Discussion: "On the Reference Length and Mode Mixity for a Bimaterial Interface" (Agrawal, A., and Karlsson, A. M., 2007, ASME J. Eng. Mater. Technol., 129, pp. 580–587)

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In a recent paper [1], the authors revisited a basic question of interfacial fracture mechanics, namely, the choice of the *characteristic reference length* l_c in the open model of interface cracks [2], and introduced a new procedure for an estimation of l_c based on the interface fracture toughness measurements. It is well known that the choice of a reference length l is related to the position along the abscissa axis of the *interface fracture toughness curve* for an elastic bimaterial, which represents the interfacial fracture toughness $\Gamma_{int}(\psi)$ as a function of the local phase angle ψ of the stress intensity factor [3]. The following two comments are essential with regard to the procedure for an estimation of l_c proposed by the authors in Sec. 3.2 and applied to their experimental results in Sec. 5.

First Comment. The procedure introduced by the authors tacitly assumes that the hypothetical interface fracture toughness curve is symmetric with respect to a vertical axis. However, a certain asymmetry of toughness curves for some bimaterials has been indicated by several toughness measurements [4–6] and also by numerical predictions [7]. Such an asymmetry is associated with different crack tip morphologies [8], with a tendency to opening or closing crack faces at a crack tip and to different shapes and volumes of the near-tip plastic zones [4,7] corresponding to the opposite signs of ψ.

In the case of an asymmetric toughness curve, the procedure introduced may lead to a misinterpretation of the experimental interface fracture toughness measurements, which will be briefly illustrated in the following. Fracture toughness measurements obtained by two different specimen configurations, such as those used by the authors [1] (denoted as A and B specimens), can be represented on a unique toughness curve if the same orientation of the axes of the local coordinate system (x,y) with respect to each material (aluminum and vinyl ester in Ref. [1]) is considered in each configuration (see Fig. 1). The relevant issue in Fig. 1 is the sign of ψ_1 associated with the reference length l_1. Let ρ_I denote the distance from the crack tip to the first interpenetration point [9,10]. Then, it is noteworthy to mention that in Configuration A, e.g., $\rho_I \approx 3.7 \times 10^{-7}$ μm (the interpenetration zone is of subatomic size, thus being physically meaningless) for $\psi_1 = -45$ deg, whereas in Configuration B, e.g., $\rho_I \approx 2.7$ μm (indicating a possibly physically relevant contact between the crack faces) for $\psi_1 = 45$ deg.

Now, in light of Fig. 1, the procedure introduced by the authors can be easily interpreted, as schematically shown in Fig. 2. Due to a different coordinate system used for A specimens, the toughness curve is mirrored with respect to the ordinate axis (Fig. 2(*a*)). After evaluation of l_c, both toughness curves, in Figs. 2(*a*) and

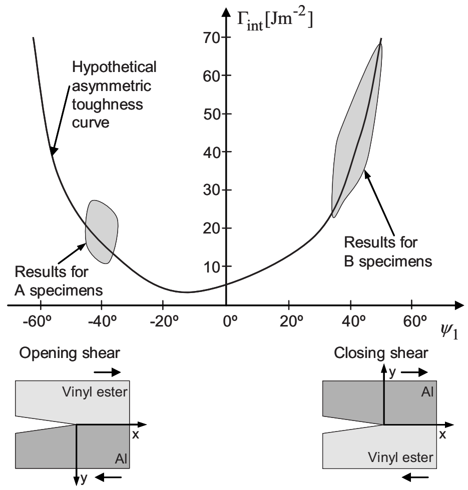

Fig. 1 Local configurations of A and B specimens in Ref. [1], and a hypothetical asymmetric interface fracture toughness curve with the experimental results from Ref. [1]

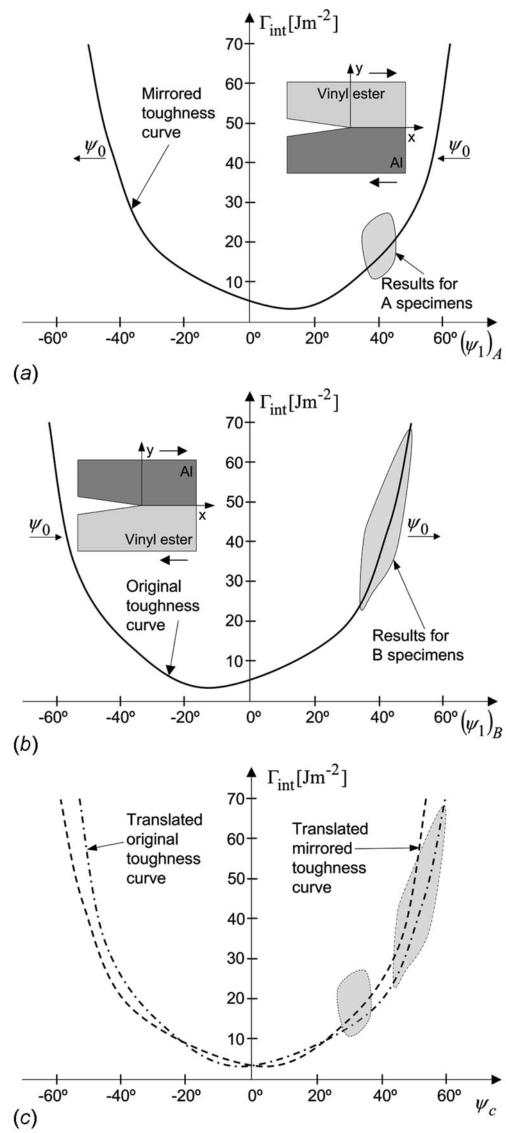

Fig. 2 (*a*) Mirrored toughness curve for A specimens, (*b*) toughness curve for B specimens, and (*c*) translated toughness curves by the procedure introduced in Ref. [1]

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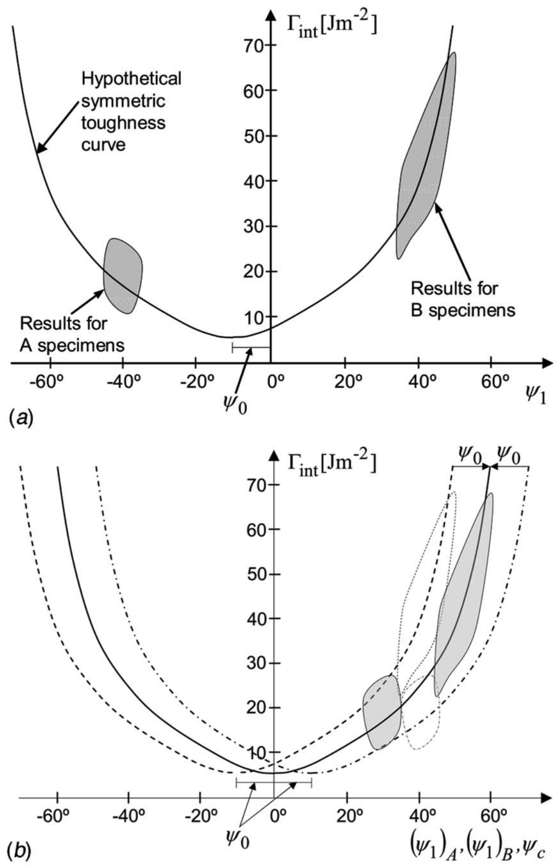

Fig. 3 (*a*) Hypothetical symmetric toughness curve, (*b*) Mirrored and original toughness curves and the resultant toughness curve obtained by the procedure introduced in Ref. [1]

2(*b*) are translated by an angle of magnitude $\psi_0 = \varepsilon \ln(l_c/l_1)$, resulting in two relatively close but different toughness curves (see Fig. 2(*c*)), which should not be interpreted as a unique toughness curve, as was done in Fig. 6 in Ref. [1].

Second Comment. In the case of a symmetric toughness curve for a bimaterial, the characteristic reference length l_c, estimated by the procedure introduced by the authors, leads to the toughness curve $\Gamma_{int}(\psi_c)$, which is symmetric with respect to the ordinate axis and achieves its minimum for $\psi_c = 0$ deg. This fact is illustrated schematically in Fig. 3, where it is seen that the distance between the original and the mirrored toughness curves is $2\psi_0$, ψ_0 giving the position of the minimum of the toughness curve. Translating each curve by an angle of magnitude $\psi_0 = \varepsilon \ln(l_c/l_1)$ results in a unique toughness curve, as done correctly in Fig. 6 in Ref. [1].

Summarizing, the value of l_c estimated by the procedure introduced in Ref. [1] has a clear physical meaning, but only in the case of interface fracture toughness curves which are symmetric with respect to a vertical axis.

References

[1] Agrawal, A., and Karlsson, A. M., 2007, "On the Reference Length and Mode Mixity for a Bimaterial Interface," ASME J. Eng. Mater. Technol., **129**, pp. 580–587.
[2] Rice, J. R., 1988, "Elastic Fracture Mechanics Concepts for Interfacial Cracks," ASME J. Appl. Mech., **55**, pp. 98–103.
[3] Hutchinson, J. W., and Suo, Z., 1992, "Mixed Mode Cracking in Layered Materials," Adv. Appl. Mech., **29**, pp. 3–191.
[4] Liechti, K. M., and Chai, Y. S., 1992, "Asymmetric Shielding in Interfacial Fracture Under In-Plane Shear," ASME J. Appl. Mech., **59**, pp. 295–304.
[5] Swadener, J. G., Liechti, K. M., and de Lozanne, A. L., 1999, "The Intrinsic Toughness and Adhesion Mechanisms of a Glass/Epoxy Interface," J. Mech. Phys. Solids, **47**, pp. 223–258.
[6] Dollhofer, J., Beckert, W., Lauke, B., and Schneider, K., 2001, "Fracture Mechanics Characterization of Mixed-Mode Toughness of Thermoplast/Glass Interfaces (Brittle/Ductile Interfacial Mixed-Mode Fracture)," J. Adhes. Sci. Technol., **15**, pp. 1559–1587.
[7] Tvergaard, V., and Hutchinson, J. W., 1993, "The Influence of Plasticity on Mixed Mode Interface Toughness," J. Mech. Phys. Solids, **41**, pp. 1119–1135.
[8] Stringfellow, R. G., and Freund, L. B., 1993, "The Effect of Interfacial Friction on the Buckle-Driven Spontaneous Delamination of a Compressed Thin Film," Int. J. Solids Struct., **30**, pp. 1379–1395.
[9] Hills, D. A., and Barber, J. R., 1993, "Interface Cracks," Int. J. Mech. Sci., **35**, pp. 27–37.
[10] Graciani, E., Mantič, V., and París, F., 2007, "On the Estimation of the First Interpenetration Point in the Open Model of Interface Cracks," Int. J. Fract., **143**, pp. 287–290.