WAVELET TRANSFORM FOR POLYMER COMPOSITES

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Industrial composite materials consist of a large number of microstructural components with different characteristics, the combination of which determines the properties of the material as a whole. The processes used in composite materials are described by differential equations with rapidly oscillating coefficients. The numerical solution of these problems requires significant computational costs, since it involves the use of a small step computational grid. This led to the emergence of a new area of mathematical research, the purpose of which is to construct methods for mediating partial differential operators such that the resulting solutions of equations with average coefficients are close to the solutions of the original equations and adequately describe the behaviour of the composite. The effective characteristics of composite materials are determined experimentally or numerically.

The efficiency of discrete wavelet transformation in damage identification based on transient heat conduction experiments in [1]. The examples of damage detection based on real experiments of transient heat transfer and measurements of temperature fields with the infrared digital camera showed a good qualitative agreement with the examples based on numerically simulated experiments.

However, most often, when testing prototypes, a number of difficulties arise related to the choice of sizes and shapes of samples, the exclusion of the influence of edge zones of fastening of the sample and internal defects, the creation of the stress state or thermal fields necessary for calculations. In addition, the methods of testing and processing the results are different for different types of composite materials - a single approach is hardly possible here. These shortcomings complicate the determination of the characteristics of the composite based on experiment, and the experimental results given in the literature in some cases differ significantly.

The existing analytical estimates of the characteristics of composites for elastic constants, thermal and filtration properties usually give a wide range of possible values of material properties and are used only for a rough estimate.

The lack of classical mediation methods encourages the development of new mathematical approaches. The basis of one of the approaches was the use of wavelets - a class of basic functions used in digital signal processing, as well as in information compression, pattern recognition [2].

One of the main advantages of the wavelet transform is the ability to obtain a representation of quantities at the scale of interest. Using the wavelet transform, one can obtain an average representation of a function (coarse scale - "low resolution") and highlight its local properties (small scale - "high resolution").

The influence of thermal and geometrical parameters on the temperature distribution in multilayer composites, associated with dimensionless time, was determined using a numerical finite element model for the wavelet transform [3]. Experimental analysis shows differences in heat distribution in intact and defective structures. The delamination thickness has a significant effect on the temperature in the defect zone. This transformation property is associated with multi-scale analysis of the function under study or analysis with variable resolution.

The main novelty of this work lays in the analysis of the wavelet transform for extruded polystyrene, expanded polystyrene and polyurethane studied in [4]. The coefficient of thermal conductivity is determined by the differential method of local heat influence. The method of local heat influence is based on applying a heat flux of constant density to the sample surface through a probe with a heater, while the second probe remains undisturbed by the thermal effect area.

The wavelet transform method was selected to analyze the thermal conductivity of materials in the range of 0.2 – 1.4 $W \cdot m^{-1} \cdot K^{-1}$. Wavelet analysis is used for the decomposition, reconstruction, and denoising reduction of thermal conductivity time series $\Delta t = Nt'$, where $t' = 100\,s$, $N = 1, 2, ..., 15$ is the argument shown in Fig. 1.

Discrete wavelet transform is based on wavelet coefficients, which are scalar products of the signal $f(t)$ and the mother wavelet ψ_{mn}. Discrete inverse transform is defined by the following relationship

$$f(t) = \sum_{m,n} (f, \psi_{mn}) \psi_{mn} = \sum_{m} \sum_{n} d_m[\mathrm{n}] \psi_{mn}\,, \qquad (1)$$

where the wavelet coefficients $d_m[\mathrm{n}](f, \psi_{mn})$ define the common features of the signal $f(t)$ and the wavelet.

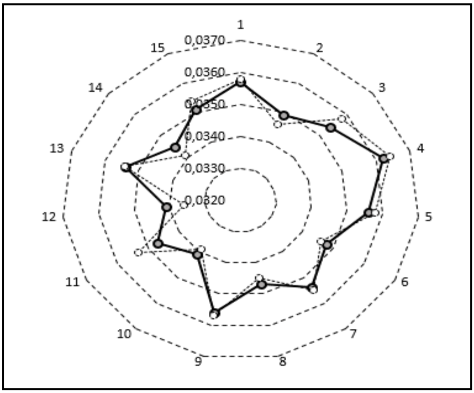

Figure 1. Relative thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$) amplitude subsidence for extruded polystyrene ($\sigma_1' = 0.0022$). Wavelet – solid curve, signal – dotted curve.

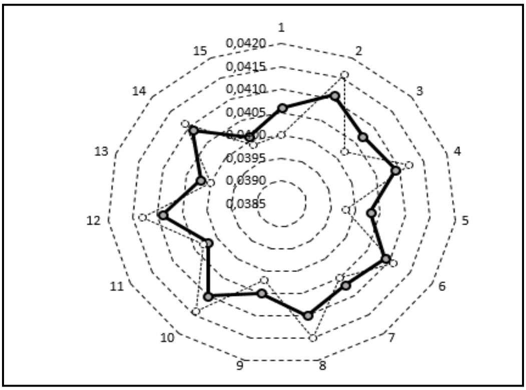

Figure 2. Relative thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$) amplitude subsidence for expanded polystyrene ($\sigma_3' = 0.0024$). Wavelet – solid curve, signal – dotted curve.

Multiresolution analysis of the signal is based on discrete wavelet transform and can be defined by the following equation

$$f(t) = \sum_{j=-\infty}^{J} \sum_{n \in Z} d_j[\mathrm{n}] + \sum_{n \in Z} a_j[\mathrm{n}]\varphi_j \ , \qquad (2)$$

where $a_j[\mathrm{n}]\varphi_j$ are the approximation coefficients representing the low-frequency components, and $d_j[\mathrm{n}]$ are the detail coefficients representing the high-frequencies of signal $f(t)$.

The parameter m allows one to determine the scale level, and the parameter n enables signal location in time when signal $f(t)$ should be analyzed.

The results of a comparative analysis for the thermal conductivity signal and the Daubechies wavelet of the order of 2 are shown in Fig. 1, 2.

Conclusions. An increase in the average relative amplitude subsidence for extruded polystyrene (Fig. 1) indicates a worse wavelet decomposition process of the thermal conductivity signal for heterochain polymers in comparison with uniform closed-pore structures, which include extruded polystyrene foam.

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