Researches regarding the static and dynamic behaviour of composites with natural reinforcements

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Abstract. In this paper, some composite materials were built in this way: the reinforcement is made with natural fibers (there were used two types of natural fibers in this way: hemp and cotton) and the matrix is made from epoxy resin. The Resoltech 1050 epoxy resin is used, with its Resoltech 1050 hardener. The casting was made at room temperature and the matrix was applied using the brush. The static experimental conditions are characterized by tensile loading of the build specimens and the determination of statically Young modulus. There was used an Instron Universal testing machine and the force-extension curves were obtained. The dynamic parameters were determined from the bars free vibrations. The next experimental montage was used: the bars were clamped at one end and were left free at the other end. At the free end, a Brüel&Kjaer accelerometer with 0.04 pC/ms\textsuperscript{2} sensitivity was placed in order to record the beams dynamic response. A force was applied at the free end to bend the beams and after bending, the force was cancelled and the beams were left to freely vibrate. The accelerometer was connected to a signal conditioner Nexus and the signal conditioner was connected to a data acquisition system SPIDER 8 made by Hottinger Baldwin Messtec. The acquisition system was connected to a notebook and the experimental parameters were obtained through CATMAN EASY software. From the free vibrations recording, the next mechanical parameters were determined: the eigenfrequency of the first eigenmode, the damping factors per unit mass and per unit length, the loss factor and the dynamic Young modulus.

1. Introduction

The persistance of plastic materials in the environment, the depletion of petroleum resources, concerns over emissions during incineration and so on have spurred efforts to develop biodegradable materials. A good solution was found to combine petroleum based materials with biodegradable ones to compete in markets with 100% petroleum-based materials. Over the last decade, there are made combinations of biofibers like kenaf, flax, jute, sisal, wood and so on with polymer matrices to produce composite materials that can compete with synthetic composites such as glass-polypropylene or glass – epoxies [1].

From the plant fibers used in combination with synthetic polymers, there can be mentioned the next categories [2]:
- seed fibers: are collected from seeds or seed cases; some examples are: cotton and kapok
- leaf fibers or hard fibers: are collected from leaves; some examples are: bananas and pineapples
- bast fibers: are collected from the inner bark or bast that surrounds the plant stem; some examples are: hemp, flax, jute, kenaf, ramie
- fruit fibers: are collected from fruits; as an example, the coconut fiber can be mentioned
- stalk fibers: are collected from the stalk of plants; some examples are: wheat, rice, bamboo or straw.

Natural fibers represent reinforcing materials suitable for composites due to combination between agreeable mechanical properties and environment protection advantages (renew ability and biodegrability). The advantages of using natural fibers compared to synthetic ones are: relatively low cost, abundance in nature, low weight, low density, decreased damages to the manufacturing equipments, refined surface finishing of castings compared to composites reinforced with artificial reinforcements like glass fiber, relative eligible mechanical properties and so on [3-7]. The plant fibers have also the specific properties (ratio of property-to-density), strength and stiffness comparable with the values of glass fibers [8-10].

In this paper there are studied some green composites with the matrix made from epoxy resin reinforced with natural fibers: hemp and cotton. There are built some samples and there are studied their static and dynamic mechanical characteristics.

2. Samples used for study
Some samples have been built for this study with the geometry given in table 1. A general view with the built samples is given in figure 1. The samples reinforced with hemp will be marked as sample 1 and the ones reinforced with cotton will be marked as sample 2.

| Table 1. Samples geometry |
|---------------------------|
| Sample | 1 | 2 |
| Thickness (cm) | 0.53 | 0.53 |
| Width (cm) | 1.45 | 1.45 |
| Specific mass (kg/m) | 0.11 | 0.11 |

2.1. Dynamic study
The samples free vibrations were studied in this paper. The samples were clamped at one side, and a Bruel&Kjaer accelerometer was placed at the free end, at a distance of 10 cm from the free edge. A force was applied at the free end and the bars were left to freely vibrate. Like in [11] and [12], several free lengths values were considered for the samples (values in cm): 27, 29, 31, 33, 35, 37. All the experimental results and the dynamic stiffness (marked as EI), loss factor (marked as η) and the dynamic Young (marked as Edyn) are given in table 2.

| Table 2. Dynamic mechanical characteristics |
|---------------------------|
| Free length [cm] | Eigenfrequency [1/s] | Damping factor per unit mass [Ns/m/kg] | Sample no. | Damping factor per unit length [Ns/m/m] | Loss factor | Dynamic Young modulus [MPa] |
|---------------------------|
| 37 | 9.2593 | 1.0779 | 1 | 0.237 | 0.037 | 3138 |
| 35 | 10.34 | 1.2785 | 1 | 0.281 | 0.039 | 3133 |
| 33 | 10.991 | 1.421 | 1 | 0.313 | 0.041 | 2797 |
| 31 | 12.345 | 1.6486 | 1 | 0.363 | 0.043 | 2748 |
| 29 | 14.73 | 1.8657 | 1 | 0.41 | 0.04 | 2997 |
| 27 | 16.433 | 2.214 | 1 | 0.487 | 0.043 | 2802 |
| 37 | 6.5789 | 0.9386 | 2 | 0.206 | 0.045 | 1584 |
| 35 | 7.234 | 1.065 | 2 | 0.234 | 0.047 | 1533 |
| 33 | 8.09 | 1.2 | 2 | 0.264 | 0.047 | 1516 |
| 31 | 9.276 | 1.3675 | 2 | 0.301 | 0.047 | 1552 |
| 29 | 10.456 | 1.553 | 2 | 0.342 | 0.047 | 1510 |
| 27 | 11.088 | 1.734 | 2 | 0.381 | 0.046 | 1504 |
The free vibrations experimental recording gives the possibility of damping calculus in this way:
- there are determined the values where the displacement is zero;
- there is determined the cancellation movement period (more precisely $T$ is the double time gap between two consecutive cancellations);
- the frequency $\nu$ and the pulsation $\omega$ are determined with (1)[12];
- the damping factor per unit mass is determined with (2)[12].

$$\nu = T^{-1}; \quad \omega = 2 \cdot \pi \cdot T^{-1} \tag{1}$$
$$\mu = T^{-1} \cdot \ln(\Delta_j/\Delta_{j+1}) \tag{2}$$

- the damping factor per unit length is determined with (3)[12]:

$$C = 2 \cdot \mu \cdot (\rho A) \tag{3}$$

In (3) we have marked with $\Delta_j$, $\Delta_{j+1}$ the maximums separated by periods. The loss factor can be determined with (4) according to [12].

$$\eta = \mu \cdot (\pi \cdot \nu \cdot \xi)^{-1} \tag{4}$$

**Figure 1.** The built samples

**Figure 2.** The experimental recording for the free vibrations (sample 2, free length of 37 cm)

**Figure 3.** The damping factor per unit mass calculus (sample 2, free length of 37 cm and 5 cycles)

**Figure 4.** The damping factor per unit mass calculus (sample 2, free length of 37 cm and 5 cycles)
In the relationship (4) we have marked with: \( \omega_\xi \) - eigen pulsation; \( \mu \) - damping factor per unit mass; \( \eta \) - loss factor; \( \nu_\xi \) - the eigen frequency; \( t \) - time; \( \xi \) is the number of the eigenmode.

The dynamic Young modulus \( E \) values can be determined with (5).

\[
E = \left(\frac{l}{\beta}\right)^4 \left[\nu \pi 2 \left(\rho A\right)^{0.5} / l^{0.5}\right]^2
\]  

(5)

2.2. Static tests

The samples were tensile loaded on an universal testing machine INSTRON, with the maximum force of 100 tf. The test was made according to ASTM D790-02 [13].

**Figure 5.** The damping factors versus free length curve (sample 1)

**Figure 6.** The damping factors versus free length curve (sample 2)

**Figure 7.** The Force-extension curve – sample 1

**Figure 8.** The Force-extension curve – sample 2

2.3. Results and discussions
The experimental results from the dynamic tests were written in table 2. By studying the tables 1 and 2, the next conclusions can be written:
- the damping factors per unit mass and per unit length increase with the free length decrease;
- for the sample 1, the dynamic Young modulus has increased values
- for the sample 2, the dynamic Young modulus has smaller values than the static one
- the eigenfrequency increases with the free length decrease;
- the dynamic Young modulus is not influenced by the samples free length (has almost the same values).

The next static experimental results were obtained:
- sample 1: static elasticity modulus = 2571 MPa, yield stress = 17.296 MPa, breaking strength = 24.257 Mpa
- sample 2: static elasticity modulus = 1993 MPa, yield stress = 18.523 MPa, breaking strength = 24.248 Mpa.

From the fig. 7 and 8 the next conclusions can be extracted:
- the characteristic curves has three stages:
  o stage 1: the loading is supported by both matrix and fibers, which assures the composite material cohesion and also the Hook law is checked, appearing a proportionality between stress and strains
  o stage 2: there appears a non-linearity in the characteristic curve because the tensile strength in the matrix is reached and it breaks in some points; in this domain the adhesion between the fibers and the matrix is lost and pluckings of reinforcement from the matrix appear
  o stage 3: there is almost a linearity between the stress and strain which suggests that the composite breakage is made when in the fibers is reached the tensile strength

3. Conclusions
The damping factors analysis show that these factors must be experimentally determined for each type of material and sample, being difficult to deduce a quantitative correspondence with the parameters which influence the damping directly or indirectly.

The values of damping factors may depend on several features such as: sample dimensions, specific mass or the quantity of material from sample, elastic and damping properties of component materials. The sample width can influence the damping coefficient, by the fact that it determines the surface in which the air friction acts on the sample.

This type of composites can be used for: planes floor building, door frames, roofing sheets, ships floor building, walls of civil constructions, concrete forming or to strengthen thin reinforced concrete slabs.

The added value of the study presented in this paper was:
- providing information regarding the dynamic characteristics (eigenfrequency, damping factors per unit and length mass, dynamic Young modulus and stiffness, loss factor) for some composite materials with refinrocements from industrial hemp and cotton
- providing information regarding the static mechanical characteristics for composites with epoxy resin as matrix reinforced with natural fibers (industrial hemp and cotton)
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