Surface activation of polyamide fibers by radio-frequency capacitive plasma for application of functional coatings

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Abstract. The results of experimental researches on the modification of polyamide fibrous materials for technical purposes by low-pressure radio-frequency capacitive discharge plasma are presented. The effect of plasma modification on the wettability of polyamide fibers and their adhesive properties was studied.

1. The Introduction

For the development of textile and light industries in Russia, as well as increasing import substitution, it is not so much the development of new types of fibers and yarns, as the modification of existing ones, in order to give them the desired properties. Polyamide fibrous materials for technical purposes need to improve the adhesive properties, which will ensure their more effective impregnation with modifying solutions and polymeric binders in the preparation of composite materials, as well as the preparation of the fiber surface for their subsequent metallization.

For the modification of synthetic textile fibers used radio-frequency plasma discharge of low pressure. As opposed to traditional methods of processing, electrophysical methods, including plasma ones, are resource-efficient, environmentally friendly and require only one-time investments [1]. The results of previous researches [2-5] show that the treatment of textile materials by plasma of radio-frequency capacitive discharge of low pressure allows to change the surface properties, for example, to improve the adhesion characteristics. The plasma of the radio-frequency discharge allows modification of synthetic materials without their destruction, and the physico-chemical mechanism of action ensures the stability of the effects after plasma modification.

2. Materials, methods and equipment

The use of the radio-frequency plasma discharge of low-pressure in the processes of modification of fibrous materials was investigated on samples of polyamide fibers for technical purposes (Technical Specification 2272-103-77319717-2012).

For the modification of polyamide fibers was applied to the experimental radio-frequency plasma installation with individually designed cassette for treatment of fibrous materials, which are located in the interelectrode space and providing the opportunity for uniform modification of all parts of the winding fibrous material.

The change of morphology of surface of polyamide fibers was determined by confocal laser scanning microscopy with the Olympus Lext OLS 4100. The effect of plasma modification on the
change in wettability of fibrous materials was estimated by determining the capillarity index (GOST 29104.11–91). Adhesive properties of polyamide fibers was evaluated by determining the adhesive strength of the fiber with the cured matrix by the method of wet-pull-out, designed to KNRTU with the IMET RAS by A.A. Baykov [6].

3. Results
To establish the regularities of the effect of radio-frequency plasma on the samples of polyamide technical fibers, their processing was carried out when changing the input parameters of the installation within the following limits: discharge power $W_p = 0.7-1.5$ kW; processing time $t = 60-600$ s; pressure in the working chamber $P = 30-50$ Pa; plasma gas flow $G = 0.01-0.04$ g/s; plasma – argon and argon/propane-butane in a ratio of 70/30.

The results of confocal laser scanning microscopy of surface of polyamide fibers before and after their plasma modification are shown in fig. 1.

According to microscopic analysis on the surface of the initial polyamide fibers observed the presence of technical impurities and mechanical impurities in samples modified by plasma in the medium of argon and argon/propane-butane, there is a purification of the surface of the fibers. It is obvious that as a result of ion bombardment in the process of plasma treatment, physical spraying of mechanical impurities and components of the oiling agent occurs regardless of the plasma-forming medium used, which leads to smoothing of the fiber surface [7].

The effect radio-frequency plasma modification on the change in the capillary index of polyamide fibers is shown in fig. 2.
The importance of capillarity, mm

Control sample | Modified sample in plasma of argon | Modified sample in plasma of argon/propane-butane

Figure 2. The capillarity index of the polyamid fibers before and after the plasma modification

After plasma treatment of argon/propane-butane a decrease in capillarity index is observed in comparison with the initial samples by 27.6%. The decrease, as a result of plasma treatment, the values of the capillarity index can be due to both physical and chemical processes taking place in the surface layers of fiber-forming polymers due to the addition of plasma-forming gas components. Studies of changes in the capillarity index for samples after 2 months after their plasma modification show that the obtained effects are stable over time.

On the basis of the adsorption theory of adhesion, it can be argued that the change in the physical properties of the polyamid fibers will contribute to the change in their adhesive properties to the polymer matrices. To confirm this effect, adhesion of the polyamid fibers to the polymer matrix was investigated (fig. 3).
Figure 3. The effect of the plasma modification on the normalized value of breaking load of the microcomposite

Plasma modification of polyamide fibers in the plasma of argon/propane-butane leads to an increase in the value of the normalized value of the breaking load of the microcomposite by 1.5 times, whereas after treatment in an inert gas of argon this indicator does not change. The results obtained are due to the grafting of hydrocarbon radicals occurring during plasma modification in a polymer-forming plasma and the formation of intermediate layers in polymer-polymer systems during the creation of a composite material. This leads to an increase in the affinity of the components of the adhesive compound, which leads to an increase in the adsorption of macromolecules of the adhesive by the substrate surface and the appearance of adsorption intermediate layers. The exact mechanism of adhesion can be determined by determining the nature of intermolecular interactions in the contacting layer between the components of the composite material.

4. Conclusions
The obtained results showed that the effect of plasma modification depends on the composition of the plasma-forming gas. The radio-frequency plasma modification of polyamide fibrous materials for technical purposes in the plasma-forming of argon/propane-butane allows to increase their adhesive properties, which makes it possible to effectively impregnate them with polymeric binders, as well as to apply functional coatings with high adhesion to the fibrous substrate on their surface.

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