Mechanical Properties of Composite Materials Reinforced with Wheat Straw

DUMITRU BOLCU[1], MARIUS MARINEL STANESCU[2], ION CIUCA[3], OCTAVIAN TRANTE[3], GABRIELA DINU[4]
[1] University of Craiova, Faculty of Mechanics, 165 Calea Bucureşti, 200620, Craiova, Romania
[2] University of Craiova, Department of Applied Mathematics, 13 A.I. Cuza, 200396, Craiova, Romania
[3] Faculty of Engineering and Materials Science, University Politehnica Bucharest, 313 Splaiul Independenţei, 060042, Bucharest, Romania
[4] University Politehnica of Bucharest, 313 Splaiul Independentei, 030138, Bucharest, Romania

In this paper, we obtained experimentally the elasticity modulus and tensile strength, for four types of composite materials made of epoxy resin reinforced with wheat straw, with different spatial orientation for reinforced. Using experimental results, we have obtained the original formulas, for the calculus of tensile strength and elasticity modulus, for the types of specified materials. These relationships are dependent on the percentage of fibers oriented in the direction of request, and which have the length equal with the test sample. In the case in which the percentage is equal to unit, the relations coincide with the ones from unidirectional composite materials. We determined experimentally the coefficient of internal damping and eigen frequencies, for bars embedded at one end and free at the other, made from epoxy resin reinforced with wheat straw, targeted unidirectional, bidirectional and random.

Keywords: composite materials, elasticity modulus, tensile strength, damping coefficient, wheat straw

Composite materials allow obtaining wide range of mechanical properties. Consequently, it is difficult to determine the mechanical characteristics depending on the proportion of composite components. Existing theories, assimilates composites as homogeneous, generally anisotropic, in which material constants are obtained according to the properties of constituents.

A common theory used to calculate the elastic properties, is the mixtures theory based on similarity of elementary gas mixtures. Respecting the composite structure, constituents are presumed overlapping in space, each having elementary deformations.

Using the theory of mixtures, in [1] are determined simple relations, which give good results for Young's modulus and Poisson's coefficients along the fiber. Extreme values of elastic modules were determined in [2, 3], in the case of fibers randomly distributed, and with different diameters.

In [4] is given a model which allows calculation of the sliding module using a mathematical transliteration of the fiber-matrix interactions, and simultaneously taking into account differences in arrangement of fibers in two directions of the composite section. This model is used in [5], to make a micromechanics analysis to substances of composite, and its behaviour.

For some composites that are reinforced with fibers in [6] is shown the existence of nonlinear stress-strain relations. In [7] it is shown that nonlinear behaviour is due to the matrix material, which mainly affects slip module, while the stress-strain relations in the direction of the fibers, and the transverse direction remains almost linear.

The most common types of defects of fibrous composites are fiber breakage, fiber matrix detachment, cracks in the matrix, and for fibers of large diameter radial cracks. The study of these defects is done in [8] and [9], presenting a general theory of defects in the case of composite materials laminates. The theory is based on the average strain in each layer, and allows the state of defective rolling vary, the purpose of calculating the intensities of the different mechanisms of failure, until the final rupture [10], and extend the model for a wide range of temperatures [11]. Forms of evolution of law of defects generally vary depending on the type of material, reflecting dependence between mechanisms and defects depending on: size of fibers, matrix hardness, microstructure and interface zone between fiber and matrix.

Researches about the properties of composite materials with random distribution of reinforcement are made in [12]. Using the mediation formula of values for longitudinal and transversal elasticity modulus , is obtained a relationship for the elasticity modulus of composite plate with random distribution of reinforcement. For this type of composite is given a relationship for calculating of strength tensile. Using finite element method in [13] is studied the behaviour of composite materials reinforced with long fibers.

In specialized literature, the composite materials based on resin and natural fibers have been less studied. Natural fibers receiving now attention from the various fields of activity, show a desire to use organic materials. Besides biodegradability, the advantages of natural fibers are: low density, low cost and better damage tolerance.

Fibers of Boehmeria Nivea (nettle of China) are comparable in terms of tensile strength with glass fibers, are seen as a possible replacement for glass in interior fittings truck assemblies. Hemp is used to replace glass fiber in super-high roof vans Ford Transit, [14-16]. The advantage of hemp is that it does not require pesticides when growing is separated by a mechanical process and is less irritating to the skin than glass fiber.

In [17] is studied the influence of technological factors on properties of composite materials based on resin and textile fibers and the properties of composites materials made of resin reinforced with cotton, flax and hemp. The studied technologies were: manual training technology,

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* *email: bolcu@mecanica.ucv.ro*

cold molding, molding injection in vacuum, with closed matrix. Among the obtained conclusions we mention:

-tensile strength in the traction case, increases with the pressing force, with volumic participation by fibers, with tensile strength of fibers, and is influenced by the relative elongation of the fibers;

-bending resistance by shock, increases with the proportion of fiber in section, pressing force and breaking strength of fibers; is inversely proportional to the elongation at break of fibers, and it has great value in the case in which the textil material is not spinning, under the form of tow agglomeratedi;

-in the three types of studied materials (cotton, flax and hemp), elasticity modulus and shear module, have the smallest values at composites material based on cotton and the largest values at composites material based on hemp;

-sound absorption coefficient has an increased character relative to frequency, and is inversely proportional to density.

Elasticity modulus and tensile strength

To determine the properties of composites reinforced with wheat straw were made four sets of samples, based on epoxy resin, in which wheat straw were included as:

-in first set of samples, the wheat straw were first stretched and after, they were arranged unidirectionally (fig.1);

-second set of samples was made with wheat straw, stretched first, and were arranged in alternating layers, targeted two perpendicular directions (fig. 2);

-third set of samples was made from wheat straw, with random arrangement (fig. 3);

-fourth set was made with wheat straw, with random arrangement, but maintaining the privileged direction of fiber orientation (fig. 4).

All sets of samples have the volumetric proportion of wheat straw equal to $V_f = 0.5$.

For the first two sets of samples all of wheat straw are disposed in the direction of application, and have length equal to the length of the specimens tested.

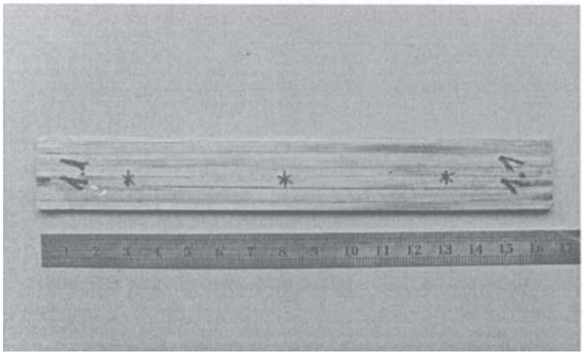


Fig.1

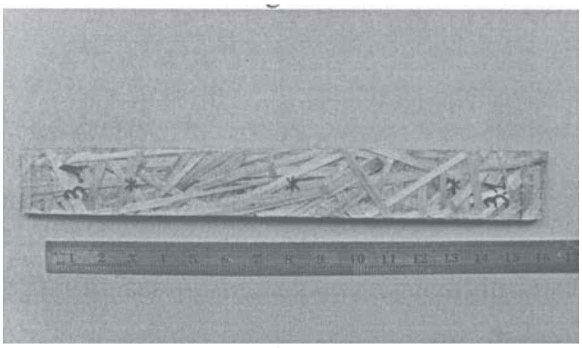


Fig. 3

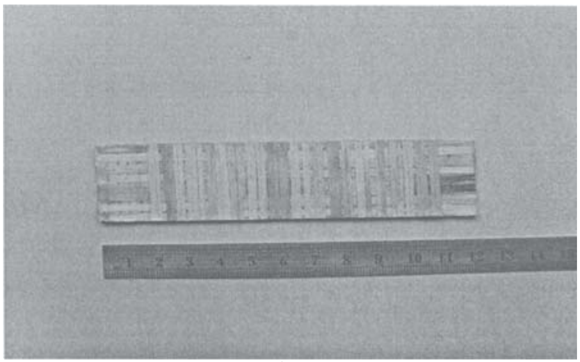


Fig. 2

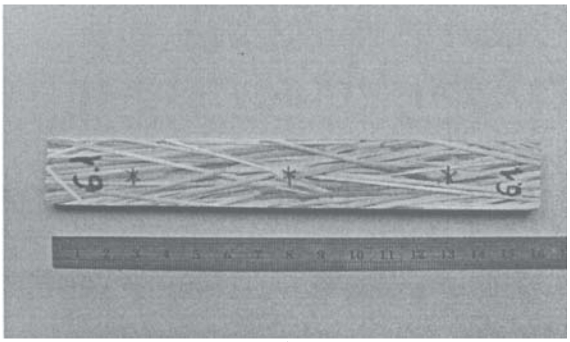


Fig.4

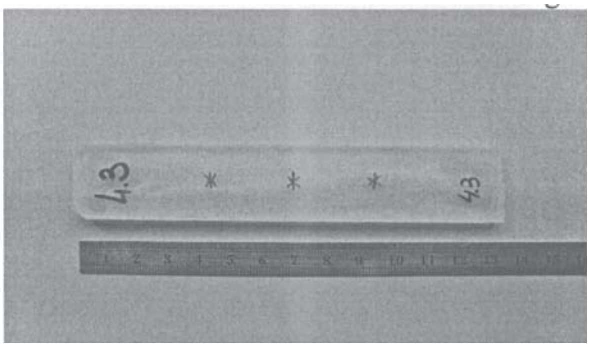


Fig. 5

Table 1

Set of samples	Elasticity Modulus $E\left(MPa\right)$	Tensile Strength $\sigma_r\ \left(MPa\right)$
1	4030	43,3
2	3135	29,6
3	2251	10,6
4	2591	16,3
5	1994	20,6

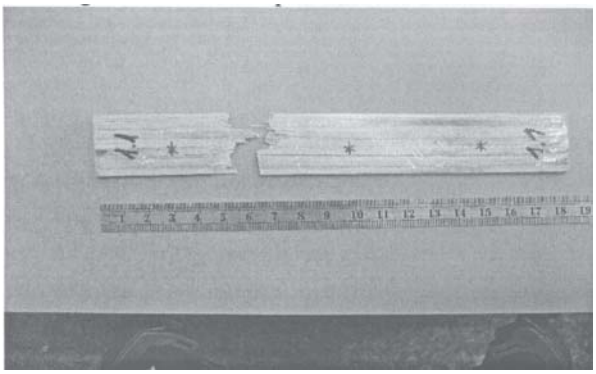


Fig. 6

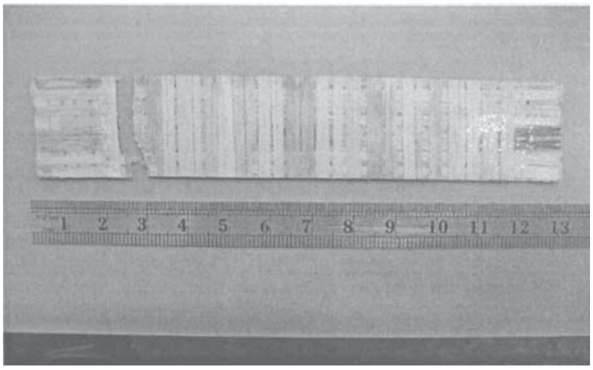
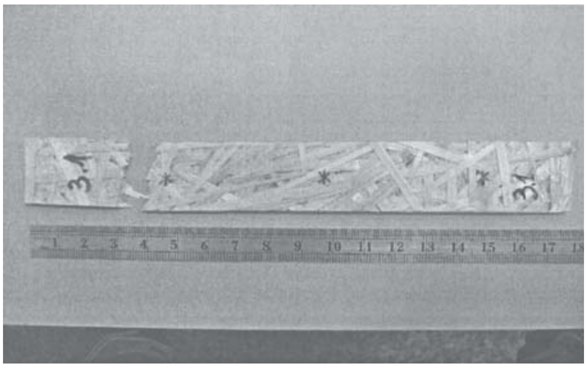


Fig. 7



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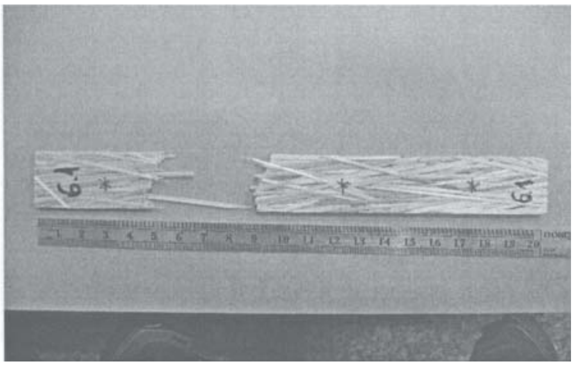


Fig. 9

For the last two sets of samples the number of fibers in the direction of application, with length equal to that of samples, is very low due to the spatial arrangement of wheat straw.

A fifth set of samples was made of resin of which were made all sets of samples reinforced with wheat straw.

All five sets of samples were subjected to tensile. In table 1 are given the medium values for elasticity modulus and tensile strength for each set of samples.

How the test-pieces are broken , is presented in figures 6 - 10.

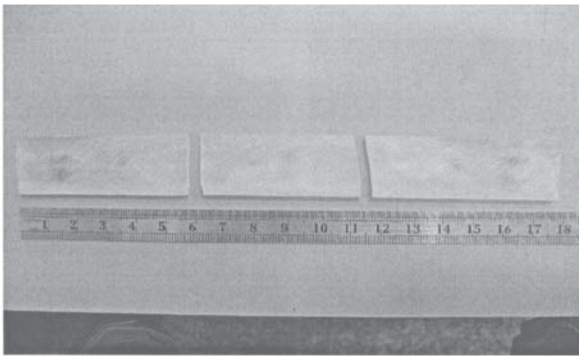


Fig. 10 for sample of set 5

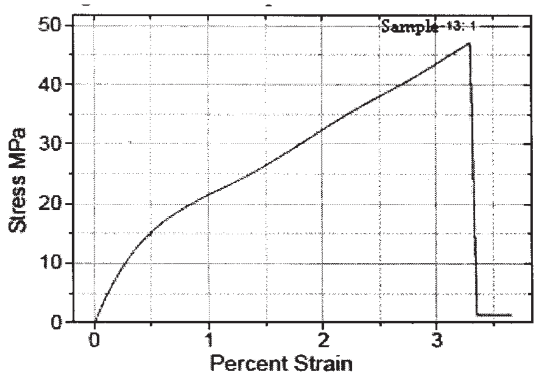


Fig.11

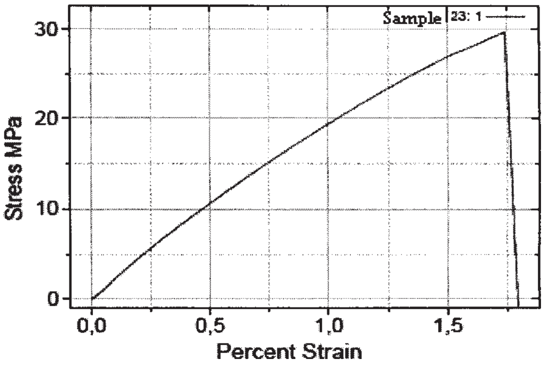


Fig.12

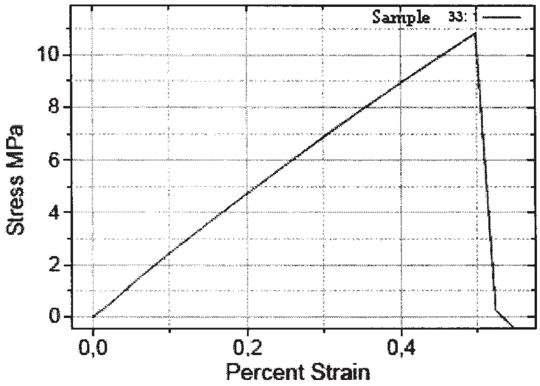
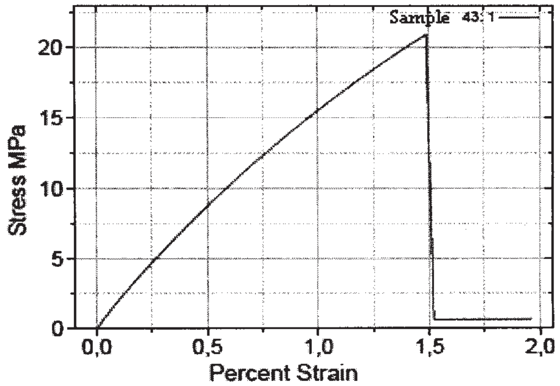


Fig.13

In each set of samples, we present characteristic curve for the sample which has the highest tensile strength in the set. Characteristic curves are presented in figures 11-15 for set of samples 1-5.

From table 1, we can see that the elasticity modulus and tensile strength are very different, although the volumetric proportion of reinforcement is the same for all samples. In addition, for tensile strength in the case of samples 3 and 4, we obtained lower values compared with tensile strength of the matrix. This may be explained by the fact that wheat straw can take effort, but only in their longitudinal direction. Therefore, the composite



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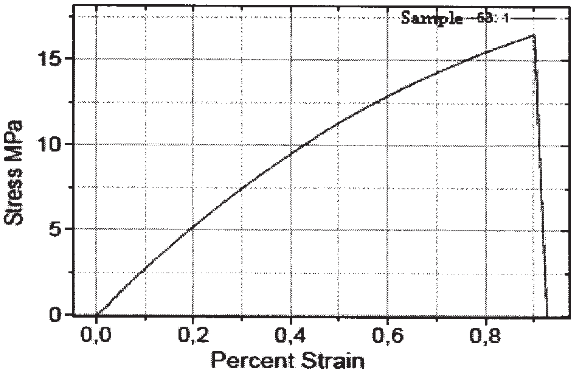

Fig.15

characteristics depend on the value of the percentage of fibers that are oriented on direction of application, and have length equal to the test sample.

We note by:

$$c=\frac{n_e}{n_f}, \tag{1}$$

where:

- n_f is the total number of fibers used for reinforcement;
- n_e is the number of fibers, oriented to the direction of application, having length equal to the length of the test-piece.

For the first set of samples $c=1$, for the second set of samples in which phases are targeted on two perpendicular directions, we have $c=0.5$, and for samples of set 3 with random distribution $c=0$.

To calculate the breaking strength, we propose the relationship:

$$\sigma_r=\sigma_{rl}\cdot\frac{E_mV_m+c\cdot E_fV_f}{E_mV_m+E_fV_f}, \tag{2}$$

where:

- σ_{rl} is resistance to fracture for unidirectional composite (for the samples considered σ_{rl}=43.3 MPa);
- E_m is elasticity modulus for the matrix;
- E_f is elasticity modulus for fibers;
- V_m is the volumetric proportion of matrix;
- V_f is the volumetric proportion of fibers.

For elasticity modulus we propose the relationship:

$$E(c)=E_mV_m+f(c)\cdot E_fV_f, \tag{3}$$

where $f(c)$ is a function satisfying the condition $f(1)=1$. The function $f(c)$ must be chosen so that the elasticity modulus for $c=0$ has the value from table 1. We propose for function $f(c)$ the following expression:

$$f(c)=\frac{a+c}{a+1}. \tag{4}$$

From conditions $E(1)=4030$ and $E(0)=2251$ we get a = 0.075.

For a = 0.5 with (3) we obtain E = 3141 MPa which confirms the assumptions which we had done. Using equation (3), we obtain for the fourth set of samples c = 0.191.

Using equation (2), we obtain the following values for tensile strength:

-for the first set of samples (c=1): σ_r = 43.3 MPa;
-for the second set of samples (c=0.5): σ_r = 27.1 MPa;
-for the third set of samples (c=0): σ_r = 10.7 MPa;
-for the fourth set of samples (c=0.191): σ_r = 16.9 MPa.

Damping coefficient

To study the internal damping of composite materials reinforced wheat straw, we use a model with a degree of freedom, which is subject to a viscoelastic connection (type visco-elastic). Mathematical model of vibration for such a model, in Laplace images, is given in [18]:

$$\bar{x}(s)=\frac{\bar{F}(s)+m\cdot(sx_0+v_0)}{ms^2+E(s)}, \tag{5}$$

where:

- $\bar{x}$(s) is the Laplace image of the movement;
- *m* is the mass for model;
-x_0 and v_0 are the initial conditions ((x_0=x(o); v_0=x(0));
- $\bar{F}$(s) is the Laplace image of external force;
- E(s) is characteristic of the link.

Feature E(s) of the link, which shapes the composite bar, depends on:

- conditions to limit which are established according to the capture bar;
- elastic properties of the material (for bar);
- damping properties of the material bar;
- cross section dimensions of the bar;
- bar length.

Bar vibrations are obtained by inverting Laplace in relation (5). Considering that external force is zero, we obtain the dynamic response of the form:

$$x(t)=\sum_{i=1}^{n}A_ie^{\mu_it}\sin(2\pi\upsilon_it+\varphi_i), \tag{6}$$

where:

- ν_i are eigen-frequencies;
- μ_i are the coefficients which characterized the damping harmonic vibration with frequency ν_i.

Eigen-frequencies are determined with the relationship (given in [19-20]):

$$\upsilon_i=\frac{\beta_i^2}{2\pi l^2}\cdot\sqrt{\frac{EI}{\rho A}}, \tag{7}$$

where:

- *l* is the length of the bar;
- *E* is the elasticity modulus of bar material;
- ρ is the density of bar material;
- *I* is the moment of inertia - axial, for the section of bar;
- *A* is the area for the bar section;
- β_i depends on the support of the bar.

We have measured vibrations produced by an initial deformation, for bars from first three sets of samples. Measurements were made on bars embedded at one end and free at the other. Variation in time of vibrations was presented in figure 16-18 for set of samples 1-3.

In table 2, there are given the dimensions of the bars, on which we have made measurements and values determined for the damping coefficient, and frequency.

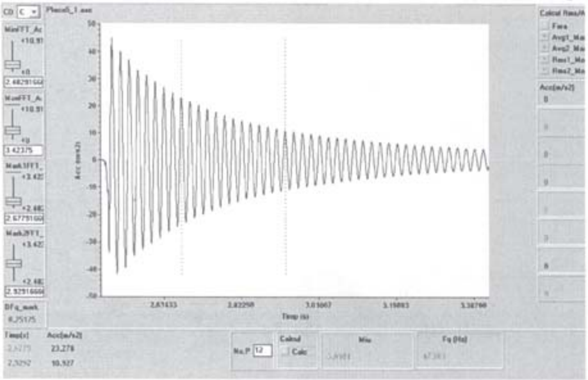

Fig.16

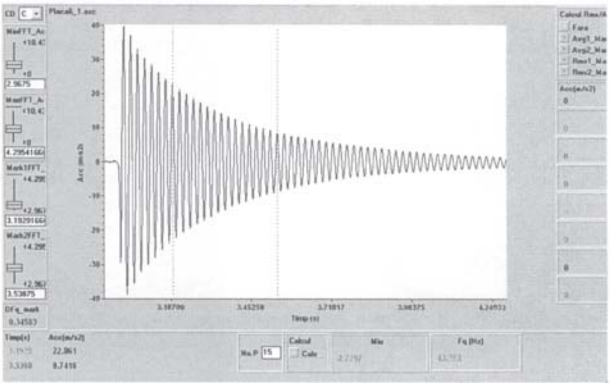

Fig.17

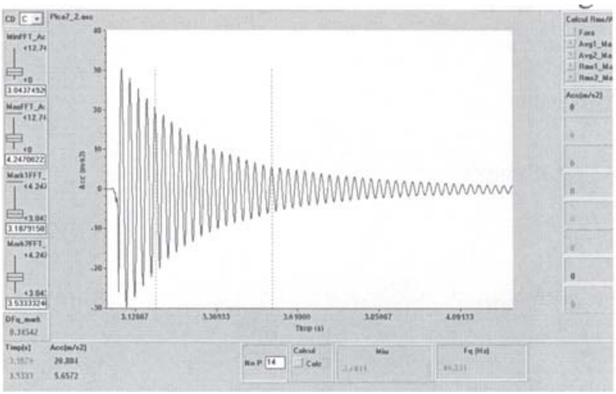

Fig.18

Table 2

Sample	Length (*mm*)	Width (*mm*)	Thickness (*mm*)	Damping coefficient	Frequency (*Hz*)
1	141.5	29,9	3.1	−3,0101	47.761
2	99.9	27,6	2,3	−2,7797	43,373
3	140.5	29.2	3.8	−3,7811	40.531

Conclusions

Analysis of sections of breaking and characteristic curves, shows that there is a brittle fracture that occurs abruptly, without plastic deformations, and without a flow area. We obtained a type of fracture in which occurs the separation between the fiber and the matrix (the fibers are pull out from the resin) and a type of fracture, in which fibers and matrix are broken simultaneously, the resin keeping the contact with straw in the rupture zone (which was made after a direction perpendicular to the requested direction).

Because samples have the same volumetric proportion of reinforcement and experimental results for elasticity modulus and tensile strength are very different, we can conclude that mechanical properties depend on the spatial arrangement of wheat straw. We appreciate that the elastic and strength properties, depend in special on the number of fibers oriented in the direction of application, and which have the same length with the test sample tested. For composites which have a random distribution of wheat straw, the number of fibers which assume the request is much smaller than the total number of fibers. Therefore, for these composites elasticity modulus and tensile strength have lower values than for unidirectional composites.

For elasticity modulus, in the case of all samples, we obtained higher values compared with elasticity modulus of the matrix. This fact shows that regardless of orientation reinforcement, there is an increase in stiffness. Analysis of data obtained shows that the elasticity modulus increases proportional with the value of the coefficient c which gives the proportion of fibers that are in the direction of application.

An increase proportional to the coefficient c is also noted for breaking strength. Thus, for samples with a coefficient small (the straw samples randomly arranged), tensile strength has lower values than those obtained for the matrix. This can be explained as follows: straw have strength only on their longitudinal direction while on perpendicular direction, the strength is negligible, because the fibers (that form the straw) are detached from each other.

Theoretical relations proposed for elasticity modulus and tensile strength, determined on the basis of experimental results show that mechanical properties depend on the properties of resin and the straw, their proportion, and how they are arranged the wheat straw.

In the case of vibrations, eigen-frequencies can be determined theoretically depending on the bar size, its material and its mode of support (boundary conditions). For the damping coefficient there is not a theoretical expression, it must be determined experimentally. Damping coefficient is independent of fiber orientation. This is explained by the fact that all particles from a section of composite material, vibrating the same, regardless of direction in which are oriented the wheat straw in that section. We can appreciate that this damping coefficient depends on the thickness of the bar, so the amount of material subject to vibrations.

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