Using of radio-frequency capacitive discharge plasma for modification of jute fabrics

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Abstract. The article considers issues related to the effect of plasma treatment on the properties of jute fabrics and their component fibers. The modes of plasma treatment of jute fabrics were selected. The surface changes of jute fibers were studied by using scanning electron atomic force microscopy. According to the results of the experiments, an increase in the strength characteristics of jute fabrics treated with radio-frequency capacitive discharge was revealed, and the roughness of the surface of jute fibers was estimated.

1. Introduction
Currently, materials from various types of bast fibers (jute, hemp, etc.) are gaining popularity in the global consumer market. Jute fibers have increased rigidity, so they are mainly used only for the production of technical textiles. However, in recent years, many European countries are increasingly resorting to the modification of feedstock and use it to create fundamentally new types of fibers and materials based on them. India is the largest producer of a variety of jute products. For example, jute fibers began to be used for the manufacture of decorative fabrics, national clothes, shoes, greeting cards, molded door panels.

Thanks to scientific developments and modifications today jute can be used to replace expensive natural fibers.
In this study, the modification of jute fabrics by radio-frequency capacitive discharge is used. Bast fibers from any plant feedstock have great tensile strength to mechanical impact. The tensile strength of jute fiber is third after linen and hemp. However, some types of modification can lead to deterioration of these parameters.

The aim of this work is to study the physical and mechanical properties of jute fabric and its constituent fibers, modified by a radio-frequency capacitive discharge.

2. Materials and methods
Jute fibers and jute bag fabric ordinary were selected as the objects of research; GOST 30090-93 «Bags and bag fabrics. General technical specifications». The treatment was carried out on an experimental plasma installation of a radio-frequency capacitive discharge with the following technical characteristics: a generator frequency (f) was 13.56 MHz, pressure (P) in the vacuum chamber 26 Pa, the anode amperage (I_a) was 0.4 A, the plasma-forming gas is argon, the value of plasma-forming gas flow (G) was 0.04 g/s, the processing time (t) 3 min [1]. The treatment of materials was carried out with a variation of the voltage at the anode (U_a) varied from 2.5 to 3.5 kV. The strength characteristics of fabric samples were determined on the electromechanical tensile testing machine (Metrotest, Russia) by standard methods after plasma treatment [2]. The strength of jute fibers was determined by an indirect method on a device for determining the strength of wool fiber. The fibers surface was examined by confocal laser microscopy using the Olympus LEXT OLS 4000 microscope (Olympus corporation, Japan).

3. Results and discussion
To determine the nature of the impact of radio-temperature plasma on the physical and mechanical properties of jute fabrics and threads, both standard and special research methods were used. Studies of the mechanical characteristics of jute fabric were carried out before and after plasma treatment according to GOST 3813-72 [2]. A summary data of the experiments are presented in table 1.

| Table 1. Mechanical characteristics of jute fabric samples |
|-------------------------------|------------|-------------|-----------------|----------------|
|     The fabric | Breaking load force, N | Elongation, mm | Relative elongation, % | Breaking load, N by GOST 30090-93, no less |
|----------------|-----------------|----------------|-----------------|----------------|
|               | Sample №1 (U_a =2,5 kV) |               |                 |                 |
| the warp      | 713,50          | 174,05         | 16,03           |                 |
| the weft      | 528,24          | 182,58         | 21,71           |                 |
| Sample №2 (U_a =3,0 kV) |               |                 |                 |                 |
| the warp      | 801,93          | 172,25         | 14,83           | the warp 539;   |
| the weft      | 463,41          | 183            | 22              | the weft 55     |
| Sample №3 (U_a =3,5 kV) |               |                 |                 |                 |
| the warp      | 846,2           | 174,19         | 16,13           |                 |
| the weft      | 575,44          | 188,75         | 25,83           |                 |
| Control sample |                 |                 |                 |                 |
| the warp      | 710,39          | 167,51         | 13,12           |                 |
| the weft      | 461,29          | 181,27         | 20,84           |                 |

The data in table 1 show that the plasma treatment of jute fabric in the selected range of input parameters of the plasmatron allowed to increase the breaking load force in comparison with untreated samples. All measured strength values of jute fabrics do not deviate from GOST 30090-93.
The best value of tensile strength have the sample subjected to plasma modification at a voltage at the anode \((U_a)\) 3.5 kV; it can withstand 20% more load than the original sample. The elongation of the test samples also changes.

Due to the fact that after plasma treatment of jute fabric the value of breaking load force of the samples increased, the next step was a study of the strength of the jute fibers which are components of jute threads. One of the important indicators of wear-resistance of textile materials is the strength of their component fibers. As a rule, it depends on the thickness and structure of the fibers. The jute elementary fiber has an uneven channel, which in some places expands, in some narrows to a minimum. Therefore, to determine the strength of jute fibers, it is necessary to use a lot of samples of them, at least 100 for each experiment.

During the experiment, it was found that the samples modified by plasma are 45% stronger than the original fiber samples. These data are compared with the values in table 1.

Various researches have shown that plasma modification of textile fibers leads to changes in their surface structure [3-5].

Laser scanning microscopy was used to study surface changes of jute fibers. Microscopic examination of jute fibers reveals that their surface becomes more ordered, the surface roughness of the samples decreases.

Microphotographs of jute fibers samples are shown in figure 1.

![Microphotographs of jute fibers](image)

**Figure 1.** Microphotographs of jute fibers in the study of their surface roughness: a) control sample; b) sample treated at a voltage at the anode of 3.5 kV

The main parameters characterizing the surface roughness have a certain letter designation used in the documentation \((R_z, R_a, R_{max}, S_m, S_i, T_p)\).

In this work, the surface roughness of the samples was estimated by the parameters \(R_a\) and \(R_z\). The parameter \(R_a\) is the arithmetic average of the absolute values of the profile deviations within the base length, microns; \(R_z\) is the sum of the average absolute values of the heights of the five largest protrusions of the profile and the depths of the five largest depressions of the profile within the base length, microns.

The parameter \(R_a\) is the most informative and provided with reliable measuring instruments. The parameter \(R_z\) is used for the normalization of small irregularities (range from 0.025 to 0.1 μm) and on small in size surfaces where it is almost impossible to apply groping instruments.

Figure 2 shows the change in the roughness of the samples, which was estimated by changing the parameters \(R_a\) and \(R_z\) depending on the plasma treatment modes.
Figure 2. Study of roughness of jute fibers samples: 1 – control sample, 2 – sample treated at a voltage at the anode of 2.5 kV, 3 – sample treated at a voltage at the anode of 3.0 kV, 4 – sample treated at a voltage at the anode of 3.5 kV.

The control sample revealed a greater value of roughness, which means that the fiber is more friable and less strong. Samples treated with radio-frequency capacitive discharge have lower peak values (Rz, Ra), that indicate about decrease the roughness. The treatment of samples by argon plasma-forming gas leads to compaction and smoothing of jute fiber micro relief. In turn, the compaction of the structure leads to increase the strength characteristics, which is compared with the data of table 1.

4. Conclusion

Thus, plasma modification of jute materials does not have a negative influence on their mechanical characteristics. The strength of samples of jute fabrics increases by 20 %, and the strength of fibers by 45 %. A study of the effect of plasma modification on the surface change of jute fibers showed a decrease in their roughness. On the basis of the experiments, the plasma modification mode f = 13.56 MHz, P = 26 Pa, G = 0.04 g/s, Ia = 0.4 A, Ua = 3.5 kV, t = 3 min was selected, at which a complex improvement of the studied parameters occurs.

References

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