

Investigation of the properties of carbon fiber reinforced plastics after the seawater exposure

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Abstract. The results of experimental studies of the mechanical characteristics of carbon fibers (CFRPs) before and after their exposure at seawater are presented. The choice of seawater as an operation medium is due to the fact that this carbon fiber is intended for the manufacture of power elements of a manned underwater vehicle. Carbon fibers were made using vacuum infusion technology based on an epoxy binder, and biaxial carbon fabric was used as a reinforcing material. The prepared samples were kept in seawater for 384 h, which made it possible to estimate the amount of water absorption, as well as the change in mechanical characteristics after exposure to seawater. It has been established that the strength of CFRPs does not change during interlayer shear, decreases by 14% during bending, and the value of the elastic modulus, after exposure to seawater, decreases by 17%.

Keywords: carbon fiber reinforced plastics, seawater, bending, interlayer shear, seawater resistance.

1. Introduction
Carbon fibers differ from many other types of reinforcing materials used in the manufacture of polymer composites by their high strength and elastic characteristics [1-4]. They are widely used in the manufacture of critical products in various industries, including the production of shipbuilding structures. In the last decade, carbon fiber reinforced plastics have been widely used in port facilities, ships, hydrometeorological equipment and other structures subject to long-term corrosive effects in corrosive environments. Structures made of carbon fiber reinforced plastics, like other types of polymer composite materials, can be manufactured by a variety of methods. The choice of manufacturing technology depends on many factors, including the serial production, geometric features, dimensions, etc. For the manufacture of thin-walled hull structures, including manned underwater vehicles, prepreg technology is most often used, or modern methods of direct molding, of which the most widely used technologies are vacuum infusion and pressure impregnation [5-11]. The reliability of CFRP forms depends on their resistance to the action of various operational factors. Much attention in the technical literature is paid to the elevated-temperature effect [12, 13], much less attention is paid to the effect of lower-temperature effect [14, 15], and a very limited number of works are devoted to the resistance of polymers and composites based on polymer binders to the action of water and various chemical media [16].

The resistance of materials to the action of operating media is the degree to which their original mechanical characteristics are preserved. Water is the most common operating medium and, with prolonged exposure, CFRP can degrade. It is worth noting that the composite structure must remain operational, considering unforeseen climatic conditions, which, among other things, may be caused by natural disasters [17]. The authors of [14] identify the following main reasons: destruction of the polymer matrix, delamination at the fiber-polymer matrix interface, destruction of individual fibers and delamination. With the exception of the destruction of individual fibers, all other types of destruction can cause a decrease in the strength of CFRP when exposed to water. If it is required to assess the short-term effect of water, then in this case the exposure time does not exceed several days. If the task is to determine the resistance of the composite to prolonged exposure to water, then the exposure time is a month, a year, or even more. There are no uniform criteria for assessing the water resistance of polymer composite materials, but it is known for polymer adhesives that if the decrease in strength does not exceed 10-15% within 30 days, then such materials are classified as water resistant [12].
The purpose of this work is an experimental study of the carbon plastics properties after the seawater exposure.

2. Objects

The objects of testing are samples of carbon plastics based on carbon biaxial fabric CBX300 with reinforcement direction +45/-45 based on Toray T700 yarn. A composition of EC 57 epoxy resin and W 61 hardener was used as a binder. Curing was carried out at a temperature of 80 °C for 6 h. Samples of carbon plastics were made using vacuum infusion technology. The choice of this technological process is associated with its satisfactory quality and high economic efficiency.

3. Research methods

The work determined the mechanical characteristics of CFRPs at interlayer shear and bending. The method for testing CFRP for interlayer shear was developed on the basis of ASTM D2344 / D2344M - 16 "Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates" and GOST 32659-2014 (ISO 14130: 1997) "Polymer composites. Test methods. Determination of the apparent ultimate strength at interlaminar shear by the method of testing a short beam". The CFRP specimen was mounted on two supports (the distance between the supports was 40 mm) and loaded in the middle at a constant rate until its destruction. The samples had the shape of a rectangular parallelepiped with dimensions of 10x6x50 mm. The bending test method for CFRP was developed based on GOST 56805-2015 (ISO 14125: 1998) “Polymer composites. Methods for determining mechanical characteristics in bending”. For these tests, the same device was used to fix the samples as in the tests for interlayer shear, but the distance between the supports was 50 mm and the dimensions of the samples were - 10x3x60 mm. It is known [16] that methods for assessing the strength of polymer composite materials reinforced with fiber fillers at interlayer shear and bending are sensitive to the geometric dimensions of the sample and the ratio of the distance between the supports to the sample thickness, the values of which were maintained with an accuracy of ± 0.3 mm. For testing, a universal testing machine Zwick Z 100 was used, which, in accordance with GOST 28840, provided linear movement of the active gripper (traverse) at a given constant speed and load measurement with an error of no more than ± 1% of the measured value. For fixing the specimens during the tests for interlayer shear and three-point bending, devices were used, which were a tip and supports (the radius of the loading tip was 5.0 ± 0.2 mm, the radius of the supports was - 2.0 ± 0.2 mm). Interlaminar shear and bending tests were carried out at the same strain rate equal to 10 mm / min. As a result of the studies, the average value of the indicators was estimated when testing 5 samples.

The work also determined the value of water absorption of carbon fiber reinforced plastics when exposed to seawater. The test procedure was developed in accordance with GOST 4650-2014 (ISO 62: 2008) “Plastics. Methods for Determining Water Absorption”. Lots of CFRP samples were weighed, then kept for 384 h in a sealed container with seawater, dried (drying was carried out in air at room temperature until completely dry), and then reweighed using an analytical balance in accordance with GOST 24104–88. All tests were carried out before and after holding carbon plastics in sealed containers with seawater for 384 hours. Seawater was prepared in accordance with GOST 31959-2012 on the basis of distilled water, sodium chloride, magnesium chloride, calcium chloride, and a number of other additives.

4. Results and discussion

The results of mechanical tests of carbon fiber reinforced plastics before and after exposure at seawater are given in table 1.

| Criteria                      | Initial | After exposure at seawater |
|-------------------------------|---------|----------------------------|
| Strength at interlayer shear, MPa; | 67      | 67                         |
| Dispersion, MPa               | 2       | 6                          |
| Bending resistance, MPa;      | 1400    | 1200                       |
| Dispersion, MPa               | 93      | 136                        |
| Bending elastic modulus, GPa  | 92      | 76                         |
| Dispersion, GPa               | 4       | 5                          |

The analysis of the obtained results showed that the average values of the interlayer shear strength after exposure to seawater did not change, but the value of the standard deviation (dispersion) increased. The nature of the
destruction of the samples before and after exposure remained practically unchanged, and most of them were destroyed along the fiber-polymer matrix interface.

The flexural strength of CFRPs after exposure to seawater decreased by 14.4%, and the flexural modulus decreased by 17.4%. The reason for such a significant decrease in the flexural strength and modulus, while maintaining the mechanical characteristics during interlayer shear, is probably the cracking of the epoxy matrix under the action of bending stresses. One of the methods for increasing the resistance of polymer composite materials, including carbon fiber reinforced plastics, to cracking, is the use of hybrid materials based on thermosetting and thermoplastic matrices as binders. As a thermosetting material, as a rule, epoxy compounds are used, and as a thermoplastic material, polysulfones, polyethersulfones and other similar materials, called superconstructive ones, are used [18-20].

The results of assessing the value of water absorption are shown in table. 2. To carry out this series of tests, 1 mm deep defects were artificially applied to one batch of samples using a drill with a diameter of 4 mm.

| Duration of the seawater exposure, hrs | Weight of CFRPs after the seawater exposure, gms. | CFRP without defects | CFRP with defects |
|---------------------------------------|------------------------------------------------|---------------------|------------------|
| Sample thickness is 3 mm              |                                                 |                     |                  |
| 0                                     | 13,839                                          | 10,9142             |                  |
| 1                                     | 13,8425                                         | 10,9174             |                  |
| 3                                     | 13,8442                                         | 10,9212             |                  |
| 5                                     | 13,8475                                         | 10,9206             |                  |
| 48                                    | 13,8604                                         | 10,9306             |                  |
| 120                                   | 13,8680                                         | 10,9404             |                  |
| 384                                   | 13,8899                                         | 10,9685             |                  |
| Sample thickness is 6 mm              |                                                 |                     |                  |
| 0                                     | 20,8982                                         | 4,1873              |                  |
| 1                                     | 20,9019                                         | 4,1887              |                  |
| 3                                     | 20,9046                                         | 4,1887              |                  |
| 5                                     | 20,9055                                         | 4,1882              |                  |
| 48                                    | 20,9209                                         | 4,1896              |                  |
| 120                                   | 20,9339                                         | 4,1916              |                  |
| 384                                   | 20,9656                                         | 4,1967              |                  |

The analysis of the obtained results showed that the mass of samples with a thickness of 6 mm (without defects) after exposure to seawater for 384 h increased by 0.32%, and with a defect by 0.22%. For thinner samples (3 mm thick), opposite patterns are characteristic, the mass of samples without defects after exposure to seawater for 384 s increased by 0.36%, and for samples with a defect - by 0.49%.

However, to compare the obtained values of the values of water absorption for samples without defects and with defects, according to the data given in table. 2, it is impossible, since they have different sizes, and the scale factor is of great importance here. Thus, the mass of samples with a thickness of 3 mm with defects is 21% less than without defects, and for samples with a thickness of 6 mm, the mass of samples with defects is almost 5 times lower than without defects. If we introduce correction factors for the sizes of samples, it turns out that the value of water absorption of samples made of carbon fiber reinforced plastics with defects is higher than for similar samples without defects. However, for all the samples of carbon fiber reinforced plastics studied, the value of water absorption is less than 1%, which indicates their high resistance to the action of seawater.

5. Conclusion
The results of experimental studies of the strength of CFRPs under interlayer shear, bending strength and elastic modulus before and after holding them in the seawater for 384 hours were carried out. It was found that the strength of CFRPs in bending after exposure to seawater decreased by 14%, the values of the modulus flexural resilience decreased by 17%, and the interlayer shear strength did not change. The paper suggests that the reason
for the decrease in bending strength and modulus, while maintaining the mechanical characteristics during interlayer shear, is the cracking of the epoxy matrix under the action of bending stresses. An experimental assessment of the water resistance value of carbon fiber reinforced plastics was carried out and it was found that it does not exceed 1%, which indicates their high resistance to the action of seawater. Tests for water resistance were carried out for standard specimens and specimens with a defect applied, which showed that the presence of a defect on the surface of CFRP leads to a decrease in water resistance.

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