Phase field modeling of brittle fracture simulation on the cell-based smooth finite element framework

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Abstract

Fracture is one of the main failure phenomena of engineering materials and structural components. Therefore, simulating fracture behavior using numerical methods has captured many researchers' attentions. Among various numerical techniques, phase field method is able to produce complex crack patterns, including crack branching and crack coalescence. It has some advantages over the Extended Finite Element Method, Cohesive Zone Element Method and the Virtual Closure Crack Technique.

Phase field method, known as the variational approach to fracture, was first proposed by Francfort and Marigo [1], who presented the fracture problem by minimizing a potential energy based on the Griffith's theory of brittle fracture inspired by the works of Mumford and Shah and Ambrosio and Tortorelli. A spectrum decomposition of strain tensor was proposed by Miehe [2] based on the hypothesis that the crack propagation was dominated by tension part of strain energy. The finite element method is considered as an excellent choice to solve stress equilibrium equations and phase field evolution equations of fracture phase field method [3]. But, the framework based on the standard FEM will produce inevitably the overestimated stiffness and the mesh distortion are the main factors that have an influence on the accuracy of solution.

In this work, a novel phase field model for brittle fracture is developed based on cell-based smooth finite element method (CS-FEM). The proposed model can effectively alleviate the mesh distortion resulted from tension-compression split and non-linearity of stress equilibrium equation lying in the phase field method based on the standard FEM. A second-order stress tensor and a fourth-order constitutive tensor based on decomposition of strain tensor are derived vigorously. A fundamental framework of CS-FEM is established to solve the phase field fracture problems, implemented by User-defined Element (UEL) subroutine of ABAQUS software. The derived stress tensors and the elastic constitutive tensors in the proposed fracture phase field model is validated by solving two benchmark numerical examples containing a horizontal notch from the midpoint of the left edge to the center in a square plate.

Finally, influences of phase field parameter, CS-FEM parameter, mesh size and irregularity on the crack surface evolution are investigated. Numerical studies show that the width of the phase field transitional zone has great significant influence on the crack propagation and the peak value of force. According to the expression of fracture surface density, the wider the transitional zone is, the smaller the fracture energy density is. The number of the smooth cell is not the main factor that affects the results remarkably. The choice of 4 smooth cells is optimal on account of computational cost and convergence. Mesh size is inversely to the peak value of load-displacement curves and the total number of mesh will influence the total stiffness of structure. In a word, they are mesh-sensitive. Mesh irregularity has slight impact

on the results. As long as the mesh of the crack propagation zone is refined enough, the result will not change apparently. Compared to the phase filed model based on standard FEM, the simulation results demonstrate that the proposed fracture phase field based on the CS-FEM is not affected by mesh distortion distinctly.

Keywords: Phase field; Brittle fracture; Cell-based smooth finite element method; Tenison-compression split; Crack path

References

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