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# WAVELET-BASED HOMOGENIZATION FOR HETEROGENEOUS COMPOSITES

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One of the most effective approaches to computational modeling of composite systems is the homogenization method. The homogenization method assumes that there is some scale relationship between the constituent components and the entire volume of the composite [1]. Therefore, this procedure can be formulated as the introduction of two-scale systems that are related by a scale parameter that is a small real value (tending most often to zero). However, the impossibility of introducing scaling with a coefficient greater than two in composite structures, as well as the too high sensitivity of composite homogenized characteristics to the interrelations of geometric scales are a significant drawback of such methods [2].

Multiscale methodology based on wavelet analysis is currently a very modern and widely developed numerical method in signal theory [3]. Multiscale analysis allows the study of composite systems with multiple geometric scales, which is more realistic for most engineering composites (scales of microdefects, interface, reinforcement and the entire structure). Wavelet analysis is a particularly promising tool in the field of composite materials. Wavelet transforms allow the construction of multiscale heterogeneous structures using specific wavelets, which ideally reflects the manufacturing process. In addition, wavelet transforms allow the multidimensional decomposition of the composite material spatial distribution and physical properties using wavelets of different types introduced at different scales [4].

In this paper, an improvement of the methodology of spatial averaging over local volumes of a composite structure and classical asymptotic homogenization is presented. The result obtained using the theory of asymptotic homogenization is given for deterministic composites exhibiting two separate geometric scales related by a scale parameter. The scale parameter is treated as a positive real number tending to 0, and, alternatively, as some small positive parameter. This parameter can be considered as some real function introduced as a wavelet function relating two or more separate geometric scales of the composite.

The strategy of the multiscale solution consists of the reduction and homogenization of linear and unidirectional problems for the scalar characteristics of composite samples. The mathematical description of the homogenization is based on the use of a bounded linear operator. Since the parent functions describe the transfer processes, the bounded linear operator can be written as a matrix. This matrix is finite for all cases where the multiscale analysis is defined on a bounded domain. It should be noted that in the finite-dimensional case, if we consider a multiscale analysis defined on a domain in R, each subsequent reduced equation has half as many unknowns as the original equation. Thus, the reduction preserves the coarse-scale behavior of the solutions, significantly reducing the number of unknown quantities.

In the Haar-wavelet basis, the basic operators are obtained from the reduced equation and have a simple form and have a rank corresponding to the number of unknowns in the characteristic equation. In addition, these operators correspond to block-diagonal and n-rank matrices and, therefore, there are many diagonal blocks, each of which has a reduced rank. The solutions of the characteristic equations have the same "average" or coarse-scale behavior as the solutions of the equations for the mother wavelets. The main advantage of this averaging procedure is the possibility of varying the kinetic coefficients on an arbitrary set of intermediate scales. This contrasts with the classical examples of averaging, which did not allow any intermediate scales.

In addition to fixing the general structure for multiscale reduction and homogenization, it can be pointed out that the use of a Haar basis (or multiwavelet basis) for systems of linear ordinary differential equations provides an advantage in performing numerical calculations. Moreover, since the Haar functions at a fixed scale do not have overlapping supports, the recurrence relations for the operators and forcing terms in the equation can be written as local relations and solved explicitly. Thus, an explicit local reduction and homogenization procedure is possible for ordinary differential equations. In this case, each characteristic equation in wavelet analysis can be rewritten as a coupled first-order system. Considering that the characteristic coefficients represent the physical properties of the components of a composite with a total number of different scales tending to infinity, one can give a similar definition of the average coefficient for a composite with a certain finite number of scales. The main calculations are carried out taking into account the relationship between the physical constants of the layers of the laminated composite, as well as the order of decomposition. The homogenized system, both in terms of deterministic and stochastic effective coefficients, was analyzed numerically using the classical finite element method and by applying stochastic numerical methods. The calculation procedure used a matrix representation of the set of boundary conditions, linking the material parameters of the composite components. The results indicate that the relationship of the material parameters significantly affects the effective parameters of the local volumes of the composite structures. Similar limiting values in the real and imaginary parts of the homogenized parameter, as well as the singularities of the imaginary part, can be represented as nonlinear functions of both design parameters of the numerical analysis.

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Energia słoneczna jest ważnym sektorem zrównoważonego rozwoju, który obejmuje wykorzystanie paneli słonecznych i kolektorów do przekształcania energii świetlnej odpowiednio w energię elektryczną i ciepło. Główne kwestie badane w tym obszarze obejmują rozwój niezawodnych i odpornych na zużycie technologii, zwiększenie wydajności systemów solarnych i ich integrację z ogólną infrastrukturą energetyczną. Główny nacisk kładziony jest na obniżenie kosztów energii wytwarzanej przez instalacje solarne i zwiększenie ich niezawodności.

Znaczenie energii słonecznej jako istotnego obszaru redukcji śladu węglowego i zapewnienia bezpieczeństwa energetycznego [2]. Sposoby osiągnięcia tych celów