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Lattice simulations for evaluating interface fracture of masonry composites

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ABSTRACT

The brick–mortar bond is often the weakest link in the masonry composites. The localization of fracture processes at this bi-material interface plays an important role in the failure of this assemblage. These micro-level fracture processes control the nonlinear behavior of the brick–mortar interface which significantly affects the global behavior of the masonry structure in the continuum macro level. This study focuses on 2-D lattice-based fracture simulations to characterize progressive debonding of brick–mortar interfaces and to determine fracture properties in unreinforced masonry composites. Using the fundamental argument of Griffith which transforms potential energy into surface energy, lattice erosion is used to determine the critical energy release rate and other fracture quantities from basic strength properties of lattice struts that are removed upon failure. This micro-level information serves to upscale the lattice fracture arguments onto the meso-scale to quantify the fracture energy of traction-separation cohesive zone models in the context of continuum F.E. simulations of heterogeneous media like masonry.

1. Introduction

Masonry is the oldest building material which is still used in building constructions around the world for its low cost material and broad availability, its sound insulation properties and energy efficiency, and also construction simplicity. There have been important new developments in analyzing masonry structures in the form of composite material in the last decades. However, due to the lack of in-depth insight and probably models for the complex behavior of masonry composite consisting of brick, mortar, and the bond in between, its development of design rules has not kept pace with those of concrete and steel.

This might be one main reason to prevent the innovative applications of structural masonry. Unreinforced masonry is a heterogeneous, inelastic, and anisotropic material made of two major components, brick units and mortar joints exhibiting very different stiffness, strength and ductility properties. The brick–mortar interface which is the weakest part in the masonry composite plays an important role in the failure of this assemblage. A number of investigations have been conducted on different aspects of masonry and the interface behavior between brick and mortar joints, where an interface element was usually considered with a continuum-based damage or plasticity formulation to account for the brick–mortar interface degradation [1–10]. In the methods based on the theory of plasticity and damage mechanics, the displacement field is continuous over the domain and special techniques need to be accounted for embedding discontinuities and cracks on the domain. However, in the approaches based on fracture mechanics, the displacement field is discontinuous which accounts for the cracks and strong discontinuities.

There have been rare investigations regarding the interfacial fracture properties and toughness of masonry interfaces. In many bi-material systems like composites and microelectronic devices, the fracture of interfaces is a critical phenomenon, which in many circumstances governs the failure behavior of those systems. The fracture of bi-material interfaces has been studied by many researchers. Muskhelishvili [11] in his pioneering work employed the concept of complex variables and complex functions to represent the displacement and stress fields of plane problems using complex variables. He used complex functions since the properties of a complex variable are generally well-known. Williams [12] investigated the plane problem of dissimilar materials with a semi-infinite crack. He observed for the first time that stresses at the crack tip have an oscillatory character of type $r^{-1/2}\sin(\varepsilon \log r)$, where r is the radial distance from the crack tip and ε is a function of bi-material elastic mismatch. Rice and Sih [13] developed a method for determining Goursat functions for dissimilar materials bonded along straight-line interfaces. They combined an Eigen-function

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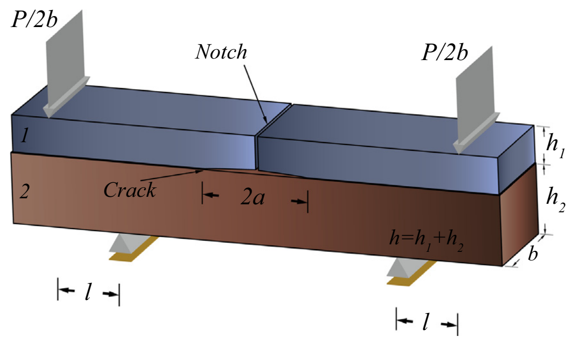

Fig. 1. The pre-notched bi-material four-point bending beam with two symmetrical interfacial cracks [18].

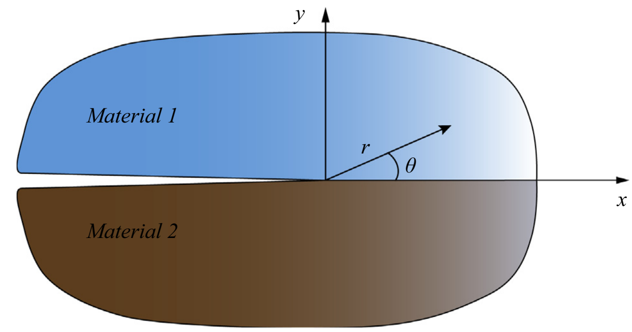

Fig. 2. A small region near crack tip along bi-material interface.

expansion method with the complex function of Muskhelishvili to solve the problems of isolated forces on surface of a semi-infinite crack and an infinite plate with a crack subjected to stresses at infinity. England [14], Erdogan [15], and Rice [16] also investigated the singular near-tip field of the interface crack problems. Parks [17] developed the "virtual crack extension" method which is a Finite Element technique for determining elastic crack tip stress intensity factors. In this method, the single crack is "advanced" by moving nodal points rather than by removing nodal tractions at the crack tip and performing a second analysis. Charalambides and his colleagues [18] devised an interesting test specimen which is capable of measuring the fracture resistance of bi-material interfaces. The test specimen is a four-point bending beam made of two dissimilar materials with a notch at the middle of the beam, as shown in Fig. 1. In their numerical Finite Element solutions, they obtained graphs for the energy release rate, stress intensity factor, and loading phase angle considering a pre-cracked notched symmetric composite beam model. Matos et al. [19] presented a numerical method for calculating stress intensity factors in bi-material interfaces. Their method is based on the *J*-integral using the "virtual crack extension" method, or energy method developed by Parks [17,20]. They compared the stress intensities obtained by the energy method and the "crack surface displacement" method. Charalambides et al. and Matos et al., in their simulations, considered a pre-cracked Finite Element mesh with length *a* and applied the virtual crack extension

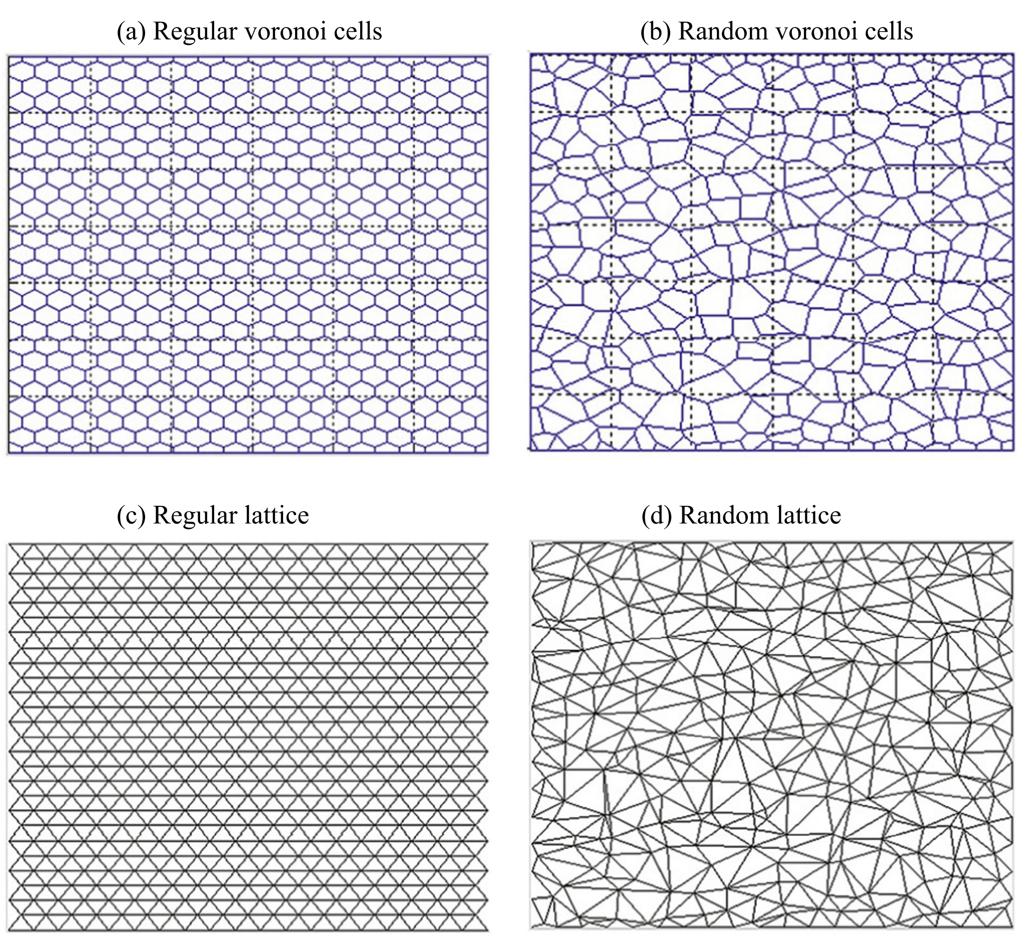

Fig. 3. Discretization process of a rectangular continuum domain into particles and lattice struts using Voronoi formulation, (a) a regular discretization, (b) a random discretization, (c) a regular lattice, and (d) a random lattice.