UDC 620.22-419.8

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Influence of production technology of fiberglass on the strength characteristics

The influence of the fiberglass prodaction technology on their strength characteristics was investigated by tests of tension and compression of specimens that were cut along the warp and weft of fiberglass plates made by thermo-vacuum forming and vacuum infusion. The results of the studies showed a greater strength of the fiberglass made by the method of thermo-vacuum molding.

Composite materials (CM) gradually replace traditional metals in constructions of vehicles, and, in particular, aircraft for military and civilian purposes. In the designs of civil aircraft in the 90th years of the 20th century, the volume of CM approached 15% [1], and in the most advanced B.787 and A350, the weight of the CM already reaches 50% and above. Constructions of modern vehicles and aircraft mainly use polymeric composite materials (PCM) of glass- carbon and orhanoplasty, the designs of which are much more technological than similar metal and have a significantly lower weight, although PCM is much more expensive. The most common PCMs in different designs are fiberglass plastics, which are used in aviation constructions since the 1940's, with the fiberglass was reinforced the rear part of the fuselage of the training plane "Valti VT-15" [2]. The effectiveness of the use of PCM depends on the manufacturing technology, as well as the mechanical characteristics of PCM depend on it, and the main among them are the strength and rigidity characteristics at a tension and compression.

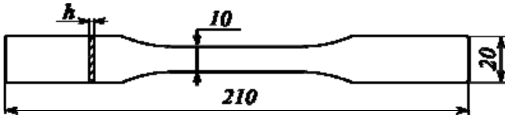
The research of PCM characteristics in tension and compression tests on the basis of developed standards has been systematically launched in the USA since the early 70's of the 20th century, which was reported in one of the most authoritative publications on the mechanics of composites MIL-17 (CMH-17) [3]. Comparative analysis of strength at tension and compression of PCM of two types - basaltplastic of 2 implementations and fiberglass of 2 implementations was presented in the work of the authors [4]. Now study the influence of various technologies of PCM on the characteristics of strength not given sufficient attention, although the properties of PCM formed during their manufacture.

In this paper, the effect of two typical technologies of fiberglass plastic glass often called fiber reinforced plastic (GFRP) production on the characteristics of strength during stretching and compression was investigated. Two of the most technology-the method of thermo-vacuum molding and the method of vacuum infusion-were chosen for analysis. For the purpose of studying the strength characteristics of the fiberglass, a series of specimens were developed for these testing in tension and compression. In order to ensure uniform conditions for the production of specimens, in order to avoid the effect of temperature and humidity on the results of studies ×in one day, on one cutting table of glass fiber fabric «Airglass 220 twill 2 × 2» with the use of epoxy resin «Larit L 285» and hardener «H 287» were 2 plates are formed by the two mentioned molding methods..

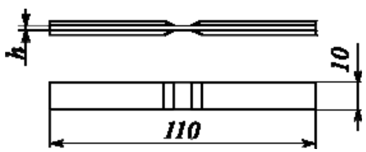
Plates were formed from 9 layers of the specified fiberglass fabric with the recommended thickness of the monolayer of 0.235 mm, which allowed to provide a total thickness of the package of layers (lamina) of 2 mm or more. The first plate was made using the technology of thermo-vacuum forming with manual layering of layers. Initially, from pre-cut billets of fiberglass fabric, a prepreg was made by manually applying a degassed binder and controlling the weight of the prepreg obtained. This allows to provide the optimal (from the position of strength) the amount of the binder in the package 38 ÷ 42 %. The final results of calculations of the amount of binder gave the value 39,7 %. The layers of prepreg were laid on a flat shape trimmed divider and a vacuum bag was formed from above. The treatment was carried out under a vacuum pressure of 0.9 ± 0.05 bar and a temperature of 23 ± 2 ° C for 24 hours.

The second plate was made by vacuum infusion method. The cut-off layers of glass fiber fabric «Airglass 220 twill 2 × 2» were laid out on a flat plate and the vacuum bag was further formed for implementation of the molding method by vacuum infusion. The vacuum bag for infusion includes a vacuum film, a distribution grid, a sacrificial fabric, a sealant, and also a vacuum and spiral tube. After complete injection, the binder polymerization was carried out for 24 hours at a temperature of 23 ± 2 ° C. Posttermopping of both plates was carried out for 14 days at a temperature of 23 ± 2 ° C until the polymerization of the binding agent was complete.

The manufactured plates were cut using a cutting machine with numerical control. From each fabric plate, 8 samples were cut in the direction of the warp (0 °) and in the direction of the weft (90 °) in the form of a double-sided blade (Fig. 1a) for tension tests in accordance with international standards ISO 527-1 та ISO 527-4 [5, 6]. Also, 7 strips of 110 × 10 мм^2 in the direction of the warp and in the direction of the weft were cut from the plates. Of these bands, samples were made by gluing the pads, which are a double-sided blade in thickness to the standard ISO 14126 [7] (see Fig. 1,b),



a



b

Fig. 1. Sketches of specimens for tensile tests (a) and compression (*b*)

The thickness of the plates after molding and ending the polymerization according to the measurements of the thickness of the specimens before the test was h = 2,10 ± 0,03 мм for I implementations (thermo-vacuum forming) and h = 2,29 ± 0,03 мм for II implementations (vacuum infusion). As the technology I implementation of the thermo vacuum molding method allowed to determine the volumetric binding content of 39.7% (approximately 40%), this allows to determine the approximate volume of binder content for II implementation by vacuum infusion, which was approximately 45%.

Tensile tests were carried out on the test machine FP-10 of the company "Heckert" by tension the specimens until they break with the construction of the diagram load - deformation (P - Δl) and following determination of ultimate tensile strength σ_{tu} (F_{tu}), which was determined by the formula

$$\sigma_{tu} = \frac{P_{\max}}{A}; \qquad (1)$$

where P_{max} – maximum breaking load, H;

A – average cross-sectional area, мм^2.

Four series of specimens were tested on 5 samples each, which were cut from fiberglass plates, manufactured by two different technologies (I - thermo-vacuum forming with manual layering of layers, II - vacuum infusion). A specimen of one series (1.9.1 - 1.9.5) before and after the test is presented in photos of Fig. 2a and Fig. 2b, respectively.

a *b*

Fig. 2. Specimen up to *(a)* and after test *(b)* in tension

The specimens were tested on compression on the same machine FP-10 using a special transforming mechanism and a developed and manufactured device. A detailed description of this device was presented at [4]. This device allows testing in accordance with the international standard ISO 14126 and the American standard ASTM D 6641.

Analogously with the tensile test, four series of specimens were tested for compression, which had to be broken down to determine the ultimate strength using formula (1), but in compression, the photos of one specimen to the test are presented in Fig. 3a, and after destruction on Fig. 3b.

a *b*

Fig. 3. Specimen up to compression *(a)* and after *(b)*

The results of tensile and compression tests with the data of their static processing - standard deviation (SD) and the coefficient of variation (CV) are presented in the table 1 .

Table 1 Generalized test results of *ultimate strength in tension and compression: SD* - *s*tandard deviation; C*D* - *coefficient of variation*

Load type	Load direction	Thermo-Vacuum molding			Vacuum infusion		
		$\sigma_{tu\ mean}$, MPa	SD, MPa	CV, %	$\sigma_{tu\ mean}$, MPa	SD, MPa	CV, %
Tension	Along the warp (0°)	471,7	6,24	1,32%	432,3	21,14	4,89%
	Along the weft (90°)	437,8	13,27	3,03%	389,8	9,762	2,50%
Compression	Along the warp (0°)	362,3	19,93	5,50%	326,2	13,74	4,20%
	Along the weft (90°)	331,4	14,61	4,41%	255,6	12,18	4,77%

The graphical representation of the results of the tests in tension and compression in the form of comparative histograms is presented in Fig. 4.

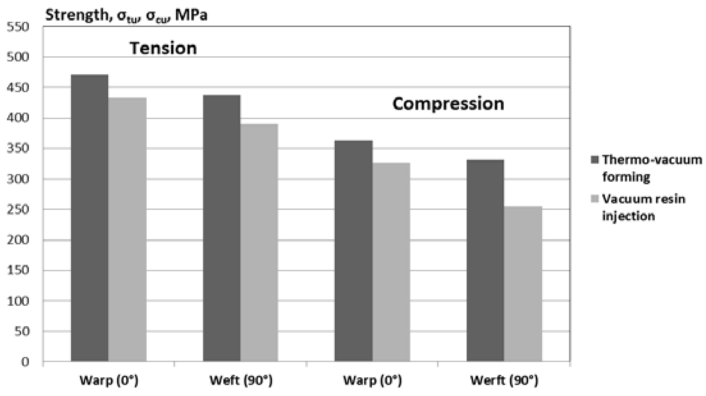


Fig. 4. Histograms of tensile and compression ultimate strength of specimen made by different technologies in the direction of the warp and weft

Conclusions

1. The use of the technology of thermo-vacuum molding for the production of fiberglass makes it possible to obtain laminate from 9 layers and an average thickness of 2.10 mm with a volume of glass fiber content of about 60% and, accordingly, a binding

agent of about 40%, which is close to optimal, unlike glass-plastic made by the method of molding by vacuum infusion with an average thickness of 2.29 mm and a volume content of glass fiber 55% and, respectively, a binder 45%, which is further from the optimal ratio.

2. The strength of specimen made of fiberglass made by the technology of thermo-vacuum molding was found to be greater for all comparative batches compared to samples made by the method of vacuum infusion. Moreover, at tension along the warp, the difference is - 8.35% and along the weft the difference is - 11.0%, and in compression along the warp the difference is - 10.0% along the weft - 22.9%. If, at tension, this difference can be explained by a greater than 8.30% thickness of specimens produced by the method of vacuum infusion, then in compression difference is already explained by the influence of production technology.

3. The strict observance of the manufacturing technology allows us to obtain a composite with high durability characteristics and the method of thermo-vacuum molding ensures the production of high-quality fiberglass plastics.

4. An important indicator of the quality of a composite is the ratio between the ultimate strength at compression and at tension $\sigma_{cu} / \sigma_{tu}$. The closer it is to the unit, the better the composite is. According to this indicator, the fiberglass made by the method of thermo-vacuum molding proved to be better, since for him the ratio $\sigma_{cu} / \sigma_{tu}$ for specimen taken along the warp is equal to 0.768, and along the weft - 0.757 in comparison with specimens made by the method of vacuum infusion, for which similar the ratio is 0.754 and 0.665, respectively.

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