STUDIU PRIVIND PROPRIETĂŢILE MECANICE ALE PLATBANDELOR COMPOZITE CU RANFORSANŢI DIN FIBRE LIBERIENE
A STUDY REGARDING THE MECHANICAL PROPERTIES OF COMPOSITES PLATBANDS WITH REINFORCEMENTS FROM BAST FIBERS

COSMIN MIHAI MIRIŢOIU [1], CRISTIAN OLIVIU BURADA [2] *
[1,2]*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 it is experimentally determined, using some known methods, the loss and damping factors, equivalent dynamic Young modulus and flexural rigidity for composite platbands with natural reinforcement. There were created created the next samples: from hemp and cotton, with 15 mm width and 4 respectively 6 mm thickness. Four layers were used for the cotton fibers with different proportion for the epoxy resin, obtaining samples with the mass of 38 and 98 grams. Four and five layers for the hemp fibers were used, obtaining samples with the mass of 38 and 98 grams. In addition to the dynamic values, the static mechanical characteristics (tensile strength, yield strength, static elasticity modulus, and so on) by tensile testing were obtained.

În această lucrare se determină experimental, folosind câteva metode deja cunoscute, factori de amortizare şi de pierdere a energiei, modulul lui Young dinamic echivalent şi rigiditatea la încovoiere pentru platbande compozite cu ranforsant natural. S-au creat următoarele epruvete: din cânepă şi bumbac, cu o lăţime de 15 mm şi cu grosimi de 4 şi 6 mm. S-au folosit 4 straturi de bumbac cu diferite proporţii ale răşinii epoxidice, obţinând epruvete cu masa de 38 şi 98 grame. S-au folosit 4 şi 5 straturi de fibre de cânepă, obţinând epruvete cu masa de 38 şi 98 grame. In plus faţă de valorile dinamice, s-au obţinut proprietăţile mecanice statice (rezistenţă la rupere, limită de curgere, modul de elasticitate static, etc.) prin solicitare la tracţiune.

Keywords: *damping factor, loss factor, Young modulus, bast, seed, hemp, cotton*

1. Introduction

During the time, plastic materials have been highly valued because of their versatility and low cost [1]. The materials can be applied in wide domains, such as: packaging, structural (building and reinforcind materials), trasportation (automotive, watercraft and aircraft parts), electrical components, biomedical (gloves, masks, coverings, prothesis parts, and so on) or customer products such as toys, cameras or watches [1]. The usage of these plastics has become a quite important concern due to their negative impact over the environment like emissions during incineration, entrapment and ingestion by fish, fowl or other animals [2] and so on. That is why the industry is developing biobased or "greener" materials because these offer a potential solution to the one mentioned above [2]. Natural fibers are viable alternatives to glass fibers, being combined in composite materials. Their advantage is low cost, density, have competitive mechanical properties, carbon dioxide sequestration, sustainability, recyclability and biodegradability. The tensile strengths and Young modulus values of these natural fibers are generally lower than the fiber glass and are not suitable for high performance military and aerospace applications [3]. The hemp fibers are 40% cheaper than the glass fibers, have excellent moisture and mechanical stress resistance, are not attacked by moths, high tenacity (approximately 20% higher than flax) but low elongation at break, coarser compared to flax and are difficult to bleach [2].

The natural fibers used in composites can be grouped as it follows [2]:

- wood fibers
  - soft and hard woods
  - recycled wood fibers such as newspapers or magazine fibers
- non wood natural fibers
  - straw fibers: rice, wheat, corn straws
  - bast: kenaf, flax, jute, hemp
  - leaf: henequen, sisal, pineapple leaf fiber
  - seed or fruit: cotton, coir
  - grass: bamboo, switch grass, elephant grass

The mechanical properties of hemp fibers are [1, 2, 4, 5]: Young modulus 26000 – 90000 MPa, tensile strength 450-900 MPa, elongation 1.6%. In [4], for neat hemp fibers the Young modulus is 21400 MPa, the tensile strength is 286 MPa and

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

the elongation at break is 2%. For bacterial cellulose modified hemp fibers, the Young modulus is 8800 MPa, the tensile strength is 171 MPa and the elongation at break is 2.9% [4]. For bacterial cellulose modified hemp fibers with purification, which means the extraction of post-bacterial cellulose modified fibers with NaOH at 80^{0}C, the Young modulus is 8000 MPa, the tensile strength is 130 MPa and the elongation at break is 2.9% [4]. Also, in [5], it is shown that hemp fibers posses high vibration damping capacity, which makes them useful in sporting goods or musical instruments applications.

The cotton fibers consist of the unicellular seed hairs of the balls from the cotton plant. These have a length from 25 to 60 mm and diameters between 12 and 45 m. They are resistant to alkalis but degraded by acids. The mechanical properties of cotton fibers are [1 - 5]: density: 1,5 up to 1,6 g/cm^3, tensile strength: 287 – 800 MPa, static Young modulus: 5500 – 12600 MPa, elongation at break : 3 – 8%.

Some hybrid composites reinforced with banana-glass, hemp-glass and banana-hemp-glass fibers were developed in [6]. For these composites, mechanical properties like tensile strength, flexural strength and impact strength were investigated. As a general conclusion, the hybrid composite reinforced with banana-hemp-fiber has higher mechanical characteristics than the other two studied and can be used as an alternate material for synthetic fiber reinforced composite materials. Some tensile and flexural behaviour tests of hemp fiber reinforced virgin and recycled high density polyethylene (HDE) matrix composites were made in [7]. It was found that the tensile strength of hemp fiber composites decreases from 253 to 2.20 MPa with the hemp content increase from 10% to 30% when compared with samples made of 50% fresh and 50% recycled HDE. The tensile and impregnation behaviour for hemp and flax/paper/epoxy composites is presented in [8]. The experimental results suggest that the adding thin sheets of paper at the surface of reinforcement layers, stabilizes and increases the composite tensile strength but slightly decreases the static Young modulus. One of the ways to modify the lignocellulosic material composition is the ultrasonic processing [9]. It was found that flax and hemp fibers underwent 4.52% and 4.13% weight loss and were found less sensitive to the ultrasonic processing than coir fibers which had a 9.17% weight loss. Tensile characteristics of polylactic acid biocomposites made from prepregs composed of woven polylactic acid (PLA)/hemp-Lyocell hybrid yarn fabrics were described in [10]. The composite made from the satin Lyocell/PLA fabric had the best mechanical properties. The effect of calcined nanoclay on micro structural and mechanical properties of chemically treated hemp fabric – reinforced cement composites was studied in [11]. For the studied composites, there are presented the density, flexural strength and fracture toughness.

In [12] there is made a research regarding composite plates made from polyester resin reinforced with cotton fibers. The results have shown that the structural performance of cotton fiber composites is satisfactory for structural parts with low requirments from the loading point of view, such as panels and doors. There are also made comparisons between these composites and the ones made from flax/sisal fibers. The usage of cotton fibers in medical applications is presented in [13]. The research in [14] was to produced cotton fiber-based composites that can be stafetly disposed off after their intended use without polluting the atmosphere. The was combined cotton and other natural cellulosic fibers with an appropriate biodegradable binder fiber. The results from those studies with their respect for their sustability of automotive applications are discussed.

In this paper, some new results to the dynamic behavior for composites with reinforcements from bast (hemp type) and seed fibers (cotton type) by determining the dynamic Young modulus, the damping factor per unit mass and length, the loss factor and flexural rigidity were added. In the engineering literature a few information is presented related to these aspects. In addition, there were also determined the static mechanical characteristics and comparisons were made with existing materials.

2. The tested specimens

2.1 Dynamic test

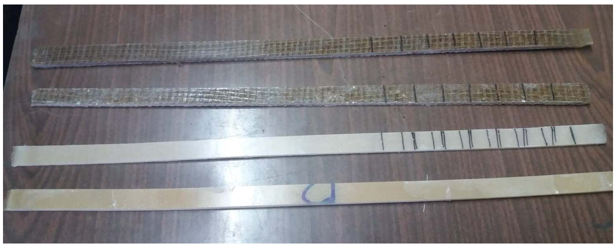

Fig. 1 - A general view with the composite materials / *O vedere generală cu materialele compozite.*

Composite platbands were built and presented in Fig. 1, with natural reinforcement (hemp and cotton) with 15 mm width and 4 respectively 6 mm thickness in this way:

- 4 layers were used for the cotton fibers with different proportion for the epoxy resin, obtaining samples with the mass of 38 (4 mm thickness) and 98 grams (6 mm thickess) named as sample 1 and 2

- 4 and 5 layers were used for the hemp fibers, obtaining samples with the mass of 38 and 98 grams, named as sample 3 and 4.

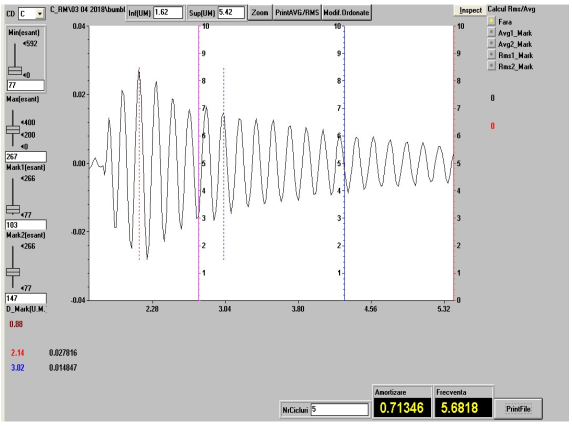

Fig. 2 - The damping factor determination for the sample 1, with 370 mm free length / *Determinarea factorului de amortizare pentru epruveta 1, cu lungimea liberă de 370 mm.*

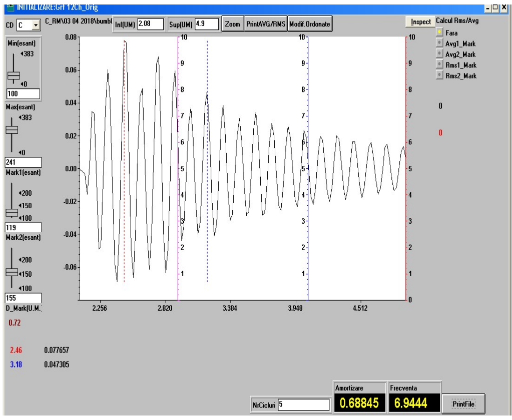

Fig. 3 - The damping factor determination for the sample 2, with 370 mm free length / *Determinarea factorului de amortizare pentru epruveta 2, cu lungimea liberă de 370 mm.*

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 [15] and [16], several free lengths values were considered for the samples (values in mm): 270, 290, 310, 330, 350, 370. The accelerometer was connected to a measuring system which is compound by: signal conditioner

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]
4	0.095	370	5.68	0.71	1	0.135	0.04	2292
4	0.095	350	6.57	0.84	1	0.16	0.041	2456
4	0.095	330	7.35	1.06	1	0.201	0.046	2429
4	0.095	310	8.06	1.19	1	0.226	0.047	2275
4	0.095	290	9.6	1.36	1	0.258	0.045	2471
4	0.095	270	10.905	1.6	1	0.304	0.047	2396
6	0.245	370	7.81	1.04	2	0.51	0.042	1926
6	0.245	350	8.56	1.1	2	0.539	0.041	1853
6	0.245	330	9.45	1.18	2	0.578	0.04	1785
6	0.245	310	10.8	1.3	2	0.637	0.038	1815
6	0.245	290	12.46	1.4	2	0.686	0.036	1850
6	0.245	270	14.16	1.5	2	0.735	0.034	1796
4	0.095	370	6.94	0.68	3	0.129	0.031	3422
4	0.095	350	8.35	0.98	3	0.186	0.037	3967
4	0.095	330	9.25	1.43	3	0.272	0.049	3847
4	0.095	310	10.36	1.84	3	0.35	0.057	3758
4	0.095	290	11.93	2.43	3	0.462	0.065	3816
4	0.095	270	13.19	3.29	3	0.625	0.079	3505
6	0.245	370	9.61	1.4	4	0.686	0.046	2916
6	0.245	350	10.9	1.55	4	0.759	0.045	3004
6	0.245	330	12.5	1.85	4	0.906	0.047	3122
6	0.245	310	14.106	2.174	4	1.065	0.049	3096
6	0.245	290	15.98	2.52	4	1.235	0.05	3043
6	0.245	270	18.18	2.984	4	1.462	0.052	2960

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]	Sample *Epruvetă*	Free length *Lungime liberă*	EI [Nm^2]
1	370	0.183	2	370	0.895	3	370	0.274
1	350	0.197	2	350	0.86	3	350	0.317
1	330	0.194	2	330	0.829	3	330	0.321
1	310	0.182	2	310	0.843	3	310	0.301
1	290	0.198	2	290	0.859	3	290	0.305
1	270	0.192	2	270	0.834	3	270	0.281
4	370	1.354						
4	350	1.395						
4	330	1.45						
4	310	1.438						
4	290	1.413						
4	270	1.375						

Table 3

Coefficients from the damping factor calculus formula and the correlation factor R^2
Coeficienții din formula de calcul a factorului de amortizare și factorul de corelație R^2

Sample number *Număr epruvetă*	α	β	γ	χ	$\delta \cdot 10^{-8}$	R^2
1	772.7952	-9.506667	0.04400984 6	-9.0554901· ·10^{-5}	6.9743423··10^{-8}	0.99921622
2	-14246.839	195.19806	0.96079723	0.0020510019	-1.6152134··10^{-6}	0.99999713
3	2861.7553	-33.703719	0.14974041	-0.00029679889	2.2107891··10^{-7}	0.99993308
4	20746.969	-236.49789	1.042482	-0.0020764314	1.5639672··10^{-6}	0.99996781

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 [15] and [16] where good results for other composite sandwich platbands were obtained. In Fig. 2 and 3 the damping factor per unit mass determination for the samples 1 and 2 by considering 5 cycles and 370 mm free length was presented.

From the free vibrations recording, the damping factor per unit mass was determined in this way [15]:

- 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 $\upsilon = \dfrac{1}{T}$ and the pulsation $\omega = \dfrac{2\pi}{T}$;
- it was determined the damping factor

$$\mu = 0{,}5 \cdot c = (\mathrm{KT})^{-1} \ln \frac{A_i}{A_{i+k}}, \tag{1}$$

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.

All the dynamic results are written in Tables 1 and 2. The dynamic parameters were determined with the same formulas used in [15 - 17].

The damping factor per unit length and eigenfrequency variations are presented in Fig. 4 and 5.

By using the same methodology from [15], a direct calculus formula was determined for the damping factor per unit mass, for each sample.

$$\mu^2(L) = \alpha + \beta L + \gamma L^2 + \chi L^3 + \delta L^4 \tag{2}$$

In (2) it was marked with *L* the platband free length. The coefficients from the formula (2) were presented in Table 3 with the value of the correlation factor R^2.

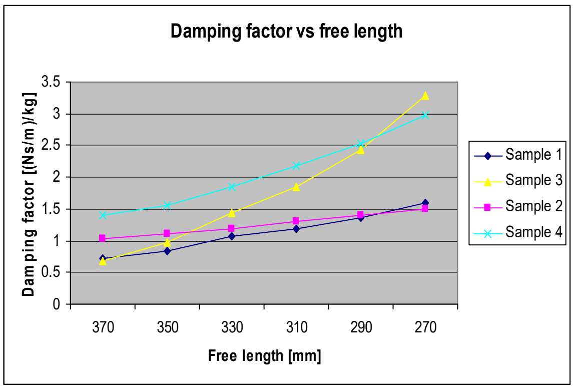

Fig. 4 - The damping factor per unit mass variation versus the platbands free length/ *Variația factorului de amortizare pe unitatea de masă în funcție de lungimea liberă a platbandelor.*

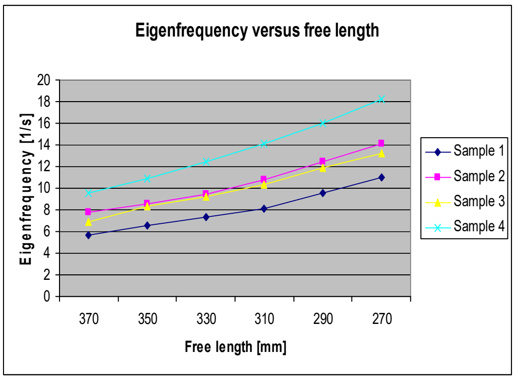

Fig. 5. - The eigenfrequency variation versus the platbands free length/ *Variaţia frecvenţei proprii în funcţie de lungimea liberă a platbandelor.*

2.2. Static test

The specimens were tensile tested on an Instron universal testing machine, with the maximum force of 100 tf according to the condition of ASTM D638 - 14 standard [18]. In Fig 6 and 7 the macroscopic shape of the breaking section for the specimens 1 and 3 is presented, respectively the tensile testing for the sample 3. In Fig. 8 the characteristic curve for the samples 1 and 2 is presented.

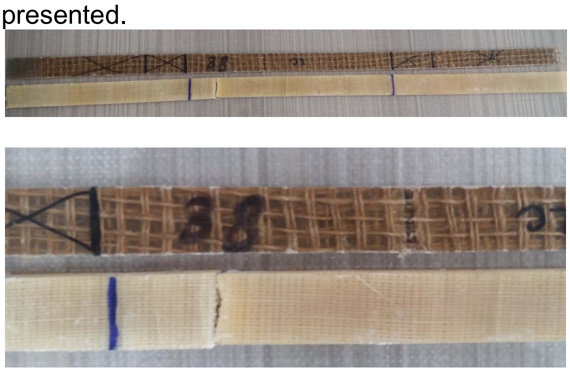

Fig. 6 - The breaking section macroscopic shape for the 1 and 3 samples / *Forma macroscopică a secţiunii de rupere pentru epruvetele 1 şi 3.*

Fig. 7 - The tensile test of the sample 3 on the Instron universal testing machine / *Încercarea la tracţiune a epruvetei 3 pe maşina de încercări universale Instron.*

For all the samples have been calculated a volume fiber of V_f= 0,24 by using the rule of mixture.

The next static experimental results were

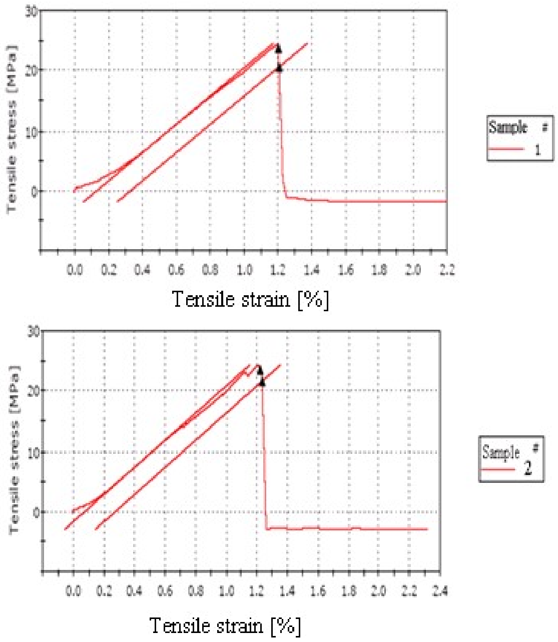

Fig. 8 - The characteristic curve for samples 1 and 2 / *Curba caracteristică pentru epruvetele 1 şi 2.*

obtained:

- sample 1: static elasticity modulus = 2344 MPa, yield stress = 20,606 MPa, breaking strength = 23,745 MPa
- sample 2: static elasticity modulus = 2239 MPa, yield stress = 21,633 MPa, breaking strength = 23,520 MPa
- sample 3: static elasticity modulus =1788 MPa, yield stress = 15,887 MPa, breaking strength = 18,040 MPa
- sample 4: static elasticity modulus = 2583 MPa, yield stress = 17,296 MPa, breaking strength = 25,007 MPa.

2.3. Scanning electron microscopy (SEM) investigation

In Fig. 9 the scanning electron microscopy (abbreviated as SEM) images for the sample 1 breaking section were presented. In order to capture these images, a Phenom Pro X SEM was used.

The Phenom Pro X SEM has an integrated spectrometer. So, the element identification was made in the point marked as ***5*** in Fig. 10. In Fig 11 is presented the obtained spectrum and the chemical elements are listed in Table 4.

This type of structure can be used to strengthen thin reinforced concrete slabs, for example at the study described in [19]. The proposed composite has almost similar mechanical properties (like the Young modulus, at almost the same fiber ratio: 0,2 in our research and 0,19 in [20]) with the one presented in [20], but has the advantage that the reinforcement is biodegradable compared to the fiber glass which is not.

Fig. 9. - The tensile test of the sample 3 on the Instron universal testing machine / *Încercarea la tracţiune a epruvetei 3 pe maşina de încercări universale Instron.*

Table 4

Element identification on the sample 1 breaking section/ *Identificare elementală în secţiunea de rupere a epruvetei 1*

Element Number	Element Symbol	Element Name	Weight Concentration	Error
6	C	Carbon	55.6	0.4
8	O	Oxygen	41.3	0.3
17	Cl	Chlorine	1.4	1.2
19	K	Potassium	1.2	0.9
48	Cd	Cadmium	0.5	1.1

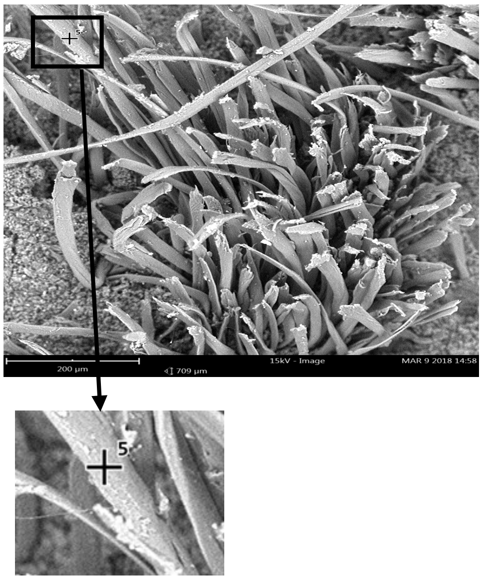

Fig. 10 - The chosen point for the element identification / *Punctul ales pentru identificare elementală.*

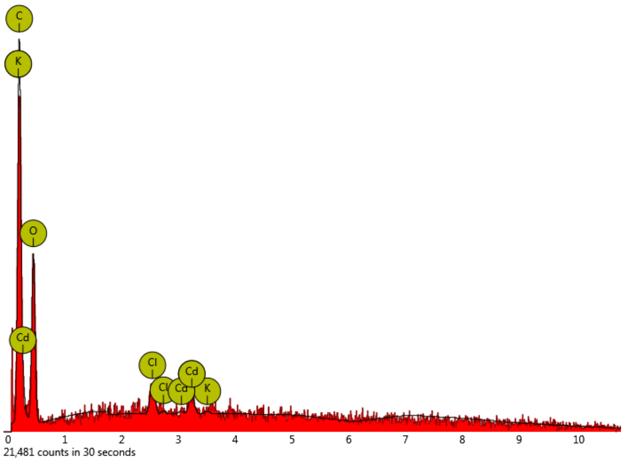

Fig. 11. - The obtained spectrum / *Spectrul obţinut*

3. 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 seed (cotton) and bast (hemp) fibers
- providing the element identification for composites reinforced with cotton fibers
- prividing a direct calculul formulae for the damping factor per unit mass depending of the sample free length.

From the static and dynamic tests the next conclusions can be extracted:

- 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
- by adding more resin quantity to the sample produces a lower static and dynamic Young modulus
- the breaking strength between samples 1 and 2 is almost the same meaning that, in the last stage of the tensile test the composite breakage is made when in the fibers is reached the tensile strength
- at the tensile test, the breakage took place in the calibrated area
- a dependance between the static and dynamic Young modulus couldn’t be found (only for sample one), the dynamic one being higher for the samples reinforced with hemp

- the characteristic curve has 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 (in the sample 1 characteristic curve, for example) 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.

From the SEM breaking section images can be concluded that the matrix had a fragile fracture and the reinforcement a tensile one (its width tends to be smaller in the breakage area, so the fiber deforms before breakage).

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.

This composite has comparable mechanical properties with composite platbands made from poliester resin reinforced with fiber glass (with the same reinforcement volume ratio), but has the advantage that the reinforcement is biodegradable and the fiber glass is not.

REFERENCES

1. S., Pilla, A., Kovats, et. al., Handbook of Bioplastics and Biocomposites Engineering Applications, New Jersey: John Wiley & Sons, 2011.
2. A., Mohanty, M., Misra, L., Drzal, Natural Fibers, Biopolymers and Biocomposites, New York, Taylor & Francis Group, 2005.
3. N., Hu, et. al., Composites and their applications, Rijeka, In Tech Publishing, 2012.
4. A., Hodzic, R., Shanks, Natural fibre composites. Materials, processes and properties, Philadelphia, Woodhead Publishing Limited, 2014.
5. L., Pil, F., Bensadoun, J., Pariset, I., Verpoest, Why are designers fascinated by flax and hemp fibre composites? ,Composites: Part A, 2016, **83**, 193.
6. R., Bhoopathi, M., Ramesh, C.,Deepa, Fabrication and property evaluation of banana-hemp-glass fiber reinforced composites, Procedia Engineering, 2014, **97**, 2032.
7. S., Singh, D., Deepak, L., Aggarwal, V., K., Gupta, Tensile and flexural behavior of hemp fiber reinforced virgin-recycled HDPE matrix composites, Procedia Materials Science, 2014, **6**, 1696.
8. G., Lebrun, A., Couture, L., Laperriere, Tensile and impregnation behavior of unidirectional hemp/paper/epoxy and flax/paper/epoxy composites, Composite Structures, 2013, **103**, 151.
9. S.,Renouard, C., Hano, J., Doussot, J., P., Blondeau, E., Laine, Characterization of ultrasonic impact on coir, flax and hemp fibers, Materials Letters, 2014, **129**, 137.
10. B., Baghaei, M., Skrifvars, Characterization of polylactic acid biocomposites made from prepregs composed of woven polylactic acid/hemp-Lyocell hybrid yarn fabrics, Composites: Part A, 2016, **81**, 139.
11. A., Hakamy, F.,U.,A.,Saikh, I., M.,Low, Effect of calcined nanoclay on microstructural and mechanical properties of chemically treated hemp fabric – reinforced cement nanocomposites, Construction and Building Materials, 2015, **95**, 882.
12. I., G., Raftoyiannis, Experimental Testing of Composite Pannels Reinforced with cotton fibers, Open Journal of Composite Materials, 2012, **2**, 31.
13. S., K., Bajpai, Mary, G., Chand, N., The use of cotton fibers as reinforcements in composites, Biofiber Reinforcements in Composite Materials, 2015, 320.
14. M., G., Kamath, G., S., Bhat, D., V., Parikh, D., Mueller, Cotton Fiber Non Wovens for Automotive Composites, The Journal of Engineering Fibers and Fabrics, 2018, **13**(2), 34.
15. 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.
16. 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.
17. C.O., Burada, C.M., Miriţoiu, D., Bolcu, M.M., Stănescu, Experimental determinations of the damping factor and stiffness for new sandwich platbands with different reinforcement and core, Romanian Journal of Materials, 2014, **44(4),** 405.
18. ASTM D 638-14 Standard Test Method for Tensile Properties of Plastics
19. N. Ţăranu, D. Banu, G. Oprişan, M. Budescu, L. Bejan, Strengthening of thin reinforced concrete slabs with composite strips, Romanian Journal of Materials, 2013, **43**, 3.
20. C.O., Burada, M.M., Stănescu, C.M., Miriţoiu, D., Bolcu, Static and dynamic behaviour of platbands made from poliester resin reinforced with randomly dispersed glass fiber, Romanian Journal of Materials, 2017, **47**¸ 296.

****