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A Spatiotemporal Nonlocal Model for Overall Dynamics of Composites and Its Analytical Solutions

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ABSTRACT

The prediction of overall dynamics of composite materials has been an intriguing research topic more than a century, and numerous approaches have been developed for this topic. One of the most successful representatives is the classical micromechanical models which assume that the behavior of a composite is the same as its constituents except for the difference in mechanical properties, e.g., effective moduli. With the development of advanced composite materials in recent years, especially metamaterials, it is found that the classical micromechanical models cannot describe complex dynamic responses of composites such as the dispersion and bandgaps of elastic waves. Thus, some generalized continuum models for composites proposed at the end of last century, e.g., the Willis formulation and Mindlin models, have attracted the attention of scientists. But in these generalized continuum models, the relations of their coefficients or operators to the microstructural information are unclear. The generalized continuum models with microstructure-dependent coefficients for overall dynamics of composite materials are still scarce.

In this work, we develop a spatiotemporal nonlocal model for overall dynamics of composites through a bottom-up dynamic homogenization method. All the coefficients of our model can be explicitly determined by microstructural parameters. Our model can capture the dispersion and bandgaps of elastic waves in composites, and degenerate into the spatiotemporal nonlocal models, temporal nonlocal models, spatial nonlocal models and classical micromechanical models available in the literature, so it sheds light on the physical mechanisms of these models. The analytical solutions of our spatiotemporal nonlocal models are further derived to manifest the overall dynamic responses of composites. We first find that the spatiotemporal nonlocal model has two different Green's functions for the convolutions with respect to the initial condition and the body force, which are radically different from those of other continuum models. The analytical solutions of our model are validated by comparison with the results obtained by direct numerical simulations of a sandwich composite strip through the finite element method. Finally, the analytical solutions are used to quantitatively depict the microstructural effects on overall dynamics of composites. The framework of this work is also applicable for other physical systems, e.g., heat conduction in composites, diffusion in multi-phase systems, and multi-field coupling analysis in piezoelectric composites.

KEYWORDS

Spatiotemporal nonlocal model; dispersion relation; dynamic green's function; homogenization method

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.