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THE SEQUENTIAL STATIC FATIGUE ALGORITHM: A FAST APPROACH TO PREDICT COMPOSITES DELAMINATION GROWTH UNDER FATIGUE LOADINGS

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ABSTRACT

Delamination is among the most common and dangerous forms of damage in composite laminates [1]. Considering the widespread use of these materials in industrial sectors like aeronautics or automotive, predicting their propagation under fatigue loads is of extreme importance. Cohesive Zone Models (CZMs) and Virtual Crack Closure Techniques (VCCT) are generally the most adopted techniques for this purpose.

Compared to VCCT, CZMs are less mesh sensitive, and do not require the presence of an initial crack. However, CZMs are usually based on traction-separation laws that make use of fitting parameters and parameters that are not easy to obtain experimentally. Conversely, VCCT is a fracture mechanics approach that can accurately predict the Strain Energy Release Rate (SERR) at a crack tip, and through that, the quasi-static response of cracked parts. Respect to the CZMs, the VCCT offers several advantages, above all a simpler implementation. If combined with a Paris-like growth model, VCCT can also be used to predict fatigue crack growths. Such capability is implemented via the Direct Cyclic (DC) algorithm of Abaqus [2]. Pirondi et al. [3] compared the performance of the DC algorithm with other CZMs, showing similar accuracy, but highlighting how the DC could be up to 14 times slower. Moreover, the DC algorithm implements a single Paris law throughout the entire simulation, disregarding the effect of the local mode-mixity of the SERR on the Paris law's parameters [4].

In this work, an efficient VCCT-based approach for the prediction of delamination growth in composite laminates called "Sequential Static Fatigue" (SSF) is presented. The SSF algorithm exploits the scripting capabilities of Abaqus via Python [2,5]. The algorithm prepares, launches, and read results from a series of static simulations, each associated to a specific cycle of the simulated laminate's load history. The cycle interval between each simulation is computed using the local SERR at the crack tip and a Paris-like crack growth law. Unlike the DC algorithm, the SSF is able to use Paris parameters dependent on the local SERR mode-mixity.

The SSF algorithm was first validated against the experimental data published in [6]. The algorithm performed well, with a slight overprediction of the growth rate due to the local distribution of the SERR at crack tip, as reported in Figure 1. Moreover, several simpler cases were used to compare the SSF and DC performance in terms of efficiency. These are reported in Table 1, together with the relative results. As shown, the SSF significantly outperformed the DC algorithm, being between two and three orders of magnitude faster, while accuracy was comparable.

Overall, the newly developed SSF algorithm is a valid alternative to both the VCCT-based DC approach and to CZMs aiming to predict delamination growth under fatigue loadings. It is capable of very good accuracy with a significantly improved time efficiency. Compared to the DC algorithm, it also allows the use of Paris parameters that are dependent on the local SERR mode-mixity. Further enhancement of the SSF approach are currently under development, namely the capability of implementing an adaptive mesh and the effect of the load ratio.

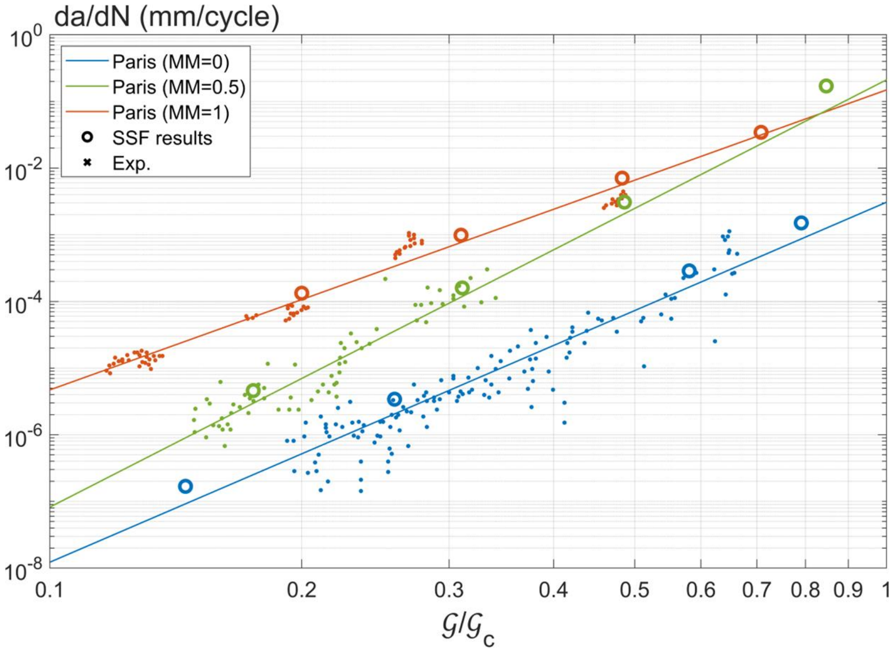

Figure 1: Validation of the SSF against data published in [6]

Table 1: SSF and DC performance comparison on different simulation cases

Simulation case	DC time	SSF time	Time ratio
Mode I propagation 0.5 mm mesh 0.5 mm propagation	39 h, 58 m, 54 s	2 m, 46 s	867
Mode I propagation 1 mm mesh 10 mm propagation	86 h, 42 m, 45 s	8 m, 29 s	613
Mixed-mode propagation 1 mm mesh 10 mm propagation	76 h, 3 m, 15 s	9 m, 46 s	305
Mode II propagation 1 mm mesh 10 mm propagation	52 h, 43 m, 48 s	14 m, 56 s	212

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