Фундаментальные проблемы современного материаловедения. 2022. Т. 19. № 1. С. 125–131
Fundamental'nye problemy sovremennogo materialovedenia (Basic Problems of Material Science (BPMS)). 2022; 1(19): 125–131

Научная статья
2.6.1. Металловедение и термическая обработка металлов и сплавов (технические науки)
УДК 620.22:621.375.826
doi: 10.25712/ASTU.1811-1416.2022.01.014

ИССЛЕДОВАНИЕ ВЛИЯНИЯ КОГЕРЕНТНОГО ИЗЛУЧЕНИЯ НА СВОЙСТВА АРАМИДНЫХ ВОЛОКОН И ТКАНЕЙ

Ольга Витальевна Андрухова[1†], Сергей Владимирович Овечкин[2], Татьяна Витальевна Андрухова[3], Татьяна Михайловна Жуковская[4], Сергей Леонидович Кустов[5], Людмила Владимировна Науман[6]

[1, 2, 4, 5, 6] Алтайский государственный технический университет им. И.И. Ползунова, пр. Ленина, 46, 656038, Барнаул, Россия
[2] Алтайский государственный университет, пр. Ленина, 61, 656049, Барнаул, Россия
[1] ova17@yandex.ru[†], https://orcid.org/0000-0001-8181-883X
[2] sergei260895@mail.ru, https://orcid.org/0000-0002-9758-6145
[3] atvtata123@mail.ru
[4] 14maple10@mail.ru
[5] ksl72@inbox.ru
[6] luda_nau@mail.ru

Аннотация. В работе исследуется влияние когерентного лазерного излучения на свойства поверхности и тонкого приповерхностного слоя арамидных волокон и тканей. Была проведена экспериментальная оценка капиллярности и смачиваемости, упруго-прочностных и трибометрических характеристик СВМ волокон и тканей, предварительно обработанных в поле лазерного излучения мощностью 300 мВт и 500 мВт с длинами волн 532 нм и 410 нм соответственно в зависимости от времени экспозиции образца непосредственно сразу после облучения, через 12 часов, 24 часа и 456 часов после воздействия. Установлено, что при облучении наблюдается улучшение адгезионной способности и гидрофилизация поверхности, при этом не изменяются, а возможно и улучшаются упруго-прочностные характеристики материала. На основе проведенных исследований предложен метод фотоактивации поверхности арамидного волокна с использованием когерентного лазерного излучения малой мощности.

Ключевые слова: арамидные волокна и ткани, когерентное лазерное излучение, поверхностные и физико-механические свойства.

Для цитирования: Андрухова О.В., Овечкин С.В., Андрухова Т.В., Жуковская Т.М., Кустов С.Л., Науман Л.В. Исследование влияния когерентного излучения на свойства арамидных волокон и тканей // Фундаментальные проблемы современного материаловедения. 2022. Т. 19, № 1. С. 125–131. doi: 10.25712/ASTU.1811-1416.2022.01.014.

Original article

STUDY OF THE EFFECT OF COHERENT RADIATION ON THE PROPERTIES OF ARAMID FIBERS AND FABRICS

Olga V. Andrukhova[1†], Sergey V. Ovechkin[2], Tatyana V. Andrukhova[3], Tatyana M. Zhukovskaya[4], Sergey L. Kustov[5], Lyudmila V. Nauman[6]

[1, 2, 4, 5, 6] I.I. Polzunov Altai State Technical University, Lenin Pr., 46, Barnaul, 656038, Russia
[2] Altai State University, Lenin Pr., 61, Barnaul, 656049, Russia
[1] ova17@yandex.ru[†], https://orcid.org/0000-0001-8181-883X
[2] sergei260895@mail.ru, https://orcid.org/0000-0002-9758-6145
[3] atvtata123@mail.ru
[4] 14maple10@mail.ru
[5] ksl72@inbox.ru
[6] luda_nau@mail.ru

Abstract. The paper investigates the effect of coherent laser radiation on the properties of the surface and a thin near-surface layer of aramid fibers and fabrics. An experimental assessment of capillarity and wettability, elastic-strength and tribometric characteristics of high strength synthetic material fibers and fabrics, pretreated in the field of laser radiation with a power of 300 mW and 500 mW with wavelengths of 532 nm and 410 nm, respectively, depending on the exposure time of the sample, was carried out immediately, 12 hours, 24 hours and 456 hours after exposure. It was found that during irradiation, an improvement in the adhesion capacity and hydrophilization of the surface is observed, while the elastic-strength characteristics of the material do not change, and possibly improve. Based on the studies carried out, a method of photoactivation of the surface of an aramid fiber using coherent low-power laser radiation is proposed.

Keywords: aramid fibers and fabrics, laser radiation, surface and mechanical properties.

For citation: Andrukhova, O. V., Ovechkin, S. V., Andrukhova, T. V., Zhukovskaya, T. M., Kustov, S. L. & Nauman, L. V. (2022). Study of the effect of coherent radiation on the properties of aramid fibers and fabrics. *Fundamental'nye problemy sovremennogo materialovedenia (Basic Problems of Material Science (BPMS))*, 1(19), 125–131. (In Russ.). doi: 10.25712/ASTU.1811-1416.2022.01.014.

Introduction

The task of creating new materials is to find other methods for modifying existing components. A wide range of applications dictates the need to modify the properties of the surface and a thin near-surface layer of aramid fiber and fabrics without changing their bulk characteristics [1, 2].

Previously proposed methods for activating the fiber surface: radiation-chemical treatment [3]; plasma modification of the surface [4-6], the use of which can lead to deterioration or loss of some properties of fibers, with a visible improvement in others, and also complicates the technological process and the environmental situation in production [7]. And since the aim of the work is to search for new methods for modifying aramid fibers [8-9] (high strength synthetic material), devoid of these problems, a method of photoactivation of the aramid fiber surface using low-power coherent laser radiation is proposed [10].

The study used laser radiation with a power of 300 mW and 500 mW with wavelengths of 532 nm and 410 nm, respectively, depending on the exposure time of the sample.

When studying the effect of electromagnetic radiation on the capillarity and wettability of an aramid filament (fiber bundle), depending on the wavelength, we used previously prepared non-irradiated test-samples and irradiated aramid filaments (exposure time $\tau = 40$ seconds). The threads were also fixed on a test bench, and water was poured into the pallet at room temperature. In the course of the experiment, the total duration of which was 60 minutes, with an interval of 10 minutes, the height of the capillary rise of liquid (water) in the fiber was measured for each sample.

The experiment progress

Analysis of the kinetics of changes in the height of the liquid column in the samples over time (Fig.1) made it possible to establish that the time of exposure of the sample in water selected in the experiment corresponds to the establishment of hydrostatic equilibrium of the liquid column – the $h(t)$ curve reaches equilibrium.

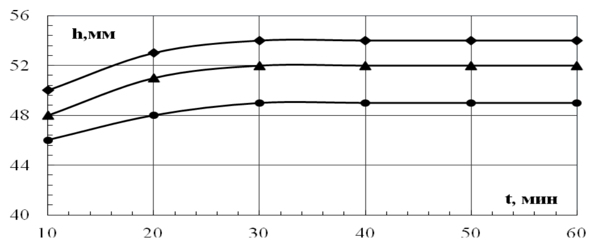

Fig.1. Curves of dependences $h(t)$ for three different samples

The observed scatter of the obtained values for each series of experiments is, apparently, due to not the same tension of the aramid ropes in the test bench.

For the analysis of the obtained experimental data, Table 1 shows the time-averaged values of the investigated physical quantity for each series of experiments.

The change in the capillarity of the aramid fiber during irradiation is clearly shown in the generalized diagram for three types of samples (Fig.2).

Table 1. Average values of the height of the capillary liquid column

Sample type	$\bar{h}$, mm									
	1	2	3	4	5	6	7	8	9	10
Without irradiation	47	53	46	48	48	51	53	52	52	50
λ=532 nm	65	68	58	66	60	56	55	62	57	60
λ=410 nm	58	62	57	66	56	57	67	56	55	65

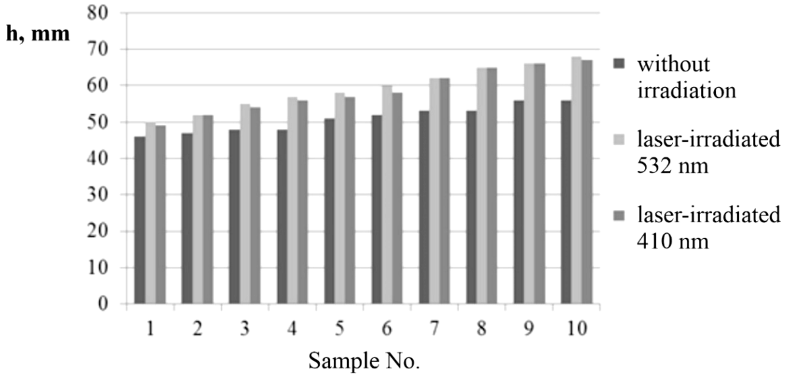

Fig.2. Comparison of the capillarity of non-irradiated and irradiated samples

Thus, from the resulting diagram, the following conclusions can be drawn:

1. Samples that have not been exposed to irradiation have the lowest capillarity. In this case, the average value of the height of the capillary sample rise is about 49 mm.
2. Under irradiation, regardless of the wavelength of coherent electromagnetic radiation, an increase in the capillarity of the samples is observed. The average value of the height of the capillary column rise was 61 mm for the green wavelength range and 59 mm for the violet one (about 25% with an irradiation time of 40 seconds).

To check the duration of the effect of laser radiation on the fiber, an experiment was carried out in which the height of the capillary column rise in the fibers irradiated with a laser with a wavelength of coherent radiation λ_1 = 532 nm and different exposure times after it was determined. The samples were investigated immediately after irradiation, 12 hours, 24 hours and 456 hours (≈19 days) after irradiation.

For the purity of the experiment, the samples were also investigated without irradiation, since the rise of the capillary column is influenced by external factors: atmospheric pressure, air temperature and humidity in the room. During the experiment, it was found that, regardless of external conditions, an increase in capillarity is observed in all samples of irradiated fibers. That is, the effect obtained is preserved.

To analyze the results obtained, the relative height of the liquid column in the sample was determined: $\delta = \frac{h_{\lambda,t}}{h_0}$, where $h_{\lambda,t}$ is the height of the capillary column in the irradiated sample, h_0 – in the unirradiated bundle of aramid fiber. The diagram "relative height – exposure time" (Fig.3) illustrates well the fact that the effect obtained is not temporary. At first, there is a slight drop in the capillarity of the fiber (from 0 to 12 hours), but then this value takes on a stationary value.

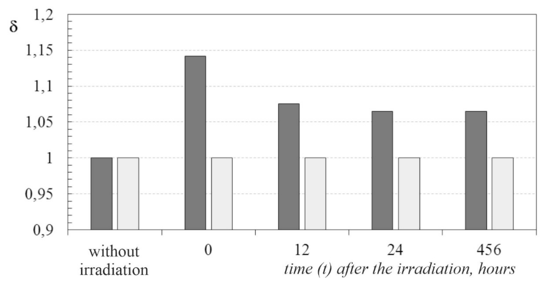

Fig.3. Diagram of the dependence of the relative height of the capillary column in the fiber on the time elapsed after exposure to laser radiation

To analyze the dependence of laser radiation effectiveness on the exposure time, aramid filaments were treated with a laser (λ = 532 nm) with different exposure times on the sample: 10, 30, 60, 180 and 300 seconds, respectively. For a visual comparison of the data obtained, a diagram "capillary column height – irradiation time" was plotted, shown in Fig.4. The analysis of the obtained results showed that there is an increase in the capillarity of the aramid fiber depending on the irradiation time. However, there is a certain threshold of the irradiation efficiency, after which the height of the capillary liquid column stops changing. Apparently, this is due to the fact that with a constant radius of capillary tubes in aramid fibers, the contact angle reaches its limiting value.

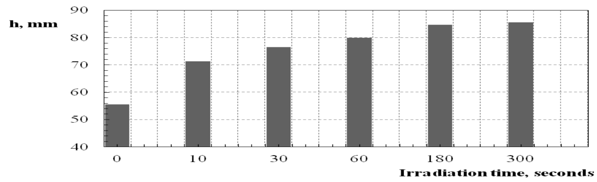

Fig.4. "Capillary column height – irradiation time" diagram

Taking into account that the radius of the capillary $r_0 \approx 0.16$ mm does not change when the fiber is irradiated, and the remaining parameters included in the expression are determined only by external conditions and, using the data on the height of liquid rise in the capillary with a change in the irradiation dose, the contact angle was calculated for every case. Fig.5 shows a graph of the aramid fiber wetting contact angle dependence on the irradiation time of the sample.

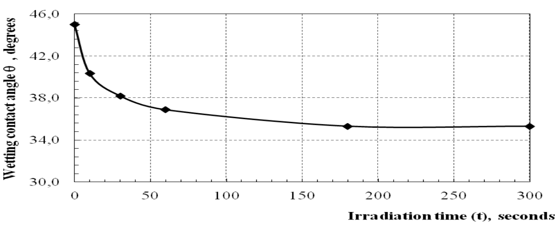

Fig.5. Curve of the dependence of the contact angle of aramid fiber wetting on the irradiation time

The analysis of the obtained results showed that there is an increase in the capillarity of the aramid fiber depending on the irradiation time. However, there is a certain threshold of the irradiation efficiency, after which the height of the capillary liquid column stops changing. Apparently, this is due to the fact that with a constant radius of capillary tubes in aramid fibers, the contact angle reaches its limiting value.

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Obviously, with an increase in the irradiation time, an increase in the height of the capillary column rise is observed, which is due to a decrease in the contact angle of wetting. Thus, irradiation of the aramid fibers improves the wettability of the aramid fibers, which improves the impregnation of the aramid filler with the binder component and creates a strong bond between the fiber and the matrix.

To study the effect of laser radiation on the strength of a para-aramid fiber and determine the breaking load, using the INSTRON electromechanical testing machine, in the first series of experiments, individual threads were tested for breaking after 20 seconds of irradiation in the visible part of the electromagnetic radiation spectrum (λ_1 = 532 ± 10 nm and λ_2 = 410 ± 10 nm) using solid-state semiconductor lasers. An unirradiated thread was used as a control sample.

In automatic mode, the maximum breaking load was determined, which determines the strength of the material, Young's modulus and maximum tensile stress (elastic properties of the material). For greater clarity of the effect of laser irradiation on the characteristics of aramid filaments, the average values of the parameters recorded in the experiment were summarized in one Table 2.

Based on the data in Table 2, a diagram was built, presented in Fig.6.

Table 2. Average values of mechanical characteristics of aramid thread at break

Sample type	Maximum load (N)	Young's modulus (MPa)	Maximum tensile stress (MPa)
Without irradiation	45,57	238378,28	5802,25
λ_1= 532 nm	44,00	229985,53	5602,05
λ_2 = 410 nm	42,42	208064,52	5401,39

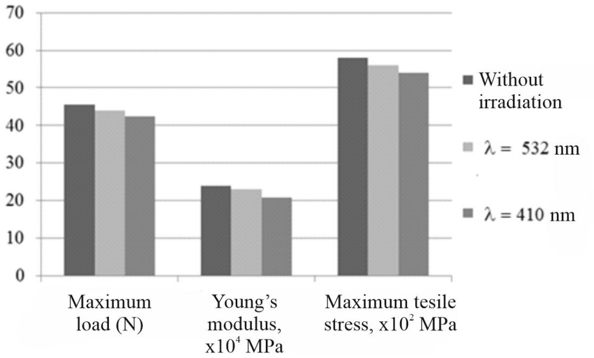

Fig.6. Diagram of elastic-strength characteristics of threads before and after irradiation

Thus, from the results obtained, it follows that under the influence of electromagnetic radiation, the elastic-strength characteristics of the aramid fiber decrease.

In the second series of experiments, tensile tests were performed on strips of aramid fabric 10 mm wide. Strips not exposed to laser action were used as control samples. For greater clarity of the effect of laser irradiation on strips of aramid tissue characteristics, the average values of the parameters recorded in the experiment were summarized in one Table 3. Based on the data in Table 3, the diagram presented in Fig.7 was built.

Table 3. Average values of mechanical characteristics of aramid fabric at break

Sample type	Maximum load (N)	Young's modulus (MPa)	Maximum tensile stress (MPa)
Without irradiation	553,84	6775,25	276,92
λ_1 = 532 nm	607,48	5983,41	303,74
λ_2 = 410 nm	603,85	4863,02	301,92

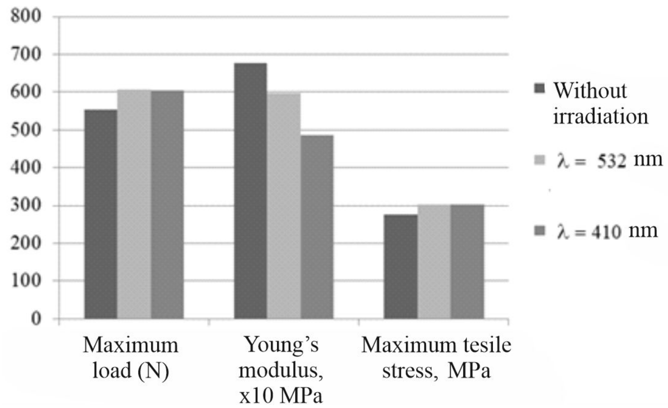

Fig.7. Diagram of elastic-strength characteristics of aramid tissue before and after irradiation

Conclusion

Thus, from the results obtained, it follows that under the influence of electromagnetic radiation, the elastic-strength characteristics of aramid fabric with twill weave threads noticeably change the mechanical properties of the material.

Apparently, the decrease in the strength characteristics of individual aramid threads and their growth in the case of exposure to tissue samples is due to the fact that under the action of electromagnetic radiation, the destruction of covalent bonds between the surface atoms of the fibers is observed and leads to the formation of surface radicals. In a tissue sample, under the influence of laser radiation, covalent bonds are partially restored between the surface atoms of adjacent threads. As a result, the strength increases markedly, but the elasticity of the sample decreases.

Taking into account the nature of the effect of laser radiation on aramid fibers and fabrics, it seems possible to develop a low-cost and relatively inexpensive method and technology for modifying aramid fiber using laser radiation.

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Information about the authors

O. V. Andrukhova – Candidate of Physical and Mathematical Sciences, Assistant Professor, I.I. Polzunov Altai State Technical University.

S. V. Ovechkin – Technical Engineer, I.I. Polzunov Altai State Technical University.

T. V. Andrukhova – Candidate of Physical and Mathematical Sciences, Assistant Professor, Altai State University.

T. M. Zhukovskaya – Candidate of Physical and Mathematical Sciences, Assistant Professor, I.I. Polzunov Altai State Technical University.

S. L. Kustov – Candidate of Physical and Mathematical Sciences, Assistant Professor, I.I. Polzunov Altai State Technical University.

L. V. Nauman – Candidate of Physical and Mathematical Sciences, Assistant Professor, I.I. Polzunov Altai State Technical University.

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Информация об авторах

О. В. Андрухова – кандидат физико-математических наук, доцент Алтайского государственного технического университета им. И.И. Ползунова.

С. В. Овечкин – инженер-техник Алтайского государственного технического университета им. И.И. Ползунова.

Т. В. Андрухова – кандидат физико-математических наук, доцент Алтайского государственного университета.

Т. М. Жуковская – кандидат физико-математических наук, доцент Алтайского государственного технического университета им. И.И. Ползунова.

С. Л. Кустов – кандидат физико-математических наук, доцент, заведующий кафедрой физики Алтайского государственного технического университета им. И.И. Ползунова.

Л. В. Науман – кандидат физико-математических наук, доцент Алтайского государственного технического университета им. И.И. Ползунова.

Авторы заявляют об отсутствии конфликта интересов.
The authors declare that there is no conflict of interest.

Статья поступила в редакцию 10.12.2021; одобрена после рецензирования 11.01.2022; принята к публикации 21.01.2022.

The article was received by the editorial board on 10 Dec. 21; approved after reviewing 11 Jan. 22; accepted for publication 21 Jan. 22.