FREQUENCY DEPENDENCE OF VIBRATION DAMPING IN REINFORCED COMPOSITES

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When artificially devised composite materials are exposed to external effects in a wide frequency range, they can be effectively utilized if they have known damping characteristics corresponding to the frequency of the external effect.

In investigations of the influence of the direction of the reinforcement on the damping properties it is usual to determine the logarithmic vibration decrement $\delta$ [1-8], which characterizes the damping properties of the material only at one point of the frequency range of the fundamental resonance: at the resonance frequency. It is also assumed [4] that the magnitude of the relative energy dissipation (RED) is $\psi = 2\delta$ although this is correct only for the case of frequency-independent attenuation of vibrations. To judge the relation of the damping characteristic of reinforced composites by the vibration decrements is not always correct for the entire frequency band of the fundamental resonance, especially when the decrements are large, because the dependence of the damping factor on the frequency of the external effect is nonlinear. The object of the present work is to investigate the regularities of the change of the characteristics of RED of vibrations in the frequency band of the fundamental resonance on the direction of the reinforcement of the composite.

Out of the known methods of determining the characteristics of vibration damping [4-6], only the phase method, based on the dependence of the phase shift between the external distorting force and its induced displacement on the magnitude of the RED $\psi$, makes it possible to obtain numerical values of $\psi$ for frequencies differing from the resonance frequencies. The authors of [5, 6] present the following dependence for determining RED with the amplitude of forced vibrations $a$:

$$\psi_a = 2\pi \left(1 - \frac{\omega_a^2}{P_a^2}\right) \tan \varphi_a,$$  \hspace{1cm} (1)

where $\omega_a$ is the frequency of the forced vibrations with amplitude $a$; $P_0$ is the natural vibration frequency; $\varphi_a$ is the phase angle between the distorting force and the displacement caused by it with amplitude $a$. To determine the amplitude-dependent RED, the authors of [4, 6] also suggested the dependence

$$\psi_a = 2\pi \left(1 - \frac{\omega_a^2}{P_a^2}\right) \tan \varphi_a,$$  \hspace{1cm} (2)

which differs from (1) in that instead of $P_0$, which does not take energy dissipation into account, it contains $P_a$, the resonance frequency of displacement with amplitude $a$, which makes it possible to take into account the nonlinearity of the resistance.

Below we present the results of measurements of the phase responses $\psi_a = f_i(\omega_a)$, obtained at the section of damping of anisotropic structures of the Institute of Applied Problems of Mechanics and Mathematics, Academy of Sciences of the Ukrainian SSR. The phase responses of the tested specimens were ascertained with the same amplitude $a$; this made it possible to compare $\psi_{1a}$ and $\psi_{2a}$, and also to eliminate the effect of the amplitude $a$ on the damping characteristics.

The phase response was ascertained on an installation (Fig. 1) based on the instrument IChZ-9 which was designed at the Specialized Design Bureau of Scientific Instrumentation, Institute of the Mechanics of Polymers of the Academy of Sciences of the Latvian SSR. The RED was determined from the phase responses (Fig. 2) in flexural vibrations of specimens made of basalt-fiber reinforced plastic [3, 7] 10 x 17 x 180 mm in size, with packing of the fibers
Fig. 1. Block diagram of the installation for determining phase response: 1) instrument IChZ-9; 2) indicator unit; 3) generator unit; 4) excitation transducer D-41; 5) receiving transducer D-42; 6) electronic voltmeter V2-17; 7) chronometric frequency meter F5041; 8) phase meter F2-13; 9) tested specimen.

Fig. 2. Phase response of specimens with orientation of the reinforcement 0 (1), 15 (2), 30 (3), 45 (4), 60 (5), 75 (6), and 90° (7) with \( \omega_a = P_0 \) (a) and \( \omega_a \geq P_0 \) (b).

1:1 and orientation of the reinforcement 0, 15, 30, 45, 60, 75, and 90°. We also determined the logarithmic decrement \( \delta_a \) on the resonance frequency \( P_0 \) of the flexural vibrations over the width of the resonance peak. The frequency \( P_\alpha \) and also the frequencies corresponding to \( 0.5 \cdot \alpha \) were measured with a frequency meter. The voltages proportional to \( \alpha \) and \( 0.5 \cdot \alpha \) were checked with an electronic voltmeter. To determine the phase shift \( \varphi_a \) between the signals proportional to the acting force and the consequent displacement, a phase meter was used. From the reading of the frequency meter at the instant of equality \( \varphi_a = 90° \) we determined the natural vibration frequency \( P_0 \). The relative error of determining RED is due to the error of measuring the frequencies \( \omega_\alpha \), \( P_\alpha \), and it does not exceed 6-8%, and at the resonance frequencies \( \omega_\alpha = P_\alpha \) it is within the limits 4.5-5.5%. The phase responses were obtained with constant amplitude of displacement for all specimens in the frequency range of the fundamental resonance corresponding to \( 0 \leq \varphi_a \leq 180° \). On the axis of ordinates in Fig. 2a, the angles between the external force and the induced displacement \( \varphi_a \) at the frequencies \( P_\alpha \) are marked off.

The obtained phase responses for \( 0 \leq \varphi_a < 90° \) correspond to the model with linear viscous resistance (LVR) because with increasing damping the difference between \( \varphi_a \) and 90° and between \( P_\alpha \) and \( P_0 \) increases (see Fig. 2a). The greatest attenuation was found in specimens with orientation of 30, 45, and 60°. With further increase of the excitation frequency, only the phase responses with orientation 0, 15, 75, and 90° and with small RED correspond to the model of LVR (see Fig. 2b). The mutual intersections and transitions of the phase responses of specimens with orientation 30, 45, and 60° (see Fig. 2b) with large RED indicate that the attenuation factor \( h \) is nonlinear and that the phase response does not correspond to the model with LVR. The nonlinearity of the dependence \( h(\omega_\alpha) \) of these specimens shows particularly with frequencies \( \omega_\alpha \geq P_0 \), even with small displacements \( a \leq 80 \mu m \). The phase response of specimens of basalt-fiber reinforced plastics with orientation 30, 45, 60° is characterized by considerable nonlinearity which is apparently due to the inclusion of new mechanisms of energy dissipation connected with the structural damping at the fiber-matrix interface, and which is not taken into account by the model with LVR.