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A Quadtree-Polygon-Based Scaled Boundary Finite Element Method for Crack Propagation Modeling in Functionally Graded Materials

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Abstract

This paper presents a method to improve the computational efficiency of the scaled boundary finite element formulation for functionally graded materials. Both isotropic and orthotropic functionally graded materials are considered. This is achieved using a combination of quadtree and polygon meshes. This hybrid meshing approach is particularly suitable to be used with the SBFEM for functionally graded materials because of the significant amount of calculations required to compute the stiffness matrices of the polygons/cells in the mesh. When a quadtree structure is adopted, most of the variables required for the numerical simulation can be pre-computed and stored in the memory, retrieved and scaled as required during the computations, leading to an efficient method for crack propagation modeling. The scaled boundary finite element formulation enables accurate computation of the stress intensity factors directly from the stress solutions without any special post-processing techniques or local mesh refinement in the vicinity of the crack tip. Numerical benchmarks demonstrate the efficiency of the proposed method as opposed to using a purely polygon-mesh based approach.

Keywords: scaled boundary finite element method, functionally graded materials, quadtree, fracture, crack propagation

1. Introduction

The scaled boundary finite element method (SBFEM) is a semi-analytical numerical technique that was developed by Wolf [1]. The initial development of the SBFEM was targeted at solving problems of unbounded media to overcome the prevalent difficulties in mainstream numerical approaches to model the radiation damping condition in the far-field [2]. It was later discovered that the SBFEM also has niche applications in problems related to fracture [3]. Specifically, the asymptotic stress fields in the vicinity of stress concentrations are analytically represented in the semi-analytical solutions of the stress field in the SBFEM. Therefore, unlike conventional numerical methods such as the finite element method (FEM), fine meshes in the vicinity of crack tips or local enrichment functions are not required when modeling fracture. Only a single subdomain/polygon that encompasses a crack tip is required. This advantage has enabled the development of efficient algorithms to model crack propagation under linear elastic conditions e.g. [4, 5, 6], cohesive fracture e.g. [7, 8, 9] and elasto-dynamic fracture e.g. [10, 11].

The theory of the SBFEM has been recently, further developed for functionally graded materials (FGM) by Chiong et al. [12]. This development was possible through the introduction of scaled boundary shape functions. The shape functions are applicable to star convex polygons with an arbitrary number of sides. The material gradient is locally approximated by a least squares polynomial fit over a rosette of sampling points defined over each polygon in the mesh.

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