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A note on crack trajectory in an elastic strip bounded by rigid substrates

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The directional stability of a crack in brittle materials is an issue of concern both from the standpoint of failure containment as well as mixed mode fracture. The majority of works devoted to this subject deal mainly with homogeneous and isotropic materials. In this note attention is drawn to a unique form of crack trajectory that was observed in fracture testings of tri-material, DCB type specimens loaded primarily in mode I [1]. As shown in Fig. 1, cracking was confined to the adhesive layer, with the advancing tip alternating consistently between the bounding metal adherends. The repetition rate of the characteristic pattern ($A-C$) is several times the thickness of the inner layer, t. Such growth pattern was observed in both fracture testings of adhesive joints and laminated composites, see Figs. 2 and 3. In the latter case, the laminate was multidirectional, but the failure itself occurred in the two 90 deg plies at the laminate midplane. These plies are bounded from each side by a zero degree layer that evidently barred crack shifting as did the metal adherends in Fig. 2. Figure 3b shows that within the two 90 deg plies, the crack tip followed a wavy path that avoided fiber breakage, thereby resulting only in matrix cracking. Because in the loading plane these plies are macroscopically homogeneous and

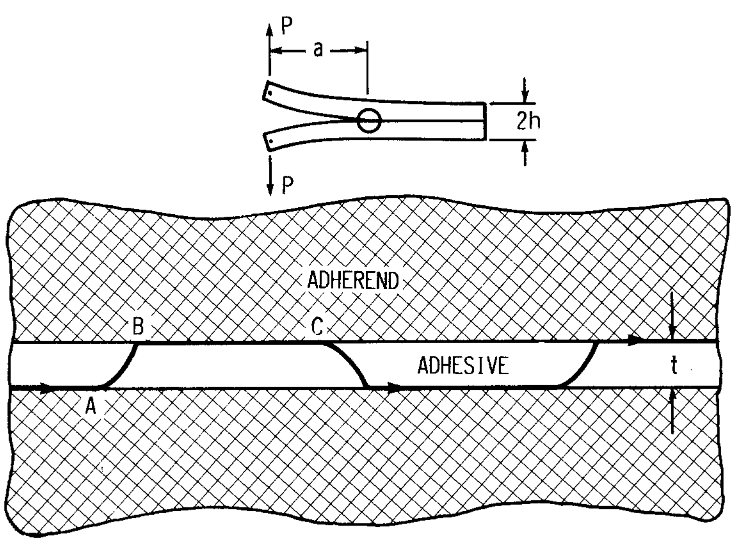

Figure 1. Crack trajectory (heavy line) in a DCB adhesive joint fracture specimen. The lower part is a magnified view of the circled area in the upper part.

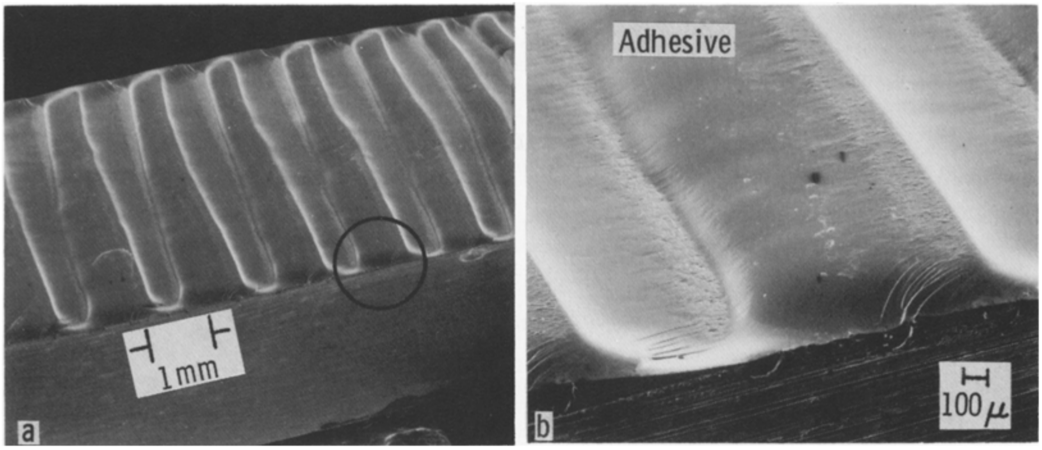

Figure 2. Alternating crack trajectory observed in testing of adhesive joint specimen at two magnifications. Growth is from left to right. Adhesive is Narmco 5208, a brittle epoxy. Adherend is aluminum. $t = 0.25$ mm, $h = 6.3$ mm.

isotropic, the mechanism responsible for the fracture pattern in the composite and in the adhesive joint specimens must be identical.

Crack path deviation in symmetrically-loaded isotropic specimens is generally explained from stability considerations. A crack is considered directionally unstable if it drastically shifts upon suffering a small perturbation. Experiments show that in a given test specimen the stability condition is governed by the crack length, and the tendency towards instability increases with increasing crack length. In particular, the transition from directionally stable to unstable cracking occurred when the slenderness ratio, a/h, (see Fig. 1) roughly exceeded unity [2].

Several analytical works have reported qualitative agreement with crack deviation experiments [2–4]. In these works it was shown that the stability of a crack is directly

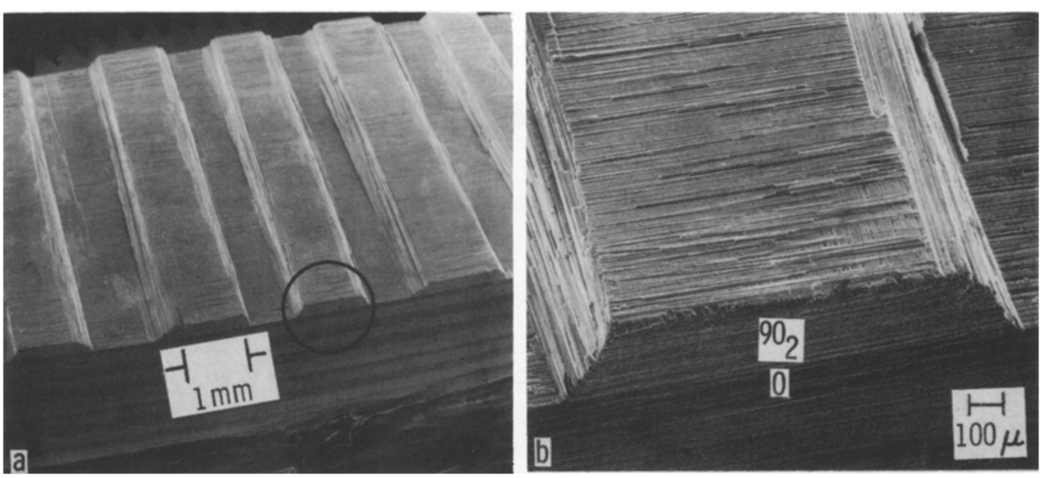

Figure 3. Alternating crack path in a T300/5208 multidirectional laminate. Layup is $(\pm 45/0_2/\pm 45/0_2/\pm 45/0/90)_{2s}$. Failure occurred in the two 90 deg plies at the laminate midplane. These plies are bounded from above and below by a zero degree ply with fiber orientation coinciding with that of the crack. The thickness of the 90 deg plies is 0.25 mm and the half laminate thickness is 3.1 mm.

controlled by the sign of the non-singular stress acting parallel to the crack line. While an analogous analysis for the present case tends to be complicated by such effects as material discontinuity and the free boundary, the essence of the crack structure from Fig. 1 is believed to be easily understood by deduction from the homogeneous and isotropic counterpart. Consider the interface crack with a crack tip at point A from Fig. 1. For the cases in Figs. 2 and 3, $a/h \gg 1$ so that judging from the homogeneous case [2] the crack is expected to shift, say along the path AB. At point B the crack is similarly expected to turn again. However, the free surface generated by the path AB modifies the crack tip stress field, with the gross effect of producing a local crack of small dimension. This increases the crack path stability, which may account for the colinear growth along BC that was observed in the experiments. (Note such a growth cannot be attributed to a weak interface, in both Figs. 2 and 3 the fracture along BC was cohesive). Now as the crack tip advances away from the free surface AB the length of the local crack increases, which leads to a gradual loss of directional stability. Evidently, the crack becomes unstable at point C where the crack length, $\overline{BC}$, is approximately four times the bond thickness, t. This process then continues indefinitely, with every deviation path being the mirror image of its predecessor.

Beyond the interesting geometrical aspects of the failure pattern in Fig. 1, we note a case in which crack directional stability consideration adversely affects the interpretation of fracture test results in nonhomogeneous materials. Quite often the interlaminar fracture toughness of multidirectional laminates is evaluated using a slender beam, DCB type configuration. With a possible exception of the case where the crack plane is located between two zero degree plies, the fracture path is generally found to wander into neighboring plies, thereby leading to intraply cracking and therefore to a nonconservative estimate of the true interlaminar fracture toughness [1]. This is manifested in the case of Fig. 3 where the calculated G_{IC} ($\sim$ 300 N/m) exceeds by a factor of four the interlaminar fracture of the laminate as evaluated using a 0/0 type interface. From the discussion above, however, it is quite possible that this tendency for crack path deviation producing large apparent toughness in a DCB type specimen would be totally suppressed if a compact tension type specimen (i.e. $a/h < 1$) is used instead. In fact, the occurrence of a planar, true interlaminar fracture in a bi-directional interface (i.e. 0/90, 0/45, etc.) was demonstrated in [1].

References

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