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A Multi-Scale Model on the Electromechanically Coupled Sensing Characteristics of Low-Dimensional Nanocomposite Strain Sensor

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ABSTRACT

In contrast to the conventional piezoelectric sensor, the CNT-based nanocomposite strain sensor (CNCSS) serves as a new category of high-performance strain sensor. The bottleneck for evaluating sensing capacities of CNCSS lies in the nonlinear electromechanical coupling mechanism and extra high computational costs of multi-scale simulation. In this paper, a novel multi-scale FE^2 model and a machine learning accelerated FE-RNN computational model have both been developed on the strain sensing capacities of high-performance CNCSS. First, a multi-scale electromechanically coupled FE^2 model is established for the CNCSS with a realistic configuration. The electromechanically coupled mechanism is illustrated by a loading-dependent tunneling model, which is highly dependent on the tunneling distance between the adjacent CNTs. The developed coupled FE^2 model is able to predict the strain sensing performance of CNCSS with a macroscopic configuration while considering specific microstructural characteristics. Then, an electromechanically coupled recurrent neural network (RNN) surrogate model is utilized to accelerate the FE^2 model in the microscopic scale. The developed FE-RNN model can accelerate the microscopic simulation of RVE for a continuous range of microstructural parameters. The predicted sensing characteristics via the developed FE^2 model and accelerated FE-RNN model are both highly consistent with the experiment of CNT/epoxy nanocomposite strain sensor under a realistic configuration. Especially at the high strain loading, the predicted results reflect the sharp increase of sensing capacities for CNCSS. The accelerated FE-RNN approach is concluded to possess the advantage over the FE^2 model on the structural analysis by significantly reducing the computational costs by 97%. The developed FE-RNN scheme is capable of providing rapid design instructions for the microstructure of high-performance strain sensors.

KEYWORDS

Sensing behaviors; strain sensor; multi-scale; realistic configuration

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