

THE MECHANICS OF INTERFACE FRACTURE: (1) BRITTLE HOMOGENEOUS AND BI-MATERIAL INTERFACES

S. Wang¹, C.M. Harvey and J.D. Wood

*Department of Aeronautical and Automotive Engineering, Loughborough University, Loughborough,
Leicestershire LE11 3TU, United Kingdom*

Abstract: A powerful analytical methodology is discovered and is used to partition the total energy release rate of mixed-mode 1D fractures on brittle homogeneous or bi-material interfaces into its mode I and II components based on the classical and shear-deformable plate theories and 2D elasticity. Previously unsolvable problems are solved and confusions explained.

1. Introduction

Although interface fracture generally occurs as mixed-mode fracture with all three opening, shearing and tearing actions (i.e. mode I, II and III), 1D interface fracture has received more attention as it is simpler and still captures the essential mechanics. The expression ‘1D interface fracture’ means that a fracture propagates in one direction with mode I and mode II action only. Examples of 1D interface fracture include through-width delamination in double cantilever straight and curved beams and blisters in layered plates and shells (Figure 1). A central task in studying 1D interface fracture is to partition the total energy release rate (ERR) of a mixed-mode fracture into its individual mode I and II ERR components.

2. Results

A powerful orthogonal pure mode methodology is discovered based on a fundamental understanding of the mechanics of interface fracture [1-4]. The total ERR G of a 1D mixed-mode fracture on a brittle homogeneous or bi-material interface can be partitioned into its individual mode I and II ERR components, that is, G_I and G_{II} , by the following general form,

$$G_I = c_I \left(M_{1B} - \frac{M_{2B}}{\beta_1} - \frac{N_{1B}}{\beta_2} - \frac{N_{2B}}{\beta_3} - \frac{P_{2B}}{\beta_4} \right) \left(M_{1B} - \frac{M_{2B}}{\beta'_1} - \frac{N_{1B}}{\beta'_2} - \frac{N_{2B}}{\beta'_3} - \frac{P_{2B}}{\beta'_4} \right) \quad (1)$$

$$G_{II} = c_{II} \left(M_{1B} - \frac{M_{2B}}{\theta_1} - \frac{N_{1B}}{\theta_2} - \frac{N_{2B}}{\theta_3} - \frac{P_{2B}}{\theta_4} \right) \left(M_{1B} - \frac{M_{2B}}{\theta'_1} - \frac{N_{1B}}{\theta'_2} - \frac{N_{2B}}{\theta'_3} - \frac{P_{2B}}{\theta'_4} \right) \quad (2)$$

where c_I and c_{II} are two constants, and (θ_i, β_i) and (θ'_i, β'_i) (with $i=1,2,3,4$) represent the two sets of orthogonal pure modes which are material property- and thickness ratio-dependent. The pure mode sets, (θ_i, β_i) and (θ'_i, β'_i) , are different from each other when derived from classical beam or plate theory but are equal to each other when based on first-order shear-deformable beam or plate theory. When 2D elasticity is used they also coincide for homogeneous interfaces; however, for bi-material interfaces they are not only different to each other but are also crack extension size-dependent. $M_{1,2B}$, $N_{1,2B}$ and $P_{1,2B}$ are the crack tip bending moment, and in-plane and through-thickness shear forces per unit width, respectively, with subscripts 1 and 2 denoting the layers above and below the crack. Accurate predictions are observed (Figure 2) in comparison with the marked FEM results.

¹ Corresponding author

E-mail address: s.wang@lboro.ac.uk (Simon Wang)

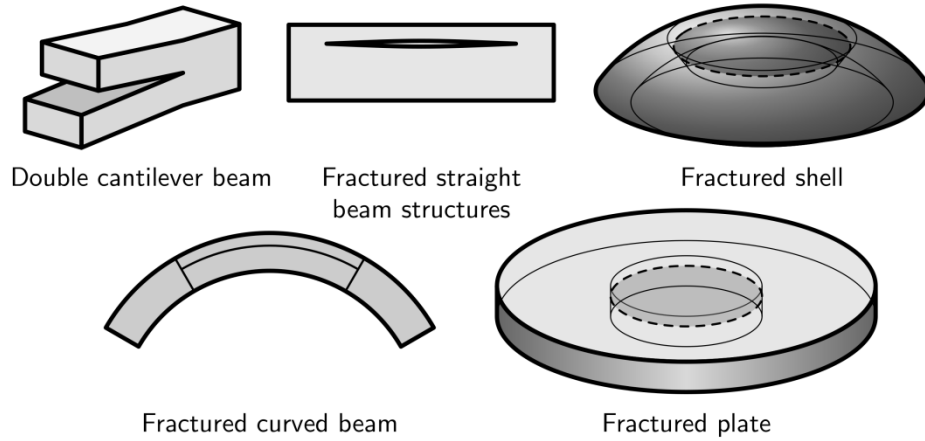


Figure 1. Examples of one-dimensional fracture

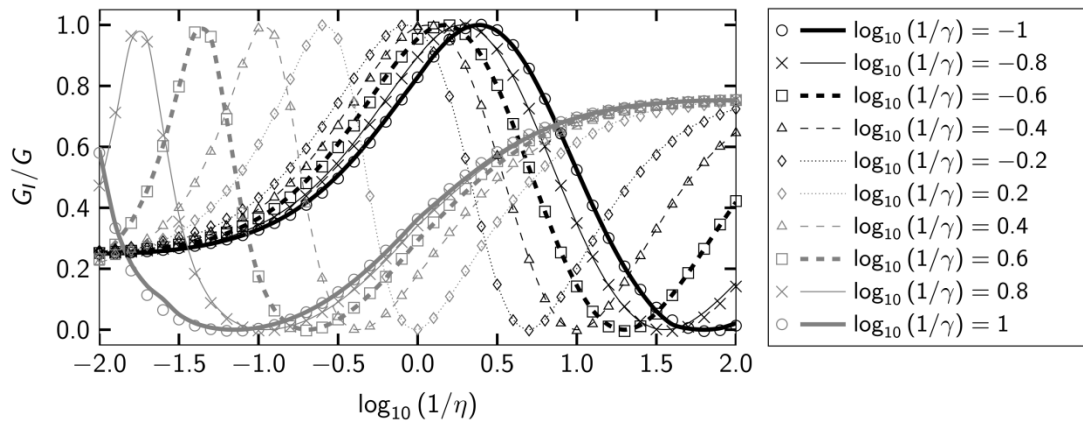


Figure 2. Comparison of the present analytical theory and FEM data for the ERR partition G_I/G at crack extension size $\delta a = 0.05$ with $N_{2B}/M_{1B} = 10$ and various thickness ratios $\gamma = h_2/h_1$ at a bi-material interface

3. Conclusions

The powerful orthogonal pure methodology reveals the fundamental mechanics of interface fractures, and solves previously unsolvable problems and clears previous confusions. The analytical theories provide valuable means for studying interface fractures on the macroscopic, microscopic and nano-scales.

References

- [1] S. Wang, C.M. Harvey. Mixed mode partition theories for one dimensional fracture, *Eng. Fract. Mech.* 2012;79:329-352.
- [2] C.M. Harvey, S. Wang, Mixed mode partition theories for one dimensional delamination in laminated composite beams, *Eng. Fract. Mech.* 2012;96:737-759.
- [3] C.M. Harvey, J.D. Wood, S. Wang, Brittle interfacial cracking between two dissimilar elastic layers: Part 1-Analytical development, *Compo. Struct.* 2015;134:1076-1085.
- [4] J.D. Wood, C.M. Harvey, S. Wang, Partition of mixed-mode fractures in 2D elastic orthotropic laminated beams under general loading, *Compo. Struct.* 2016;149:239-246.