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Indentation Based Techniques to Measure Stresses in Engineering Ceramics

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Abstract:

Engineering ceramics and glasses at Sandia are widely used in electronic packages, hermetic seals and optical components. For component functionality, the ceramic or glass is often associated with a metal or polymer, and in many cases, a strong bond is desired across this interface. Elastic and thermal expansion mismatches between the different materials create a state of residual stress in the ceramic/glass, which in extreme cases, manifest as failures during manufacturing or testing. Many of these failures occur close to, or at the interface. Thus, an understanding of the residual stress state is essential for the reliability and lifetime prediction of ceramics/glasses.

Despite the availability of enormous computing resources, a prediction of the residual stress state is not straight forward. For a model to accurately predict stresses in the ceramic/glass, knowledge of the physics and chemistry of the problem is a pre-requisite, and often for practical cases, the detailed knowledge needed is not available. For instance, chemical reactions at interfaces often create compounds whose properties are largely unknown. Viscous deformations in polymers and glass/glass-filled ceramics and the plastic behavior of metals strongly impact the residual stresses near interfaces. Therefore, precise information about the thermal environments during manufacturing and testing, and temperature-dependent thermal and viscous/elastic/plastic mechanical properties are needed for accurate prediction. For many engineering materials, these properties and proper constitutive behavior over the range of temperatures of interest are unknown.

Our work, therefore, has focused on deploying techniques for measuring residual stresses in components. We have made extensive use of indentation crack lengths using a sharp diamond (Vickers) indenter. The cracks in bilk materials are straight, and the difference in crack lengths between the stressed surface (in the component) to an unstressed surface can be related to the stress state using fracture mechanics. This simple approach has at least two limitations: (1) near curved interfaces, indentation cracks are curved, and (2) stresses are sampled over the entire crack length, which in many cases is of the order of several hundred microns. In the first part of the talk, a fracture mechanics approach that allows estimation of stresses from measurements of the curved crack lengths near curved interfaces is described. The analysis results are applied to measure stresses as a function of radial distance from a metal-ceramic interface in an electronic packaging material. In the second part of the talk, two additional approaches to measure stresses, over progressively smaller length scales, are described. The first approach is to use a cube-corner indenter, which due to its acuity, generates extremely small sized cracks. A demonstration of the technique to sample stress in ~10 micron region is demonstrated, and the successful implementation of the technique in component design is presented. A nano-indentation approach, currently under development, which may allow sampling stress across ~5 micron regions is also briefly described.

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