FEATURES OF WAVE PROPAGATION AND DAMAGE DETECTION IN REINFORCED COMPOSITES

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Introductions. Reinforced composite panels are widely used in various industries to withstand combined in-plane and out-of-plane loads with lightweight construction. Composite materials included in such structures are subjected to short-term loads such as impacts and sliding impulses. Damage occurrence due to geometric and load complexity most often occurs at the junction of different parts. It should be noted that non-destructive testing is usually quite a difficult task. Ultrasonic wave monitoring of the structure's health, which uses sensors and actuators integrated with the structure, is quite suitable for early detection of damage in structures containing reinforced materials.

Aim. The aim of this work is modeling for wave propagation studies in bulk reinforced composites and damage diagnostics in structures containing a sufficiently large number of parts with mechanical joints. The development of the model involves the analysis of governing wave equations that have exact solutions at relatively higher frequencies compared to the classical theory.

Materials and methods. The model developed in this study uses compactly supported Daubechies scaling functions, which in turn are basis functions for approximating time and one spatial dimension. Solving the governing equations allows reducing the procedure of normalizing partial differential equations to a basis spectrum of operators.

In this work, a reinforced composite plate with a sufficiently small thickness and the origin of the global coordinate system on the midplane of the plate was investigated. The calculation model corresponds to the presence of a finite number of nodal connections. The presented consideration allows us to imagine the laminate as a structure that has an even number of degrees of freedom for the formulation of the spectral element. The volume of the composite plate was characterized by the presence of a resultant force in the normal plane, as well as resultant moments of transverse forces. The corresponding fractional coefficients are given normal and shear forces in the directions of the coordinate axes and determine the direction of the moments relative to the axes of symmetry of the composite plate. The solution of the system of governing equations and the assembly of elementary stiffness matrices to obtain the global stiffness matrix have many similarities with the conventional finite element method. However, one of the main differences is that in the finite element method the time integration of the equations of motion is performed using a suitable finite difference scheme. Whereas the wavelet transform performs the dynamic stiffness generation, assembly and solution as part of a double cycle in frequency and horizontal wave number.

Results and discussion. The solution of the system of differential equations for wave propagation along the volume of the composite structure indicated the presence of a mechanical shear generated at the excitation point and deformation. The first of a set of peaks that occur in the interval of one-third of the characteristic wave propagation time can be considered as an input pulse. In the case where the wave is excited on the free plane of the composite plate, it begins to propagate towards the stiffener. The presence of connections with the stiffeners acts as a boundary for this forward propagating wave. The first reflection from the stiffeners is observed after one-quarter of the characteristic wave propagation time. The next stage is the occurrence of low-frequency components contained in the excitation load and the corresponding deformation.

The structural transmission-strain responses were analyzed for a narrowband Hanning sinusoidal input load (tone pulse). It was found that the tone pulse amplitudes were concentrated at a single frequency with a small number of side frequencies. This fact helped to explain the long distance over which the fixed reflection wave propagated even in highly dispersive media such as composite plates.

It was found that mode conversion at the junction of the joint lines and the stiffener leads to the fact that the antisymmetric incident wave mode propagating in the joint line is transmitted to the stiffener as a symmetric wave mode. Mode conversion was also recorded in the propagating waves, which were scattered by deformations while maintaining the initial frequency. It should be noted that the amplitude of the waves scattered by local deformations decreases with increasing stiffener height due to attenuation at longer displacement distances in the volume of the reinforced composite.

Conclusions. This paper presents a simulation of ultrasonic wave propagation in reinforced composite panels using the wavelet transform method. The system of governing equations for wave propagation in laminated anisotropic plates used in the calculation model allowed applying the fast Fourier transform method for the discrete spectrum. A distinctive feature of this method is its high computational accuracy, which is preserved up to wavelengths close to the plate thickness.

To perform the approximation of partial differential equations in time and one spatial dimension, compactly supported Daubechies scaling functions were used. The system of orthonormal differential equations generated in this method was rearranged and solved for wave numbers, assuming a harmonic solution in the transformed frequency-wave domain. The entire reinforced composite volume containing multiple point and extension defects was characterized by the dynamic stiffness matrix of the spectral plate element. The stiffness matrix in this computational model was generated to describe the relationship between the transformed nodal forces and displacements. The description of the stiffness fields and shear matrix elements of the reinforced composite material in the presence of embedded strains was performed using a procedure similar to the conventional finite difference equation technique. The matrix equation for the diffusion interaction of waves propagating in the composite volume and a set of dermal inclusion nodes was solved in the frequency-wavelength domain. It is found that the application of wavelet transforms for detailed detection of regions with anomalous shear characteristics can be implemented for both broadband and narrowband input loads.