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Experimental study of thin-walled structural fiberglass elements

Экспериментальные исследования тонкостенных элементов конструкций из стеклопластика

In this study an experimental method was developed in order to validate the theoretical results and error estimates, which are taken into account while calculating of the strength of thin-layer elements with defects. There were defined the physical and mechanical characteristics of the main components of glass, construction glass fiber and binders (epoxy resin or polyester resin orthophthalic). Fabrication techniques of the samples are summarized after analysis .

***Keywords**: thin walled structural, modulus of elasticity, fiberglass elements, strain gauge, composite materials.*

Разработана экспериментальная методика для проверки достоверности теоретических результатов и оценки погрешностей, которые вносят различного рода допущения в расчеты на прочность тонкостенных элементов с межслойными дефектами.

Приведены физико-механические характеристики основных компонент стеклопластика – стекловолокна, конструкционных стеклотканей и вяжущих материалов (эпоксидная смола или полиэстерная ортофталевая смола), дана краткая характеристика технологии изготовления образцов.

На основе методов математической статистики определены доверительные интервалы экспериментально полученных средних значений модуля упругости и предела прочности стеклопластика при растяжении и сжатии, предела прочности стеклопластика при изгибе.

Созданы две экспериментальные установки для проведения испытаний пластин и цилиндров из стеклопластика на действие равномерно распределенного давления. Разработана методика проведения экспериментальных исследований. Граничные условия закрепления контуров пластин и торцов цилиндра могут варьироваться от условий свободного опирания до жесткого закрепления.

Конструкции экспериментальных установок позволяют производить замеры прогибов пластин и нормальных перемещений цилиндров с помощью индикаторов часового типа с точностью измерений до $0{,}5 \cdot 10^{-5}$м. Измерение относительных деформаций проводится методом тензометрирования.

Сравнение экспериментальных данных с теоретическими результатами позволило сделать выводы о том, что в результате сравнительно низкой жесткости стеклопластиков на изгиб и слабой сопротивляемости поперечному сдвигу применение традиционной непрерывно-структурной модели при расчетах тонкостенных армированных элементов конструкций даже в начальной стадии нагружения приводит к значительным погрешностям. Кроме того, при поперечном изгибе тонких пластин, когда прогиб соизмерим с толщиной пластины, необходимо использовать в расчетах геометрически нелинейные деформационные соотношения.

***Ключевые слова**: тонкостенные, структурные, модуль упругости, стекловолокно, элементы, тензодатчик, композитные материалы.*

Розроблена експериментальна методика для перевірки достовірності теоретичних результатів і оцінки похибок, які вносять різного роду допущення в розрахунки на міцність тонкостінних елементів з міжшаровими дефектами.

Наведено фізико-механічні характеристики основних компонент склопластику - скловолокна, конструкційних стеклотканин і в'яжучих матеріалів (епоксидна смола або поліестерна ортофталева смола), дана коротка характеристика технології виготовлення зразків.

На основі методів математичної статистики визначені довірчі інтервали експериментально отриманих середніх значень модуля пружності і межі міцності склопластику при розтягуванні і стисненні, межі міцності склопластику при згині.

Створено дві експериментальні установки для проведення випробувань пластин та циліндрів із склопластику на дію рівномірно розподіленого тиску. Розроблено методику проведення експериментальних досліджень. Граничні умови закріплення контурів пластин і торців циліндра можуть варіюватися від умов вільного спирання до жорсткого закріплення.

Конструкції експериментальних установок дозволяють проводити виміри прогинів пластин і нормальних переміщень циліндрів з допомогою індикаторів годинникового типу з точністю вимірювань до $0{,}5 \cdot 10^{-5}$м. Вимірювання відносних деформацій проводиться методом тензометрування.

Порівняння експериментальних даних з теоретичними результатами дозволило зробити висновки про те, що в результаті порівняно низькою жорсткості склопластиків на вигин і слабкою опірності поперечному зсуву, застосування традиційної безперервно-структурної моделі при розрахунках тонкостінних армованих елементів конструкцій навіть в початковій стадії навантаження призводить до значних погрішностей. Крім того, при поперечному вигині тонких пластин, коли прогин сумірний з товщиною пластини, необхідно використовувати в розрахунках геометрично нелінійні деформаційні співвідношення.

***Ключові слова**: тонкостінні, структурні, модуль пружності, скловолокно елементів, тензодатчик, композитні матеріали.*

Introduction

Modern fiber composite materials with unidirectional, layered and dimensional stacking fittings are heterogeneous materials. The anisotropy of the properties and structural features of the reinforced plastics produce a number of fundamental difficulties. Among them is the establishment of the strength and elastic characteristics required to complete sufficiently the engineering certification of the material. The number of defined characteristics depends on the type of anisotropy. The principal schemes include the choice of loading, in which the characteristics of the material are most easily associated with the experimentally determined values, the choice of the analytical apparatus for the treatment of experimental and computational assessment of the application dependencies [1-5].

The first composite materials, which are widely used in various branches of modern engineering, were fiberglass. Design features of oriented glass-reinforced plastics are well known. In the first place it is a high specific strength in the reinforcement direction. However, the introduction of the main advantages into a number of difficulties is associated with a relatively low hardness of glass-reinforced plastics under transverse shear and transverse separation. Resistance to interlayer shear and transverse separation of GRP is equal to τ_{xx}=25 ÷ 50 MPa, G_{xz}=2000 ÷ 2500 MPa and σ_z=20 ÷ 55 MPa [6, 7].

Loss of bearing capacity of glass-fiber plates and shells under the action of compressive loads due to weak cross-resistance to separation and interlayer shift occurs long before reaching the stress limit values. These shortcomings are particularly noticeable when the composite material has a different kind of structural defects [8, 9].

Production technology and characteristics of glass samples

As a reinforcement in the manufacture of fiberglass structures there was used high modulus glass fiber, or roving. The strength of monofilament lies in the range from 3.4 GPa to 4.5 GPa. The standard deviation is approximately ± 10%. The main reason for this wide variation is the presence of defects in the fibers and the influence of atmospheric moisture.

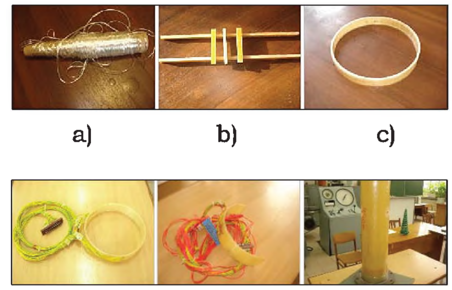
The results of tensile tests of fiber bundles or strands is about 20% lower than the average values for monofilaments. This is explained by the fact that after the rupture of individual fibers in the bundle there appears a significant overweight of the rest of the fibers. One of the drawbacks, which limits the use of glass fiber rovings, is a small value of the elasticity modulus. The maximum value of elasticity modulus of unidirectional composites lies in the range 41.0 - 55.2 GPa.

Epoxy resin ED-20 grade, as well as polyester resin, is widely used as a binder. Other types of epoxy resins are also used: brominated flame - with a high fire resistance, flexible epoxy resin with a high coefficient of toughness and ductility. As a part of the epoxy resin compositions, various curing agents and plasticizers are additionally applied. The most widely used curing agents are metilnadikangidrid and triethanolamine. As the plasticizer dibutyl phthalate can be used. Tensile strength of epoxy resin castings is in the range 55 – 130 MPa, tensile modulus - 2.8 - 4.2 GPa, flexural strength - 120 MPa.

The material and structure of the samples

The research results presented in this paper have been obtained for the two types of samples: semi-circular patterns and large thin-walled cylinders made of composite materials.

In the first stage of the study samples were obtained with circular and semicircular form, the inner diameter



a) b) c) d) e) f)

Fig. 1. Examples of materials used in different experiments

of which was 192 mm and an outer diameter - 200 mm. Fig. 1 shows examples of the materials used in different trials.

Experimental work and analysis of results

Testing of glass fiber yarns

Fig. (1,a) represents the type of fiber used in the manufacture of composite materials. Experiments were conducted in order to determine the maximum load carried by a stream, as well as to get the value of elasticity modulus of a single string. Experiments showed that the maximum load rests on the shoulders of one flow (0.5) of Newton.

Testing of synthetic yarns for maximum load. The test string consists of a large number of microthreads with different lengths. In the course of the experiment the sections of the thread with length 1.0 m were used for registration of elongation by the serial deflectometer, which is a dial gauge with a large registered stroke (20 cm) and a drive from the test thread. The load was a 6-liter bottle of water out that was filled step by step with calibrated portions of water. Dry weight of the bottle is 94.93 g, the tests were performed at load step 50 g and 100 g, thread length of 1.0 m was fixed on a support. Vertically along the filament, deflectometer is fixed, and thread covers its drive loop. The water tank (load) was suspended at the other end of the thread. Fig.2 shows the experimental methods.

The experiment revealed the following: 1. When loadings were applied in increments of 50 g, the ultimate strength (at break) of the thread was 3.75 kg. 2. When loadings were applied in increments of 100 g, the ultimate strength was 2.6 kg of yarn.

This can be explained by the following: since the length of microthreads was different, then at step load of 50 g at individual time the microthreads were gradually lengthened to a total length of the thread and joined in the general transfer of load (1), and at step load of 100 g there were observed the clippings of some microthreads, as it is shown in Table 2, while the lengthening string of jumps was more than 2 mm. The total number of microthreads decreased, which resulted in a decrease of ultimate load capacity.

Therefore, we believe that the rate of loading (step load) threads should be normalized. P.S. for reference. While testing the strength of bricks in the production, the rate of loading is normalized by GOST. This is due to the phenomenon called the creep. When the loading rate increases, the strength of bricks increases judging by the testimony of the testing equipment, because creep strain does not have time to show itself.

In our case, the situation is vice versa. This is indicated by a very small elongation of the thread before the cliff (1). Values of elasticity modulus were obtained after a few experiments, and the results were analyzed in the program Excel in order to obtain the values of elasticity modulus equal to $1.233 \cdot 10^4$ MPa.

Tests of the elasticity modulus of longitudinal models

Fig. (1,b) shows the types of models that were selected to determine the elasticity modulus of longitudinal models. Two types of models were chosen for the investigation. In the first type of testing of the tensile strength, the model with the dimensions (400 x 12 x 9 mm) was selected. In the second type of testing of compressive strength three models were chosen with the dimensions (100 x 12 x 8 mm). Three types of load were used for each model to measure the intensity of the load. There was obtained a large number of readings for each sample, and then the results were analyzed in Excel in order to get the values of the elasticity modulus. After analysis, we calculated the average values of readings. (The average value of strain gauge coefficient is equal to -). The calculated values of the load cell were determined using Hooke's law. The test results are shown in Fig. (3) and are summarized in Table (1).

Testing a model of the composite rod with a curved grating

There were conducted two types of tests of composite rods with the curved shape, as shown in Fig. (1). In the first type of tension testing two samples were selected two samples as a model.

Fig. 2. Testing method for the thread of a composite material

Fig. 3. The process for obtaining of experimental data on longitudinal models

The samples had an internal diameter (192 mm), outside diameter (200 mm), thickness (4 mm) and width (25 mm). It was necessary to determine whether the form of samples is fixed during the entire process or not. The results of this process are shown in Fig. (4, a, b). As to the second type of compression tests, the selected models had the same dimensions as the model of the first type of testing, as it is shown in fig. (4, c). The results of all tests are presented in Table (2).

Assessment of the elasticity modulus of circular multilayer composite rods.

Results of empirical studies were designed and the samples were fabricated, as shown in Fig. 1, d. The form of the samples allows to test different models of circular or semicircular shape at different loads.

Fig. 5 represents a discontinuous system for static testing of metal models (2007 P - 0.5), (D - 20) and model (CBM - 50).

a) b) c)

Fig.4. Manufacturing method of experimental model of the composite rod with a curved grating

Table 1. ***The analysis results of evidences for the longitudinal model***

Type of experiment	Number of samples	Number of strain gauge	Load (Kg)	Downloads	Maximum Load (Kg)	Maximum load to rupture (Kg)	Elasticity modulus (MPa)	Mean elasticity modulus (MPa)
tension (experiment)	1	2	200	7	1400	3075	$2.303 \cdot 10^4$	$2.183 \cdot 10^4$
	2	2	200	7	1400	3360	$2.062 \cdot 10^4$	
compression (experiment)	1	3	100	15	1500	1625	$2.06 \cdot 10^4$	$2.24 \cdot 10^4$
	2	3	100	15	1500	1675	$2.27 \cdot 10^4$	
	3	2	100	21	2100	2165	$2.39 \cdot 10^4$	

Table 2. ***The analysis results of the composite rod with a curved grating***

Type of experiment	Number of samples	Cross-sectional area of the sample (mm²)	The maximum load failure (Kg)	Stress value (MPa)
Tensile tests	1	100	3950	197.5
	2	100	4600	230
Compression tests	1	100	135	6.75
	2	100	145	7.25

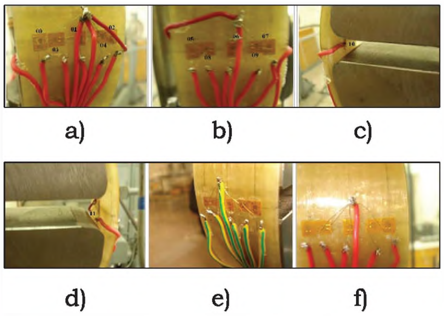


Fig. 6. Points of strain labels

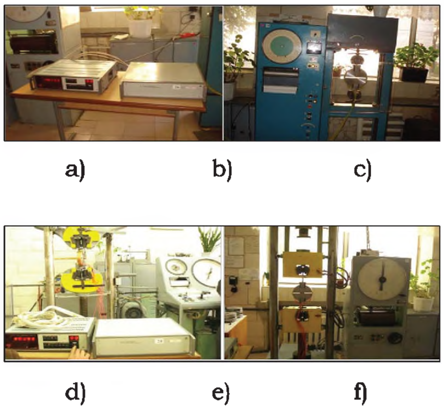


Fig. 5. The principle of operation of devices and equipment used to test various components of bent rods in order to obtain the elasticity modulus

Measurement and recording of strains and stresses. To measure the strain gauges KF4P1-3-200 was used with a base of 3 mm. Rosette consisted of two strain gauges. Points of strain labels are shown in Fig. 6 The average value of the strain gauge coefficient is equal to -. K =0.000002.

Scheme labels on cylindrical samples of strain gauges are shown in Fig. 7. Strain gauges, methods of their labeling, and strain measurement are the same as for the subjects of the plates.

For tensile tests two types of samples were chosen in order to find the value of the elasticity modulus. After the installation various tests were carried out to determine the values of elasticity modulus for these models. The results of these tests are summarized in Table 3.

Testing the model of the elasticity modulus of multi layered composite semicircular rods.

In tests of semicircular rod made of composite material two models were selected in order to determine the values of vertical and horizontal displacement in the form. Fig.8 presents the testing method, devices and equipment used in experiments aimed at setting-type strain (2007 P - 0.5).

A number of strain gauges was established for each model. The sensors are shown in Fig. 9. The results of these tests are represented in Table 4.

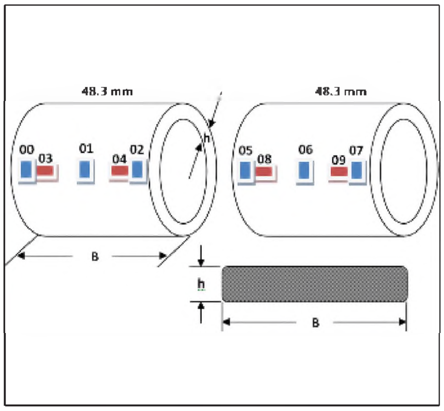


Fig. 7. Point labels of strain gauges on cylindrical samples

Table 3. ***The results of various tests for assessment of elasticity modulus of the composite model of a circular rod***

Model Number	Number of experiments	Load (Kg)	Number of samples	Maximum load (kg)	Number of strain gauge	Cross-sectional area of the sample (mm²)	Elasticity modulus (MPa)	Mean elasticity modulus (MPa)
1	1	50	11	470	10	193.2	3.781*10⁴	3.582*10⁴
	2	50	11	470	10	193.2	3.876*10⁴	
	3	50	10	450	10	193.2	3.301*10⁴	
	4	50	10	450	10	193.2	3.368*10⁴	
	5	100	20	2000	10	193.2	4.47*10⁴	4.465*10⁴
	6	100	20	2000	10	193.2	4.46*10⁴	
2	1	50	10	450	10	196.4	3.419*10⁴	3.511*10⁴
	2	50	10	450	10	196.4	3.618*10⁴	
	3	50	10	450	10	196.4	3.883*10⁴	
	4	50	10	450	10	196.4	3.124*10⁴	
	5	100	20	2000	14	196.4	5.23*10⁴	5.055*10⁴
	6	100	20	2000	14	196.4	4.92*10⁴	

Table 4. ***The results of various tests for assessment of elasticity modulus of the composite model of semi-circular rod***

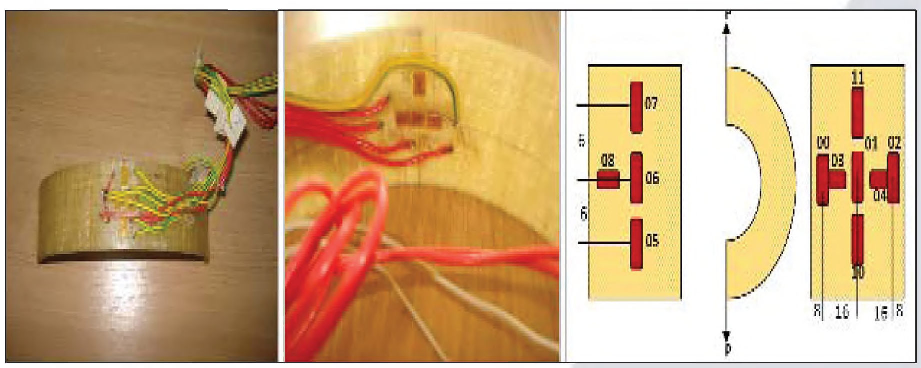
Model Number	Number of experiments	Number of strain gauge	Load (Kg)	Number of samples	Maximum load (kg)	Cross-sectional area of the sample	Elasticity modulus (MPa)	Horizontal displacement	Vertical displacement
1	1	14	2	8	16	200	$4.056*10^4$	12.9	22.34
	2	14	2	8	16	200	$4.084*10^4$	11.32	19.89
2	1	14	2	8	16	200	$4.109*10^4$	12.33	20.26
	2	14	2	8	16	200	$4.275*10^4$	11.85	21.24

a) b) c)

Fig. 8. The principle of operation of devices and equipment used to test various components of bent rods in order to obtain the elasticity modulus and displacement

Conclusion

The comparison of experimental data with theoretical results allow to conclude that as a result of relatively low hardness of glass-bending and weak resistance to transverse shear, the use of conventional continuous-structural model for the calculation of reinforced thin-walled structural elements, even in the initial stage of loading, leads to significant errors. In addition, the transverse bending of thin plates, when the deflection is commensurate with the thickness of the plate should be used in the calculations of geometrically non-linear deformation relationships.



a) b) c)

Fig. 9. Dots stickers strain

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