An Improved Peridynamic Model with Energy-Based Micromodulus Correction Method for Fracture in Particle Reinforced Composites

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Abstract. We introduce an improved bond-based peridynamic (BPD) model for simulating brittle fracture in particle reinforced composites based on a micromodulus correction approach. In the peridynamic (PD) constitutive model of particle reinforced composites, three kinds of interactive bond forces are considered, and precise definition of mechanical properties for PD bonds is essential for the fracture analysis in particle reinforced composites. A new micromodulus model of PD bonds for particle reinforced composites is proposed based on the equivalence between the elastic strain energy density of classical continuum mechanics and peridynamic model and the harmonic average approach. The damage of particle reinforced composites is defined locally at the level of pairwise bond, and the critical stretch criterion is described as a function of fracture energy based on the composite failure theory. The algorithm procedure for the improved BPD model based on the finite element/discontinuous Galerkin finite element method is brought forward in detail. Several numerical examples are performed to test the feasibility and effectiveness of the proposed model and algorithm in analysis of elastic deformation, crack nucleation and propagation in particle reinforced composites. Additionally, the impact of distribution, shape and size of particles on the fractures of composite materials are also investigated. Numerical results demonstrate that the improved BPD model can effectively be used to analyze the fracture in particle reinforced composites.

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1 Introduction

With the development of science and technology, particle reinforced composites, such as the concrete materials, polymer composites and short-fiber reinforced composites, are widely used in the construction, industry and other fields due to their good mechanical properties [1–3]. Fracture and failure are important problems in the service process of composite materials, and understanding the fracture and failure in particle reinforced composite material is essential for the design of composite parts with increased fracture toughness. Some numerical simulation techniques have been proposed to compute the fracture and failure of particle reinforced composites. Li et al. [4] introduced a finite element model to analyze the influence of volume fraction of particles on the deformation and failure of composites. Gao et al. [5] established a microstructure finite element model to predict the effect of particle size and shape on the plastic deformation and fracture of particle reinforced composites. However, the traditional finite element method needs mesh reconstruction to deal with fracture problems. After that, Belytschko and Black [6] proposed the extended finite element method (XFEM) by introducing the enrichment function in the traditional finite element method. Then, Ye et al. [7] integrated the XFEM into ABAQUS to simulate crack growth and predict the effect of reinforcing particles on the crack growth of composites. Du et al. [8] combined the XFEM with indirect tensile test to analyze the influence of the initial crack configuration on the enhancement effect of aggregate particle composite materials. However, the pre-crack is required for the simulation by the XFEM. The phase field model can well describe the initiation, propagation and coalescence of the cracks without assuming the pre-crack in advance. Lu et al. [9] applied the phase field model to simulate the crack nucleation and propagation in brittle linear elastic two-phase perforated/particle composites under quasi-static tensile load. Da et al. [10] used the phase field method to approximate the discontinuity surface of composites, and the fracture resistance of the composite material was optimized by redistributing the inclusion phase. Besides, Pan et al. [11] proposed a discrete element method combined with the cohesive zone model to study the relationship between the micro-geometric heterogeneity and rock crack initiation and failure mode.

Peridynamics (PD) theory, introduced by Silling [12] in 2000, is a nonlocal model that uses spatial integration instead of differentiation to rebuild the equation of motion, which solves the singularity problem caused by spatial discontinuity in the fracture problem. Based on this, PD model is widely used in the study of crack nucleation and propagation [13–17]. Different from the homogeneous materials, particle reinforced composites have more complicated deformation behaviors due to the existence of bi-material interfaces and the differences between the components of composites. Some works have fo-