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Dynamic Mechanical Behaviors of Lattice Structures with Explicit Direct FE^2

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ABSTRACT

Lightweight lattice structures exhibit significant potential in energy absorption, wave manipulation, and thermal insulation due to their high degree of design freedom. However, the design of performance-guided, sophisticated lattice architectures poses substantial challenges for numerical simulation, particularly under dynamic loading conditions due to strong nonlinearities. Single-scale finite element analysis of large-scale lattice structures is computationally prohibitive for such problems. To address this limitation, multiscale finite element approaches have been developed, among which the Direct finite element square (Direct FE^2 or DFE^2) method, originally proposed by Tan [1] and subsequently extended by Liu [2,3], has shown considerable promise.

In this work, a three-dimensional explicit DFE^2 framework is proposed and implemented within a stress and density scaling framework to eliminate potential contact issues between representative volume elements within a single macroscopic element. Both global and local impact responses of additively manufactured lattice structures are investigated using the proposed method, and corresponding drop-weight impact experiments are conducted to validate the numerical predictions. The simulation results show approximate agreement with experiments in terms of engineering stress–strain responses and deformation patterns. Discrepancies between simulations and experiments are primarily attributed to the simplified beam-based lattice modeling and the inter-cell interactions.

The engineering applicability of the proposed method is further demonstrated through the simulation of a simplified automotive bumper filled with lattice structures subjected to oblique impact loading. The method successfully captures the sequential deformation mechanisms with favorable accuracy and significantly reduced computational cost. These results demonstrate the strong potential of the explicit DFE^2 framework for efficient and reliable prediction of the dynamic mechanical performance of lattice structures.

KEYWORDS

Lattice structures; dynamic mechanical behaviors; direct FE^2

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