FIBRE-MATRIX DEBONDING IN TRANSVERSE CYCLIC LOADING OF UNIDIRECTIONAL COMPOSITE PLIES

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ABSTRACT

Fatigue of composite materials is of great concern in load-carrying structures. In fact, most failures of composite structures can be attributed to fatigue. Due to the heterogeneity of composite materials at different scales, a large variety of interacting mechanisms contribute to fatigue failure. If the incipient mechanisms at the onset of damage accumulation could be better understood, bases for a physically based fatigue law may be built and measures could be taken in order to extend the lifetime of the material.

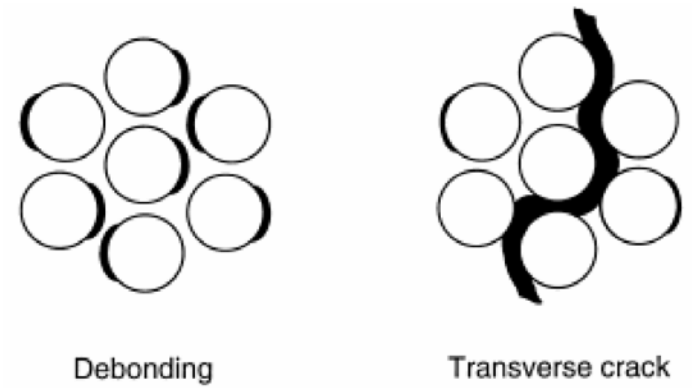

Figure 1- Drawing of the formation of debonds and subsequent link-up and transverse cracking (under uniaxial transverse horizontal loading in the figure).

The first observable type of damage in fatigue of composite laminates is generally transverse cracking in plies with oblique fibre orientation to the direction of the largest principal ply strain. Microscopic investigations have shown that the transverse cracks are initiated from coalescence of fibre-matrix debonds, both in static and cyclic loading [1]. A schematic illustration is shown in Figure 1. In paralell, several numerical studies have also been developed [2, 3], aiming to clarify the particular case of static transversal tension loads in unidirectional composites, leading to the conclusion that this micromechanism of failure can be explained by the appearance of cracks in the interfaces between the fibres and the matrix that, after growing to a certain extension along the interfaces, change their direction of propagation, kink into the matrix and continue their growth through it. The coalescence between them then takes place, leading to the macro failure of the composite in the direction perpendicular to the load.

Focusing on fatigue loading, a relevant aspect is that, for composite materials, tension-compression fatigue has shown to be more deleterious than tension-tension fatigue. The physical reason for the adverse effect of tensioncompression loading at ply level has not been clarified entirely and remains even more unclear at micromechanical level. Details of the detrimental effects of compressive load excursions, for the particular case of pure unidirectional transverse composites, can be found in [4, 5].

Based on the evidence mentioned above, the present work focuses on the propagation of interface cracks, in order to study, by means of a single fibre model, the micromechanical growth of an interface crack in presence of both, tension-tension and tension-compression fatigue. The main objective is to analyze, at micromechanical level, the origin of the more damaging effect of T-C than T-T cycles. In order to achieve this, experimental and numerical studies have been developed.

The experimental study, consisting in a single-fibre composite test, has shown, at micromechanical level, how the debonding angle of the interface crack evolves versus both T-C and T-T cycles, having been able to detect, at this level, the more deleterious effect of T-C fatigue than T-T fatigue. A summary of the results obtained is presented in Figure 2.

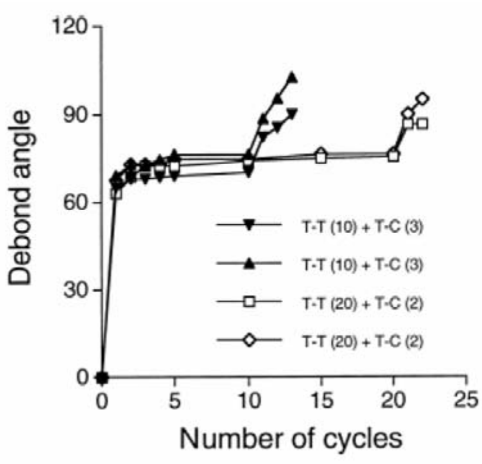

Figure 2- Results of the evolution of the debonding angle versus the number of cycles in the single-fibre composite test.

The numerical study, consisting on a single-fibre BEM model, has made possible to analyze separately the influence of the different parts of the loading cycles (tension and compression) over the interface crack propagation. The results of this analysis, in terms of the Energy Release Rate (ERR), Figure 3, give an explanation of the more damaging effect of T-C than T-T cycles, previously observed with the experimental test. This micromechanical explanation is based in the different character of ERR for tension and compression and the rising character of G_I in compression, for the debonding range of interest, as well as the smaller value of G_{Ic} versus G_{IIc}.

Thus, the results obtained prove, at micromechanical level, the negative influence on compressive excursions in fatigue loading and show the relevant possibilities that micromechanical studies (experimental and numerical) have to help in the understanding of the mechanisms of failure of composite materials.

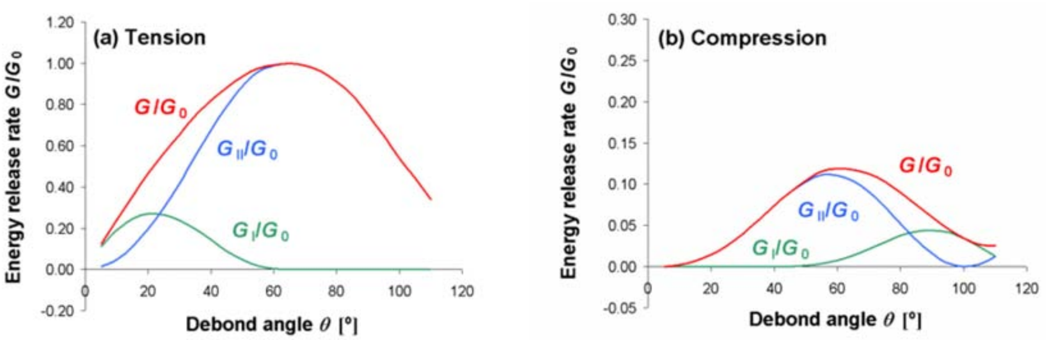

Figure 3- Energy release rate with mode I and II contributions with a far-field stress of 1 Pa in (a) tension and (b) compression.

REFERENCES

[1] Gamstedt, E.K. and Sjögren, B.A., “Micromechanisms in Tension-Compression Fatigue of Composite Laminates containing Transverse Plies”, Composites Science and Technology , Vol. 59, 167-178, 1999.

[2] París, F., Correa, E. and Cañas, J., “Micromechanical view of failure of the matrix in fibrous composite materials”, Composites Science and Technology, Vol. 63, 1041-1052, 2003.

[3] París, F., Correa, E. and Mantič, V., “Kinking of transversal interface cracks between fibre and matrix”, Journal of Applied Mechanics., submitted for publication.

[4] Rotem, A. and Nelson, H.G., ”Failure of a laminated composite under tension-compression fatigue loading”, Composites Science and Technology ,Vol. 36, 45-62, 1989.

[5] El Kadi, H. and Ellyin, F., ”Effect of Stress Ratio on the Fatigue of Unidirectional Glass Fibre/Epoxy Composite Laminae”, Composites, Vol. 25, 917-924, 1994.