CERCETĂRI PRIVIND PROPRIETĂŢILE MECANICE ALE MATERIALELOR COMPOZITE RELIZATE DIN PÂSLĂ ŞI RĂŞINĂ EPOXIDICĂ
RESEARCHES REGARDING THE MECHANICAL PROPERTIES OF COMPOSITES MADE FROM FELT AND EPOXY RESIN

COSMIN MIHAI MIRIŢOIU, CRISTIAN OLIVIU BURADA *
Universitatea din Craiova, Facultatea de Mecanică, Dep. de Mecanică Aplicată şi Construcţii civile, Strada Calea Bucureşti, Nr. 107, Cod 200512, Craiova, România,

In this paper there are presented researches regarding wool felt platbands with and without matrix. In the introduction, the state of are in the felt materials researches is presented. Then, there are built some samples made from felt without and with matrix (epoxy resin was used as a matrix). There are determined some mechanical parameters like: breaking strength, static Young modulus, elongation at break, maximum force at break, dynamic Young modulus, loss factor, damping factor and eigenfrequency.

În această lucrare sunt prezentate cercetări în legătură cu platbande din pâslă cu şi fără matrice. În introducere, este prezentat un stadiu actual cu privire la cercetări cu materiale din pâslă. Apoi, sunt construite câteva materiale din pâslă cu şi fără matrice (ca matrice, s-a folosit răşina epoxidică). Sunt determinate câteva caracteristici mecanice precum: rezistenţă la rupere, modul Young static, alungire la rupere, forţa maximă la rupere, modulul lui Young dinamic, factorul de pierdere a energiei, factorul de amortizare şi frecvenţa proprie.

Keywords: *damping factor, loss factor, Young modulus,felt, epoxy resin*

1. Introduction

Felt is considered to be one of the oldest known textile, usually produced by matting, condensing and pressing fibers together. Felt can be made from natural fibers like wool or animal fur, or from synthetic fibers like *petroleum*-based *acrylic* or *acrylonitrile* or *wood pulp* - based *rayon.* Wool presents the structure of a green composite with the next main morphological components: cuticle, cortex and cell membrane [1]. Those are hierarchized with additional subcomponents [1].

Felt can be used for vibration isolation, sound absorption, noise reduction, air filtering, home construction and so on [2]. In [2] the wave propagation and dispersion in microstructured wool felt is studied. There is shown that both normal and anomalous dispersion types exist in wool felt material. It is also shown that for certain ranges of physical parameters negative group velocity will appear. There is explained and demonstrated the influence of the material parameters on the form of a propagating pulse.

In [3] there was proposed an anti-felting finishing process based on recycling waste wool material. The wool fabric was treated with the keratin polypeptides, extracted by protease from the waste wool. From the surfaces point of view, there were not obtained big differences between the woll fabrics treated with the keratin polypeptides and those with fresh ones. But there was obtained an improvement in whiteness, softness, dyeability, hydrophilicity and an acceptable loss in weight (about 1%) and in strength (about 6.1% in warp direction) after fixation of the extracted keratin polypeptides onto the fabrics.

In [4], some hybrid laminated made from glass/wool felts with epoxy resin were tested to tensile, flexural and falling weight impact loading up to penetration. There were used two combinations of samples, one with glass felt, wool felt and glass felt (abbreviated as GWG) and the other having same glass felts but two layers of wool felts (abbreviated as GWWG). For GWG were obtained: 59.1 ± 1.5 – tensile strength (MPa), 4560 ± 350 – Young modulus at tensile test (MPa), 138.1 ± 2.7 flexural strength (MPa), 7430 ± 440 – Young modulus at flexural test (MPa).

In [5], new fiber reinforced composites based on epoxy resin with both protein (wool) and lignocelluloses (jute) natural fibers were studied. Wool-based and hybrid (wool/jute) composites with two different stacking sequences (intercalated and sandwich) were developed. Their microstructure has been investigated through optical and scanning electron microscopy, whereas their quasi-static

* Autor corespondent/*Corresponding author*,
E-mail: cristian.burada@yahoo.com

mechanical behavior has been evaluated in tension and bending. The specimens were marked in the next way: W-33 , W-40 composites with 33% and 40% wool fibers, J_2W and J_3W respectively for sandwich hybrid jute-wool composites. There were obtained the next results [5]:

- tensile strength: W-33= 26.85±8.26 MPa, W-40= 31.05 ± 7.48 MPa, J_2W= 40.24 ± 6.75 MPa, J_3W= 50.51 ± 1.36 MPa
- tensile modulus: W-33= 1850±520 MPa, W-40= 2100 ± 410 MPa, J_2W= 3500 ± 380 MPa, J_3W= 4970 ± 160 MPa.

In [6], a constitutive equation that describes the deformation wave propagation in the felt material was derived using a hysteretic piano hammer model. A nonlinear partial differential equation with third-order terms that takes into account the elastic and hereditary properties of a micro structured felt is used to study a pulse propagation in the one-dimensional case. In the end, the rate of the wave attenuation in the felt material is estimated.

Experimental testing of piano hammers, which consist of a wood core covered with several layers of compressed wool felt were made in [7]. The research highlighted that all hammers have the hysteretic type of the force compression characteristics. It was also shown that different mathematical hysteretic models could be used to describe the dynamic behavior of the hammer felt.

In this paper some wool felt composites combined with epoxy resin are developed. In the first part of the paper, their static mechanical properties are studied. In the second part there are made some investigation regarding their dynamic behavior being the main contribution of this research, because in the engineering literature there is given few information regarding the dynamical mechanical properties for these types of composites.

2. Experimental tests

2.1 Used specimens

Two types of felts with randomly disposed fibers were used, presented in fig. 1 (marked in the paper as type 1 – F1) and fig. 2 (marked in the paper as type 2 – F2). Five rectangular specimens (having 3 mm thickness and 20 mm width) were cut from the felt plates to be tested. Then, the plates were impregnated with epoxy resin and their mechanical properties were also studied (marked in the paper as type 1 – FE1, marked in the paper as type 2 – FE2) (having 6.5 mm thickness and 20 mm width).

2.2. Static mechanical characteristics determination for the two types of felts with and without matrix

The specimens were tensile tested on an Instron Universal Testing Machine, with maximum force of 1000 kN and Bluehill software. A general view with the tested specimen is presented in Fig. 3. In Figures 4 and 5 there are presented the characteristic curves for two samples from types 1 and 2 of felt. These curves were chosen to be presented beucase their values were very close to the nominal one. The experimental results are written in Table 1.

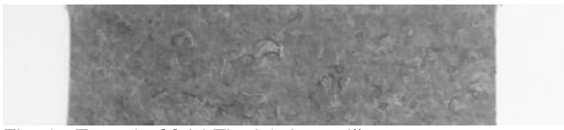

Fig. 1 - Type 1 of felt/ *Tipul 1 de pâslă.*

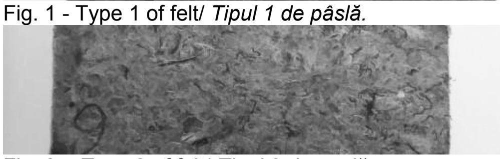

Fig. 2 - Type 2 of felt/ *Tipul 2 de pâslă.*

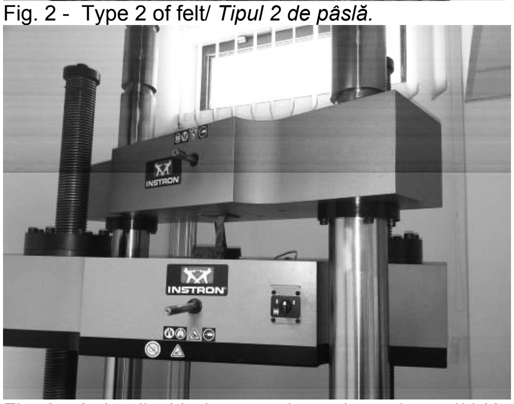

Fig. 3 - A detail with the tested specimen (type 1)/ *Un detaliu cu epruveta încercată (tipul 1).*

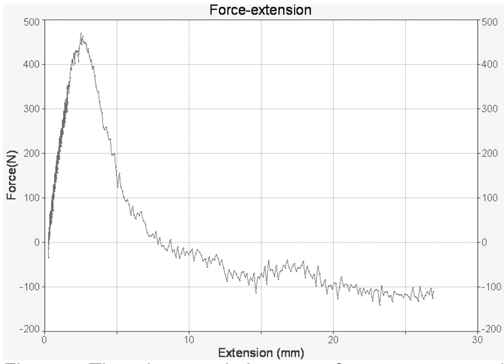

Fig. 4 - The characteristic curve for a representative sample from type 1 – F1 / *Curba caracteristică pentru o epruvetă reprezentativă din tipul 1 - F1.*

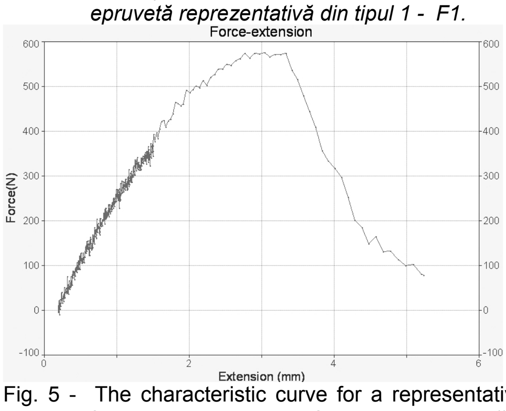

Fig. 5 - The characteristic curve for a representative sample from type 2 – F2 / *Curba caracteristică pentru o epruvetă reprezentativă din tipul 2 – F2.*

Table 1

Experimental results for static loading / *Rezultate experimentale pentru solicitare statică*

Type *Tip*	Breaking strength (MPa) *Rezistenţa la rupere (MPa)*	Yield stress (MPa)/ *Limita de curgere (*MPa)	Elongation at break (%)/ *Alungirea la rupere* (%)	Young modulus (MPa)/ *Modulul lui Young (*MPa)
F1	6.25± 1.22	3.65±1.24	3.4±1	1098±100
F2	8±1.25	6.5±1.28	5.3±1	2095±100

Table 2

Experimental results for static loading / *Rezultate experimentale pentru solicitare statică*

Type *Tip*	Breaking strength (MPa) *Rezistenţa la rupere* (MPa)	Yield stress (MPa)/ *Limita de curgere* (MPa)	Elongation at break (%)/ *Alungirea la rupere* (%)	Young modulus (MPa)/ *Modulul lui Young* (MPa)
FE1	15.95± 1.35	14.5±1.1	3.3±1	2714±120
FE2	43±3.05	11±1.1	6.2±1	3003±110

The same test was applied for the specimens from felt with epoxy resin. In Figures 6 and 7 there the characteristic curves for two samples from types 1 and 2 of felt with epoxy resin are presented. These curves were chosen to be presented beucase they were very close to the nominal value. The experimental results are written in Table 2. The test were made according to the ASTM D638 - 14 standard [8].

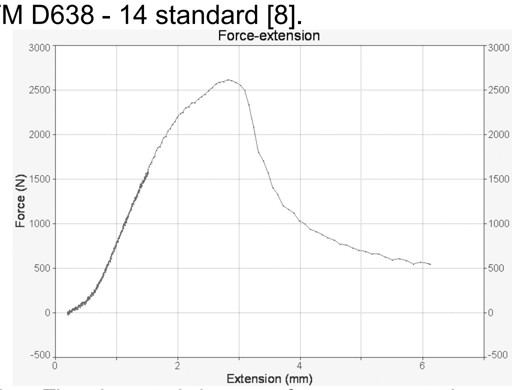

Fig. 6 - The characteristic curve for a representative sample from type 1 – FE1 / *Curba caracteristică pentru o epruvetă reprezentativă din tipul 1 - FE1.*

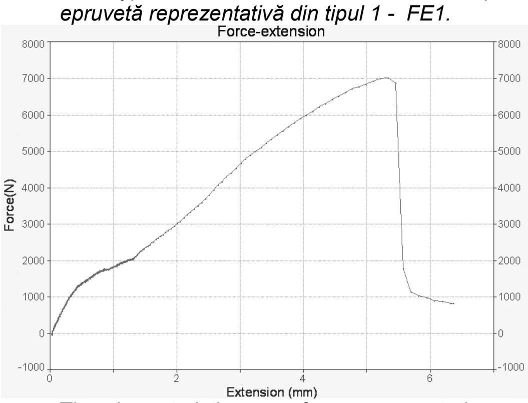

Fig. 7 - The characteristic curve for a representative sample from type 2 – FE2 / *Curba caracteristică pentru o epruvetă reprezentativă din tipul 2 – FE2.*

In order to validate the experimental results for the elasticity modulus the methodology from [9] was used. According to [9] the formula (1) was obtained for the elasticity modulus after a linearization of the $\sqrt{E_l \cdot E_t}$ parameter. In Fig. 8 there is presented a general view with the breaking section for a FE -1 sample. The picture was taken with an optical microscope OLYMPUS with camera

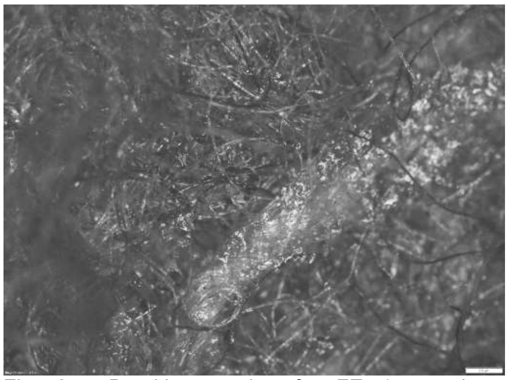

Fig. 8 - Breaking section for FE 1 sample cathegory/ *Secţiunea de rupere pentru o epruvetă din categoria FE 1*

$$E = E_m \cdot V_m + V_f \cdot \sqrt{E_t \cdot E_l} = E_m \cdot V_m + V_f \cdot \sqrt{E_m \cdot E_f \cdot \frac{E_m \cdot V_m + E_f \cdot V_f}{E_m \cdot V_f + E_f \cdot V_m}} \quad (1)$$

that has Stream Essentials software installed on a desktop.

In (1) the next notations were made:

- E_m the matrix Young modulus (3300 MPa for this research)
- V_m the matrix volume fraction (0.6 for this research)
- E_f the fibers elasticity modulus (1098 and 2095 MPa for this research)
- V_f the fibers volume fraction (0.4 for this research)
- E_l the elasticity modulus along the fibers direction (determined with (2))
- E_t the elasticity modulus across the fibers direction (determined with (3)).

$$E_l = E_m V_m + E_f V_f \quad (2)$$

$$E_t = \frac{E_f \cdot E_m}{V_f \cdot E_m + V_m \cdot E_f} \quad (3)$$

Numerically, for each samples the next values and erros compared to the experimental values were obtained for the equivalent Young modulus:

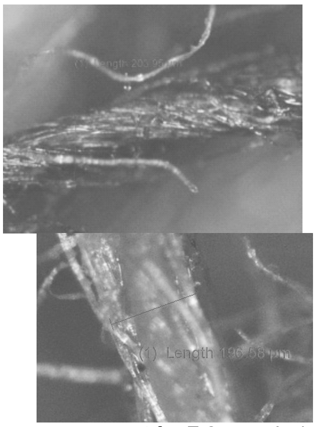

Fig. 9 - A fiber measurement for F 2 sample / *O măsurătoare a fibrei pentru epruveta F 2.*

- FE 1 – 2822 MPa, error 3,83%;
- FE 2 – 3251 MPa, error 7,63 %.

There were also measured the fiber dimensions in the breaking area and it was seen that the fibers are not only disposed randomly but also their diameter varries. For example, in different areas, the fiber diameters measured were presented in Fig. 9 and 10 for F -2 sample.

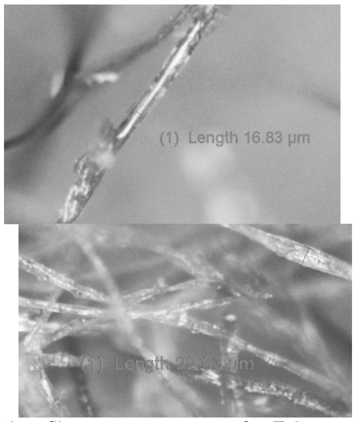

Fig. 10 - Other fibers measurement for F 2 sample / *Alte măsurători de fibre pentru epruveta F2.*

Fig. 11 - A sample from FE 1 for dynamic tests / *O epruvetă din FE 1 pentru testele dinamice.*

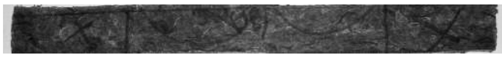

Fig. 12 - A sample from FE 2 for dynamic tests / *O epruvetă din FE 2 pentru testele dinamice.*

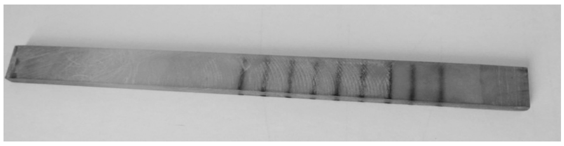

Fig. 13 - A sample from E for dynamic tests / *O epruvetă din E pentru testele dinamice.*

2.3. Dynamic mechanical characteristics determination for the two types of felts with and without matrix, and a sample only with the matrix

For the dynamic test, samples from FE 1 and FE 2 were cut. An example with those samples was given in Fig. 11 and 12. Also, in Fig. 13 there is presented sample with only the matrix (the epoxy resin, abbreviated as E).

The platbands were clamped at one end and left free at the other end. At the free end, an B&K 8309 accelerometer was placed in order to record the free vibrations. Like in [10] and [11], several free lengths values were considered for the samples (values in mm): 190, 170, 150 and 130 mm. The accelerometer was connected to a measuring system which is compound by: signal conditioner B&K NEXUS 2692-A-0I4 and data acquisition system HBM SPIDER 8. The SPIDER 8 apparatus was connected to a notebook through USB port. A similar experimental setup was used before in [10] and [11] where good results for other composite sandwich platbands were obtained.

The differential equation of transversal free vibrations has the form [12]:

$$c^2\frac{\partial^4 w}{\partial x^4}+\frac{\partial^2 w}{\partial t^2}=0 \qquad (4)$$

parameter c being determined with (5).

$$c=\frac{1}{2\pi}\sqrt{\frac{EI}{\rho A}} \qquad (5)$$

In (4) and (5) we have marked with: w the transversal movement of bar medium fiber, ρA the specific mass, ρ material density, A the bar transversal section, E the Young modulus, I the section moment of inertia.

If there was considered:

$$w=W(x)e^{i\nu t} \qquad (6)$$

the next differential equation is obtained:

$$\frac{d^4W}{dx^4}-\frac{\nu^2}{c^2}W=0 \qquad (7)$$

If Laplace transform is applied to (7) we obtain the form [12,13]:

$$\overline{W}(p)=\frac{1}{p^4-\frac{\nu^2}{c^2}}\left[p^3W(0)+p^2W'(0)+pW''(0)+W'''(0)\right] \qquad (8)$$

If there were taken into account the relationships (10) [13] and the next solution (9) was obtained for the differential equation (7):

$$W(x)=W(0)S\left(\sqrt{\frac{\nu}{c}}x\right)+\sqrt{\frac{c}{\nu}}W'(0)T\left(\sqrt{\frac{\nu}{c}}x\right)+\frac{c}{\nu}W''(0)U\left(\sqrt{\frac{\nu}{c}}x\right)\frac{c}{\nu}\sqrt{\frac{c}{\nu}}W'''(0)V\left(\sqrt{\frac{\nu}{c}}x\right) \quad (9)$$

$$\begin{cases}
\dfrac{1}{p^4-\dfrac{\nu^2}{c^2}}=0{,}5\dfrac{c}{\nu}\left(-\dfrac{1}{p^2+\dfrac{\nu}{c}}+\dfrac{1}{p^2-\dfrac{\nu}{c}}\right)\\
L^{-1}\left(\dfrac{1}{p^4-\dfrac{\nu^2}{c^2}}\right)=\dfrac{c}{\nu}\sqrt{\dfrac{c}{\nu}}\left(\dfrac{sh\left(\sqrt{\dfrac{\nu}{c}}x\right)-\sin\left(\sqrt{\dfrac{\nu}{c}}x\right)}{2}\right)=\dfrac{c}{\nu}\sqrt{\dfrac{c}{\nu}}V\left(\sqrt{\dfrac{\nu}{c}}x\right)\\
L^{-1}\left(\dfrac{\sqrt{\dfrac{\nu}{c}}}{p^4-\dfrac{\nu^2}{c^2}}\right)=\dfrac{c}{\nu}\left(\dfrac{ch\left(\sqrt{\dfrac{\nu}{c}}x\right)-\sin\left(\sqrt{\dfrac{\nu}{c}}x\right)}{2}\right)=\dfrac{c}{\nu}U\left(\sqrt{\dfrac{\nu}{c}}x\right)
\end{cases}$$

$$\begin{cases}
L^{-1}\left(\dfrac{\dfrac{\nu}{c}}{p^4-\dfrac{\nu^2}{c^2}}\right)=\sqrt{\dfrac{c}{\nu}}\left(\dfrac{sh\left(\sqrt{\dfrac{\nu}{c}}x\right)+\sin\left(\sqrt{\dfrac{\nu}{c}}x\right)}{2}\right)=\sqrt{\dfrac{c}{\nu}}T\left(\sqrt{\dfrac{\nu}{c}}x\right)\\
L^{-1}\left(\dfrac{\dfrac{\nu}{c}\sqrt{\dfrac{\nu}{c}}}{p^4-\dfrac{\nu^2}{c^2}}\right)=\dfrac{ch\left(\sqrt{\dfrac{\nu}{c}}x\right)+\sin\left(\sqrt{\dfrac{\nu}{c}}x\right)}{2}=S\left(\sqrt{\dfrac{\nu}{c}}x\right)\\
S(0)=1;T(0)=U(0)=V(0)=0
\end{cases} \quad (10)$$

$$\begin{cases}
W'(x)=W(0)\sqrt{\dfrac{\nu}{c}}V\left(\sqrt{\dfrac{\nu}{c}}x\right)+W'(0)S\left(\sqrt{\dfrac{\nu}{c}}x\right)+\sqrt{\dfrac{c}{\nu}}W''(0)T\left(\sqrt{\dfrac{\nu}{c}}x\right)+\dfrac{c}{\nu}W'''(0)U\left(\sqrt{\dfrac{\nu}{c}}x\right)\\
W''(x)=W(0)\dfrac{\nu}{c}U\left(\sqrt{\dfrac{\nu}{c}}x\right)+W'(0)\dfrac{\nu}{c}V\left(\sqrt{\dfrac{\nu}{c}}x\right)+W''(0)S\left(\sqrt{\dfrac{\nu}{c}}x\right)+\sqrt{\dfrac{c}{\nu}}W'''(0)T\left(\sqrt{\dfrac{\nu}{c}}x\right)\\
W'''(x)=W(0)\dfrac{\nu}{c}\sqrt{\dfrac{\nu}{c}}T\left(\sqrt{\dfrac{\nu}{c}}x\right)+W'(0)\dfrac{\nu}{c}U\left(\sqrt{\dfrac{\nu}{c}}x\right)+W''(0)\dfrac{\nu}{c}V\left(\sqrt{\dfrac{\nu}{c}}x\right)+W'''(0)S\left(\sqrt{\dfrac{\nu}{c}}x\right)
\end{cases} \quad (11)$$

With S,T,U,V the Krîlov functions were marked in (9). If we differentiate in relation with time (9) we obtain the form (11):

The (10) and (11) can be easily used to determine the eigenfrequency of the first eigenmode. So, if a bar is clamped at one end and free at the other, the limit conditions (12) can be used.

$$W(0)=W'(0)=W''(l)=W'''(l)=0 \quad (12)$$

Relationship (12) leads to the equations system (13), with β parameter given by (14). If we equal to 0 the main determinant of (13) we obtain (15), with the solution 1.875 for the first eigenmode. From (14) we determine the eigenfrequency of the first eigenmode (16) by taking into account also the relationship (5). In (16) we have marked with l the bars length.

$$\begin{cases} W''(l) = W''(0)S(\beta) + \frac{c}{v}W'''(0)T(\beta) = 0 \\ W''(l) = W''(0)\sqrt{\frac{v}{C}}V(\beta) + W''(0)S(\beta) = 0 \end{cases} \quad (13)$$

$$\beta^2 = \frac{v}{c}l^2 \quad (14)$$

$$ch\beta \cos\beta = -1 \quad (15)$$

$$v = \left(\frac{\beta}{l}\right)^2 c = \left(\frac{\beta}{l}\right)^2 \frac{1}{2\pi}\sqrt{\frac{EI}{\rho A}} \quad (16)$$

From the free vibrations recording, the damping factor per unit mass was determined in this way [10,11]:

- there were determined the values at which the displacement is zero (meaning the points where the graph intersects the time axis);
- it was determined the period of movement cancellation, more precisely, T is the time interval double, between two successive cancellations;
- it was determined the frequency $\upsilon = \frac{1}{T}$ and the pulsation $\omega = \frac{2\pi}{T}$;
- it was determined the damping factor per unit mass

$$\mu = (\mathrm{KT})^{-1} \ln \frac{A_i}{A_{i+k}}, \quad (17)$$

where A_i and A_{i+1} are maximums separated by K periods and c is the damping factor per unit length.

Important remark: because the form of the platbands deformed medium fiber is similar to their first vibration eigenmode, the measured frequency was considered as the first eigenfrequency.

The damping factor per unit length is determined with (18).

$$C = 2 \cdot \mu \cdot \langle \rho A \rangle \quad (18)$$

Starting from the vibrations general formula, a procedure to determine the loss factor was presented in [14].

$$\mu = \zeta \cdot \omega_\xi = \zeta \cdot 2 \cdot \pi \cdot v_\xi \Rightarrow \zeta = \frac{\mu}{2 \cdot \pi \cdot v_\xi}, \eta = 2 \cdot \zeta \ [13]$$

$$\Rightarrow \quad (19)$$

$$\eta = \frac{\mu}{\pi \cdot v_\xi}$$

In the relation (19) we have marked with: ζ- critical damping; ω_ξ- eigen pulsation; μ- damping factor per unit mass; η- loss factor; v_ξ- the eigenfrequency; t- time; ξ is the number of the eigenmode.

From (16), the dynamic stiffness and dynamic Young modulus can be determined with (20) and (21).

$$EI = \left(\frac{l}{\beta}\right)^4 \left(v \cdot 2\pi\sqrt{\rho A}\right)^2 \quad (20)$$

$$E = \left(\frac{l}{\beta}\right)^4 \left(v \cdot 2\pi \cdot \frac{1}{\sqrt{I}}\sqrt{\rho A}\right)^2 \quad (21)$$

All the dynamic results are written in Tables 1, 2 and 3.

Table 1

Experimental results, geometrical and mechanical characteristics
Rezultate experimentale, caracteristici geometrice şi mecanice

Width *Lăţime* [mm]	Specific Mass *Masă specifică* [kg/m]	Free length *Lungime liberă* [mm]	Eigenfrequency *Frecvenţă proprie* [1/s]	Damping factor per unit mass *Factor de amortizare pe unitatea de masă* [(Ns/m)/kg]	Sample no. *Număr epruvetă*	Damping factor per unit length *Factor de amortizare pe unitatea de lungime* [(Ns/m)/m]	Loss factor *Factor de pierdere a energiei*	Dynamic Young modulus *Modul de elasticitate dinamic* [MPa]
20	0.072	190	16.15	2.26	FE 1	0.325	0.045	170.7
20	0.072	170	19.96	3.2	FE 1	0.461	0.051	167.1
20	0.072	150	25.74	5.09	FE 1	0.733	0.063	168.5
20	0.072	130	33.89	7.29	FE 1	1.05	0.068	164.8
20	0.072	190	25.31	2.46	FE 2	0.354	0.031	419.4
20	0.072	170	31.19	3.53	FE 2	0.508	0.036	408.1
20	0.072	150	40.474	5.35	FE 2	0.77	0.042	416.6
20	0.072	130	53.24	7.76	FE 2	1.117	0.046	406.7

Table 2

The dynamic flexural rigidity / *Rigiditatea dinamică la încovoiere*

Sample *Epruvetă*	Free length *Lungime liberă*	EI [Nm^2]	Sample *Epruvetă*	Free length *Lungime liberă*	EI [Nm^2]
FE 1	190	0.078	FE 2	190	0.192
FE 1	170	0.077	FE 2	170	0.187
FE 1	150	0.077	FE 2	150	0.191
FE 1	130	0.075	FE 2	130	0.186

Table 3

Mechanical characteristics for sample E *(without reinforcement)/ Caracteristici mecanice pentru epruveta E* (fără ranforsant)

Width *Lăţime* [mm]	EI [Nm^2]	Free length *Lungime liberă* [mm]	Eigenfrequency *Frecvenţă proprie* [1/s]	Damping factor per unit mass *Factor de amortizare pe unitatea de masă* [(Ns/m)/kg]	Sample no. *Număr epruvetă*	Damping factor per unit length *Factor de amortizare pe unitatea de lungime* [(Ns/m)/m]	Loss factor *Factor de pierdere a energiei*	Dynamic Young modulus *Modul de elasticitate dinamic* [MPa]
20	0.035	190	11.26	2.06	E	0.272	0.058	75.53
20	0.041	170	15.19	2.78	E	0.367	0.058	88.09
20	0.043	150	20.14	4.2	E	0.554	0.066	93.86
20	0.041	130	25.99	6.3	E	0.832	0.077	88.19

In Fig. 14 and 15 the damping factor per unit mass determination for the sample FE 2 by considering 5 cycles and 190 mm free length was presented. The damping factor per unit length and eigenfrequency variations depending on the platbands free length are presented in Fig. 16 and 17. The loss factor variation versus the platbands free length is presented in fig. 18. For the sample E, in Fig. 19 there is presented the free vibration for the 170 mm free length and in Fig. 20 the damping factor determination by considering 5 cycles.

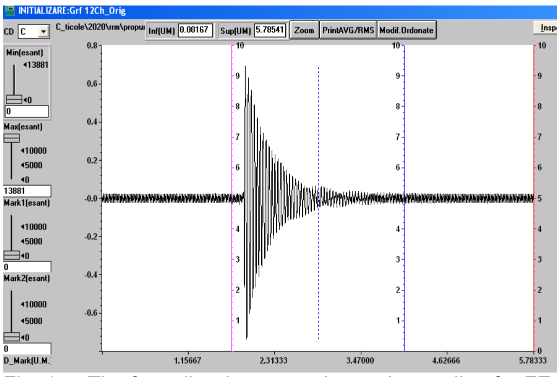

Fig. 14 - The free vibrations experimental recording for FE 2 sample with 190 mm free length / *Înregistrări experimentale ale vibraţiilor libere pentru epruveta FE 2 cu 190 mm lungime liberă.*

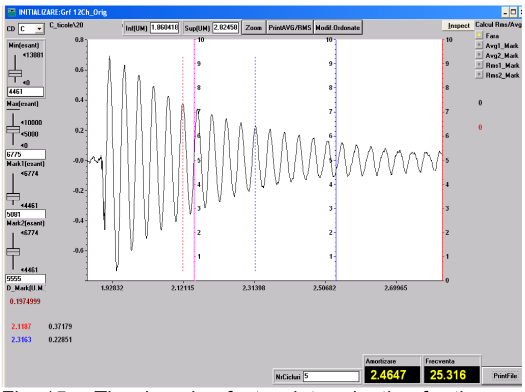

Fig. 15 - The damping factor determination for the sample FE 2, with 190 mm free length / *Determinarea factorului de amortizare pentru epruveta FE 2, cu lungimea liberă de 190 mm*

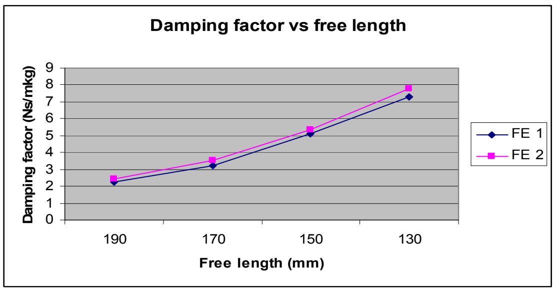

Fig. 16 - The damping factor per unit mass variation versus the platbands free length/ *Variaţia factorului de amortizare pe unitatea de masă în funcţie de lungimea liberă a platbandelor.*

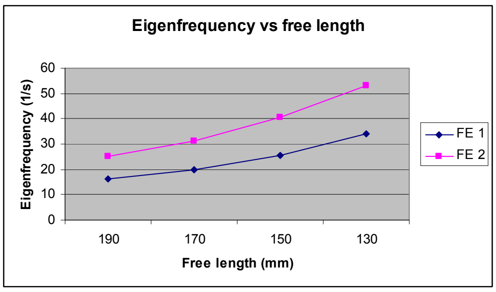

Fig. 17 - The eigenfrequency variation versus the platbands free length/ *Variaţia frecvenţei proprii în funcţie de lungimea liberă a platbandelor.*

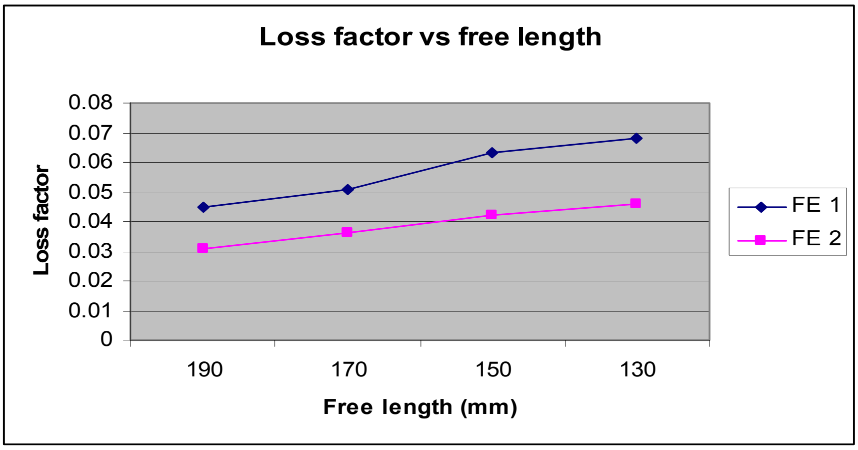

Fig. 18 - The loss factor variation versus the platbands free length/ *Variaţia factorului de pierdere a energiei în funcţie de lungimea liberă a platbandelor.*

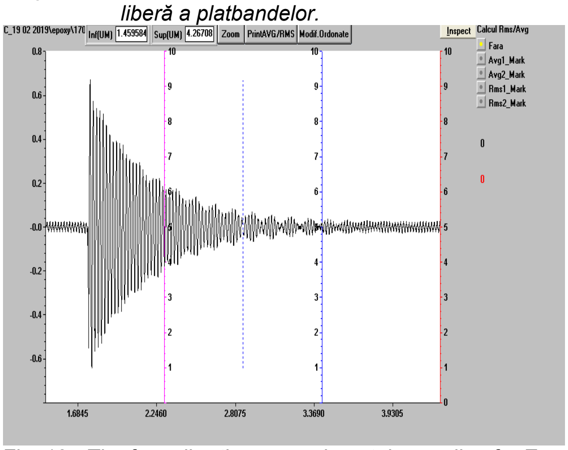

Fig. 19 - The free vibrations experimental recording for E sample with 170 mm free length / *Înregistrări experimentale ale vibraţiilor libere pentru epruveta E cu 170 mm lungime liberă.*

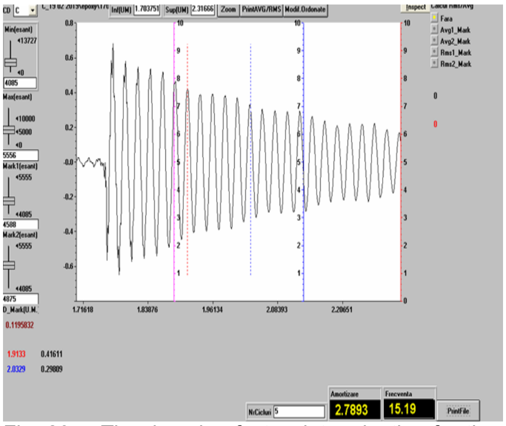

Fig. 20 - The damping factor determination for the sample E 2, with 170 mm free length / *Determinarea factorului de amortizare pentru epruveta E, cu lungimea liberă de 170 mm.*

3. Discussions

From the tensile test, and Figures 4,5,6 and 7 we can extract the next conclusions:

- the second type of felt (F 2) has increased mechanical properties when compared to the first one in both cases, with and without matrix (epoxy resin)
- the breakage took place in the calibrated area
- the second type of felt (F 2) has also increased elongation at break compared to the first type (F 1)
- the specimens impregnated in epoxy resin from FE 2 type have almost triple the breaking strength when compared to FE 1 type, this can be explained by the fact that there are more fibers with higher diameter (thickness) in FE 2 compared to FE 1; the fibers thickness as seen in Fig. 9 and 10 varries a lot and there cannot be extracted a conclusion regarding the fibers nominal thickness.

The characteristic curves have three different domains: in the first domain, 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; in the second domain 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; in the last domain 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; the are some inflexion points until the samples breakage (for example in the sample FE 2 characteristic curve presented in Fig. 7) which show that not all the fibers were broken at the same time, a part of them broke in the same time and the loading is subjected by the remained fibers. In Fig. 4 and Fig. 5, at the begining of the tensile test, we can see some irregularities in the characteristic curve which represent the fact that, at the begining of the experiment, the specimen has a tendency to slip from the testing machine grips.

From the dynamic results we can extract the next general conclusions (Tables 1,2 and 3, Fig. 15, 16, 17, 18, 19 and 20):

Table 4

Static mechanical characteristics of felt - reinforced composites
Caracteristici mecanice static pentru compozite ranforsate cu pâslă

Samples *Epruvete*	FE 1 [this study]	FE 2 [this study]	Hybrid glass wool glass GWG - epoxy resin [4]	Hybrid glass wool wool glass GWG - epoxy resin [4]	Wool 33% - epoxy resin [5]	Wool 40% - epoxy resin [5]	Jute felt 20% - polyester resin [15]	Hemp felt 20% polyester resin [15]
Breaking strength (MPa) *Rezistenţa la rupere (MPa)*	15.95	43	59.1	62.5	26.85	31.05	47.35	37.82
Young modulus (MPa)/ *Modulul lui Young (MPa)*	2714	3003	4560	7430	1850	2100	6790	6700
Samples *Epruvete*	Wool – Jute hybrid J_2W - epoxy resin [5]	Wool – Jute hybrid J_3W - epoxy resin [5]						
Breaking strength (MPa) *Rezistenţa la rupere (MPa)*	40.24	50.51						
Young modulus (MPa) *Modulul lui Young (MPa)*	3500	4970						

Table 5

Dynamic mechanical characteristics for some composites with natural fibers/ *Caracteristici mecanice dinamice pentru compozite cu fibre naturale*

Samples *Epruvete*	FE 1 [this study]	FE 2 [this study]	Cotton with epoxy resin [17]	Rectangular honeycomb core from kevlar, reinforced with kevlar-carbon and epoxy resin [18]	Hemp with epoxy resin [17]
Dynamic stiffness EI [Nm^2]/ *Rigiditatea dinamică EI [Nm^2]*	0.076	0.189	0.191	0.926	0.3

- the eigenfrequency, damping factor per unit mass and loss factor increase with the specimens free length decrease (with the exception at the E specimens where, at 190 and 170 mm, the loss factor remains the same)
- the variations of eigenfrequency and damping factor per unit mass are almost exponential
- the dynamic mechanical characteristics for FE 2 samples are higher than the FE 1 samples, this conclusion was expected because FE 2 samples have also increased static mechanical characteristics when compared to FE 1
- the dynamic Young modulus could be determined by making an arithmetic mean for the obtained values (because these are almost similar) and we obtain: FE 1 – 167.77 MPa, FE 2 – 412.7 MPa
- the dynamic stiffness could be determined by making an arithmetic mean for the obtained values (because these are almost similar) and we obtain: FE 1 – 0.076 Nm^2, FE 2 – 0.189 Nm^2.

The values of damping factors per unit mass and length 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 mass or specific linear mass influence the damping factor by the fact that the samples with higher mass and width, the deformation energy which is stored in the sample through the initial deformation, is dissipated in a larger quantity of material.

In Table 4, there were presented the mechanical characteristics of the specimens studied in this research compared to other similar specimens from the engineering literature. The aim is to make comparions between the proposed composite in this paper and similar materials (with the same area of application).

From the Table 4 it can be seen that the proposed specimens studied in this paper have comparable properties with the ones already studied (in some cases higher values, but in other smaller ones).

In Table 5, there are written the dynamical stiffness of the specimens studied in this paper compared to other similar specimens from the engineering literature. From the Table 4 it can be seen that the proposed specimens studied in this paper have comparable properties with the ones already studied

The novelty inserted by this paper is the information information regarding the dynamic characteristics (eigenfrequency, damping factors per unit and length mass, dynamic Young modulus and stiffness, loss factor) for some composite meterials with refinrocements from wool felt. This composite can be used to strengthen thin reinforced concrete slabs, like the study presented in [16].

4. Conclusions

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 meterials with refinrocements from wool felt

- providing information regarding the static mechanical characteristics for composites with epoxy resin as matrix reinforced with wool felt.

This type of composites can also be used for: to reinforce the planes and ships floor and for building the walls of civil constructions for vibration damping. The materials presented in Table 3 can also be used in the same area like the composites studied in this research. As we can see from the Table 3 results, the proposed materials from this study can replace similar materials having, in some cases, improved mechanical characteristics.

REFERENCES

[1] H., Zahn, et. al., Wool as biological composite structure, Ind Eng Chem Prod Res Dev, 1980, **19,**496.

[2] D., Kartofelev, A., Stulov, Wave propagation and dispersion in microstructured wood felt, Wave motion, 2015, **57**, 23.

[3] Z., Du., B., Ji., K., Yan, Recycling keratin polypeptides for anti-felting treatment of wool based on L-cysteine pretreatment, Journal of Cleaner Production, 2018, **183**, 810.

[4] S., Boria, C., Santulli, et. al., Potential of wool felts in combination with glass fibres: Mechanical and low velocity impact assesment, Composites Part B, 2017, **118**, 158.

[5] C., Santulli, F. Sarasini, et. al., Mechanical behaviour of jute cloth/wool felts hybrid laminates, Materials and Design, 2013, **50,** 309.

[6] D. Kartofelev, A., Stulov, Propagation of deformation waves in wool felt, Acta Mech, 2014, **225**, 3103.

[7] A. Stulov, Dynamic behavior and mechanical features of wool felt, Acta Mech, 2004, **169**, 13.

[8] ASTM D 638-14 Standard Test Method for Tensile Properties of Plastics

[9] C.O., Burada, M., M., Stănescu, C., M., Miriţoiu, A., Bolcu, Static and dynamic behaviour of platbands made from polyester resin reinforced with randomly disposed glass fiber, Revista Română de Materiale – Romanian Journal of Materials, 2017, **47**, 267.

[10] C.M. Miriţoiu, D. Bolcu, M.M. Stănescu, I. Ciucă, R. Cormos, Determination of Damping Coefficients for Sandwich Bars with Polypropylene Honeycomb Core and the Exterior Layers Reinforced with Metal Fabric, Materiale Plastice, 2012, **49,** 118.

[11] C.M. Miriţoiu, C.O. Burada, M. M. Stănescu, A. Bolcu, Dynamic and static behaviour of composite sandwich platbands with kevlar honeycomb core, Romanian Journal of Materials, 2018, **48** (1), 101.

[12] M., M., Stănescu, et. al., Experimental Researches Concerning the Properties of Composite Materials with Random Distribution of Reinforcement, Materiale Plastice,2009, **46,** p. 73.

[13] W., Nowacki, Dynamics of elastic systems, 1969, Technical Publishing House, Bucharest.

[14] C.O., Burada, C.M., Miriţoiu, et. al., The vibration behaviour of composite platbands reinforced with glass fiber, Romanian Journal of Materials, 2015, **45**, p. 244.

[15] A., Hodzic, R., Shanks, Natural Fibre composites. Materials, processes and Properties, Woodhead Publishing, 2004.

[16] N. Ţăranu, D. Banu, G. Oprişa, M. Budescu, L. Bejan, Strengthening of thin reinforced concrete slabs with composite strips, Romanian Journal of Materials, 2013, **43**, 3.

[17] C.M. Miriţoiu, C.O. Burada, A study regarding the mechanical properties of composite platbands with reinforcements made from bast fibers, Romanian Journal of Materials, 2019, **49**, p. 279.

[18] C.O., Burada, C.M., Miriţoiu, et. al., Dynamic and static behaviour of composite sandwich platbands with kevlar honeycomb core, Romanian Journal of Materials, 2018, **48**, p. 101.

****