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RESEARCH INTO THE ELASTICITY AND DUMPING FACTORS OF THE POLYMER COMPOSITES REINFORCED WITH GLASS, CARBON AND ARAMID FIBERS

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Main rheological parameters of the laminar polymer composites reinforced with glass, carbon and aramide fibers were investigated by the author in an experimental way. The methods of analyse of free torsional vibrations of the composite elements were applied. The results were as follows:
– comparison of the rheological properties (elasticity and dumping factors) between tested composites
– comparison between manufacturers catalogue data on the shear modulus G and the results of experiment
– aproximation of the relation between shear modulus G and elasticity modulus E.

1. Introduction

The major type of the polymer composite that was in common use – was since a time a composite reinforced with glass fibers. Mechanical properties of this kind of material are sufficiently known. New kinds of fibers that have become accessible in Poland for last few years involve a necessity for gaining the experience in new kind of polymer composites – especially in the those reinforced with carbon or aramide fibers.

The present research have a pre-investigation character and do not clear out the matter.

The tube-elements were chosen for the tests for the following reasons

- A simple analysis of the mechanical properties of the tested elements may be applied. Taking into consideration, the anisotropy of the composites –

the tube-elements allow us to keep maintained direction of the fibers and to avoid the influence of the free bands of the element on the stress-state inside it.

- The tube-elements in contract to of the plate-elements allow us to reduce operation of cutting the plate on the specimens; (this is important especially for the composites reinforced with aramide fibers).

2. Description of the specimens

Each tube was built in such a way that the belt of the fabrics was winded up on the 26 mm diameter shaft. As the result the each specimen has 3 layers of the fabrics as a main structure and locally 4 layers in the position of tuck (10 mm segment of the perimeter of the tube).

The specimen length was 0.84 m.

Pressing by the plastic foil band was applied when forming the tubes.

Two types of the specimen were built:

Type A – with the fibers positioned in the direction $45° \div 45°$ to the length-axis of the tube,

Type B – with the fibers positioned in the direction $0° \div 90°$ to the length-axis of the tube.

Three kinds of the fabrics were applied:

Table 1. Properties of the interglas fabrics [2]

Symbol of the fabrics	Element. weight [g/m^2]	Proportion of the fibers: transversal/ longitudinal	Type of braid	Thickness of 1 layer δ^* [mm]	Young mod. in longitud. direction E^* [GPa]
"92 125" Interglas glass fabric	280	0.93	"Köper 2/2"	0.25	≈ 21
"98 151" Interglas carbon fabric	245	1.00	"Köper 2/2"	0.28	≈ 55
"98 630" Interglas glass fabric	220	1.00	"Leinwald"	0.35	≈ 22

Note: Symbol * concerns 50% volume fraction.

Since the assortment of fabrics was limited it was impossible to apply the fabrics with the same parameters of elementary weight or thickness and type of braid.

It should be kept in mind when comparing the results of the tests. However the elementary weights are close one to another in a maximum aveilable degree.

Taking into consideration the technological process of specimen production (hand sating and hand winding-up the plastic foil belt on the external surface of the tube), the volume factors of the sating are not equal.

Table 2. Volume fraction of the composites used in specimens

Direction of fibers	Glass	Carbon	Aramide
$45° \div 45°$	0.30	0.47	0.58
$0° \div 90°$	0.60	0.51	0.58

3. Description of the method for the elasticity investigation

The method for analysis of the free torsional-vibration of the system with the specimen as the twisted tube was applied for investigation.

Physical model of the system is shown in Fig.1.

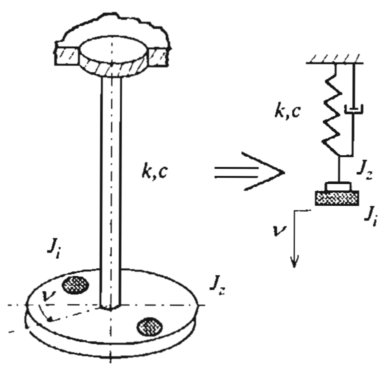

Fig. 1. Physical model of the system

Assumptions:

1. The system is linear and dumping coefficient has a viscous character.
2. The mass is concentrated in the lower point of the tube and only the I Mode of torsional vibration has been taken into consideration.

List of symbols:

z	–	longitudinal axis
c	–	dumping coefficient, (coefficient of viscous friction), [Nm/(rd/s)]
k	–	coefficient of elasticity, [Nm/rd]
J	–	moment of inertia of the whole system about z, [kgm^2]
J_z	–	reduced moment of inertia for the tube and lower holder, [kgm^2]
J_i	–	moment of inertia of the ith pair of the test-masses, [kgm^2]
ω_0	–	frequency of the torsional vibration without dumping, [rd/s]
ω	–	frequency of the torsional vibration with dumping, [rd/s]
ν	–	the angle of torsion measured in the lower end of tube, [rd]
t	–	time, [sec].

Parameters of the system are: c, k, J.
The equation of the motion has the following form

$$J\ddot{\nu} + c\dot{\nu} + k\nu = 0 \tag{3.1}$$

or

$$\ddot{\nu} + 2\sigma\dot{\nu} + \omega_0^2\nu = 0 \tag{3.2}$$

where

$$\sigma = \frac{s}{2J} \qquad \omega_0^2\frac{k}{j} \tag{3.3}$$

The solution to the equation of motion has the form

$$\nu = \nu_0 e^{-\sigma t}\cos(\omega t + \psi) \tag{3.4}$$

where

$$\psi = \sqrt{\omega_0^2 - \sigma^2} \tag{3.5}$$

The values of parameters c, k – are approximated on the base of various tests by introduction to (6) the values ω, σ – received from experiments with I-various masses (moments of inertia)

$$\begin{aligned} c &= 2(J_z + J_i)\sigma_i \\ k &= (\omega_i^2 + \sigma_i^2)(J_z + J_i) \end{aligned} \tag{3.6}$$

where index i denotes the values of ith pair of the test-masses added to the system. J_z likewise c or k is the unknown parameter in these equations.

4. Description of the measuring device

The measuring device is shown on the Fig.2.

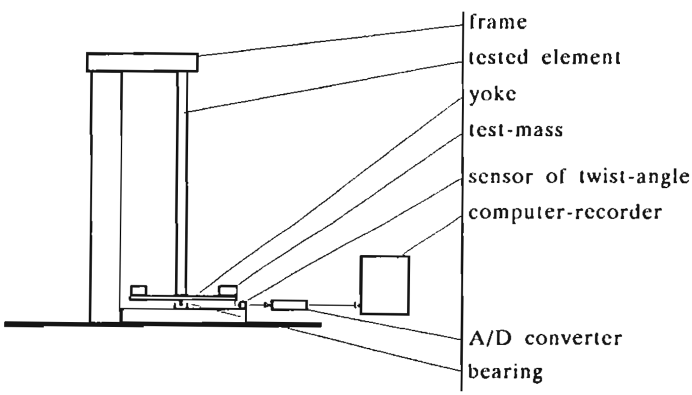

Fig. 2. Device for investigation into elasticity and dumping properties of the composite tube

5. Results of experiment

The values of elasticity coefficient k and dumping coefficient c are shown in Table 3.

They refer to the frequency of torsional vibration in the range: 1.6 ÷ 10.6 Hz.

Table 3. The values of elasticity coefficient k and dumping coefficient c

Direction of the fibers/kind of fibers		Glass	Carbon	Aramide
$45° \div 45°$	k [Nm/rd]	250	428	238
	c [Nm/(rd/s)]	0.05	0.05	0.10
$0° \div 90°$	k [Nm/rd]	82	87	46
	c [Nm/(rd/s)]	0.09	0.08	0.07

A sample of the recorded vibration is shown in Fig.3.

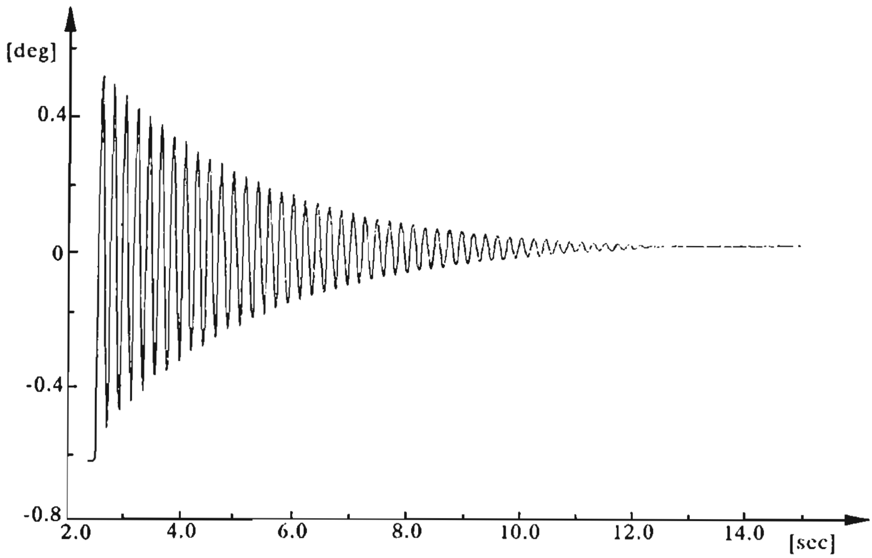

Fig. 3. Sample of the torsional vibration of the system with twisted composite tube

6. Relation between the elasticity coefficient k and the shear modulus G

Very important information for the constructors is the value of modulus G.

On the base of Bredt's formula (cf Brzoska (1961)) it is possible to find the relation between k and G.

According to Bredt

$$\nu = \frac{M_s l}{4GF^2} \oint \frac{ds}{\delta} \tag{6.1}$$

where

l	–	length of twisted tube, [m]
M_s	–	twisting moment, [Nm]
F	–	area of the cross-section of the tube, [m^2]
s	–	curve coordinate along the contour edge of the cross-section of the tube
ν	–	angle of torsion, [rd]
δ	–	thickness of the tube wall, [m].

For the constant δ we can find that

$$k = \frac{M_s}{\nu} = \frac{4F^2G\delta}{l\oint ds} \tag{6.2}$$

For the regular tube with diameter D the relation has the form

$$k = \frac{\pi D^3 G\delta}{4l} \tag{6.3}$$

Equation (6.3) is true for 1-layer structure while $\delta \ll D$.

In the case of tube built of three layers of materials – it is statically indeterminate and the total value of twisting moment M_s is the superposition of three twisting moments acting in each particular layers, respectively

$$M_s = M_{s1} + M_{s2} + M_{s3} \tag{6.4}$$

Assuming that the angle of torsion is the same in each layer we can find that

$$k = \frac{M_s}{\nu} = \frac{4G\delta}{l}\sum_i \frac{F_i^2}{\oint ds_i} = \frac{\pi G\delta}{4l}\Big[(D+\delta)^3 + (D+3\delta)^3 + (D+5\delta)^3\Big] \tag{6.5}$$

Calculating of the modulus G in the multi-layer composites is not very precise since:

- Determination of the particular thickness of the layer is difficult because of the heterogeneity of the composite
- It depends on the volume fraction (composite with the same number of layers may have, for instance double thickness, but it does not mean that it has double value of the G-modulus in the same time).

Thus it is more useful to use the factor G' defined as $G' = G\delta$.

Values of the factor G' and approximate values of the factor G calculated for the data obtained in experiment are shown in the Table 4.

Table 4. Values of the modulae $G' = G\delta$ and G

Direction of the fibers/kind of fibers		Glass fabric "92125"	Carbon fabric "98151"	Aramide fabric "98630"
$45° \div 45°$	$G\delta$ [MN/m]	3.3	6.3	3.4
	G [GPa]	≈ 6.3	≈ 19.7	≈ 11.4
$0° \div 90°$	$G\delta$ [MN/m]	1.2	1.2	0.6
	G [GPa]	≈ 4.5	≈ 3.3	≈ 2.0

7. Discussion of the results

In case of specimens type A $(45° \div 45°$ – direction of the main strain overlaps the direction of fibbers. It means that elasticity properties of this kind of specimen depend mostly on the Young modulus of the fibbers.

It is confirmed by the results of the experiment (see Table 5.)

Table 5

num / den	Ratio of elasticity coeff. – experimental data			Ratio of elasticity coeff. – catalogue data (aprox.)		
	$G\delta_{glass}$	$G\delta_{carb}$	$G\delta_{aram}$	$G\delta_{glass}$	$G\delta_{carb}$	$G\delta_{aram}$
$G\delta_{glass}$	1	1.9	1.03	1	2.6	1.05
$G\delta_{carb}$	0.53	1	0.5	0.43	1	0.4
$G\delta_{aram}$	0.97	2.0	1	0.95	2.5	1

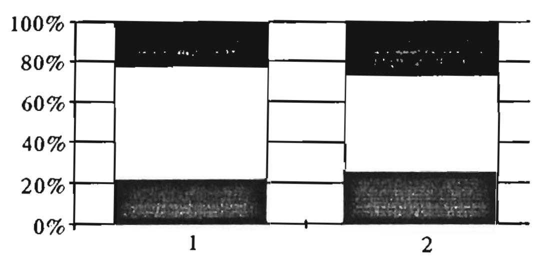

Fig. 4. Proportions of the modulae E (bar 1) and factors $G\delta$ for various types of composites (for aramide, carbon, glass, respectively)

Table 3 draws the attention to the dumping coefficient of the aramide composite that is 2-times higher than for other kinds of reinforcement.

In the case of specimens type B $(0° \div 90°)$ – the matrix plays an important role in transferring the strains. It is confirmed by the results of the experiment; the factors $G\delta$ for glass and carbon composites are almost the same. Similar situation is for the dumping coefficient c.

The aramide composite broke this rule, but it is important to notice that the type of braid is different in this case. The influence of the type of braid shall be checked in the future.

The comparison between catalogue data [3] and experimental data for fibreglass composite is shown in Fig.5.

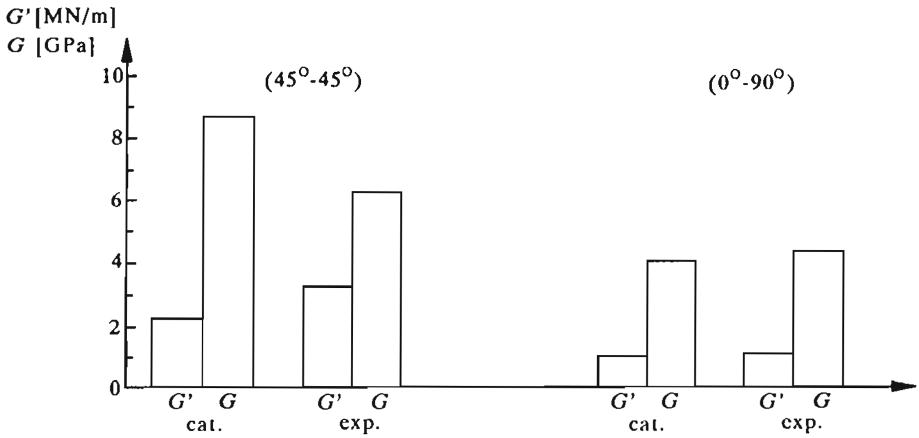

Fig. 5. Comparison between catalogue data and experimental data for fibreglass composite (fabrics 92125)

The differences for the case $(45° \div 45°)$ might be caused by the low value of volume fraction of tested tubes.

In the end of this paper is shown the comparison between results obtained by means of the classic (i.e. static) and the dynamic measurement methods of elasticity coefficients, respectively. The aramide composite is used for sample:

$$k_{dyn} = 46 \mathrm{Nm/rd} \qquad k_{stat} = 35 \mathrm{Nm/rd}$$

This difference is very significant and is caused by reologhical properties of this composite.

8. Conclusions

- The method of analysis of the free vibration of the composite elements seems to be a good tool for investigation into elasticity and dumping properties of the composites.
- The results of this pre-investigation of the elasticity properties are close to the results published by the manufacturer of the fabrics used in the tested specimens.
- The measured value of elasticity coefficient of the composite strongly depends on the kind of method used for measuring. Signifficant difference between static or dynamic methods is the effect of reologhical properties of this composite.

References

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Badania właściwości sprężysto-tłumiących kompozytów polimerowych zbrojonych włóknami szklanymi, węglowymi lub aramidowymi

Streszczenie

W pracy opisano badania eksperymentalne podstawowych cech reologicznych kompozytów polimerowych zbrojonych włóknami szklanymi, węglowymi lub aramidowymi. Wykorzystano przy tym metodę analizy swobodnych drgań skrętnych układu, w którym próbka kompozytowa występowała jako rura skręcana. Zamieszczone rezultaty badań dotyczą:

- porównanie współczynników sztywności i tłumienia kompozytów o różnych rodzajach włókien i kierunkach zbrojenia;
- porównanie wartości momentów sztywności postaciowej katalogowych (producenta) i uzyskanych z eksperymentu;
- relacji między modulem sztywności postaciowej a modulem Yanga dla prętów o diagonalnej orientacji włókien.

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