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Susanta Ghosh
Michigan Technological University, susantag@mtu.edu

Mark Coldran

Praveen Bulusu

Upendra Yadav

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Mechanics of Micro-Architectured Glass: Inverse Identification of Interface Properties and a Novel Analytical Model

Susanta Ghosh[1], Mark Coldran[2], Praveen Bulusu[1], Upendra Yadav[1], Trisha Sain[1]
(1) Department of Mechanical Engineering-Engineering Mechanics, Michigan Technological University, Houghton, MI, USA, e-mail: susantag@mtu.edu
(2) Currently at Ford Motor Company, MI, USA.

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Brittle materials such as glasses and ceramics are generally very stiff and hard but lack the toughness of metals when comparing their ability to absorb mechanical energy, resistance to catastrophic crack propagation, and ultimate strain to failure. These shortcomings in material properties severely limit the applications of glass and ceramics.

Recent experiments [1,3] have demonstrated that bio-inspired interlocking micro-architectures within a brittle material can increase its ductility and fracture toughness remarkably. These interlocking micro-architectures are generated by creating weaker interfaces in the bulk. The interface is designed such that it partitions the bulk into jigsaw shaped interlocking teeth. Under tensile loading the crack is guided through the weak interface and the teeth get engaged through interlocking, which is the key to higher toughness.

Despite showing tremendous promise to improve material properties, there is a lack in computational and analytical models for these interlocked systems. Besides, sufficient information about interface properties is not available from experiments.

<u>Finite element modeling and identification of the interface properties from the experiment</u>:

In the present paper the interface properties and the coefficient of friction, are inversely identified from the experimental data by developing a finite element model involving mixed mode cohesive zone technique for the weak interface, frictional contact for the teeth interlocking. Further, a novel approximate analytical model is derived for the opening-mode fracture at the interface and complete pullout response of the interlocking teeth. The analytical model also incorporates cohesive zone technique, non-Hertzian contact mechanics. The mode I fracture experiment is modeled using finite element software ABAQUS [2], see figure 1. The cohesive and contact properties used in the finite element mode are inversely identified from the experimental data published in [1].

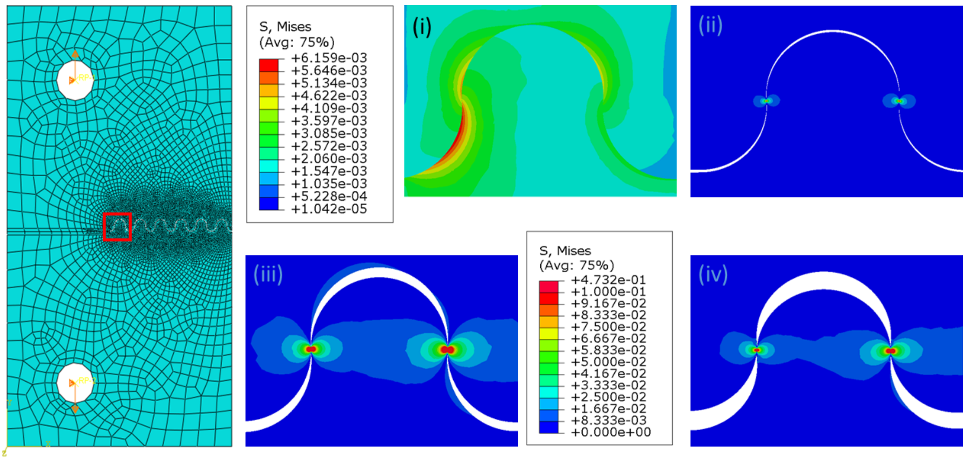

Figure 1: The FE model and the corresponding von Mises stress at the first tooth for (i-iv) 2, 20, 100, 170 μm displacements respectively.

Numerical-analytical Model:

The overall approach consists of obtaining the contact and the cohesive forces in terms of the displacements, and using it in the moment equilibrium equation to determine the applied load. The proposed numerical-analytical model was derived using a non-Hertzian contact solution (following [3,4]) at the contact points between the tabs approximating them as disks, and kinematic unzipping modeled as independent of resultant forces apart from some minor corrections due to elastic deformations. The numerical-analytical model endowed with the inversely identified interface properties could match accurately with our finite element prediction and the published experimental results as shown in figure 2.

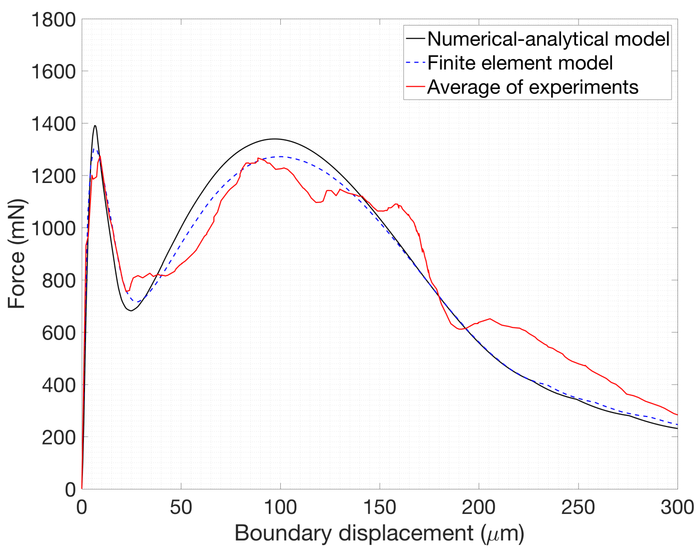

Figure 2: Force-displacement curves obtained from the experiments, the finite element model (FEA), and the numerical-analytical model.

The proposed experimentally validated, computational model and numerical-analytical model of this interlocking behavior would enable performance optimization of the interlocking micro-architecture system and their large-scale applications.

Acknowledgments

SUPERIOR, a high-performance computing cluster at Michigan Technological University, was used in obtaining the finite element results presented in this abstract.

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