

PROCEEDINGS

Explicit Computational Homogenization of Woven Fiber-Reinforced Composites with Efficient Penalty-Based Periodic Boundary Conditions

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ABSTRACT

Computational homogenization is increasingly used to predict the effective mechanical response of fiber-reinforced composites. For woven composites with progressive damage, interfacial decohesion, large deformation and contact, explicit finite element methods provide better robustness than implicit methods in strongly nonlinear regimes. However, the enforcement of periodic boundary conditions often leads to a substantial loss of computational efficiency in commercial explicit solvers, which limits the practical application of explicit multiscale analysis. In this work, an efficient framework is developed for imposing periodic boundary conditions in explicit finite element homogenization. Four representative constraint-enforcement approaches, including the transformation method, the Lagrange multiplier method, the penalty method and Nitsche's method, are examined within a unified explicit time-integration framework. The analysis shows that the conventional transformation and Lagrange multiplier approaches destroy the diagonal structure of the lumped mass matrix and introduce dense mass-like operators, resulting in poor computational scalability. By contrast, the stiffness-penalty and Nitsche-type formulations preserve the diagonal mass structure and are therefore more suitable for explicit analysis. Based on this understanding, a non-intrusive penalty-based implementation is proposed for commercial explicit finite element solvers by using high-stiffness spring elements to enforce periodic boundary conditions. The proposed approach is first verified on a homogeneous three-dimensional unit cell and then applied to a mesoscale three-dimensional woven composite model involving cohesive interfaces, damage evolution and contact between cracked surfaces. The results show that the proposed method can reproduce the initial homogenized stress-strain response obtained by the implicit solver, while achieving superior robustness in the strongly nonlinear regime where implicit analysis may fail to converge. The present study provides an efficient and practical route for explicit computational homogenization of advanced woven fiber-reinforced composites, and offers useful guidance for multiscale simulation of complex composite systems with strong nonlinearity and internal interactions.

KEYWORDS

Computational homogenization; explicit fe method; periodic boundary conditions; progressive damage

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