Experimental research regarding some dynamic parameters determination for sandwich bars reinforced with carbon fiber

C M Miriţoiu [1*], C O Burada [1], D F Tărâţă [1], A Bolcu [1], V Ionică [1]

[1]Faculty of Mechanics, University of Craiova, 165 Calea Bucureşti, 200620, Craiova, Romania.

*miritoiucosmin@yahoo.com

Abstract. For this study, we have built some composite sandwich bars with polypropylene honeycomb core reinforced with carbon fiber. We have clamped the bars at one end and we left them to vibrate freely. From the free vibrations we have determined the damping factors per unit mass and length, loss factor, dynamic Young modulus, dynamic stiffness and the frequency of the first eigenmode. The general conclusions obtained from the vibrations results show tat 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 the 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 to the sample produces a smaller deformation if the stiffness is higher.

1. Introduction

Although carbon fiber is the most common reinforcement used in composite materials, many types of research still refer to this material. For example, in [1], the relationship between the property variables of the carbon fiber monofilament and the macroscopic parameters of the composites is established by using a regression tree, a type of decisions tree model, in machine learning. After a series of parameters adjustments and model selection, it was established a model with a better-generalized performance. Carbon fiber reinforced plastic is a multi-phase solid material which is a compound of two or more materials with different physical or chemical properties usually used in aerospace engineering [2]. In [3] a computational micromechanics model based on a representative volume element is used to predict the failure envelopes of unidirectional carbon fiber reinforced polymer composites. The proposed failure criteria have shown significant improvement according to the computational and experimental results obtained compared to classical failure criteria models.

Because of high tensile strength and modulus, lightweight, good compressive strength, temperature, and chemical resistance, excellent electrical and thermal conductivity, polyacrylonitrile-based carbon fibers are used as essential constructions in advanced composites [4-6]. In [7] polyacrylonitrile (PAN)-based carbon fibers (CFs) were electrochemically deposited and graphene oxide (GO) and three different kinds of comonomers, including diacetone acrylamide (DAAM), acrylic acid (AA) and phenol (Pheno), were electrografted onto CF surfaces. It was found a tensile strength increase of 5, 22.6 and 17% for GO-DAAM, GO-AA, and GO-Pheno compared to untreated carbon fibers.

In this paper, we study the vibration behavior for some composite sandwich bars with the core made from polypropylene honeycomb reinforced with carbon fiber. We clamp the bar at one end, and we apply a force at the other end, which is free. At the free end, we put an accelerometer to record the free vibrations. From the free vibrations, we determine the damping factors per unit mass and length, the eigenfrequency, the dynamic Young modulus, the dynamic stiffness, and the loss factor.

2. Free vibrations of finite length bars. Analytical background

The differential equation of transversal free vibrations has the form [8]:

$$c^2 (\partial^4 w/\partial x^4) + (\partial^2 w/\partial t^2) = 0 \quad (1)$$

parameter c being determined with (2).

$$c = [1/(2\pi)]\cdot[EI/(\rho A)]^{0,5} \quad (2)$$

In (1) and (2) 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.

By solving the differential equation of the transversal free vibrations (1), applying the Laplace transform and taking into account the Krîlov functions like in [9], we determine the eigenfrequency of the first eigenmode (3). In (3) we have marked with *l* the bars length, and *β* is determined from the bars boundary conditions.

$$\nu = (\beta/l)^2\cdot[1/(2\pi)]\cdot[EI/(\rho A)]^{0,5} \quad (3)$$

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 (4)[10];
- the damping factor per unit mass is determined with (5)[10].

$$\nu = T^{-1};\ \omega = 2\cdot\pi\cdot T^{-1} \quad (4)$$
$$\mu = T^{-1}\cdot\ln(\Delta_j/\Delta_{j+1}) \quad (5)$$

- the damping factor per unit length is determined with (6)[18]:

$$C = 2\cdot\mu\cdot(\rho A) \quad (6)$$

In (15) we have marked with Δ_j, Δ_{j+1} the maximums separated by periods. The loss factor can be determined with (7) according to [10].

$$\eta = \mu\cdot(\pi\cdot\nu_\xi)^{-1} \quad (7)$$

In the relationship (7) we have marked with: *ζ*- critical damping; ω_ξ- eigen pulsation; *μ*- damping factor per unit mass; *η*- loss factor; ν_ξ- the eigen frequency; *t*- time; ξ is the number of the eigenmode.

From (3) we can establish the dynamic stiffness *EI* and Young modulus *E* values (8).

$$EI = (l/\beta)^4\cdot [\nu\cdot\pi\cdot 2\cdot(\rho A)^{0,5}]^2,\ EI = (l/\beta)^4\cdot [\nu\cdot\pi\cdot 2\cdot(\rho A)^{0,5}/I^{0,5})]^2 \quad (8)$$

3. Experimental and dynamic parameters determination

We have built some sandwich bars with polypropylene honeycomb core reinforced with carbon fiber in the upper and lower layers. We have obtained the next samples sets: **set 1**: thickness 11 mm, mass 55g, width 60 mm, 2 carbon fiber layers; **set 2**: thickness 11,4 mm , mass 78 g, width 60 mm, 4 carbon fiber layers; **set 3**: thickness 21 mm, mass 75g, width 60 mm, 2 carbon fiber layers; **set 4**: thickness 21,4 mm , mass 99 g, width 60 mm, 4 carbon fiber layers; **set 5**: thickness 16 mm, mass 59g, width 60 mm, 2 carbon fiber layers; **set 6**: thickness 16,4 mm, mass 90g, width 60 mm, 4 carbon fiber layers.

Figure 1. The built samples

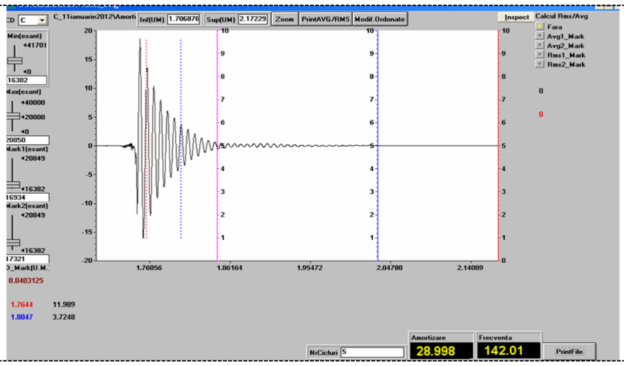

Figure 2. The eigenfrequency and damping factor per unit mass determination (set 5, 23 cm free length)

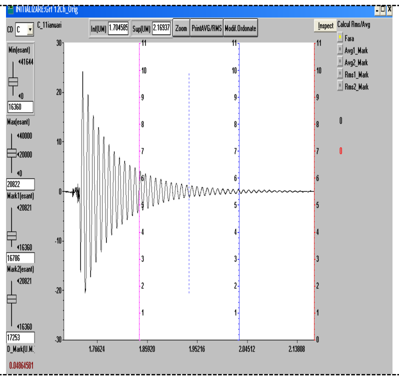

Figure 3. The vibration recording (set 1, 23 cm free length)

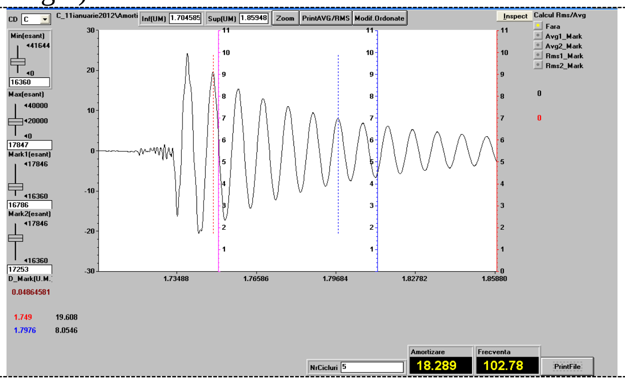

Figure 4. The eigenfrequency and damping factor per unit mass determination (set 1, 23 cm free length)

A general view of the samples is presented in figure 1. We have clamped the bars at one end, and we left them to vibrate freely. The vibrations were recorded with a Briel&Kjaer accelerometer placed at the free end. From the free vibrations, we have determined the damping factors per unit mass and length, loss factor, dynamic Young modulus, dynamic stiffness, and the frequency of the first eigenmode. We have considered the next free lengths for the bars: 20 cm, 23 cm, 26 cm, 29 cm, 32 cm and 35 cm. In figure 2, we have presented the eigenfrequency and damping factor determination for 5 cycles, set 5 - 23 cm free bar length. In figure 3, we have the vibration recordings for the set 1, the free length of 23 cm. In figure 4, we have presented the eigenfrequency and damping factor determination for 5 cycles, set 1 23 cm free bar length. All the dynamic parameters are written in table 1. The eigenfrequency and damping factor per unit mass were determined experimentally; the damping factor per unit length was determined with (6), the loss factor with (7), the dynamic stiffness and Young modulus with (8). If we make the arithmetic mean of all parameters, we obtain the dynamic mechanical characteristics written in table 2.

Table 1. Geometrical characteristics and dynamic parameters

set	width (mm)	Thickness (mm)	carbon fiber layers	mass (g)	free length (mm)	Eigenfrequency (1/s)	damping factor per unit mass (Ns/m)/kg	damping factor per unit length (Ns/m)/m	dynamic stiffness (Nm^2)	dynamic Young modulus (MPa)	Density (kg/m^3)	Specific mass (kg/m)	Loss factor
1	60	11	2	55	350	43.55	8.59	2.371	12.545	1878	208.33	0.138	0.061
1	60	11	2	55	320	53.87	10.33	2.851	13.413	2008	208.33	0.138	0.061
1	60	11	2	55	290	65.66	12.26	3.384	13.441	2012	208.33	0.138	0.059
1	60	11	2	55	260	82.33	15.75	4.347	13.65	2044	208.33	0.138	0.061
1	60	11	2	55	230	102.78	18.28	5.045	13.031	1950	208.33	0.138	0.057
1	60	11	2	55	200	122.6	23.38	6.453	10.258	1535	208.33	0.138	0.062
2	60	11.4	4	78	350	48.5	10.14	3.95	21.98	3303	295.455	0.195	0.067
2	60	11.4	4	78	320	61.22	12.88	5.023	24.478	3677	295.455	0.195	0.067
2	60	11.4	4	78	290	70.7	14.4	5.616	22.02	3308	295.455	0.195	0.065
2	60	11.4	4	78	260	85.72	17.24	6.724	20.914	3142	295.455	0.195	0.064
2	60	11.4	4	78	230	106	21.66	8.447	19.584	2942	295.455	0.195	0.065
2	60	11.4	4	78	200	130.1	26.25	10.238	16.868	2534	295.455	0.195	0.064
3	60	21	2	75	350	74.2	14.45	5.433	49.6	1068	148.81	0.188	0.062
3	60	21	2	75	320	93.6	19.14	7.197	55.165	1188	148.81	0.188	0.065
3	60	21	2	75	290	109.6	24	9.024	51.018	1099	148.81	0.188	0.07
3	60	21	2	75	260	126.71	28.31	10.645	44.058	948	148.81	0.188	0.071
3	60	21	2	75	230	168.09	36.21	13.615	47.48	1022	148.81	0.188	0.069
3	60	21	2	75	200	215.86	44.17	16.608	44.77	964	148.81	0.188	0.065
4	60	21.4	4	99	350	74.4	17.13	8.496	65.8	1340	192.757	0.248	0.073
4	60	21.4	4	99	320	93.96	20.1	9.97	73.33	1493	192.757	0.248	0.068
4	60	21.4	4	99	290	110.2	27.7	13.739	68.04	1385	192.757	0.248	0.08
4	60	21.4	4	99	260	136.99	36.3	16.021	67.932	1383	192.757	0.248	0.075
4	60	21.4	4	99	230	170.21	40.263	19.97	64.223	1308	192.757	0.248	0.075
4	60	21.4	4	99	200	225.66	49.6	24.602	64.541	1314	192.757	0.248	0.07
5	60	16	2	59	350	58.68	13.2	3.881	24.262	1188	153.646	0.147	0.072
5	60	16	2	59	320	75.7	15.63	4.595	28.214	1382	153.646	0.147	0.066
5	60	16	2	59	290	88.9	18.76	5.515	26.246	1286	153.646	0.147	0.067
5	60	16	2	59	260	108.8	22.77	6.694	25.399	1244	153.646	0.147	0.067
5	60	16	2	59	230	142.01	28.99	8.523	26.498	1298	153.646	0.147	0.065
5	60	16	2	59	200	183.4	36.11	10.616	25.269	1238	153.646	0.147	0.063
6	60	16.4	4	90	350	59.8	13.3	5.985	38.567	1748	228.659	0.225	0.071
6	60	16.4	4	90	320	75.9	17.4	7.83	43.413	1968	228.659	0.225	0.073
6	60	16.4	4	90	290	92.1	19.8	8.91	43.117	1955	228.659	0.225	0.068
6	60	16.4	4	90	260	108	24.9	11.205	38.307	1736	228.659	0.225	0.073
6	60	16.4	4	90	230	144.1	31.9	14.355	41.762	1893	228.659	0.225	0.07
6	60	16.4	4	90	200	186.9	39.4	17.73	40.168	1821	228.659	0.225	0.067

Table 2. Dynamic mechanical **c**haracteristics from the arithmetic mean values

Set	Stiffness	Young modulus	Loss factor
1	12.723	1904.5	0.06
2	20.974	3151	0.065
3	48.681	1048,17	0.067
4	67.31	1370.5	0.073
5	25.981	1272.67	0.067
6	40.89	1853.5	0.07

4. Conclusions

The damping factors analysis show that these factors must be experimentally determined for each type of material and sample, is 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.

In addition to these general conclusions, by studying the tables 1 and 2, we can add new particular ones: the damping factor per unit mass and length increases with the thickness of the bar; the damping factor per unit mass of per unit length decrease exponentially with the free length of the platband; the eigenfrequency increases with the bars thickness increase; the dynamic stiffness increases with the thickness of the ba, but the Young modulus decreases with the bars thickness increase; there were obtained higher dynamic mechanical characteristics for the samples with four layers of carbon fiber compared to the ones with 2 layer - this fact can be explained by the addition of one carbon fiber layer in the upper and lower side of the sandwich bar; the loss factor tends to increase with the thickness of the bar

We consider that, the added values of this study can be: building some new composite platbands made by classical materials (such as carbon fiber, polypropylene honeycomb) 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 (per unit mass and per unit length) for the built composite platbands; the frequency determination for the first eigenmode; the stiffness determination; the dynamic elasticity modulus calculus; the loss factor calculus.

References

[1] Q., Zhenchao, Z., Nanxi, L., Yong, C., Wenliang, 2012, *Prediction of mechanical properties of carbon fiber based on cross-scale FEM and machine learning*, Composite Structures, 212, p. 199-206

[2] J., Hu, K., Zhang, Q., Yang, et al., 2018, *An experimental study on the mechanical response of single-lap bolted CFRP composites interference fit joints*, Compos. Struct., 196, p. 76-88.

[3] Q., Sun, el. al., 2019, *Failure criteria of unidirectional carbon fiber reinforced polymer composites informed by a computational micromechanics model*, Composites Dcience and Technology, 172, p. 81-95.

[4] M., Andideh, M., Esfandeh, 2017, *Effect of surface modification of electrochemically oxidized carbon fibers by grafting hydroxyl and amine functionalized hyperbranched polyurethanes on interlaminar shear strength of epoxy composites*, Carbon, 123, p. 133-242.

[5] X., Qian, J.H., Zhi, L.Q., Chen, et al., 2018, *Evolution of microstructure and electrical property in the conversion of high-strength carbon fiber to high modulus and ultra-high modulus carbon fiber*, Compos. An ApplSci Manuf, 112, p. 111-118.

[6] X., Qian, R., Zou, Q., Ouyang, et al., 2015, Surface structural evolvement in the conversion of polyacrylonitrile precursors to carbon fibers, Appl Surf Sci, 327, p. 246-252.

[7] Z., Wen, X., Qian, et al., 2019, *Electrochemical polymerization of carbon fibers and its effect on the interfacial properties of carbon reinforced epoxy resin composites*, Composites Part A, 119, 21-29.

[8] M., M., StĂnescu, et al., 2009, *Experimental Researches Concerning the Properties of Composite Materials with Random Distribution of Reinforcement*, Materiale Plastice, 46, p. 73-78.

[9] W., Nowacki, 1969, *Dynamics of flexible systems*, Technical Publishing House, Bucharest.

[10] C.O., Burada, C.M., Miriţoiu, et al., 2015, *The vibration behavior of composite platbands reinforced with glass fiber*, Romanian Journal of Materials, 45, p. 244-254.