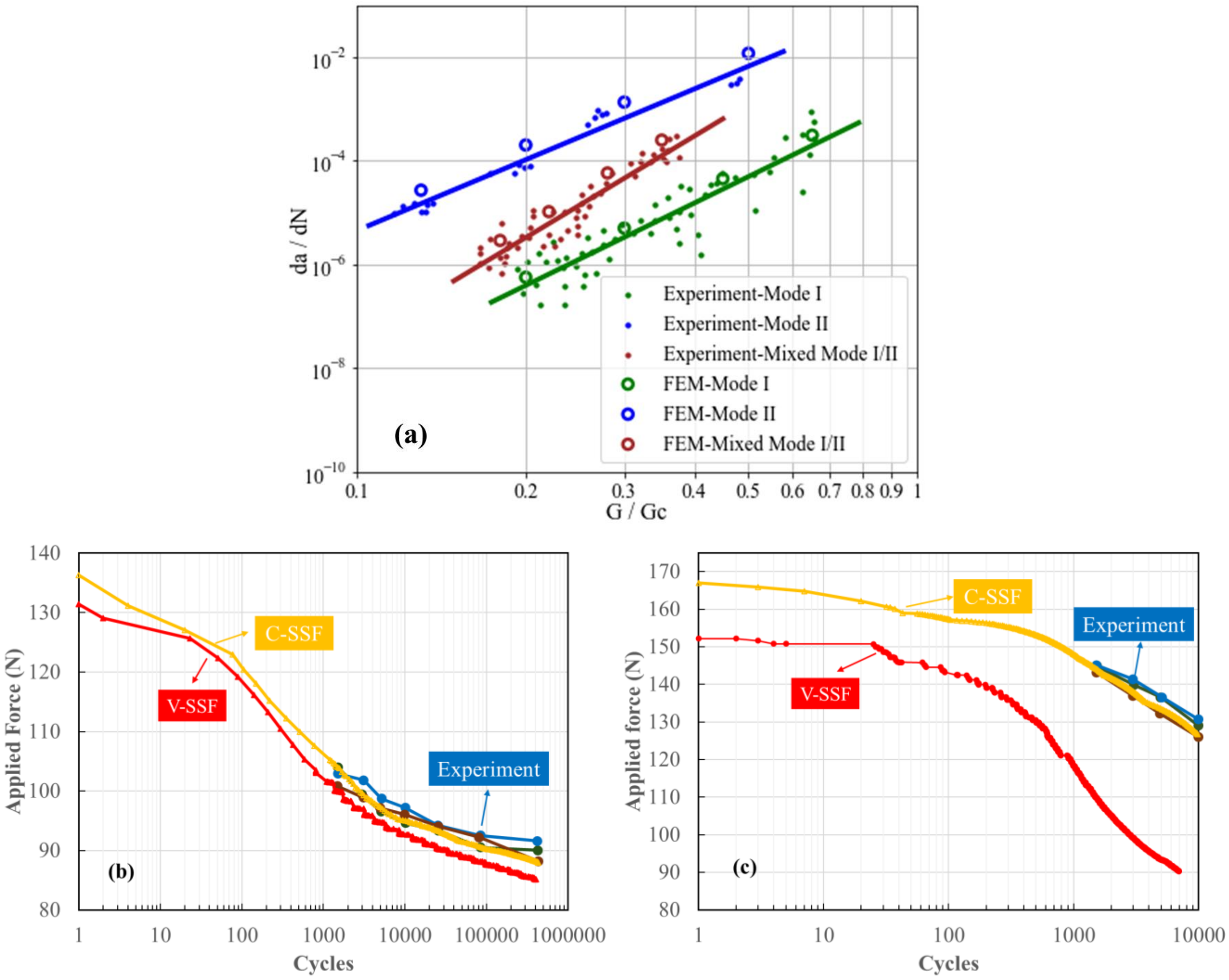

Figure 1- a) validation of the C-SSF method against data from [5], and applied forces predicted by the C-SSF method compared to experimental data [6] and the V-SSF method during b) the first fatigue step and c) the second fatigue step.

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