Composites Based on Carbon Tapes with a Copper coating Based on Organic and Inorganic Matrices

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Abstract. The results of experimental investigations into the impregnating kinetics when using the carbon tape with copper coating according to the magnetron sputtering technology are presented. The epoxy and aluminum-boron phosphate materials are used as binders. The composites based on these binders are evaluated by characteristics of porosity, matrix content, and thermal stability. It is established that metallization insignificantly affects the thermal stability but does not make it possible to increase the impregnation rate and leads to lowering the composite porosity.

1. Introduction
The application fields of polymer composite materials, in the first place carbon-filament composites, are broadened annually. This is associated with their unique mechanical and thermal characteristics, which provides their effective use as structural materials [1-3]. Main advantages of constructions made of carbon-filament composites are low weight, high strength, stiffness and wear resistance, and a whole complex of functional properties (thermal conductivity, electrical conductivity, etc.) [4-6].

The necessity of improving the operational characteristics of occurring constructions made of carbon-filament composites originates the problematic of extending for a complex of their properties. Various technologies such as oxidation, dressing, galvanic treatment, etc. are used to modify the properties of carbon tissues. One method of controlling the properties of carbon fillers is the metallization technology. The main goal of metallization is changing the microstructure, topology, and physicochemical properties of the surface of carbon tissues, which makes it possible to control their reaction ability, thermal and electrical properties, biocompatibility, and many others.

The development of carbon-filament composites with a complex of functional properties will make it possible to increase substantially the competitiveness of products. Such materials will provide an increase in the service life, a decrease in the prime cost, and an increase in efficiency of using the carbon-filament composites. The development of theoretical methods of the investigation [7-9], including the use of the apparatus of the theory of catastrophes, made it possible to predict the service life of constructions made of composites formed based on organic matrices. The organic matrices, in the first place epoxy matrices, are widely used in composite materials, while inorganic matrices have the substantially higher thermal stability. However, there is no economically effective technologies to form of them the products based on carbon tapes, which is also an urgent problem of the modern materials science.

For a long time, when producing the parts from carbon-filament composites, prepregs [3] and autoclave solidification technologies were used, which provided the specified quality but substantially increased the cost. The high cost of producing the carbon-filament composite parts is in many aspects associated with a very high power intensity of autoclaves. One effective method of decreasing the
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prime cost of fabricating the carbon-filament composite parts is the use of direct formation technologies, of which the vacuum infusion technology becomes most widespread for forming the carbon-filament composite parts [10]. Largely due to the vacuum infusion technology, the regions of applying the carbon-filament composites are broadened annually, and there is no the modern branch of industry, where they would not be used. These are aircraft construction, production of space-rocket hardware, automobile industry, mechanical engineering, building, etc. [11-15].

The goal of this work is the experimental investigation into the thermal stability and rheological properties of composites based on carbon tapes with a copper coating fabricated according to the vacuum infusion technology when using organic and inorganic binders.

2. Objects and Methods

We used the import carbon tapes of the FibArmTape-230/300 brand 0.21 mm in thickness (the surface density is 230 g/m and the elasticity modulus is 230 GPa) as the carbon filamentary fillers.

To deposit the copper coating on a carbon tape, the industrial magnetron sputtering installation (Fig. 1) with a vacuum chamber volume of 15 m³ was used. A carbon tape roll was placed onto a special facility and air was pumped from a chamber using vacuum pumps to a pressure of 3 ± 10 mmHg. Then plasma-forming gas, argon in our case, was puffed into the chamber. The glow discharge was ignited by the potential supply to the magnetron cathode from the dc power supply unit. The discharge current, voltage, pressure, and flow rate of the plasma-forming gas were controlled during the deposition of metallic coatings.

![Figure 1](image)

**Figure 1.** Layout of the MMR-1800M magnetron sputtering installation: 1 – vacuum chamber, 2 – diffusion pump, 3 – forevacuum pump, 4 – facility for tape rewinding, 5 – treated material, 6 – magnetron, 7 – magnetron supply unit, 8 – argon supply system, 9 – gas supply system, and 10 – supply unit

Copper of the M1 brand was used as a target material. The thickness of a copper coating on a carbon tape was 100 nm, which is the optimal value [4].

Two types of binders such as organic (epoxy) and inorganic (aluminum-boron phosphate) were used in the work.

The composition based on epoxy resin of the ED-20 brand was used as an organic binder, and isomethyl tetrahydrophthalic anhydride was used as a hardener; diethyleneglycol was used to decrease the viscosity.

Ruskon-355K was used as the hardener of the inorganic binder (aluminum-boron phosphate).
Composites based on a metallized carbon tape were fabricated following the uniform vacuum infusion technology but using two sets of auxiliary materials. The samples of one type were impregnated using a conductive mesh (this technology was called no. 1 in our work). The samples of the second type were impregnated without using the mesh (this technology was called no. 2 in our work). A mesh made of polyether of the CCVM-FM-KNITW-100-1.25 brand was used as a conductive mesh. This mesh had an increased heat stability, which allowed us to use it during hardening the epoxy binder at a temperature of 200°C.

When fabricating the products according to the vacuum infusion technology, the conductive mesh is always used (technology no. 1) because it provides the spread of a binder over the surface of the first layer of the reinforcing filler with a maximal speed [1]. However, it is very difficult to evaluate visually the influence of the metallic layer that coats the carbon tape on the impregnating process kinetics, which is associated with a very high moving speed of a binder front. The use of technology no. 2 allowed us to decrease substantially (practically by an order of magnitude) the impregnating process rate, which allowed us to evaluate the influence of the type of used binders and influence of metallization of the carbon tape.

The composite porosity was evaluated by hydrostatic weighing. We evaluated the values of limiting wetting angles experimentally. They were determined under the conditions maximally approached to equilibrium. To increase the determination accuracy of limiting wetting angles, not binders but their separate components were used, for example, the ED-20 resin and a liquid component of aluminum-boron phosphate binder (Russian abbreviation ABFS). To determine the limiting wetting angles, a silicon plate was used as a substrate. The copper coating was deposited on it under the same process modes as for the carbon tape.

To determine the thermal stability, a TG 209 F1 Libra thermogravimetric analyzer was used.

3. Results and Discussion

The limiting wetting angles for different binder components and coating types are presented in Table 1.

| Metallic coating type | Limiting wetting angle, °, when using ED-20 | ABFS |
|-----------------------|---------------------------------------------|------|
| No coating            | 56                                          | 74   |
| Copper                | 48                                          | 65   |

Thus, the presence of a metallic coating on the substrate surface makes it possible to decrease the limiting wetting angles. The wetting angle decreased by 14% for epoxy resin and by 12% for the inorganic material.

The impregnation kinetics for the epoxy and inorganic binders was evaluated for the samples with the same geometric shape (100 × 50 mm). The number of the carbon tape layers is 5, and the reinforcing angle is 0. The impregnation was performed at room temperature without the conductive mesh (technology no. 2). The experimental results are presented in Fig. 2.
The analysis of the experimental results shows that the use of a carbon tape with a metallic coating allowed us to increase the impregnation rate for the organic (epoxy) and inorganic (aluminum-boron phosphate) binders. However, the impregnation rate is higher when using the organic binder. For example, the carbon tape sample without the metallic coating, when using the epoxy binder, was impregnated to a length of 76 mm for 10 min, while the coated sample was impregnated to a length of 92 mm. The difference in the impregnation duration was 17.4%. The impregnation rate for the inorganic binder is lower due to its higher viscosity. The difference in the impregnation duration for a length of 100 mm was 26%.

Thus, the metallization of a carbon tape makes it possible to increase largely the impregnation process when using the inorganic binder.

Characteristics of the composites fabricated according to the vacuum infusion technology when using the carbon tape with no coating and with a copper coating are presented in Table 2. The previously used organic and inorganic materials were used as binders.

**Table 2**

Properties of composites fabricated based on organic and inorganic binders

| Characteristics | Carbon tape |                |                |
|-----------------|-------------|----------------|----------------|
|                 |             | With no metallic coating | Copper coating |
| Epoxy binder    |             | 33,6            | 31,8           |
| Matrix content, % |             | 4,9             | 3,9            |
| Porosity, %     |             | 4,5             | 4              |
| Weight loss at 200°C, % | 66,4         | 68,2           |
| Weight loss at 800°C, % |             |                |
| Aluminum-boron phosphate binder |             | 48,4            | 49,8           |
| Matrix content, % |             | 24              | 21             |
| Porosity, %     |             | 8               | 8              |
| Weight loss at 200°C, % | 8            | 9              |
| Weight loss at 800°C, % |             | 12             | 11             |
| Weight loss at 1000°C, % |             |                |                |
It is established based on our investigations that the matrix content in composites based on inorganic binders is higher than that one for epoxy binders. The substantially higher porosity is characteristic of inorganic materials, the magnitude of which exceeds 20%, while this quantity for the composites based on the epoxy matrix is lower than 5%. The presence of a copper coating on a carbon tape leads to a decrease in porosity for two types of used binders, notably, it decreases by 26% for epoxy binders and by 14% for aluminum-boron phosphate binders. It seems likely that so high porosity of the composites based on an inorganic matrix are characteristic of only the infusion formation technology and this quantity can be decreased when using other production processes, for example, pressing. The thermal stability of composites based on an inorganic matrix is substantially higher and does not exceed 9% at 800°C, while similar weight losses for composites based on an organic matrix at this temperature are higher than 66%. The presence of a copper coating on the carbon tape insignificantly affects the thermal stability.

4. Conclusions

It is established based on our investigations that it is possible to fabricate composites based on organic and inorganic binders according to the vacuum infusion technology when using carbon fibrous fillers covered with a metallic coating. When evaluating the kinetics of impregnation, it was established that the presence of the metallic coating on a carbon tape leads to an increase in the impregnation rate by 17--26% for the organic and inorganic binders. The presence of a copper coating on the substrate surface makes it possible to decrease the limiting wetting angles by 12-14%.

The presence of metallic coatings of a carbon tape makes it possible to decrease the composite porosity for two used types of matrices; however, the porosity for the inorganic matrix is higher than that one for the organic matrix by a factor of several times.

The presence of the metallic coating on a carbon tape most weakly affects the thermal stability of composites; this quantity varies insignificantly. The matrix type affects the thermal stability much more strongly. The thermal stability of composites with the inorganic matrix is higher than 1000°C because the weight loss at this temperature does not exceed 12%.

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