Studying the effect of RF-plasma treatment on the indicators of adhesion of inorganic fibers to the polymeric binder

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Abstract. The paper presents the results of a study of the effect of the plasma RF discharge on the adhesion indices (capillarity and shear strength) of glass and carbon fibers to the epoxy matrix. Plasma treatment modes were selected to maximize the adhesion of the fibers to the polymer binder.

1. Introduction
Composite materials are building materials that are widely used in various industries: aviation, shipbuilding and automotive industries; manufacture of sports equipment. Currently, the market is dominated by two types of fibers for the reinforcement of composites:
- Glass fiber (GF). Possesses high physic-mechanical properties, heat-resistant, inert.
- Carbon fiber (CF). It has greater strength and modulus of elasticity, also inert and thermostable, but much more expensive.

However, it is possible to reduce the strength of the composite material based on these fibers due to the low adhesion to the polymer binder. In addition, by increasing the adhesion, it is possible to reduce the amount of binder, thereby reducing the weight of the resulting product. To eliminate this problem and improve the mechanical properties of the resulting composite material, various methods of activating the surface of the filler are used. In previous studies [1, 2], it was found that the methods of radio-frequency plasma modification can significantly increase the adhesion of various materials to a polymeric binder.

As the object of study selected fiberglass brand T-11, (ARTIKOM LLC, Russia) and Umatex UMT42 carbon fabrics (Alabuga-Volokno, Russia).

2. Plasma treatment
To modify the carbon fiber used RF capacitive discharge plasma unit with plane-parallel electrodes. Fiber processing parameters: voltage at the anode of the generator lamp $U_a = 3.5$ kV, processing time $t= 5-45$ min, pressure in the working chamber $P = 50$ Pa, consumption of plasma gas $G = 0.04$ g / s, plasma-forming gas - air.
The glass fibers were modified by the method of radio-frequency induction plasma treatment with a non-flowing type flat inductor under reduced pressure. When modifying GF used two processing modes:

1) Plasma-forming gas is argon, power at the radio-frequency generator 150 W, pressure in the working chamber 1 Pa, the processing time is 10 min.

2) Plasma-forming gas is a mixture of argon with air in the ratio of 3:1, power at the radio-frequency generator 100 W, pressure in the working chamber 1 Pa, processing time 5 min.

3. The results of experimental studies
To determine the adhesion, two methods were used: determination of the capillarity of the fibers to the polymer matrix and the shear strength of the micro composite.

The capillarity of the fibers was measured by the height of the capillary rise of the epoxy matrix \( h \). The polymer matrix for capillarity studies was made of epoxy resin ED-20 and polyethylene polyamine hardener. The results are presented in Table 1 - for CF and Table 2 - for GF.

**Table 1.** The dependence of the height of the capillary raising of epoxy resin on the carbon fiber from the processing modes

| Voltage at the anode, kV | Processing time, min | Capillarity change, % |
|------------------------|----------------------|-----------------------|
| 3                      | 5                    | 36.36                 |
|                        | 10                   | 53.33                 |
|                        | 15                   | 57.58                 |
|                        | 20                   | 69.7                  |
|                        | 30                   | 65.45                 |
|                        | 40                   | 64.85                 |
| 5                      | 5                    | 33.33                 |
|                        | 10                   | 51.52                 |
|                        | 15                   | 52.73                 |
|                        | 20                   | 63.64                 |
|                        | 30                   | 62.42                 |
|                        | 40                   | 63.64                 |

**Table 2.** The dependence of the height of the capillary raising of epoxy resin on the glass fiber from the processing modes

| Plasma-forming gas | Processing time, min | Power at the radio-frequency generator, W | Capillarity change, % |
|--------------------|----------------------|------------------------------------------|-----------------------|
| argon              | 10                   | 150                                      | 10                    |
| argon, air         | 5                    | 100                                      | 15                    |

The adhesive strength of the bonding of the fibers with the polymer matrix was determined by the shear method. For this, two strips of fabric impregnated with epoxy glue were glued with an overlap and then, using the universal test machine Autograph AGS-X (Shimadzu), the strength of the adhesive bond was determined. The results of the study of the shear strength of CF are reflected in table 3, the GF in table 4.

**Table 3.** The dependence of the shear strength of micro plastic based on carbon fibers from processing modes

| Voltage at the anode, kV | Processing time, min | Strength change, % |
|--------------------------|----------------------|--------------------|
| 3                        | 20                   | 39.89              |
|                          | 40                   | 40.06              |
| 5                        | 20                   | 52.45              |
Table 4. The dependence of the shear strength of micro plastic based on glass fibers from processing modes

| Plasma-forming gas | Processing time, min | Power at the radio-frequency generator, W | Strength change, % |
|--------------------|----------------------|------------------------------------------|-------------------|
| argon              | 10                   | 150                                      | 26,04%            |
| argon, air         | 5                    | 100                                      | 33,64%            |

**4. Conclusion**

From the obtained results it can be seen that the use of an RF plasma discharge makes it possible to increase the capillarity of inorganic fibers and the shear strength of composites based on them. Processing of glass fibers at the RF induction plasma showed that the greatest increase in adhesion indices is observed when there is a reaction gas (air) in the discharge gap as opposed to inert (even at higher power and processing time).

When treating carbon fibers in the RF capacitive plasma, the best effect is observed with a higher anode voltage (5 kV); and with a processing time of 20 minutes, a further increase in processing time has little effect on the result.

**References**

[1] Garifullin A R, Abdullin I Sh 2015 *Bulletin of Kazan Technological University* **18** pp 69-70

[2] Garifullin A R et al 2016 *J. Phys.: Conf. Ser.* **789** 012014