DETERMINĂRI EXPERIMENTALE ALE FACTORULUI DE AMORTIZARE ŞI ALE RIGIDITĂȚII PENTRU NOI PLATBANDE SANDWICH CU RANFORSANT ŞI MIEZ DIFERIT

EXPERIMENTAL DETERMINATIONS OF THE DAMPING FACTOR AND STIFFNESS FOR NEW SANDWICH PLATBANDS WITH DIFFERENT REINFORCEMENT AND CORE

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In this paper, we have built some new composite sandwich platbands with different core (made of polypropylene honeycomb and polystyrene) and different reinforcement (glass-fiber, carbon-fiber and steel wire mesh). Starting from the dynamic response of these sandwich beams with damping, that are in free vibration, we have established a way to determine the damping factor. We have experimentally determined the damping factor per unit mass for the beams and the stiffness.

Pentru această lucrare, am construit câteva platbande sandwich din materiale compozite cu miez diferit (realizat din polistiren, respectiv din fagure de polipropilenă) şi ranforsant diferit (fibră de sticlă, fibră de carbon şi plasă din oțel). Pornind de la răspunsul dinamic al acestor grinzi cu amortizare, care se află în vibrație liberă, am stabilit o modalitate pentru a determina factorul de amortizare. Am determinat pe cale experimentală factorul de amortizare pe unitatea de masă şi rigiditatea grinzilor.

Keywords: *composite, damping factor, glass-fiber, carbon-fiber, steel wire mesh*

1. Introduction

The sandwich structures are widely used in aerospace engineering for aircraft or satellites building [1]. In the past decades, these structures have been also used for automotive, rail cars, wind energy systems and different civil constructions building [1]. An important place in the composite materials study is held by sandwich platbands and plates with constant thickness and overlapped multiple layers. Most of the studies refer to sandwich platbands or plates made of three overlapped layers with the middle layer, defined as the core of the structure, having viscoelastic behaviour and the upper and lower layer having higher elastic and strength properties.

There have been made many studies and investigations regarding sandwich beams or plates where the core is a honeycomb structure. In [2] it was investigated the mechanical behaviour and failure mechanism (such as compressive and shear deformation and strengths) of honeycomb composite consisting of Nomex honeycomb and 2024Al alloy face sheets, at different temperatures ranged 25-300^{0}C. The average elastic and strength characteristics of Nomex honeycomb were also investigated in [3]. The static and fatigue behaviour of aluminum hexagonal honeycomb cores were analyzed in [4]. In [5] there has been studied the out-of-plane compressive properties of thermoplastic hexagonal honeycombs using the finite element analysis. In [6] there was evaluated the equivalent transverse shear and in-plane moduli of honeycomb cellular structures and discussed about the structural efficiency of honeycombs. Using honeycomb test specimens made of Nomex, aluminum alloy and paper, the authors from [7] have explored the crushing phenomena of the cells. In [8] there has been examined by numerical and experimental methods the crashworthiness and rollover characteristics of a low- floor bus vehicle made of sandwich composites (aluminum honeycomb core and WR580/NF 4000 glass-fabric/ epoxy laminate face

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sheets). The authors from [9], have determined analytic formulas for the averaged elastic and strength characteristics of a honeycomb core with a hexahedral structure. They have shown that, in tension- compression, the honeycomb must be a heteromodular material with averaged elastoplastic properties. The research from [10] was about an experimental investigation on low-velocity impact responses and damage modes of sandwich composites (aluminum honeycomb core and glass/epoxy face sheets) because of the impact loading changing location and wall partition angle of the honeycomb core. In [11] it was studied the elastic properties of honeycomb sandwich plates and proposed some analytical expressions to calculate the reduced elastic parameters for these structures. The technology for obtaining the polypropylene materials reinforced with glass fibers was studied in [12]. The obtained composite materials, studied in this paper, were characterized by X ray diffraction, infrared spectroscopy and scanning electron microscopy. Based on the obtained results there can be said that the glass functioning can lead to a glass fiber – polymer better interaction. Also the glass fibers, in this study, are covered by an intimate polypropylene film.

In [13] it was investigated the temperature variation for the dielectric constant of polystyrene-graphite composite and variation of temperature-normalized capacitance. In this study, the experimental and theoretical results are quite closely.

The authors from [14] developed an original dynamic modeling for honeycomb sandwich panels. The technique was used for evaluation an equivalent orthotropic model of the honeycomb.

In [15] it was studied the impact behaviour and energy absorption of paper honeycomb sandwich panels. In [15] there are said that dynamic cushioning tests were conducted by free drop and shock absorption principle. It was analyzed the effect of paper honeycomb structure factors on the impact behavior. The main conclusions that resulted from the paper [15] were: the dynamic impact curve of paper honeycomb sandwich panel is concave and upward; the thickness and length of honeycomb cell-wall have a great effect on its cushioning properties; increasing the relative density of paper honeycomb can improve the energy absorption ability of the sandwich panels; the thickness of paper honeycomb core has an up and down fluctuant effect on the cushioning properties.

In [16], the group of authors has studied the manufacturing and testing of a sandwich panel honeycomb core reinforced with natural fabrics. 6-mm- and 10-mm-cell honeycombs were manufactured by using two compression-molding techniques. There were made experimental tests to characterize the elastic response of the composite and the core response under flat wise compression. The effective elastic properties of the core were computed via a homogenization analysis and finite element modeling.

In [17] there were made some composite platbands using the Al 3105/Polymer/Al 3105 using thin film hot melt adheres. The forming limit diagrams of the obtained composite platbands were predicted using simulations based on the Gulson- Tvergaard - Needleman damage model described in [18]. Also, the forming limit diagrams of the obtained composite platbands were evaluated through experimental researches.

The novelty inserted by the authors in this paper is characterized by the sandwich platbands: made from classical parts (like carbon-fiber reinforcement, glass –fiber reinforcement or steel wire mesh, epoxy resin, polypropylene honeycomb or polystyrene) combined in an original way.

2.Theoretical background

In the small deformations case, the transversal vibration equation for a platband can be written as [19, 20]:

$$\iint \rho(x,y) dS \cdot \ddot{v} + C \cdot \dot{v} + \iint E \cdot y^2 dS \frac{\partial^4 v}{\partial x^4} = q(x,t) \qquad (1)$$

In (1) we have marked with: *v(x,t)*- the transversal displacement of the beam section elastic center; *ρ(x,t)*- is the platband material density; *E(x,y)*- is the Young modulus of the platband material; *q(x,t)*- is the transversal force that loads the beam; *C*- is the damping factor per unit length of the platband. The damping calculus can be made by studying the free vibrations (q(x,t)=0) produced by an initial beam deformation [19, 20]:

$$v(x,0) = h(x)\,;\ \dot{v}(x,0) = 0 \qquad (2)$$

where h(x) is the initial deformation.
In this case, the free vibration of the platband can be determined with (3) [19, 20].

$$v(x,t) = \sum_{\xi=1} e^{-\mu t} \cdot \left(A_\xi + B_\xi\right) \cdot V_n(x) \qquad (3)$$

$$A_\xi = \frac{\mu}{2\pi\nu_\xi} \sin 2\pi\nu_\xi t\ ,\ B_\xi = \cos 2\pi\nu_\xi t\ .$$

In (3) we have marked with: μ- half of the damping factor per unit mass of the platband; ν_ξ- is the eigenfrequency; $V_n(x)$- are the eigenfunctions that depend on the platband ends conditions.
According to [19] and [20], the eigenfrequencies can be determined with (4).

$$\nu_\xi = \frac{\zeta_\xi \cdot (EI)^{0,5}}{2\pi \cdot (\rho A)^{0,5} \cdot l^2} \approx 0{,}1591549 \frac{(EI)^{0,5} \cdot \zeta_\xi}{(\rho A)^{0,5} \cdot l^2} \qquad (4)$$

In (4) we have marked with: *EI*- the platband stiffness; *l*- the platband length; *m*- the mass per unit length; ζ_ξ- is determined from the platband ends conditions (represents the roots of equation $(\mathrm{ch}(\zeta)\cdot\cos(\zeta)+1)^2=0$ [19]).

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 ν and the pulsation ω are determined with (5)[19];
- the damping factor is determined with (6)[19].

$$\nu = T^{-1};\ \omega = 2\pi \cdot T^{-1} \approx 6{,}2831853 \cdot T^{-1} \tag{5}$$

$$\mu = T^{-1} \cdot \ln \frac{\beta_i}{\beta_{i+1}} \tag{6}$$

In (6) we have marked with β_i, β_{i+1} the maximums separated by periods. The formulas (1), (2), (3) and (4) were previously used by us in [20] for the next composite platbands: phenolic fireproof resin reinforced with fiberglass and ortophtalic polyesteric resin reinforced with fiberglass. There were determined the eigenmodes and the elasticity modulus for these composite platbands and the results were compared with the ones obtained from tensile test on an universal testing machine. There were obtained errors bellow 4%.

3. Experimental setup

We have built some composite platbands marked in this way: *sample Fig. 1*- platband with polystyrene core reinforced with fiber-glass; *sample Fig. 2*- platband with polypropylene honeycomb core reinforced with fiber-glass; *sample Fig. 3*- platband with polystyrene core reinforced with carbon-fiber; *sample Fig. 4*- platband with polypropylene honeycomb core reinforced with carbon-fiber; *sample Fig. 5*- platband with polystyrene core reinforced with steel wire mesh; *sample Fig. 6* - platband with polypropylene honeycomb core reinforced with steel wire mesh.

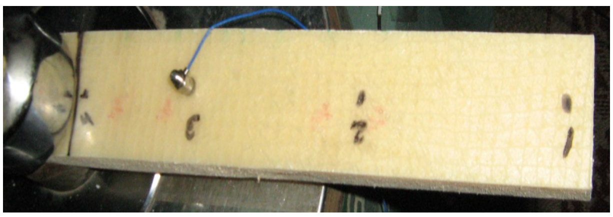

Fig. 1 - Platband with polystyrene core reinforced with fiber-glass/ *Platbandă cu miez din polistiren ranforsată cu fibră de sticlă.*

From these samples we have collected platbands that have a width of 45 mm and a thickness of 20 mm. The platbands length can influence the damping factor in the next way: the damping factor is higher if the platband length is low (because the vibration produced by an initial force is quickly damped) and it is lower if the platband length has a high value. Also, in [21] it was shown that, the damping factor per unit mass

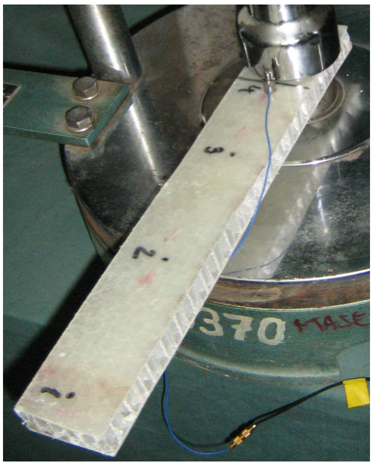

Fig. 2 - Platband with polypropylene honeycomb core reinforced with fiber-glass/ *Platbandă cu miez din fagure de polipropilenă ranforsată cu fibră de sticlă.*

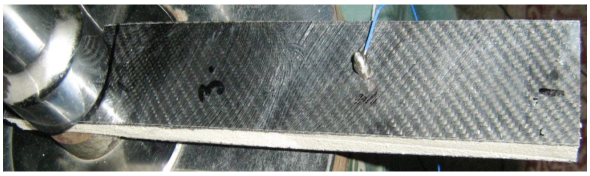

Fig. 3 - Platband with polystyrene core reinforced with carbon-fiber/ *Platbandă cu miez din polistiren ranforsată cu fibră de carbon.*

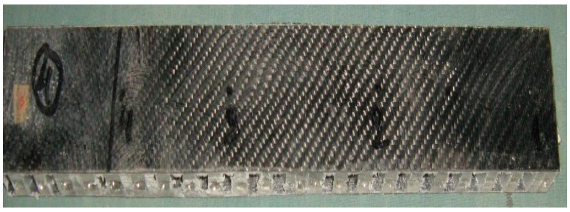

Fig. 4 - Platband with polypropylene honeycomb core reinforced with carbon-fiber/ *Platbandă cu miez din fagure de polipropilenă ranforsată cu fibră de carbon.*

Fig. 5 - Platband with polystyrene core reinforced with steel wire mesh/ *Platbandă cu miez din polistiren ranforsată cu plasă metalică.*

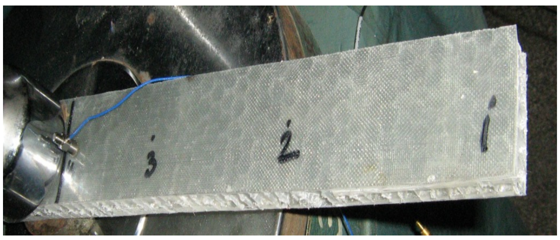

Fig. 6 - Platband with polypropylene honeycomb core reinforced with steel wire mesh/ *Platbandă cu miez din fagure de polipropilenă ranforsat cu plasă metalică.*

of the platband can be determined with relation (7).

$$\mu = A_1 \cdot \frac{1}{e^{A_2 \cdot l}} \tag{7}$$

In (7), A_1 and A_2 are two constants that depend on the composite platband material and geometrical dimensions. From relation (4) we can see that the stiffness increases if the platbands length is higher.

The sandwich platbands reinforcements were applied in this way: one layer of fiber-glass

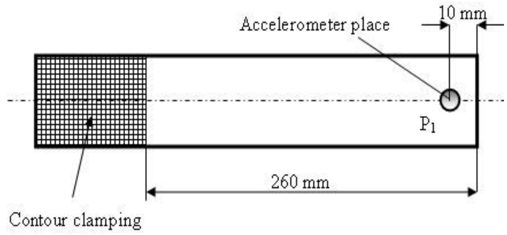

Fig. 7 - Experimental setup for the platbands/ *Montaj experimental pentru platbande.*

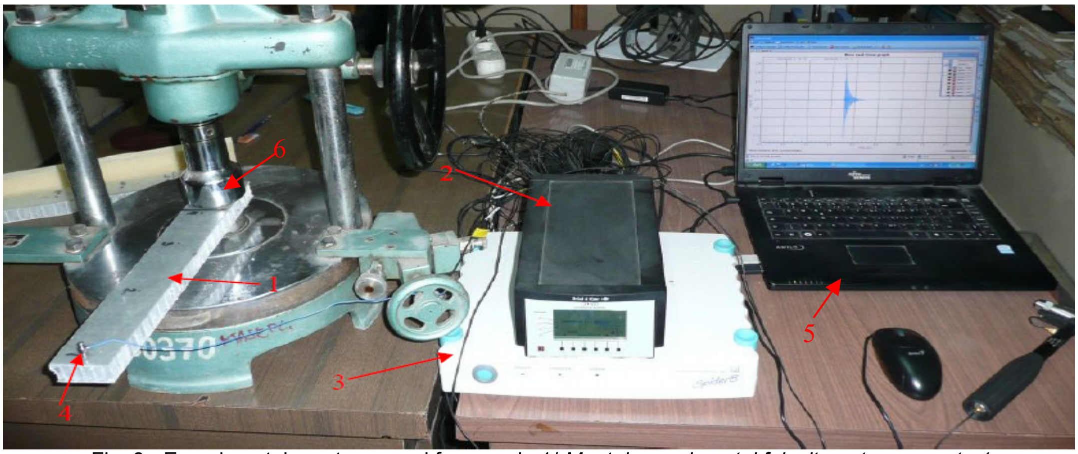

Fig. 8 - Experimental montage used for sample 1/ *Montaj experimental folosit pentru epruveta 1.*

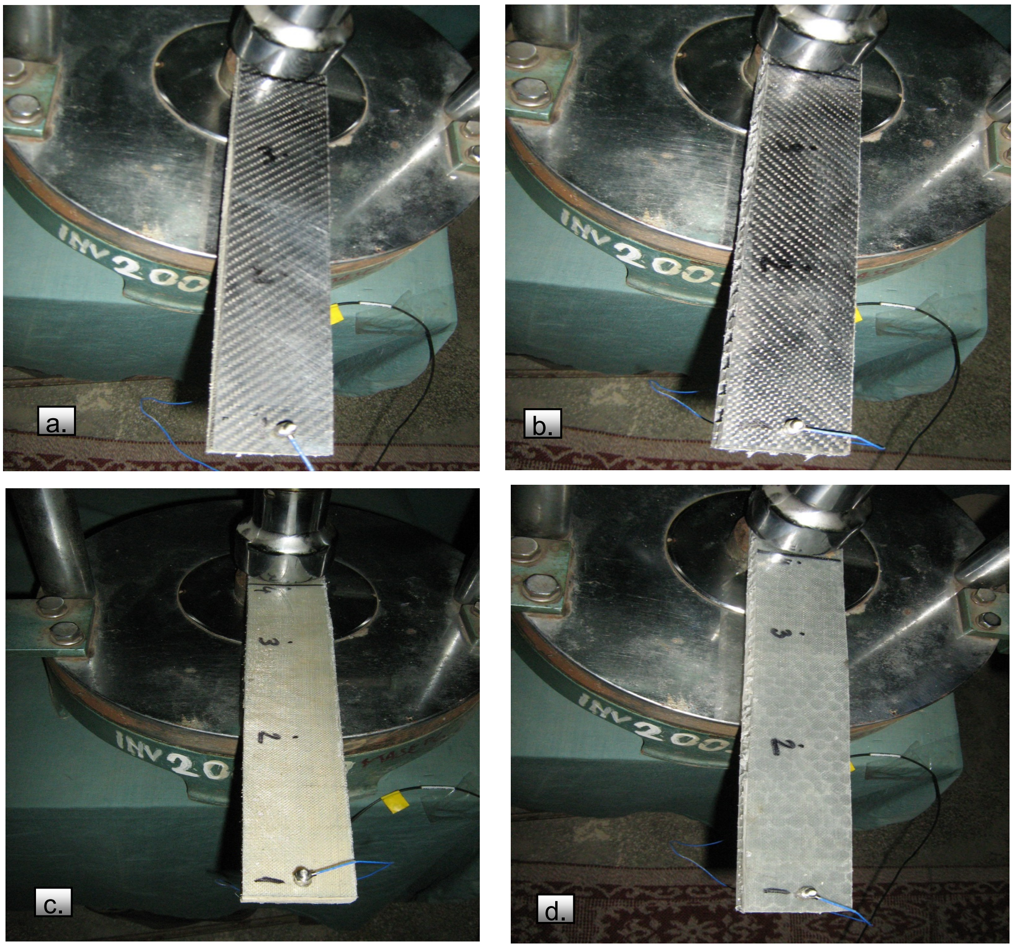

Fig. 9. a. - The experimental montage used for sample 3/ *Montaj experimental utilizat pentru epruveta 3*;
b. The experimental montage used for sample 4/ *Montaj experimental utilizat pentru epruveta 4*;
c. The experimental montage used for sample 5/ *Montaj experimental utilizat pentru epruveta 5;*
d. The experimental montage used for sample 6/ *Montaj experimental utilizat pentru epruveta 6*.

(upside and downside), one layer of carbon-fiber (upside and downside) and two layers of steel wire mesh (upside and downside). The connection between the reinforcements and the cores was made by using an epoxy resin.

The experimental setup used for the research presented in this paper is characterized by clamping the platband at one end and recording the free vibrations at the other free end. The vibrations were recorded by using an accelerometer made by Bruel&Kjaer with 0,004 pc/ms^{-2} sensitivity. A scheme of the experimental setup is presented in Figure 7.

In Figure 8 we present the experimental montage for the sample 6. In the fig. 8 we can see the next apparatus: 1- sandwich platband with polypropylene honeycomb core reinforced with metal fabric, 2- signal conditioner NEXUS 2692-A-0I4 produced by Bruel&Kjaer firm, 3- data acquisition system SPIDER 8 produced by the HBM firm, 4- Bruel&Kjaer accelerometer with 0.004 pc/ms^{-2} sensitivity, 5- notebook FujitsuSiemens connected through USB port with the SPIDER 8 apparatus; 6 – the vise that clamps the platband in order to make it immovable (it has no degree of freedom).

In Figure 9 there are presented the experimental montages for the other studied samples. For the platbands damping factor experimental determination there was applied a force at the free end of the platbands and these were left to vibrate freely. Because the form of the deformed medium fiber (the deformation was produced by the external force) is similar to its first vibration eigenmode, the first measured frequency is considered to be the first eigenfrequency.

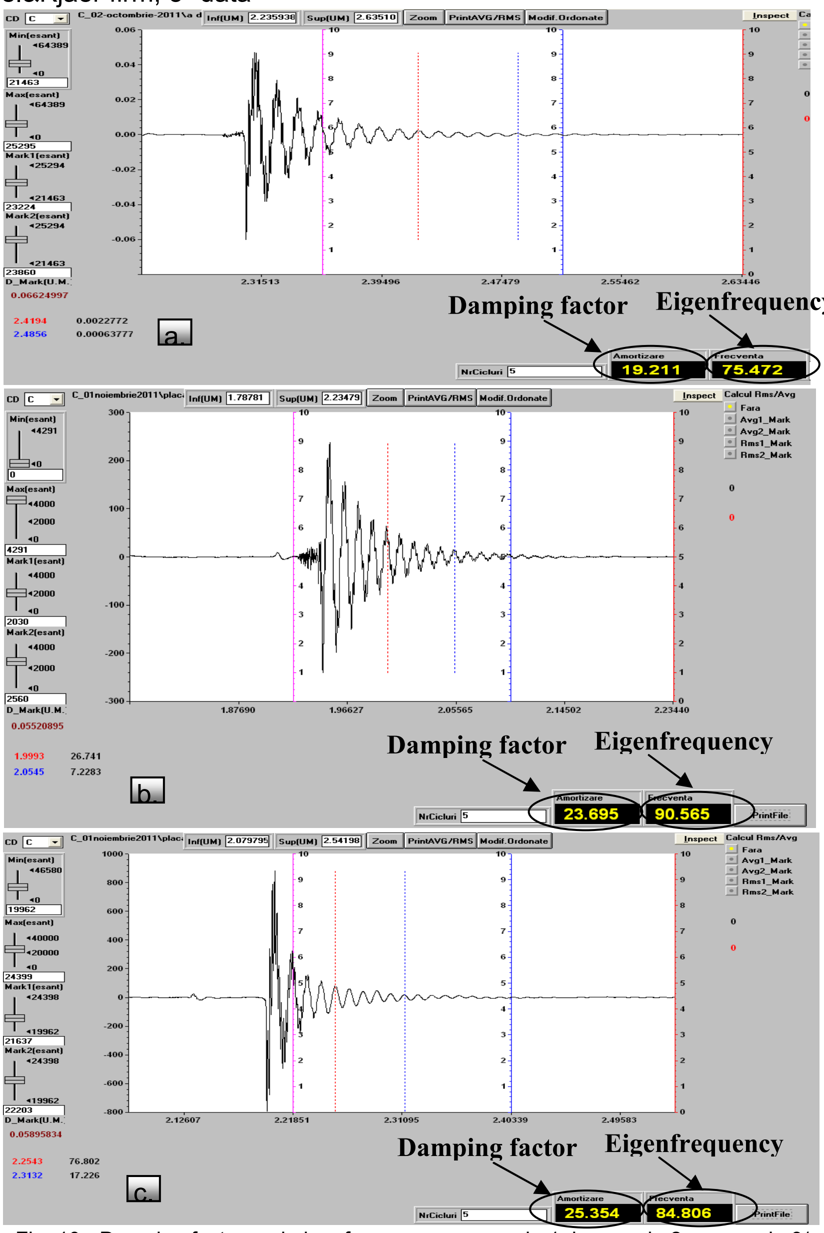

Fig. 10 - Damping factor and eigenfrequency; a. sample 1; b. sample 2; c. sample 3/
Factorul de amortizare şi frecvența proprie; a. epruveta 1; b. epruveta 2; c. epruveta 3.

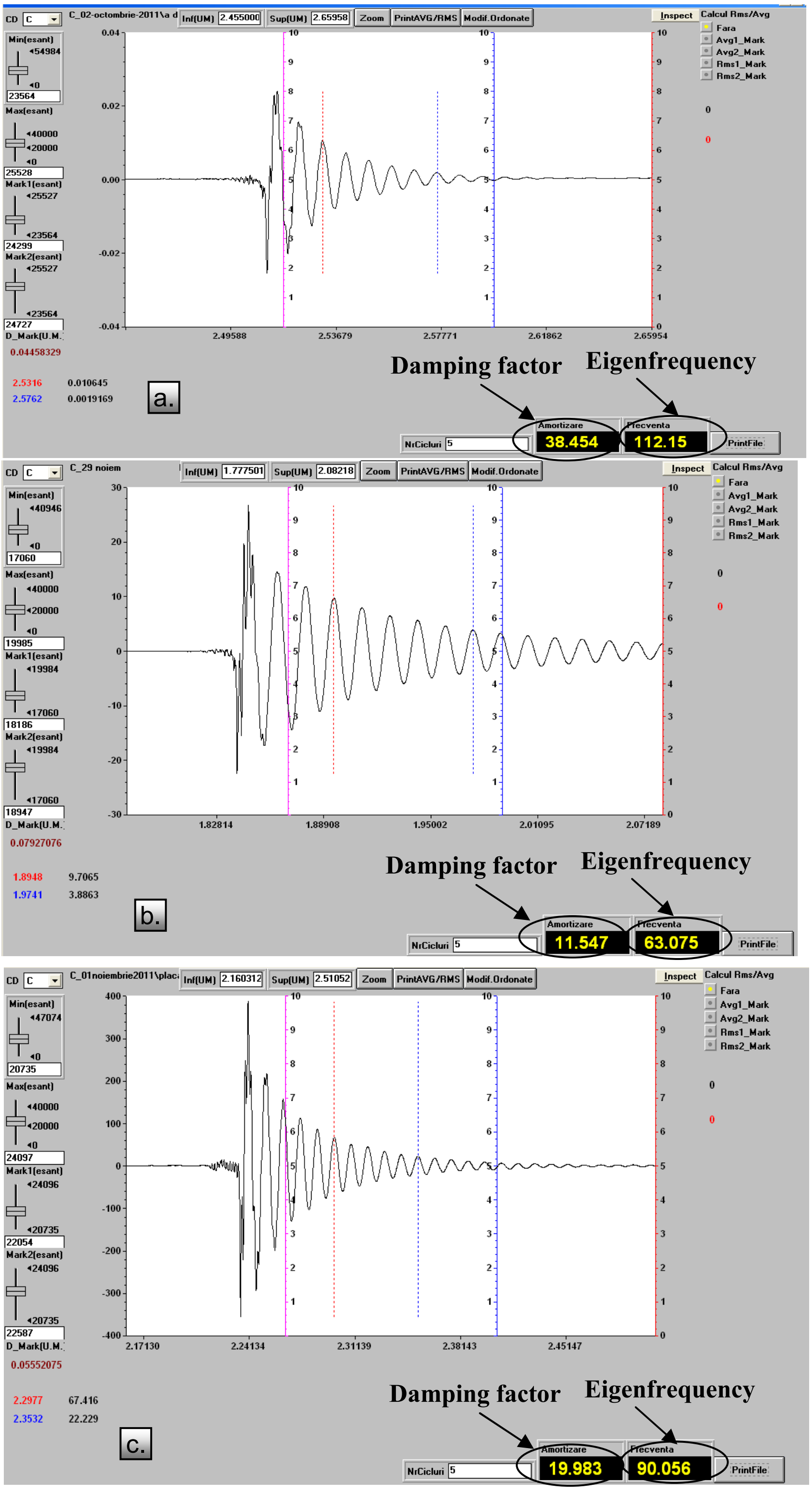

Fig. 11- Damping factor and eigenfrequency; a. sample 4; b. sample 5; c. sample 6
Factorul de amortizare şi frecvenţa proprie; a. epruveta 4; b. epruveta 5; c. epruveta 6.

4. Experimental recordings and results

In Figures. 10 and 11 there are presented the experimental recordings of damped vibrations for the samples 1,2, 3,4,5 and 6. The damping factor per unit mass was determined by using the relation (6), for five consecutive maximum values from the experimental diagrams. The five maximum values used for damping factor values are delimited in Figure 10 by the two dotted parallel lines which can be seen inside each graphic. These maximum values have been chosen after the transitory area, in order to avoid the eigenmodes vibration influences.

In Figures 10 and 11 there are presented the damping factors per unit mass and the eigenfrequencies of the first eigenmode. The experimental results for all the samples are presented in Table 2.

In order to determine the damping factor per unit length we have multiplied the damping factor per unit mass with the linear specific mass of the sample material (relation (8) [19]).

$$C = 2 \cdot \mu \cdot \langle \rho A \rangle \qquad (8)$$

In (8) we have marked with: $\rho(x,t)$- is the platband material density; *A*- is the transversal area; μ- is the half of damping factor per unit mass.

The *EI* values from Table 2 are obtained by using the relation (4) (knowing the ν_ξ values from the experimental data (Fig. 10 and 11) and the $<\rho A>$ from Table 1).

5. Stiffness validation

In order to validate the stiffness results from the Table 2 we made the next experimental test bench: we have clamped the platband at one end, we have loaded the platband with a force at the free end and we have measured the displacement with a comparative device (dial gauge with magnetic stand with a precision of 0,01 mm) (similar to the one presented in [22]). The scheme of the experimental montage is presented in Figure 12.

In order to determine the stiffness, we have used the relation (9).

$$EI = 0,(3) \cdot F \cdot \left(l \cdot \sqrt[3]{v}\right)^3 \qquad (9)$$

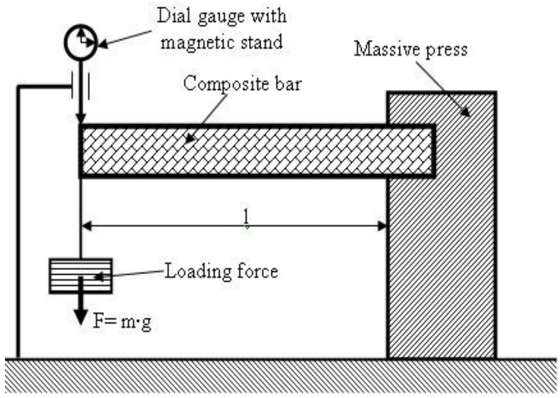

Fig. 12 - Experimental montage for stiffness calculus/ *Montaj experimental pentru calculul rigidităţii.*

In (9) we have marked with: *EI* – the platband stiffness; *F* – the force that loads the platband at its free end; *l* – the free length of the platband (for this case will be equal to 260 mm); *v* – the platband displacement measured with the comparative device. All the data are written in Table 3.

Table 1

Initial data/ *Date iniţiale*

Sample no.	Core	Reinforcement	Width [mm]	Thickness [mm]	<ρA> [kg/m]
1	Polystyrene	Fiber-glass	45	20	0.192
2	Polypropylene honeycomb	Fiber-glass	45	20	0.257
3	Polystyrene	Carbon-fiber	45	20	0.172
4	Polypropylene honeycomb	Carbon-fiber	45	20	0.218
5	Polystyrene	Steel wire mesh	45	20	0.177
6	Polypropylene honeycomb	Steel wire mesh	45	20	0.236

Table 2

Experimental results/ *Rezultate experimentale*

Sample no.	μ [(Ns/m)/kg]	C [(Ns/m)/m]	EI [Nm^2]	ν [1/s]
1	19.211	7.377	15.963	75.472
2	23.695	12.179	30.768	90.565
3	25.354	8.214	17.007	84.806
4	38.454	16.766	40.022	112.15
5	11.547	4.944	10.279	63.075
6	19.983	5.45	27.937	90.056

Table 3

Stiffness validation values

Valorile pentru validarea rigidităţii

Sample no.	v [mm]	F[N]	EI [$N \cdot m^2$]	ε_m [%]
1	0.08	0.2	14.65	8.246
2	0.04	0.2	29.29	4.793
3	0.07	0.2	16.74	1.576
4	0.03	0.2	39.06	2.409
5	0.1	0.2	11.72	12.275
6	0.05	0.2	23.43	16.005

This is an approximate method because of the errors that may appear at the dial gauge displacement reading. We have marked with ε_m in table 3 the errors for the stiffness values that appear between the two experimental methods (all the errors appear because the validation method is an approximate one, but are quite small – under 16.1%).

6. Conclusions

In this paper we have built some new original composite platbands (with classical parts but combined in an original way). For these platbands we have determined the damping factor, the frequency for the first eigenmode and the stiffness using an experimental setup described in this way: we have clamped the platband at one end and at the free end, where we have placed an accelerometer, we have determined the vibratory response produced by an initial force.

Some general conclusions regarding the damping factor determination, extracted from this study, can be:

- 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;
- 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 sample through the initial deformation, is dissipated in a larger quantity of material;
- an influence may occur due to the sample rigidity, explained by the fact that a force initially applied on the sample produces a smaller deformation if the rigidity is higher.

We can observe, from the Table 2, that the samples stiffness reinforced with carbon-fiber are much higher than the ones reinforced with fiber-glass (regardless of the core, which is with polypropylene honeycomb or polystyrene). This phenomenon can be explained by:

- the elasticity modulus of the carbon-fiber is much higher than the elasticity modulus of fiber-glass;
- the elasticity modulus of the exterior layers are superior when are made by epoxy resin with carbon-fiber than the ones made by glass-fiber with epoxy resin.

From the Table 2 we can see that, the samples with fiber-carbon and fiber-glass reinforcement are stiffer than the ones reinforced with steel wire mesh. This result can be explained by the fact that the carbon-fiber and glass-fiber, combined with epoxy resin, have superior mechanical characteristics in comparison with steel wire mesh combined with epoxy resin. Also, if the samples have a honeycomb core are more stiffener than the ones that have a polystyrene core.

A good vibrations damping results in the case where the composite materials of the reinforcing layers have higher damping capacity and elastic properties (for example the carbon-fiber with epoxy resin in comparison with the glass-fiber and steel wire mesh with epoxy resin).

We consider that, the added values of this study can be:

- building some new composite platbands made by classical materials (such as glass-fiber, carbon-fiber, steel wire mesh, polypropylene honeycomb or polystyrene) combined in an original way;
- the experimental setup: the platbands are free at one end and clamped at the other where it is measured the vibratory response applied with a known initial force;
- the values of the damping factor for the built composite platbands;
- the eigenfrequency determination of the new composite studied platbands;
- the stiffness determination and validation by two experimental methods.

These types of composite platbands can be used in practical engineering for: ship floor building, plane floor building, bus floor building, the construction of concrete forming, planes or vehicles bodies building, low weight frames that must have high vibration damping capacity and so on.

The results of the experimental determinations can be applied in the dynamics behaviour study of these composite materials (for example the damping factor calculus is important to know how the vibration produced by a force, in case of a collision for example, will be damped in time). In a future paper there will be studied the stresses in the cases of accidental collisions or the dynamic response in the case of variable loadings for various frames made by these composites.

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MANIFESTĂRI ŞTIINȚIFICE / SCIENTIFIC EVENTS

NICOM 5 - 5th International Symposium on Nanotechnology in Construction - From 24 May 2015 to 26 May 2015, Chicago, USA

Potential topics for the NICOM5 symposium illustrate the broad potential for application of nanotechnology to challenging problems involving construction materials:

- Production, functionalization and performance of nanomaterials: nanoparticles, nanotubes and novel polymers;
- Investigation of the internal structure and properties of construction materials at the nanoscale and relation of these parameters to materials performance at the macroscale;
- Instrumentation, techniques, and metrology for nanoscale investigation of construction materials;
- Nanomodification of construction materials, including functional films and coatings;
- Nanotechnology for high-strength and highperformance materials;
- Nanotechnology developments in ultra-high performance concrete;
- Nanotechnology in ceramics, glass, fiberreinforced composites and metals;
- Nanomaterials for ultimate improvement of durability;
- Self-repairing, smart and intelligent nanostructured materials;
- Photocatalysis, air-purifying and self-cleaning materials;
- Biomimetic and nano-composite materials;
- Nano-assembly and “bottom-up” design in construction materials;
- Modeling and simulation of nanostructure of construction materials;
- Nanotechnology and nanomaterials for energy efficient construction;
- Nanotechnology-enabled green materials and by-product utilization for new levels of sustainability;
- Application of nanomaterials in real world construction projects;
- Nanotechnology and nanomaterials for advanced transportation infrastructure;
- Health, safety and environmental effects related to nanomaterials application.

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