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Publication date
2025

Document Version
Final published version

Citation (APA)
Biagini, D., Monticeli, F. M., Mosleh, Y., & Pascoe, J. A. (2025). *Effect of Fibre Orientation on Fatigue Delamination Growth in CFRP*. Abstract from 12th International Conference on Composites Testing and Model Identification, Riga, Latvia.

12th International Conference on Composites Testing and Model Identification
J. Varna (Editor)
Riga, 2025

EFFECT OF FIBRE ORIENTATION ON FATIGUE DELAMINATION GROWTH IN CFRP

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Keywords: CFRP, Delamination, Fatigue, DCB, ELS, MMB

ABSTRACT

Delamination fatigue propagation is known to cause a progressive degradation of stiffness and strength in composite laminates. Since delamination tends to follow a preferential plane, fracture resistance is conveniently analysed in terms of dominant loading modes at the crack tip: mode I (opening) and mode II (shearing). To this end, coupon tests can be performed to determine the growth rates under these particular stress states. Paris parameters from such tests are then often used in numerical implementations adopting mesoscale modelling, like in the case of cohesive element traction-separation laws. The majority of coupon tests available in the literature focus on interfaces where the fibres of the upper and lower plies have the same orientation, typically aligned with the direction of delamination growth. However, most practical applications involve multidirectional laminates, where delamination tends to develop at interfaces where the upper and lower plies have mismatching angles. Studying angled interfaces may lead to different results since some fracture phenomena, like fibre bridging and crack migration, are highly dependent on fibre orientations of plies adjacent to the delaminated interface [1].

The present work experimentally explored the various effects of fibre orientation on fatigue delamination growth in the different fracture modes. IM7/8552 carbon fibre epoxy prepreg (Hexcel), a material system commonly adopted in aerospace field, was tested under mode I Double Cantilever Beam (DCB), mode II End-Loaded Split (ELS), and Mixed-Mode Bending (MMB) tests. For all cases a combination of different interfacial fibre orientations were tested and the crack growth rate curves were compared in relation to the observed fracture behaviour.

The mode I Paris curves are shown in Figure 1-a. Fiber bridging is known to enhance resistance, leading to a rightward shift of the Paris curves toward higher SERR values. It was observed that this bridging effect was limited for short pre-crack lengths (2 mm) but became more pronounced with longer pre-cracks (20 mm). A fibre bridging effect was more evident in 0/90 and 0/45 oriented interfaces compared to 0/0 interfaces. This difference arises from variations in bridging mechanisms. The 0/0 interfaces exhibited consistent fibre bridging due to nesting, whereas the 0/45 and 0/90 interfaces demonstrated more irregular bridging behaviour and a tendency for crack migration. In absolute terms a larger number of bridges were observed in oriented interfaces.

Also the mode II Paris curves (Figure 1-b) show a largely different behaviour in different orientations. In contrast to the Mode I results, the 0/0 interfaces did not yield conservative results, as reduced resistance to growth was observed in the 0/45 and 0/90 interfaces. Unlike the Mode I DCB test, the ELS test applies a bending load, which generates a local shear stress at the crack tip. This shear stress is not symmetrical with respect to the out-of-plane axis (Figure 1-d). For the same interface, such as 0/45, the location of the 45-degree ply can either be on the tensile side or the compressive side of the bending load, depending the orientation of the specimen. When the 45-degree ply was under compression (0/45), the crack followed a straight path similar to the 0/0 interface. Conversely, when the 45-degree ply was under tension (0/45), the Paris curve shifted leftward, and the crack path became significantly more tortuous when observed from the side of the specimen. For the 0/90 interfaces, however, no substantial differences were observed, regardless of whether the 90-degree ply was under tension. A similar effect

was noted in mixed-mode testing (Figure 1-c), where, depending on which side was under tension in the MMB fixture with 50% Mode I and 50% Mode II loading, both the 0/90 and 0/45 interfaces exhibited different slopes in their Paris curves.

In conclusion, fibre orientation significantly influences fatigue delamination growth in all fracture modes. This is due to variations in the formation of fibre bridging, crack tortuosity, and delamination migration, all of which depend on the layup and loading mode. An additional factor observed in the presence of Mode II is that the orientation of the local shear stress state, affects the fracture process [2] and changes the apparent fracture toughness of a given interface and its corresponding Paris curve. In order to precisely predict delamination growth in multidirectional laminates, it is therefore necessary to capture these effects, which cannot be represented by the simple coupon testing of unidirectional interfaces.

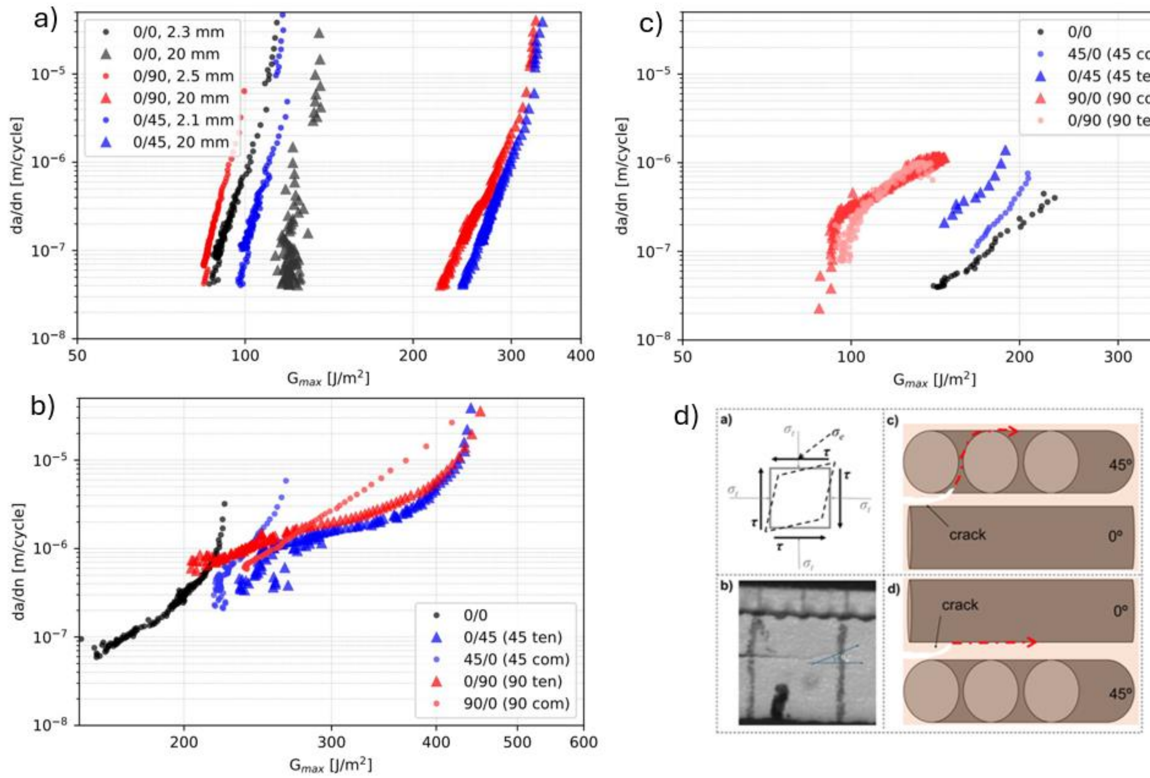

Figure 1: a) mode I Paris curves b) mode II Paris curves c) mixed-mode Paris curves d) shear orientation effect at the interface

ACKNOWLEDGEMENT

This research was funded by the European Union under GA No. 101091409 (D-STANDART). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

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