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EFFECTS OF VARIABLE AMPLITUDE FATIGUE ON DELAMINATION AND CRACK GROWTH RATE MODELS

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ABSTRACT

Load history effects in fatigue-driven delamination in fibre-reinforced polymer composites are neglected in state-of-the-art non-interaction models although this assumption highly underestimates the delamination growth under variable amplitude (VA) loading. A new phenomenon called "transient delamination growth" has been observed in recent VA fatigue experiments by the authors [1-3]. This phenomenon is a transient phase with a significantly increased crack growth rate that follows load amplitude changes in VA load spectra. In this presentation the transient delamination growth is characterised from block loading experiments and the phenomenological behaviours are integrated in a new crack growth rate (CGR) model for prediction of delamination under multi-level block loading.

The new CGR model evaluates the current crack growth rate, da/dN, by addition of a steady-state non-interaction term, da/dN_{ss}, and a transient interaction term, da/dN_{tr}, cf. Eq. (1). The steady-state term, da/dN_{ss}, is characterised from constant amplitude (CA) loading experiments. The transient term, da/dN_{tr}, is a load history dependent exponential decaying function, which is characterised from two-level block loading experiments and becomes non-zero whenever load amplitude changes occur. A delamination prediction example is provided in Fig. 1 for an arbitrary load block, i, in a multi-level block loading spectrum.

$$\frac{da}{dN} = \frac{da}{dN}_{ss} + \frac{da}{dN}_{tr} \tag{1}$$

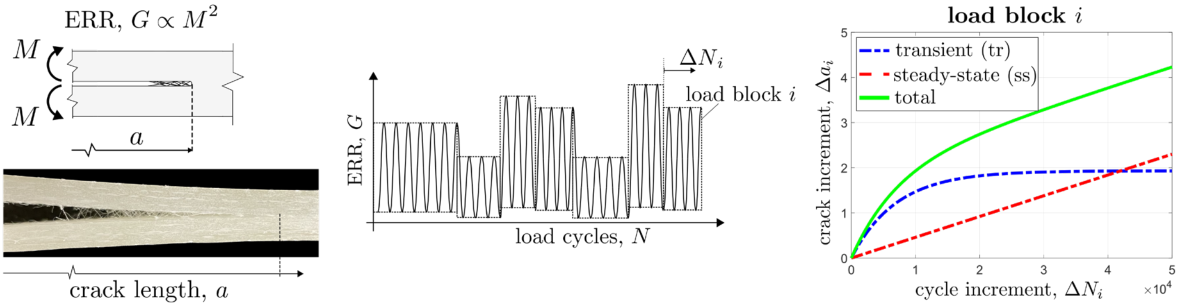

Figure 1: A pure moment loaded-DCB specimen is subjected to multi-level block loading in ERR control. The predicted crack growth is exemplified in a given load block, *i*, to the right. The total response is obtained by addition of a steady-state (ss) and a transient (tr) term, cf. Eq. (1).

Details on transient delamination growth, its' dependence on governing fatigue load parameters, the formulation of the new CGR model, and the experimental methodology used to characterise model parameters will be presented at the conference.

New experimental results will also be presented at the conference, confirming that transient delamination growth phenomena are non-negligible under VA loading. All the fatigue experiments are performed on a newly developed test fixture that subjects mode I double cantilever beam (DCB) specimens to pure bending moments and enables real-time control of the applied energy release rate, ERR, see Fig. 1. The new setup, in combination with automated and high precision measurements of the crack length, provides unique and unprecedented crack growth rate measurements during multi-level block loading under ERR-control.
The multi-level block loading experiments are used to demonstrate the capabilities and limitations of the new CGR model. The capability of the new CGR model is shown to depend on distinct characteristics of the applied load spectrum. The new CGR model is able to accurately represent the crack growth rate following high-to-low load amplitude changes in multi-level block loading experiments, see Fig. 2 (right), and reduces the error in delamination growth prediction by nearly 50% compared to state-of-the-art models, see Fig. 2 (left).

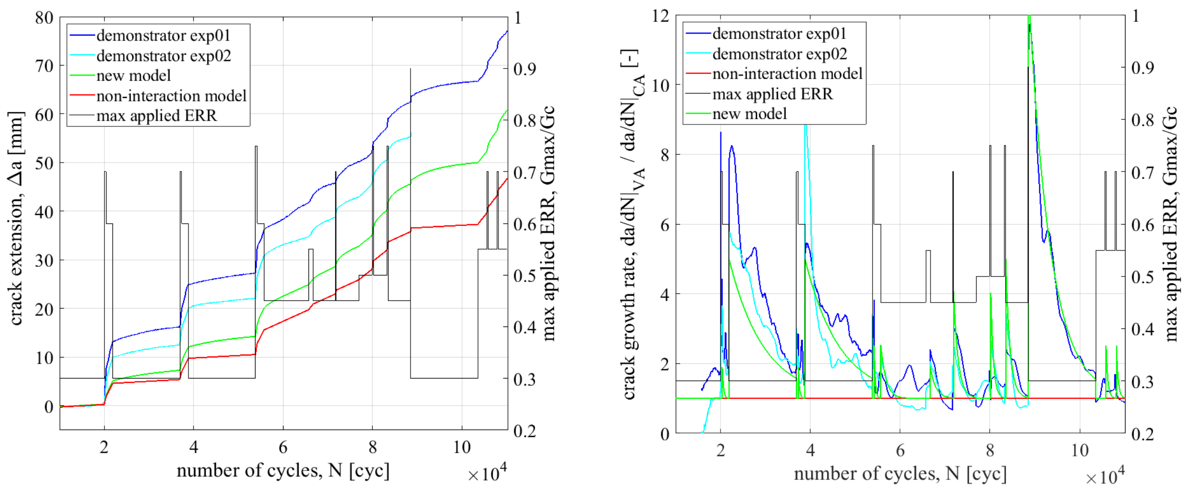

Figure 2: Experimental results and simulated results from multi-level block loading tests. The applied load spectrum is shown by the black solid line on the right axes. The left figure shows the crack length versus load cycles and the right figure shows the crack growth rate normalized with the CA baseline.

The experimental data and the new CGR model generate suitable VA fatigue data sets and benchmark examples with important phenomenological characteristics that future physics-based delamination prediction models are challenged to predict.

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