INTERFACIAL AND NEAR-INTERFACIAL FRACTURE IN CERAMIC/METAL LAYERED SYSTEMS*

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The mechanical integrity and lifetime of composite structures, wear/thermal protective coatings, and microelectronic components are often controlled by the fracture and fatigue resistance of bimaterial interfaces; these properties in turn are generally a strong function of the nature of the crack path. For metals bonded to ceramics, considerations of failure in the vicinity of the ceramic/metal interface can thus be focused on where a crack will initiate, where it will propagate, how fast it will get there and what it will do when it arrives. This work addresses the last three of these concerns by considering the behavior of cracks at, or near, a thin metallic layer joining two monolithic ceramic substrates.

Crack-path studies were studied in two model ceramic-metal-ceramic layered systems, namely alumina/aluminum and glass/copper, chosen to reflect markedly different Dundurs' elastic-mismatch parameters, α and β. By initiating cracks (using Knoop indents) in the brittle substrate at varying distances from the ceramic/metal interface in four-point bend sandwich beams, cracks in both systems were found to follow trends predicted from asymptotic analyses of near-interfacial cracks: the cracks were attracted to the metal layer when both α and $\beta > 0$ and repelled from the layer when α and $\beta < 0$. The experimentally determined (curved) crack paths were analyzed using the finite-element method to determine the directionality of the near-tip driving force (ψ) along the propagation path; specifically, cracks in both systems were found to follow a trajectory where the local mode I driving force was at a maximum, i.e., cracks followed a $K_{II} = 0$ path. Additionally, numerical calculations were carried out for straight cracks parallel to, and at various distances from, the metal/ceramic interface in order to investigate the separate roles of α and β where finite geometry effects are important. These calculations show that the deviation of the phase angle, ψ, from that predicted by asymptotic theory, is dominated by the relative stiffness of the two materials, characterized by the parameter α.

The velocity of cracks in such metal/ceramic layered systems was additionally investigated system under nominally mode I far-field loading in both cyclic and monotonic conditions. Results for the aluminum/alumina systems revealed that under monotonic loading failure was caused by cracking within the metal layer or involved re-nucleation of the crack in the ceramic substrate; in either instance, the measured toughness was approximately the same. Under cyclic loading, however, cracks were invariably found to propagate along the interface; fatigue striations were observed on the metal side of the failure, indicating that crack advance had occurred by alternating shear, similar to mechanisms in monolithic aluminum. Such considerations of both crack path and crack velocity are discussed in light of conditions for optimal mechanical integrity in ceramic/metal layered structures.

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