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EVALUATION OF CARBON-PLASTIC TUBE STRUCTURES STRENGTH PROPERTIES UNDER THE INFLUENCE OF INTERNAL UNIAXIAL PRESSURE

Carbon-plastics are widely applied in integrated launch vehicle (ILV) structures. They are rocket motor cases, nozzle cluster elements, forebodies etc. Characteristics of applied materials are defined at plate samples and models, simulating technology of structures manufacturing.

The paper considers carbon-plastics as a part of tube structures, manufactured from traditional fillers as well as modified under plasma treatment ones. It is performed the comparative analysis of carbon-plastic characteristics, obtained during mechanical tests of plate samples and internal pressure tests of models.
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Keywords: *carbonplastic; plasma; tube structure; tests.*

Introduction

Development of new materials plays a key role in the aviation, space and prospective rocket systems for improving of the mass structures finishing. Emerging of materials in particular carbon fiber reinforced plastic (CFRP), fiberglass and organoplastic significantly expanded the scope of the composites application in aircrafts.

The most promising materials for aerospace and aviation technology are carbon plastics – polymer composite materials based on carbon fibers. The properties of CFRP are determined by the composition, type of polymer matrix, type and texture of the filler, their interaction at the phases of semi-finished products obtaining, material formation and products manufacturing from it, the level and ratio of elastic, strength and deformation characteristics of the components included into material composition. Existing technologies allow obtaining structures of various shapes, including those made by winding or laying-out.

Currently, considerable attention is paid to the issues of adhesive strength at the interface of the filler-resin compound.

Research Objective

At Yuzhnoye State Design Office named afrter M.K. Yangel it has been developed a method for increasing the adhesion strength of CFRP obtained by winding method at the filler-resin interface by modifying the filler (carbon fibers) by atmospheric plasma treatment in two different media, acrylic acid and allylamine. The application of treated carbon fiber made it possible to increase the physicomechanical characteristics of carbon fiber up to ~ 25% [1].

The purpose of this paperwork is to study the physicomechanical characteristics of carbon-plastic tube structures that modeling the technology of winding of rocket-space technology structures (solid rocket motors cases and liquid-propellant tanks), which use a filler modified by atmospheric plasma.

Study Object

The object of the research was thin-walled carbon-plastic shells of tube shape with a height of 390 mm, an inner diameter of 146 mm, a wall thickness of ~ 2 mm made by prepreg winding at an angle of ± 57° to obtain an equally strong structure.

Carbon fibers of the following types were used as filler: T300 (УКН/5000 fiber) and T800 (IMS 65 24K fiber), both in the initial state and modified by atmospheric plasma treatment in acrylic acid and allylamine medium.

The thin-walled carbon plastic shell of a tube shape is shown in Figure 1.

Research Methodology

Destruction type of the winding composite shells of tube shape differs from plate analog samples by the absence of the "effect of the cut threads" and because of the weaving of binders during winding. Therefore, they are not chipped along the fibers, but the structure distortion of the filler.

Tube shells in comparison with plate-shaped samples, make possible to estimate the characteristics of CFRP with a greater degree of approximation [2].

The study of the physicomechanical properties of carbon-fiber wound structures was implemented on

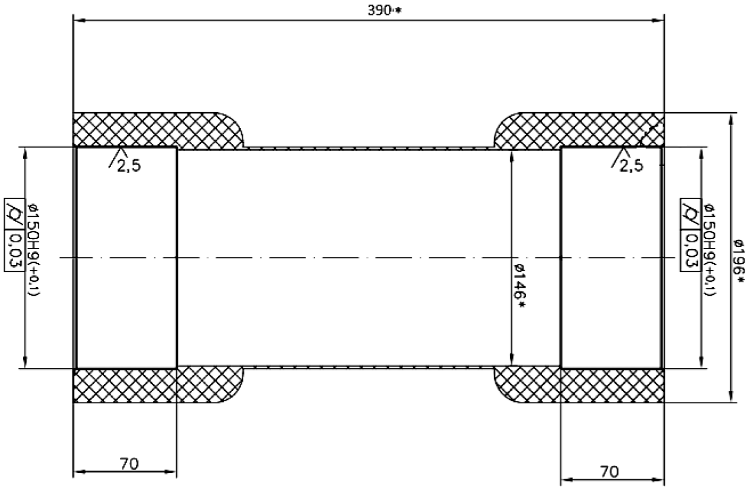


Fig. 1. Thin-walled carbon-plastic shell of a tube shape

tube samples under loading with internal pressure (the maximum pressure during fracture was 11.18 MPa). The ultimate strength , the relative deformation and the modulus of elasticity E of the material, as well as the nature of changes in these characteristics during loading at the installation sites of strain gauges were determined.

The essence of the method consists in measuring of the internal pressure and deformations in the circular (ε2) and axial (ε1) directions. According to values obtained, it is possible to determine the above listed elastic characteristics.

Processing of test results was performed in the following order:

- determination of tensile strength σ

$$\sigma = \frac{\frac{r_1^2}{r_2^2} \cdot L \cdot p}{2 \cdot N \cdot \sin\varphi} \qquad (1)$$

where $q_{разр}$ – internal pressure during sample destruction;
r_2 – internal radius of sample;
r_1 – external radius of sample ($r_1 = r_2 + \delta$, where δ – thickness of sample wall);
$L = 15$ – filler laying-out step, cm;
p – internal breaking pressure, MPa;
$N = 14$ – number of filler layers;
$\varphi = \pm 57$ – angle of filler laying-out.

- determination of relative deformation ε

$$\varepsilon = k \cdot A; \qquad (2)$$

where $k = \frac{\Delta R \cdot 100}{R \cdot S \cdot n}$ – scale division of registering device, %/mm (herein ΔR – incrementation of bridge active shoulder resistance;
R – strain gauge resistance;
$S = 2$ – strain gage strain-sensitiveness;
n – readings of the registering device at 1   unbalance);
A – current value of reading.

- elastic modulus determination E

$$E = \frac{\sigma}{\varepsilon}; \qquad (3)$$

Research Results

The paper describes the testing results performed according to this method. Hydraulic tests were carried out with an internal pressure of six thin-walled carbon-fiber shells of tube shape (from traditional (in the initial state) and carbon fibers treated with atmospheric plasma) to failure and the values of material deformation in the structure were determined.

Table 1 describes the results of calculations of the characteristics of the material of carbon-plastic tube structures based on traditional УКН/5000 and IMS65 carbon fibers, treated with atmospheric plasma in the acrylic acid and allylamine medium.

The presented results made it possible to conclude that the material characteristics, obtained on the wound tube models differ from those obtained on the plate samples (Table 2).

For instance, ultimate tensile strength of plate sample made of carbon plastic from traditional УКН/5000 carbon fiber is 666 MPa, for carbon plastic from tube structure this measures is up to 25% higher and presents 891 MPa

This indicates that in order to perform a specified calculation of the strength of the material of the structure, it is necessary to take into account the characteristics presented in Table 1. Moreover, the additional calculation of tube structures made by the winding method with a reinforcement angle of ± 57° will make it possible to determine the minimum safety factor more accurately.

Also, to obtain more complete information about the interlayer strength of materials, microstructural

Table 1

The results of calculations of the carbon plastic strength characteristics, obtained by tube structures testing

Material of tube structure (carbon-plastic)	Internal pressure during ultimate breaking stress, MPa	Strength at stretching σ, MPa		The modulus of elasticity *E*, GPA		Relative deformation ε,%	
		in axial direction	in the circular direction	in axial direction	in the circular direction	in axial direction	in the circular direction
УКН/5000 (traditional)	8,83	891	873	29	29	0,3062	0,3062
УКН/5000, modified by plasma in the acrylic acid medium	-	1020	999	32	31	0,3225	0,3225
УКН/5000, modified by plasma in the allylamine medium	9,61	970	951	31	31	0,3099	0,3099
IMS65 (traditional)	11,18	1129	1106	33	32	0,3468	0,3468
IMS65, modified by plasma in the acrylic acid medium	10,00	1000	980	34	34	0,2923	0,2923
IMS65, modified by plasma in the allylamine medium	8,53	861	844	34	33	0,2543	0,2543

Table 2

Comparison of CFRP characteristics obtained on tube structures and plate samples with a reinforcement scheme of ± 57 °

Углепластик	Breaking stress, MPa			
	on tube structure		on plate samples	
	in axial direction	in the circular direction	across reinforcement	along the reinforcement direction
УКН/5000 (traditional)	891	873	666	124
УКН/5000, modified by plasma in the acrylic acid medium	1020	999	687	130
УКН/5000, modified by plasma in the allylamine medium	970	951	676	119
IMS65 (traditional)	1129	1106	961	148
IMS65, modified by plasma in the acrylic acid medium	1000	980	982	170
IMS65, modified by plasma in the allylamine medium	861	844	963	157

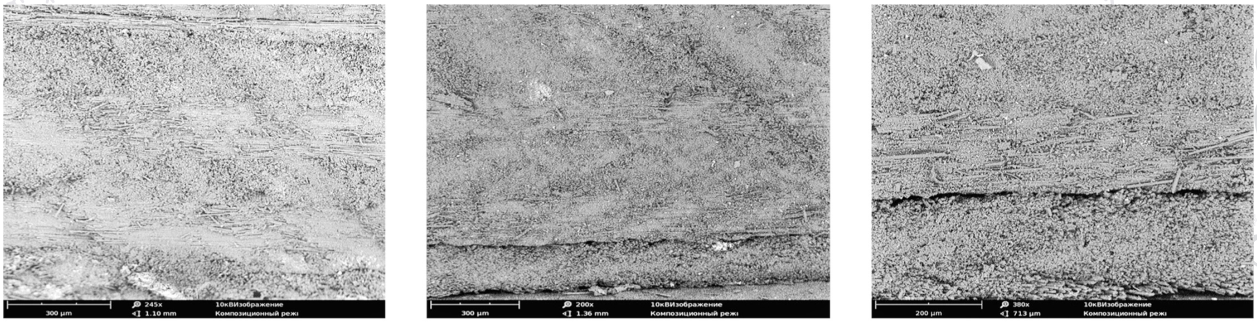
studies of carbon plastic using traditional and modified fillers were carried out on a PhenomPro microscope. For the studies, fragments of 10 × 10 × 1.5 mm were cut from each carbon-fiber shell of tube shape, destroyed during internal pressure tests.

Figure 2 shows the microstructure of the end surface of samples cut from carbon-fiber shells of tube shape based on УКН/5000 carbon fiber. The presence of microcracks between the layers for carbon-reinforced plastics on all types of fibers has been established.

Such microcracks confirm the character of tightness loss and destruction of tube-shaped shells during internal pressure tests.

Conclusions

As a result of internal pressure tests, the characteristics of carbon-plastic tubular structures of different filling were obtained. Adhesion characteristics increasing at the interface of the filler-resin compound on models made of traditional (in the initial state) and modified fillers was confirmed. It was also found that the strength characteristics of carbon-plastic wound structures differ from similar ones obtained on plate samples. Therefore, to calculate the strength of carbon plastic structures, it is recommended to apply the characteristics of the composite obtained by winding at a given reinforcement angle.



×245 УКН/5000 (traditional) carbon fiber

×245 УКН/5000 carbon fiber, modified by atmospheric plasma in the acrylic acid medium

×245 УКН/5000 carbon fiber, modified by atmospheric plasma in the allylamine medium

Fig. 2. Microstructure of the end of UKN / 5000 carbon fiber tube models (traditional and treated with atmospheric plasma in different environments)

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ОЦЕНКА ПРОЧНОСТНЫХ СВОЙСТВ УГЛЕПЛАСТИКОВЫХ ТРУБЧАТЫХ КОНСТРУКЦИЙ ПРИ ВОЗДЕЙСТВИИ ВНУТРНЕЕГО ОДНООСНОГО ДАВЛЕНИЯ

Углепластики широко применяются в конструкциях ракет космического назначения. Это корпуса ракетных двигателей, элементы сопловых блоков, головные части и т.п. Характеристики применяемых материалов определяют на плоских образцах и моделях, имитирующих технологию изготовления конструкций.

В работе рассмотрено углепластики в составе трубчатых конструкций изготовленных из традиционных, а также модифицированных под воздействием плазменной обработки наполнителей. Проведено сравнительный анализ характеристик углепластика, полученных при механических испытаниях плоских образцов и испытаниях моделей внутренним давлением. [dx.doi.org/10.29010/085.9]

<u>Ключевые слова:</u> *углепластик; плазма; трубчатая конструкция; испытания.*

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