STUDY OF DAMPING OF COMPOSITE MATERIALS WITH HYBRID RESIN MATRICE BASED ON DAMMAR REINFORCED WITH SUNFLOWER SEED SHELLS

ALEXANDRU BOLCU , MARIUS MARINEL STANESCU[*], DUMITRU BOLCU

Abstract. Humanity's ability to find solutions to protect the environment will prove that we are an intelligent species. One solution would be to use only materials from very rapidly renewable resources to make equipment and consumer goods. The study in this article falls in the direction presented earlier. More specifically, the reinforced composite materials were made from ground sunflower seed husks (waste from the production process of oil factories) and have as a matrix a hybrid resin with 50%, 60%, 70% and 80% volumic proportion of Dammar natural resin. For this type of composite materials, the vibration behavior was studied according to the proportion of natural Dammar resin in the matrix used. The eigen frequency and damping factor for the first natural vibration mode were determined experimentally.

Key words: composite materials, hybrid resin, sunflower seed shells, vibration behavior.

1. INTRODUCTION

The development of natural fiber reinforced composite materials in high performance applications requires additional information on their dynamic properties such as damping. The study of material damping is important because it significantly influences the behavior of vibrating systems, especially when operating close to resonance frequencies. Sufficient damping is required to reduce the vibrations of the structures as well as to avoid fatigue fractures [1]. Several concepts have been used to model the damping of classical composite materials [2, 3]. For natural fiber composites, some researchers have experimentally analyzed the damping performance [4–6]. Damping properties have been studied for composites reinforced with short coconut fibers [7], banana [8], flax and hemp [9], ramie/glass hybrid fibers [10], Luffa cylindrica [11] or Sansevieria cylindrica [12]. The damping properties of composite materials with hybrid resin matrix based on

University of Craiova, Faculty of Mechanics, Department of Applied Mechanics, Romania, e-mail: mamas1967@gmail.com

Dammar, reinforced with linen, cotton or hemp fabrics are studied in [13], and those reinforced with waste paper are studied in [14]. The results of these analyzes indicated that the loss factor is determined by the shape of the reinforcing fibers, and the orientation of their fibers significantly affects the damping behavior. It was observed that the damping can be improved with a slight decrease in the stiffness of the composite by generating a higher number of interfaces. In [15] a corresponding analysis is made on the damping properties of fiber reinforced polymer composites. An extensive analysis is made of several factors that determine damping, such as matrix, fiber types, fiber architecture, fiber surface modification, and incorporated fillers. The role of the interfacial region (where shear energy is stored) in improving damping properties is discussed.

Generally, three energy dissipation mechanisms are considered [16]. The first mechanism considers the damping force to be proportional to the velocity, the second mechanism considers the damping force to be proportional to the vibration frequency, and the third mechanism considers the damping rates of the vibration eigenmodes to be proportional to the square of the frequency.

In this work, the vibration behavior of composite bars made of hybrid resin based on dammar reinforced with sunflower seed husks is studied. Similar results are presented in [17], but for a smaller number of cases of Dammar volume ratios from hybrid resins.

2. THEORETICAL CONSIDERATIONS

The equation of motion for a bar of length L, in the presence of damping, is of the form [16]:

$$\ddot{w}(x;t) + 2c_0\dot{w}(x;t) - 2c_1\frac{\partial^2\dot{w}(x;t)}{\partial x^2} + 2c_2\frac{\partial^4\dot{w}(x;t)}{\partial x^4} + a^2\frac{\partial^4 w(x;t)}{\partial x^4} = 0 \tag{1}$$

with $a = \sqrt{\frac{\langle EI\rangle}{\langle\rho A\rangle}}$, where $\langle\rho A\rangle$ and $\langle EI\rangle$ are the mass and stiffness characteristics of the bar.

The term $2c_0\dot{w}$ introduces so-called external or viscous damping. The amplitudes of all modes of vibration (modal amplitudes) are attenuated at the same rate, contrary to experience. A natural interpretation of the term $-2c_1\frac{\partial^2\dot{w}}{\partial x^2}$ is that the damping force is proportional to the bending velocity. The presence of the term $2c_2\frac{\partial^4\dot{w}}{\partial x^4}$ means that the damping rates of the vibrational eigenmodes depend proportionally on the square of the frequency. This corresponds to the so-called Kelvin-Voigt model of internal damping.

The initial conditions are known:

– the state of displacements at the initial moment $w(x;0) = f(x)$,

– the state of velocity at the initial moment $\dot{w}(x;0) = g(x)$.

For a bar simply supported at the ends, the solution to the equation of motion is:

$$w(x,t) = \frac{2}{L}\sum_{n=1}^{n_0-1} e^{-\mu_n t}\left[\frac{g_n + \mu_n f_n}{\sqrt{\omega_n^2 - \mu_n^2}}\sin(\sqrt{\omega_n^2 - \mu_n^2}\,t) + f_n\cos(\sqrt{\omega_n^2 - \mu_n^2}\,t)\right]\sin\frac{n\pi x}{L} +$$
$$+\frac{2}{L}\sum_{n=n_0}^{\infty} e^{-\mu_n t}\left[\frac{g_n + \mu_n f_n}{\sqrt{\mu_n^2 - \omega_n^2}}\sinh(\sqrt{\mu_n^2 - \omega_n^2}\,t) + f_n\cosh(\sqrt{\mu_n^2 - \omega_n^2}\,t)\right]\sin\frac{n\pi x}{L} \tag{2}$$

where:

$$\omega_n = a\frac{n^2\pi^2}{L^2}, \quad \mu_n = c_0 + c_1\frac{n^2\pi^2}{L^2} + c_2\frac{n^4\pi^4}{L^4},$$
$$f_n = \int_0^L f(x)\sin\frac{n\pi x}{L}\mathrm{d}x, \quad g_n = \int_0^L g(x)\sin\frac{n\pi x}{L}\mathrm{d}x, \tag{3}$$

and n_0 is the natural number that satisfies the conditions:

$$4(c_0 + c_1\frac{n^2\pi^2}{L^2} + c_2\frac{n^4\pi^4}{L^4}) - 4a^2\frac{n^4\pi^4}{L^4} < 0, \text{ for } n < n_0,$$
$$4(c_0 + c_1\frac{n^2\pi^2}{L^2} + c_2\frac{n^4\pi^4}{L^4}) - 4a^2\frac{n^4\pi^4}{L^4} \geq 0, \text{ for } n \geq n_0.$$

Solutions of the same form, but with the corresponding eigenfunctions, are also obtained for other boundary conditions. It is observed that the motion is damped in time, practically disappearing after a certain number of oscillations. The shape of the vibration depends on the dimensions of the bar, the mass and the elastic properties of the material from which the bar is made, but also on its damping properties. If other mechanical properties, such as the modulus of elasticity, can also be determined through other experimental tests, the damping capacity and the mechanisms by which it is achieved can only be appreciated through the experimental analysis of the oscillations produced by different external excitations.

3. MATERIALS

Four hybrid resins were used to make the composite materials, combinations between the natural Dammar resin and the Resoltech 1050 epoxy resin with the related Resoltech 1055 hardener (the synthetic resin is used to initiate the polymerization process). The four hybrid resins differed in the proportion of natural resin that was 50%, 60%, 70% and 80%, with the percentage difference up to 100% being represented by the synthetic resin.

Using as a matrix the four types of resin specified previously, composite material plates with reinforcement from chopped sunflower seed shells were cast.

The casting and polymerization process were carried out at a controlled ambient temperature of 21–23^{0}C.

Samples having the length equal to 250 mm and the width equal to 25 mm were cut from the cast plates in accordance with ASTM D3039.

Figure 1 shows representative samples cut from the four plates.

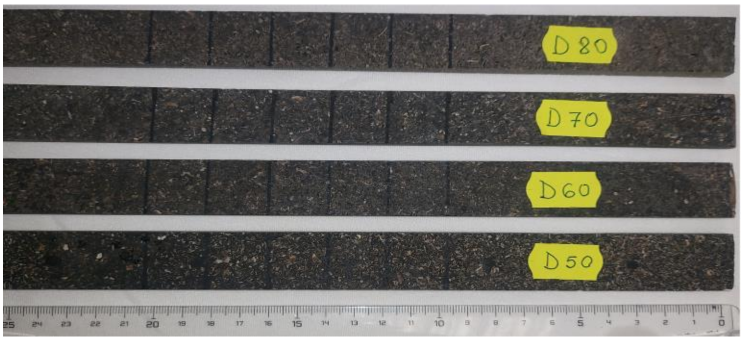

Fig. 1 – Representative samples cut from the 4 sets of composite materials.

The following abbreviations are used:

– D50 for samples made from hybrid resin composite materials with 50% Dammar;
– D60 for samples made from hybrid resin composite materials with 60% Dammar;
– D70 for samples made from hybrid resin composite materials with 70% Dammar;
– D80 for samples made from hybrid resin composite materials with 80% Dammar.

The mechanical properties such as breaking strength, elongation at break, modulus of elasticity for these types of resins and for the composite material that uses them, can be found in [13,14] and [17]. In table 1, the characteristics of the studied sets of samples are presented in a centralized manner.

Table 1

The characteristics of the sets of samples

Symbolization of the samples	Mass proportion of the resin [%]	Density [g/cm^3]	Dimensions of samples [mm]
D50	41	1.13	250×25×6.8
D60	40	1.11	250×25×6.8
D70	42	1.09	250×25×6.9
D80	41	1.07	250×25×6.9

4. EXPERIMENTAL DETERMINATIONS

4.1. SOFTWARE AND HARDWARE

The following software and devices were used to perform the experimental determinations:

– SPIDER 8 data acquisition system, produced by HBM, connected via USB port to a FUJITSU SIEMENS notebook; the setting of the data acquisition system is done through the CATMAN EASY software, which connects the two entities;

– signal conditioner NEXUS 2692-A-0I4, produced by BRUEL&KJAER, connected to the SPIDER 8 system;

– accelerometer with sensitivity 0.04 pC/ms^{-2} produced by BRUEL&KJAER connected to the signal conditioner NEXUS 2692-A-0I4;

The frequency measurement range 0–2 400 Hz set from the SPIDER 8 system.

In order to eliminate the errors introduced by the experimental system, we made for each measurement a "High Pass" Butterworth filter at a frequency of 3 Hz.

Figure 2 shows the experimental assembly used to study vibration behavior.

Fig. 2 – The experimental assembly used to study vibration behavior.

4.2. EXPERIMENTAL RESULTS

The damping coefficient and eigen frequency were determined experimentally for the four samples. The studied samples were embedded at one end, and the measuring transducer was mounted at the free end. The bar was deformed with a force applied at the free end and then allowed to oscillate. In this way the bar will oscillate according to the first natural mode of vibration. The free length of the samples was varied between 140 mm and 220 mm with an increment of 20 mm. Figure 3 shows how the natural frequency and the damping factor are determined for the recording made with the D80 sample, for the free length of 140 mm. Details on the method of determining these parameters can be found in [13] and [17].

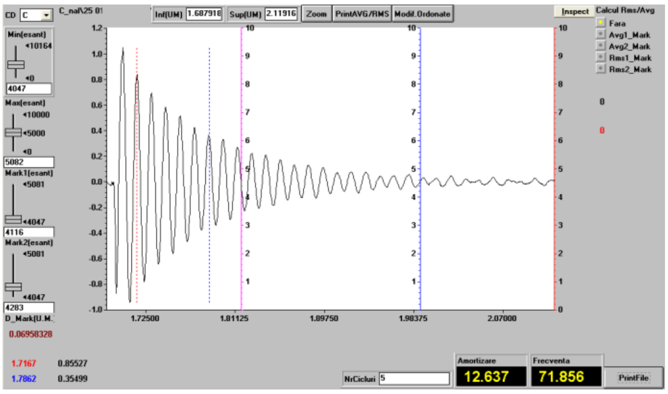

Fig. 3 – Recording of vibrations (natural frequency and damping factor) for the D80 sample, for the free length of 140 mm.

Table 2 and 3 show the results of the experimental vibration determinations for the samples of the four types of hybrid resin composite materials based on dammar reinforced with crushed sunflower seed shells. The values in the table represent the arithmetic mean of the values obtained in two experimental determinations.

Table 2

The vibration behavior of some representative samples from the D50 and D60 composites

Free Length [mm]	D50		D60	
	Frequency ν [Hz]	Damping μ [s^{-1}]	Frequency ν [Hz]	Damping μ [s^{-1}]
140	89.1	14.5	83.6	14.0
160	69.2	11.2	63.4	10.9
180	55.2	8.8	49.8	8.4
200	45.3	7.3	39.9	7.1
220	36.7	5.5	32.8	5.3

Table 3

The vibration behavior of some representative samples from the D70 and D80 composites

Free Length [mm]	D70		D80	
	Frequency ν [Hz]	Damping μ [s^{-1}]	Frequency ν [Hz]	Damping μ [s^{-1}]
140	77.3	13.1	71.8	12.7
160	58.4	10.3	55.8	10.1
180	47.5	8.2	44.6	7.9
200	37.2	6.8	35.4	6.7
220	29.3	5.1	28.7	4.9

Assessment of the vibration damping capacity for the studied materials can be done by determining the loss factor, which is calculated with the relation $\eta = \frac{\mu}{\pi \nu}$ (see [14] and [17]). For the studied composite materials, the average value of the loss factor is:

– η = 0.0506 for the D50 composite;
– η = 0.0540 for the D60 composite;
– η = 0.0558 for the D70 composite;
– η = 0.0570 for the D80 composite.

5. CONCLUSIONS

The vibration behavior of the studied composites depends on the proportion of natural Dammar resin in the hybrid resin used as matrix. The damping factor characterizes the vibration damping capacity for the studied bars and depends on the length of the vibrating bar. So, the damping factor depends both on the damping properties of the constituent materials but also on the dimensions of the bars and is therefore an element that characterizes the total vibration damping capacity for the studied samples.

The variation of damping factor with bar length is similar to the variation of vibration frequency. That is why it can be appreciated that, among the damping mechanisms presented, the predominant one is the one in which it is considered that the damping is proportional to the vibration frequency. It can be appreciated that in the equation of motion it is sufficient, for the analysis of the damping, to introduce the term of $-2c_1 \frac{\partial^2 \dot{w}}{\partial x^2}$.

Since the damping factor characterizes the overall damping properties of the entire sample, the vibration damping capacity for the materials from which the samples are made is given by the loss factor. It is observed that it increases with increasing proportion of Dammar in the hybrid resin.

The realization of cheap, reusable composite materials, environmentally friendly, with good mechanical properties, by using sunflower seed shells (which are mill waste) as reinforcement in combination with natural or hybrid resin matrices is an advantageous solution from economic point of view.

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