APPLICATION OF ADHESIVES AND PLASMA MODIFICATION TO INCREASE THE ADHESIVE STRENGTH OF FIBROUS COMPOSITES

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Abstract. It is shown that the use of amino aldehyde oligomers as an adhesive in fibrous composite materials based on synthetic fibers leads to an increase in the adhesive interaction between components. Due to the limited wettability of the synthetic fiber filler with adhesives, it is advisable to carry out preliminary RF plasma treatment of fibers in a plasma-forming air medium. The matrix polymer and the adhesive have good mutual adhesion, and the lack of adhesion between the adhesive and the synthetic fibers is compensated by the formation of functional reactive groups on the surface of the synthetic fibers during RF plasma treatment.

1. Introduction

To improve the operational characteristics of fibrous composite materials, it is important to increase the bond strength of fibrous components with a polymer binder. To increase the adhesive strength of composite materials based on reinforcing fibrous components, adhesives with reactive functional groups are used. Adhesive bonds in the fiber-adhesive-binder system are distinguished by the presence of two interfaces: fiber-adhesive and adhesive-binder. An increase in the strength of adhesive interaction in the fiber-adhesive-binder system is achieved by wetting the fiber filler with the adhesive and by intermolecular physical and chemical interactions between the fiber component, the adhesive and the matrix of the composite material. In this case, the choice of an adhesive is based on its functionality both for the fiber filler material and the matrix polymer.

To increase the adhesive bond of the components in composite materials, various methods of pretreatment of the substrate are used in order to activate its surface. Radio-frequency (RF) plasma modification is an environmentally friendly and resource-efficient technology that improves the surface and physical and mechanical properties of fibrous materials, including those for technical purposes. RF plasma treatment methods can be used to modify all major multi-tonnage synthetic fibrous materials, as well as be used in combination with other modification methods for functionalizing the fiber surface and obtaining multifunctional materials [1–4]. The advantages of RF plasma treatment include a high rate of modification processes, the absence of chemical reagents, a one-stage process, the ability to vary the processing parameters for different objects, and also the absence of a destructive effect on the internal structure of polymers.
2. Materials and methods
In this work, we investigated the possibility of using amino aldehyde oligomers based on carbamide and plasma modification by a radio-frequency (RF) discharge of low pressure to increase the adhesive strength of composite materials based on ultra-high molecular weight polyethylene (UHMWPE), high molecular weight polyethylene (HMPE), polyamide (PA) and polypropylene (PP) fibers.

Plasma modification of samples of synthetic fibers was carried out on an experimental RF plasma system with varying the following parameters: discharge power 0.4–2.2 kW; processing time 60–600 s; pressure in the working chamber 10–30 Pa; plasma-forming gas consumption 0.01–0.04 g / s; plasma-forming gas - air.

Carbamide-formaldehyde resin modified with isopropyl alcohol was used as an adhesive [5]. The amino aldehyde oligomer impregnation was carried out by passing through a bath with a solution. Epoxy ED-20 with polyethylene polyamine hardener was used as a binder.

The uniformity of the impregnation of synthetic fibers was assessed by the method of confocal laser scanning microscopy (CLSM) Olympus OLS Lext 4100. To assess the adhesion strength of microcomposites based on synthetic fibers, the normalized value of the breaking load of the microcomposite was determined on a universal testing machine Autograph AGS-X100 (Shimadzu).

3. The results of experimental studies
The results of confocal laser scanning microscopy (CLSM) of PA fiber samples modified with amino aldehyde oligomer with and without preliminary RF plasma treatment are shown in Figure 1.

![Figure 1. CLSM images of the surface of polyamide fibers: a - initial sample; b - sample modified with amino aldehyde oligomer without preliminary plasma treatment; c - sample modified with amino aldehyde oligomer with preliminary plasma treatment.](image-url)

The results obtained indicate that preliminary RF plasma modification makes it possible to achieve a uniform distribution of the adhesive over the surface of synthetic fibers.

The results of the effect of modification of UHMWPE, HMPE, PA and PP fibers with amino aldehyde oligomers using RF plasma modification on the normalized value of the breaking load of the microcomposite are shown in Figure 2.
The obtained results of determining the normalized value of the breaking load of microcomposites indicate that the samples modified with amino aldehyde oligomer without preliminary radio-frequency plasma treatment have the lowest adhesive strength. This is due to the poor degree of wetting of the original synthetic fibers with the adhesive; therefore, the destruction of the composite material occurs at the fiber-adhesive interface. Preliminary radio-frequency plasma treatment of fibers before the application of the adhesive leads to an increase in the adhesive strength of composite materials by 15–18% in comparison with the initial samples. In this case, the function of RF plasma treatment consists in cleaning the fiber surface and grafting oxygen-containing functional groups due to the oxidation of the surface layers of polymers in the plasma-forming air medium. This makes it possible to increase the physicochemical interaction and adhesion between the components of the fiber-adhesive-binder system.

**4. Conclusion**

Thus, it can be concluded that the use of amino aldehyde oligomers as an adhesive in fibrous composite materials based on synthetic fibers leads to an increase in the adhesive interaction between the components. However, due to the limited wettability of the synthetic fibrous filler with adhesives, it is advisable to carry out preliminary RF plasma treatment of fibers in a plasma-forming air medium. The matrix polymer and the adhesive have good mutual adhesion, and the lack of adhesion between the adhesive and the synthetic fibers is compensated by the formation of functional reactive groups on the surface of the synthetic fibers during RF plasma treatment.

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