A Mixed Wavelet-Learning Method of Predicting Macroscopic Effective Heat Transfer Conductivities of Braided Composite Materials

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Abstract. In this paper, a novel mixed wavelet-learning method is developed for predicting macroscopic effective heat transfer conductivities of braided composite materials with heterogeneous thermal conductivity. This innovative methodology integrates respective superiorities of multi-scale modeling, wavelet transform and neural networks together. By the aid of asymptotic homogenization method (AHM), off-line multi-scale modeling is accomplished for establishing the material database with high-dimensional and highly-complex mappings. The multi-scale material database and the wavelet-learning strategy ease the on-line training of neural networks, and enable us to efficiently build relatively simple networks that have an essentially increasing capacity and resisting noise for approximating the high-complexity mappings. Moreover, it should be emphasized that the wavelet-learning strategy can not only extract essential data characteristics from the material database, but also achieve a tremendous reduction in input data of neural networks. The numerical experiments performed using multiple 3D braided composite models verify the excellent performance of the presented mixed approach. The numerical results demonstrate that the mixed wavelet-learning methodology is a robust method for computing the macroscopic effective heat transfer conductivities with distinct heterogeneity patterns. The presented method can enormously decrease the computational time, and can be further expanded into estimating macroscopic effective mechanical properties of braided composites.

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1 Introduction

To meet the requirements for material structures and functions in aviation and aerospace engineering applications, braided composite materials as an advanced composite materials have been developed in recent years [1]. Compared with the traditional laminate composites, they have a highly integrated spatial interlocking network structure and can effectively avoid delamination failure, which give them excellent physical properties, such as good thermal stability, high heat fatigue resistance and high impact toughness, etc. In practical engineering applications, these braided composites are widely used in the manufacture of aircraft fuselage, wing and heat insulation structure and usually served under complex thermal environments [1]. Because of a great application prospect, the heat transfer performances of braided composite materials have been a research hotspot of scientists and engineers. In order to provide a solid fundamental theory and high-performance algorithm for the design and optimization of the novel braided composite materials, it is of great application value and theoretical significance to study the effective prediction method of the heat transfer conductivities of braided composite materials.

However, the complicated microscopic structure and various forming constituents of braided composite materials have long posed difficulties to predict their macroscopic effective thermal transfer properties. Up to now, researchers have developed many analytical approaches to compute the macroscopic effective thermal transfer properties of composite materials. However, these analytical methods can only predict the macroscopic effective heat transfer conductivities of composite materials with simple microscopic structure, which is ineffective to analyze the equivalent thermal performances of braided composite materials due to their complex microscopic structure [2–5]. Moreover, numerical methods have been presented to compute the macroscopic effective thermal performances of composite materials [6–11]. These numerical methods enable us to the accurate prediction and analysis of the equivalent thermal conductivities of composite materials with complicated microscopic structure. However, various microscopic structures of braided composite materials lead to repeatedly compute the microscopic cell problems for estimating the macroscopic effective material parameters of new braided composites once again, which will result in an immense cost of computational resources. Moreover, traditional numerical methods can not effectively utilize the microscopic structure information and predicted effective material parameters of previous braided composite samples for estimating the equivalent material parameters of new braided composite sample. Therefore, it is necessary to develop a novel and efficient method to predict the equivalent heat transfer conductivities of braided composites, which can avoid repeated numerical simulation.