ENERGY RELEASE RATE APPROACH FOR DELAMINATION IN A FATIGUE CRACK CONFIGURATION IN GLARE

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Summary Fatigue Crack growth in a Fibre Metal Laminate like Glare is accompanied by delamination growth at the interface between the aluminium and glass fibres. To incorporate this delamination growth in prediction methods the Energy Release Rate approach is applied. Tests were performed to determine the relationship between the 2D-delamination growth and the Energy Release Rate. The followed methodology and the experimental results are presented in this paper.

INTRODUCTION

Fibre Metal Laminates (FML's) were developed at Delft University of Technology as a family of hybrid materials that consist of bonded thin aluminium sheets and fibres embedded in epoxy. Two variants were successively developed for their excellent fatigue crack resistant behaviour: Arall, containing aramid fibres, and Glare, containing S2-glass fibres. The Glare variant will be applied in the upper fuselage of the wide-body aircraft Airbus A380, see figure 1.

Figure 1. Glare will be applied in the Airbus A380

Besides the laminates with fibres oriented in one direction, denoted as uni-directional, the laminate concept provides the possibility to apply fibres in any direction. An illustration of a typical cross-ply lay-up is given in figure 2, where three aluminium layers are interspersed with two cross-ply fibre layers. This configuration with equal amount of fibres in both directions is for Glare generally denoted as a Glare3 grade with a 3/2 lay-up.

Fatigue crack propagation in Glare

Due to the presence of bridging fibres the crack growth retardation of Glare is excellent, showing very small and approximately constant crack growth rates. Since crack propagation in Glare occurs in the metal constituents only, the applied methodology utilises Linear Elastic Fracture Mechanics to describe the behaviour. This means that the effective Stress Intensity Factor (SIF) at the crack tips in the aluminium layers is divided in two components, one describing the crack opening effect due to the far field stress and one describing the restraining effect of the bridging fibres.

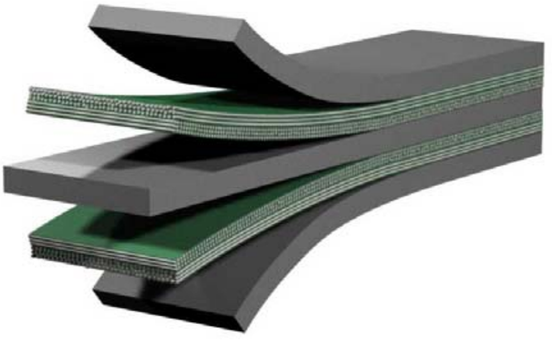
Figure 2. Typical cross-ply lay-up of a FML

To incorporate the effect of the bridging fibres in the expression for the effective SIF, the bridging stress at any location along the crack length should be known. The bridging stress at any location depends on the delamination shape and the crack opening shape along the crack length, which means that a delamination growth criterion should be determined. Whereas the crack opening in the aluminium is mainly a mode I fracture, the delamination at the interfaces is attributed mainly to the mode II fracture. The current investigation uses the Energy Release Rate (ERR) approach to determine the relation between the delamination growth and the mode II SIF at the delamination tip.

APPLIED METHODOLOGY

In early investigations it was assumed that the bridging stress was constant along a fatigue crack in Glare [1,2]. In accordance with the constant bridging stress the delamination shape was thought to be elliptical. However, recent investigations have clearly shown that the delamination shape is not elliptical and that the bridging stresses vary along the crack [3].

In order to model the delamination growth in a 3D fatigue crack configuration in Glare, as illustrated in figure 3 (a), and to verify it with experimental results, the configuration is simplified to a 2D delamination configuration as depicted in figure 3 (b). This configuration is only valid in case the crack length a in figure 3 (a) equals infinity. For the 2D configuration the entire axial load will be transferred through the fibre layer over the cracks in the aluminium layers. For this configuration the far field stresses in the individual layers and the fibre stresses in the delaminated layer can be calculated assuming constant stress distribution through the thickness. From these stresses the Energy Release Rate (ERR) can be calculated, which is related to the mode II SIF at the delamination tip.

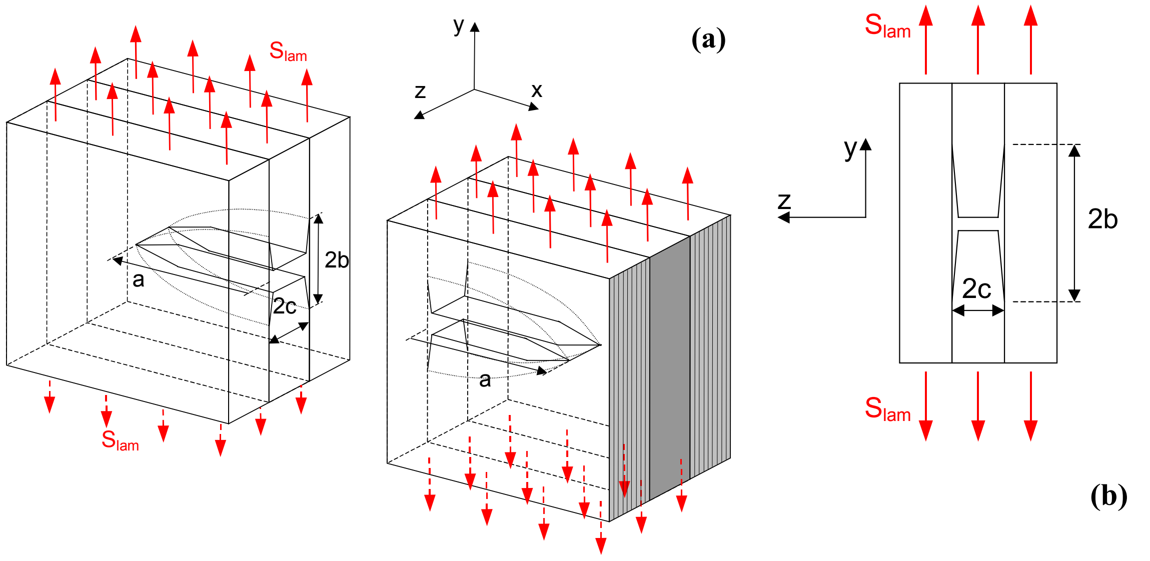

Figure 3. Fatigue crack configuration in Glare (a) and the 2D presentation of the delamination growth (b)

From experiments on 2D delamination specimens the relation between the ERR and the delamination growth can be obtained, from which a Paris type equation can be derived

$$\frac{db}{dN} = K\Delta G_d^m$$

where db/dN is the delamination growth rate and K and m are constants following from the test results. This relation can then be incorporated into the methods describing the 3D fatigue crack configuration in Glare.

EXPERIMENTS AND RESULTS

To incorporate the effect of the prepreg lay-up several Glare grades were tested: Glare 2 (uni-directional fibres layers) and Glare 4 (cross-ply fibre layers with 67% in rolling direction and 33% in transverse direction). The Glare delamination specimens were tested on a 100 kN servo-hydraulic, closed loop mechanical and computer controlled testing machine at a frequency of 10 Hz. The delamination length b was measured from both sides of the specimen as well as the crack opening in the aluminium layers.
Based on the fact that the ERR is not affected by the delamination length, each specimen was stepwise tested at several subsequent load levels with the same stress ratio. With this approach several sets of db/dN - ΔG_d could be obtained from one test specimen.
The ERR depends on the prepreg lay-up, however the db/dN - ΔG_d relation differs for the various prepreg lay-ups. Using a correction for the stress ratio, an effective ERR was determined to obtain the various curves for db/dN - $\Delta G_{d,eff}$. This relationship can be applied in the 3D configuration if the effective ERR along the delamination boundary is known.

CONCLUSIONS

From the current investigation it is concluded that the delamination behaviour under mode II loading can be related to the calculated effective ERR $G_{d,eff}$. The relation can be described by a Paris type relation, which is different for each Glare grade. This 2D relation must now be incorporated in the 3D fatigue crack configuration to determine the delamination criteria and to determine the delamination shape as result of the other parameters in this crack configuration.

References

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