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COMPETITION BETWEEN PENETRATION AND DEBONDING AT AN INTERFACE IN BRITTLE MATRIX COMPOSITES

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ABSTRACT

With their high melting point, strength and toughness, continuous fibre ceramic materials offer a great potential for elevating the operating temperature of future power generation systems [1]. To achieve high toughness in such materials, matrix cracks must deflect into the fibre/matrix interface rather than penetrate into the fibres. Experimental observations indicate that a realistic description of crack deflection must take into account the initiation of fracture mechanisms by the stress field of an approaching crack [2]. The aim of this paper is to study the initiation of interfacial debonding and penetration in the vicinity of a main crack in brittle composites.

The geometry analysed with the help of finite element computations is a representative elementary cell made of a single fibre embedded in a matrix cylinder. A matrix crack normal to the fibre direction is introduced and the ligament width between the crack tip and the fibre/matrix interface is denoted ℓ. This composite cylinder is submitted to a uniform remote axial strain. In order to derive the applied strains at initiation of debonding and penetration, use is made of an initiation criterion combining an energy and a stress conditions [3]. The energy condition compares an incremental energy release rate to the material toughness G^c. The stress condition states that the opening normal stress along the anticipated path of crack nucleation is greater than the relevant strength σ^c. It is shown that this approach leads to introduce a characteristic fracture length L^c and a structural length $L^{\max}$ [4]. The main feature of the nucleation mechanism is obtained by comparing those two lengths. A higher value of L^c such that $L^c \geq L^{\max}$ implies that the stress condition is always satisfied and that the energy condition is the governing one.

For a fixed value of the ligament width ℓ, the competition between the two fracture mechanisms can be analysed (i.e decohesion is predicted if the applied strain at initiation of debonding is lower than the applied strain at initiation of penetration).

Depending on the fracture parameters of the fibre (G_f^c, σ_f^c) and the fracture parameters of the interface (G_i^c, σ_i^c), decohesion/penetration domains are produced. As already mentioned, interesting features are evidenced by comparing the characteristic fracture lengths (L_f^c, L_i^c) with the structural lengths ($L_p^{\max}$ for penetration and $L_d^{\max}$ for debonding). The main results are schematically plotted in Figure 1 which provides mechanism maps. As expected, linear curves are obtained for large values of the characteristic fracture lengths which means that both mechanisms are controlled by the energy condition. In the case of a strong interface (as defined by the condition $\sigma_i^c / \sigma_f^c \geq \delta_1(\ell)$ where $\delta_1(\ell)$ is a structural parameter), the penetration mechanism is always activated whatever the value of G_i^c provided that G_f^c is lower than the threshold G_f^{th}. This result demonstrates that **a low toughness interface is not systematically a sufficient condition to promote the initiation of deflection.** In the case of a weak interface (as defined by the condition $\sigma_i^c / \sigma_f^c \leq \delta_2(\ell)$ where $\delta_2(\ell)$ is a structural parameter), decohesion is always possible if the interfacial toughness is smaller than the threshold G_i^{th} whatever the value of G_f^c. This result indicates that **the initiation of deflection can be achieved even if the fibre toughness is low**.

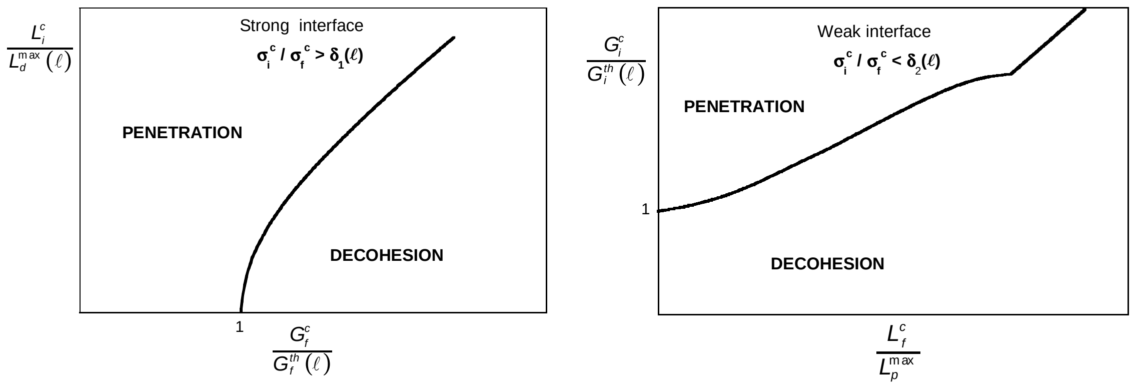

Figure 1 : Penetration/debonding domain

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