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COMPARISON BETWEEN THE INTER- AND INTRA-LAMINAR FATIGUE CRACK PROPAGATION AS OBTAINED FROM DCB AND CROSS-PLY SPECIMENS

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ABSTRACT

The fatigue life of multi-directional composite laminates is characterised, in the earlier stages, by the initiation and propagation of multiple off-axis cracks. These cracks involve the entire ply thickness and propagate along the fibre direction. In a schematic geometrical representation, thus, the crack faces belong to the 1-3 plane, where 1 is the fibre direction and 3 is the through-the-thickness direction.

To predict the damage evolution of laminates under cyclic loadings, the crack initiation and propagation must be assessed. A dedicated model was developed by the authors and presented in Ref. [1]. The crack growth rate (CGR) can be predicted based on a power law linking the CGR to the Energy Release Rate (ERR). This can be calibrated through fatigue tests on multi-directional laminates, measuring the crack length at timed intervals and correlating the CGR with the relevant ERR components. This procedure may be time consuming, mainly for non-transparent carbon/epoxy systems that would require the use of X-rays or micro-CT for measuring the crack length. Obtaining the CGR-ERR relationship through Double Cantilever Beam (DCB) tests would be easier and less time-consuming. This test was meant for characterising the delamination propagation resistance. If the fibres of the DCB specimens are all aligned along the longitudinal direction, the faces of crack belong to the 1-2 plane, where 2 indicates the transverse direction. Thus, both for off-axis intra-laminar cracks in laminates and inter-laminar cracks in DCB specimens, the crack faces lay on a plane identified by the fibre direction (1) and a direction transverse to the fibres (3 or 2). Accordingly, a question arises: is it possible to characterise the mode-I transverse crack propagation through DCB tests on unidirectional composites?

To answer this question, fatigue tests were first carried out on glass/epoxy cross-ply laminates, to characterise the transverse crack propagation under cyclic loadings. The crack growth rate was correlated to the Energy Release Rate, G_I, calculated with a shear lag approach.

Then, fatigue tests were carried out on DCB specimens obtained with the same constituents, keeping a constant maximum cyclic value of G_I. A dedicated testing procedure was developed for maintaining a fixed G_I value, based on the continuous measurement of the specimen compliance and the subsequent modulation of the maximum applied displacement. During the DCB tests, the inter-laminar crack growth was monitored and the resulting crack growth rate was correlated with the superimposed mode I ERR calculated as

$$G_I = \frac{P^2}{2b}\frac{\partial C}{\partial a} \qquad (1)$$

where P is the applied load, b is the specimen width, C the measured compliance and *a* the crack length. It can be proved that the so calculated ERR corresponds to the driving force for both the crack propagation and the dissipative phenomena occurring in the bridging region.

As an example, the calculated ERR is plotted in Figure 1 against the crack increment. The maximum ERR is roughly constant throughout the entire test, as required. The reason for keeping G_I constant is to resemble the steady state crack growth of transverse cracks, characterised by a constant value of the ERR.

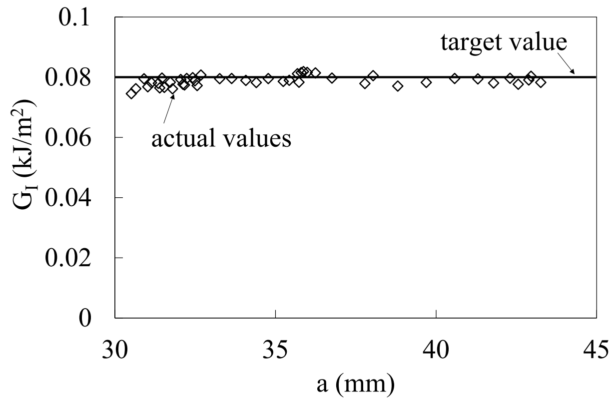

Figure 1: ERR against crack length in a DCB test

As an example of the results, Figure 2 shows the CGR obtained from a DCB test with a maximum G_I of 0.08 kJ/m^2, compared with the range relevant to a cross-ply laminate for the same ERR value. The crack growth rate in the DCB specimen decreases as the crack length increases, because of the fibre bridging. In the initial part, when the inter-laminar crack propagates from the pre-crack, no bridging occurs. The CGR is included in the range obtained from the cross-ply tests, even though in the lower part. This result was obtained also for other ERR levels.

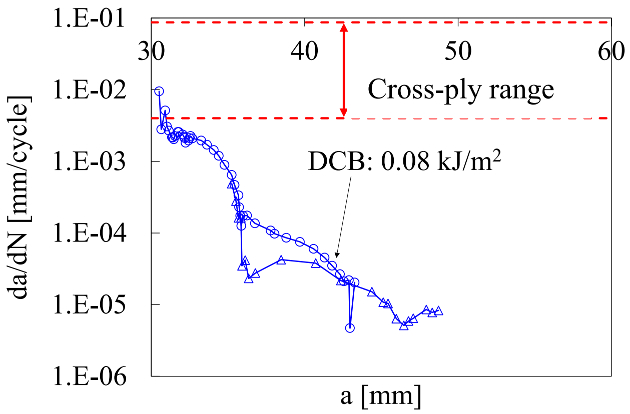

Figure 2: comparison between the crack growth rate from DCB and cross-ply specimens with the same ERR value

From the comparison between inter- and intra-laminar cracks, it was possible to conclude that the crack propagates slightly slower in the DCB than in the cross-ply specimens. The slope of the CGR-ERR curves was found to be compatible.
Further analyses will be reported in the work, including the reason for the lower CGR in the DCB tests and the effect of the fibre bridging on the ERR calculation.

REFERENCES

[1] Carraro P.A., Maragoni L., Quaresimin M., *Prediction of the crack density evolution in multidirectional laminates under fatigue loadings*, Composites science and technology, **145**, 2017, p. 24-39.