

Mode III and mixed-mode interlaminar fracture toughness and the factors affecting it

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We have previously discussed the concept of toughness in composites and its applicability as a material property [1]. We then proceeded with workshops on mode I [2] and mode II interlaminar fracture toughness [3]. We now proceed with the more complex loading modes, including mode III and mixed-mode. This paper provides a brief introduction to the challenges of defining and measuring interlaminar fracture toughness in these modes, as well as the factors that affect it.

Mode III (tearing) is the fracture mode associated with out-of-plane shear. It is less commonly studied than mode I (opening) and mode II (sliding), but it is important for certain loading cases, such as bolt holes and some impact damage scenarios. Several specimen geometries and fixture combinations have been proposed. The edge crack torsion test is the most common example [4, 5] (see Figure 1a). It uses a rectangular laminate with an edge delamination subjected to torsion. It can produce a dominant mode III and is reasonably reproducible with careful calibration. The extraction procedures are, however, cumbersome, and the test is sensitive to the details of the boundary conditions. An alternative method is the split cantilever beam test (see Figure 1b). developed by Donaldson [6]. This conceptually simple test, however, struggles to achieve full mode III. Another alternative is the angle-ply edge delamination test, also referred to as edge delamination tension [7] (see Figure 1c). Delamination migration also remains a significant concern in mode III tests [8].

Mixed-mode often refers to a combined mode I and II but could also include mode III. Achieving and maintaining a stable and well-defined mixed-mode ratio is challenging. Many of the traditional challenges in interlaminar fracture toughness measurements are even more pronounced in mixed-mode measurements: non-straight crack fronts, difficulty in detecting crack tips, especially when the mode II contribution is large, difficulty in establishing the initiation point, friction effects, and unstable crack propagation. The mixed-mode bending test is the only one that is standardised (ASTM D6671 [9]). This standard's data reduction method requires (1) the measurement of the elastic moduli E_{11} , E_{22} and G_{13} , hence requiring extra tests, and (2) accurate measurements of the delamination length, which is often challenging in practice. These challenges have led researchers to develop alternative data reduction methods [10, 11] and test fixtures, such as Arcan-type [12] or asymmetric double cantilever beam (ADCB) tests [13, 14].

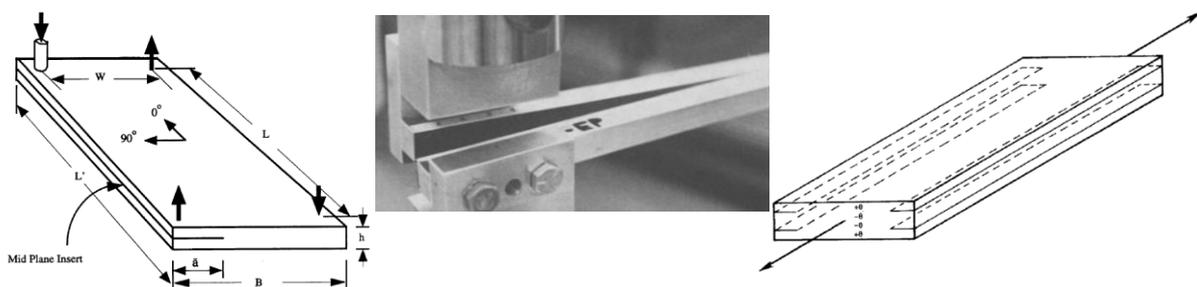


Figure 1: Mode III test geometries and fixtures: (a) the edge crack torsion test [5], (b) the split cantilever beam test [6] and the angle-ply edge delamination test [6].

Overall, mode III and mixed-mode tests are more challenging to perform than mode I and II tests. It remains a matter of debate whether it is even possible to achieve a pure mode III test, and identifying the precise mode mixity is a significant challenge. Additionally, there is debate on whether mode III should even be distinguished from mode II. Clearly, there are many challenges remaining in these test methods and their interpretation, which will provide ample food for discussion at the workshop.

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