Machine learning-boosted nonlinear homogenization

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Abstract

Previous research has established nonlinear homogenization as an efficient technique for deriving macroscopic constitutive relations and field statistics in heterogeneous (i.e. composite) materials. This method involves optimal linearization of the nonlinear composite, resulting in a best linear comparison composite that shares identical microstructure and field statistics with the nonlinear material. However, the computational time associated with this method increases as the fidelity of the material representation improves, limiting its practical implementation in commercial finite element software for large-scale structural calculations in which a Representative Volume Element must be considered at each integration point. To overcome this limitation without sacrificing precision or efficiency, machine learning can be employed to develop a digital twin of the homogenization-based constitutive law. This approach enables realtime prediction of macroscopic material behavior while maintaining accuracy. The effectiveness of this approach has been demonstrated for twophase composites with nonlinear power-law constitutive relations, and it has been successfully extended to model the complex three-dimensional behavior of viscoplastic polycrystals. In the latter case, a significant reduction in computational time has been achieved without compromising the precision of nonlinear homogenization method outputs.

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