Study of the Effect of Plasma Treatment on the Mechanical Properties of Mineral Fiber Threads

M V Antonova¹, A R Ibatullina¹, A S Parsanov¹, I V Krasina¹
¹Kazan National Research Technological University, Kazan, Russia
parsanov1982@yandex.ru

Abstract. The article describes methods for modifying glass and basalt fibers and threads, and composite materials from them. Special attention is paid to plasma methods. Twisted glass thread and basalt twisted thread are investigated in the work. Plasma treatment was used to modify the threads. The type of plasma is nonequilibrium, low-temperature; the type of discharge is high-frequency capacitive. The results of research of thread properties, such as morphological changes and breaking load of threads. The plasma-treated and non-treated samples of threads were compared. The modes of plasma modification of threads in which the increase of breaking load strength of glass threads up to 23 % and of basalt threads up to 10 % is achieved have been established.

1. Introduction
Mineral fibers find application in various industries, such as textile production, aircraft and shipbuilding, electronics and mechanical engineering. The development of these industries requires innovative materials that are significantly superior to traditional materials in performance and strength characteristics. Composite materials can meet these requirements.

For creation of modern composites, basalt fibers, which have good adhesion to various binders, are used nowadays. Composites based on basalt fibers are widely used in many industries.

For obtaining composite materials, along with basalt fibers, glass fibers are also used. One of the methods of obtaining high-strength glass fibers is its impregnation with epoxy binder.

Strength, good adhesion to binders, fire resistance and much more - all these properties are given to fibers by modification using different methods, including plasma modification. The purpose of such modification is to effectively change the surface properties of the material without worsening the physical and mechanical characteristics.

Researches on modification of basalt and glass fibers are conducted by scientists of different countries of the world [1-8].

In recent years, both industry and the scientific community have focused their attention on the development of stable composites made of basalt fibers. Polymer-based composites reinforced with basalt fiber have found application in airplanes, automobiles, ships, in construction, in petrochemical pipelines, and in wind turbine blades. Composites based on basalt fibers have excellent mechanical properties and constructional ability. But poor compatibility between the basalt fiber and the polymer matrix leads to defects and drawbacks in the composites. These drawbacks limit the development of composites based on basalt fiber reinforced polymers. The authors of [5] work have developed various methods of physical or chemical treatment of the basalt fiber surface to improve the interaction at the
interface between the fiber and the resins. As a result, a composite with improved strength properties was obtained.

Nonthermal atmospheric pressure plasma is used more and more often for modification of polymer surface. The authors [6] used argon, oxygen, hydrogen and hydrogen-nitrogen plasma at atmospheric pressure for the surface modification of basalt fibers. The treatment was carried out with the aim of detecting changes and regulating such fibre parameters as surface-active groups content, chemical resistance, roughness etc. The results showed the processes involved in etching and subsequent attachment of nitrogen and oxygen-containing polar groups, the experiments also showed a significant increase in chemical stability and high adhesion. During the study, the authors found that etching with oxygen was mostly the result of bombardment by ions, has caused a decrease in molecular weight and roughness. In this case, chemical changes on the surface of the basalt fiber with the participation of nitrogen and hydrogen are the result of neutral particles affecting the surface of the basalt fiber previously subjected to plasma activation [6].

Plasma modification methods are also used for glass fibers. For example, the authors of work [7] used tetravinylsilane polymerized in plasma to modify the surface of glass fibers. Plasma modification of glass fibers made it possible to significantly increase the interfacial shear strength as compared to untreated fibers. In tests of the interfacial shear strength of the coatings, the optimized plasma coating showed an increase in shear strength up to 26% compared to the baseline coating.

In study [8], plasma-enhanced chemical vapor deposition (PECVD) was used to modify the surface of glass fibers and preserve their volumetric properties. The fibers were used as reinforcement in a glass fiber/polyester composite. By optimizing the plasma modification parameters, the adhesion between the glass fibers and the polymer matrix was improved, as shown by a 14% increase in the shear strength of the glass fiber polymer composite.

In this work the effect of plasma treatment on the mechanical properties of basalt and glass fiber filaments was considered.

2. Materials and methods
Twisted alumina borosilicate glass thread with paraffin emulsion oiling agent; basalt twisted thread Basalt 10-68Z40-KV-12 were chosen as objects of research.

Plasma treatment was used to modify threads and tapes. Type of plasma is nonequilibrium, low-temperature; type of discharge is high-frequency capacitive.

Plasma treatment of threads was conducted using a plasma vacuum unit (capacitive discharge), an argon/propane-butane mixture in the ratio of 70/30 and 100% propane-butane was used to create the plasma medium. Treatment mode: plasma gas flow G = 0.04 grams per second, generator frequency f = 13.56 MHz, pressure in the chamber P = 26 Pa, treatment time t = 5 min, with variation of input voltage parameters at the anode Ua = 4 to 7 kV. The current strength at the anode was fixed during the treatment and ranged from 0.5 A to 0.85 A.

Determination of breaking load of glass and basalt threads was carried out on a testing machine Shimadzu AGS-X (Japan production). Research was conducted according to State Standard 6943.10-79 Glass textile products. Method for determination of breaking load and elongation at rupture. Microstructure of glass and basalt fibers was studied by confocal laser microscopy on Olympus LEXT 4000 microscope (Japan production).

3. Results and discussion
Based on the results of previous works in the field of studying the of cold plasma on the characteristics of different yarns and threads [9-13], in this work we present studies of the impact of plasma treatment parameters on the properties of mineral fiber threads.

To study plasma impact to the change of structural characteristics of glass and basalt filaments, their surface was studied by scanning electron microscopy. At micro scanning, the general state of thread surface before and after plasma treatment was studied.
During the study, it was found that samples of fibers that have been plasma treated have a more homogeneous fiber structure and less rough surface compared to untreated samples. Such effect probably arises due to equal distribution of oiling emulsions on fiber surface, filling of cracks and chips.

The change in mechanical characteristics of glass and basalt threads was investigated further. Mechanical characteristics of threads are often crucial for creation of composite materials, so their decrease is not recommended.

The results of researches of influence of plasma treatment on strength properties of glass and basalt threads are presented in figures 1 and 2.

For glass and basalt threads, three modes (by voltage at the anode) of treatment in gas discharges were chosen: in the first mode $U_a = 4$ kV; in the second mode $U_a = 5$ kV; in the third mode $U_a = 6$ kV; in all three modes, the plasma exposure time on the samples was 5 minutes. Filament samples were treated in plasma consisting of argon and propane-butane gases (percentage 70/30, respectively) and 100% propane-butane.

![Figure 1. Dependence of yarn tensile strength from plasma treatment modes, propane-butane plasma gas](image1)

![Figure 2. Dependence of yarn tensile strength from plasma treatment modes, argon/propane-butane (ratio 70/30, respectively) plasma gas](image2)

As can be seen from the graphs in Figures 1 and 2, plasma treatment in a mixture of argon/propane-butane (70/30) and 100% propane-butane at 4 kV voltage increases the breaking load of the glass fibres by up to 23%, against a standard sample. At low temperatures, the adsorption effect of air water...
on the glass fibres is eliminated, increasing their strength. In addition, the filling of voids and cracks with paraffin emulsion also improves the strength of the yarns. However, with an increase of voltage at the anode up to 6 kV in argon/propane-butane gas plasma, a radical degradation of the strength of glass filaments is observed. In the case of 100% propane-butane plasma, the strength of the modified samples stays higher compared to the control samples.

The results of treatment of basalt filaments have shown that plasma modification in argon/propane-butane (70/30) gas mixture and in pure propane-butane at 6 kV voltage increases their breaking load strength.

The experiments showed that the relative elongation of glass and basalt threads remains in the range of values of the control sample (Table 1).

| № | Plasma treatment mode                  | Glass threads | 1 | 2 | 3 |
|---|----------------------------------------|---------------|---|---|---|
| 1 | Argon/propane-butane (70/30)           | 0.23          | 0.16 | 0.16 | 0.12 |
| 2 | Propane-butane                         | 0.19          | 0.18 | 0.18 | 0.18 |

| № | Plasma treatment mode                  | Basalt threads | 1 | 2 | 3 |
|---|----------------------------------------|---------------|---|---|---|
| 1 | Argon/propane-butane (70/30)           | 0.17          | 0.19 | 0.18 | 0.18 |
| 2 | Propane-butane                         | 0.21          | 0.18 | 0.18 | 0.19 |

4. Conclusions
The paper gives an overview of researches in the field of modification of glass threads and basalt threads. The modern tendencies in world science in the field of modification of mineral fibres have been described.

The influence of plasma modification on mechanical properties and change of morphology of glass thread and basalt thread surface has been studied. The scanning electron microscope (SEM) method has established, that plasma treatment in medium of argon/propane-butane (70/30) and pure propane-butane gases contributes to fiber surface cleaning, and also to keeping its integrity.

It was found that plasma treatment in argon/propane-butane (70/30) gas mixture and in pure propane-butane at 4 kV increases the breaking strength of glass fibres up to 23%, and of basalt fibres up to 10% on average at 6 kV.

The relative elongation of glass and basalt threads after plasma treatment does not change considerably.

Therefore, the study showed that modification in cold plasma based on active, inert, polymerizing gases and based on mixtures of some of them is a perspective method to increase the strength characteristics of glass and basalt threads, as well as the transformation of their surfaces.

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