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Effective toughness of heterogeneous media

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Abstract

We propose a versatile approach to computing the effective toughness of heterogeneous media. This approach focusses on the material property independent of the details of the boundary condition. The key idea is what we call a surfing boundary condition, where a steadily propagating crack opening displacement is applied as a boundary condition to a large domain while the crack set is allowed to evolve as it chooses. The approach is verified and used to study examples in brittle fracture. We demonstrate that effective toughness is different from effective or weighted surface area of the crack set. Further, we demonstrate that elastic heterogeneity can have a profound effect on fracture toughness: it can be a significant toughening mechanism and it can lead to toughness asymmetry wherein the toughness depends not only on direction but also on the sense of propagation. The role of length-scale is also discussed.

1 Introduction

Fracture mechanics, starting with the work of Griffith [31], is a grand success of the past century with the development of a profound theory that can describe crack propagation in complex macroscopic situations. However, this theory requires an empirical parameter – the fracture toughness. How this parameter arises, or how it changes, or even what it means in the microstructural hierarchy of materials remains incompletely understood.

Over the last few decades a number of composite structures have been developed, especially in the context of ceramics, where microstructural features have been exploited to enhance the toughness. Consequently, there is an extensive literature on the fracture toughness of composite materials, e.g. [16, 19, 23, 25, 26, 30, 35, 50]. These composites also motivated systematic mathematical formulation of the change in stress intensity with perturbations in the crack front and modulus [29, 47]. However, this work is generally limited to particular microstructures of relevance to composites.

The relation between random microstructures and observable features including morphology of crack surfaces and rate dependance has received much attention with the discovery of some universal scaling laws [10, 11, 12, 45, 46]. However, these are limited to random microstructures