THE FRICTION COEFFICIENT OF POLYLACTIC ACID FILMS AFTER THE LOW-TEMPERATURE ATMOSPHERIC PLASMA TREATMENT

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Polylactic acid (PLA) is widely used in medical applications for tissue engineering [1], as scaffolds, microspheres and scaffolds for drug delivery and release [2], and for the production of threads and pins [3]. Degradation of this polymer *in vitro* mainly occurs by hydrolytic cleavage, and *in vivo* enzymes play an important role in initiating the degradation process. The decomposition products of polylactic acid are non-toxic and are eliminated in the form of CO_2 and water via the Krebs cycle [4]. Although products made from biodegradable materials, including polylactic acid, often take the form of microspheres [5], rods and scaffolds, the use of thin films may be of greater interest in ophthalmology for the creation of a corneal implant. There are various methods for creating thin biodegradable films, of which the method of casting from solutions is widely used, as it allows one to obtain films of a certain thickness. This method has a number of features, the main one of which is the different roughness of the sides [6].

Despite the advantages of this material, there are a number of disadvantages such as hydrophobicity and low surface energy, which can sharply limit the use of the polymer as a substrate for cell cultures and a corneal implant. One solution to this problem may be the use of low-temperature atmospheric pressure plasma.

The implanted material must withstand the mechanical effects of surgical instruments, and therefore it is useful to know about the tribological characteristics of the polymer implants.

The purpose of this work is to study the coefficient of friction of polylactic acid films after the low-temperature atmospheric plasma treatment.

The initial films of polylactic acid (PLA) were obtained by casting from a solution of polylactic acid with a molecular weight of Mw = 121000 g/mol (PURASORB® PL 10, the Netherlands) in trichloromethane ($CHCl_3$) (Ekros, Russia). 1% solution was poured into Petri dishes, which were placed in a fume hood until the solvent had completely evaporated (48 hours). The formed polymer films were removed from the bowl using tweezers and distilled water. To remove residual solvent, the films were placed in a vacuum chamber (pressure 10^{-3} Torr, temperature 25°C) for 24 hours.

The each side of material was treated with low-temperature atmospheric pressure plasma for 30 s.

The thickness of the films was determined using an «IKV-3 optimometer».

The surface of the material was examined using a «Hitachi TM-3000» (Japan) scanning electron microscope with a resolution of 30 nm and a «Hitachi S3400N Type II» (resolution 3 nm). Laser scanning microscopy of the surface of polylactic acid was carried out on an «Olympus Lext Ols 4100» microscope (Russia).

The study of the surface relief of films and TM was carried out using an atomic force microscope (AFM) «Solver-HV» (NT-MDT, Russia) in semi-contact operating mode. For measurements, use a cantilever brand NSG11 («NT-MDT»), the radius of curvature of the needle tip is 10 nm. The scanning area was 30*30 μm^2 and 3*3 μm^2. Surface roughness profiles were generated in the Gwyddion 2.49 and Origin 9.0 software with an accuracy of 1 nm. Roughness parameters were processed in accordance with ISO 4287:1997. For the calculation, at least 10 surface profiles were used for each group of samples. The following parameters were set: Ra, Rq, Rz.

Friction and wear studies were carried out using the finger-disk scheme under dry sliding friction conditions on a «TRIBO technik» (France) while varying the test duration (10–30m) and sliding speed (in the range (1.5–5) mm/s). A counter body was a ceramic ball. The diameter of the ceramic ball was 6 mm.

The outer side of the film surface in contact with the atmosphere had a more relief surface, in contrast to the smoother inner side (fig. 1).

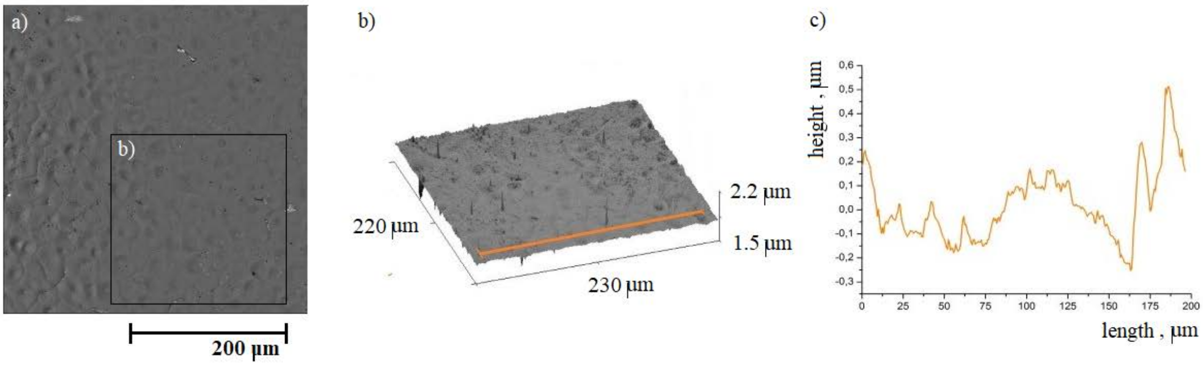

Figure 1 – Images (a, b) and surface profile (c) of the inner side of the film.

The outer side of the initial film has parameter Ra = 7.5 ± 2.0 nm, parameter Rq = 11.5 nm, and parameter Rz = 116.0 nm. The inner side of the film has parameter Ra = 4.8 ± 1.0 nm, parameter Rq = 7.1 nm, parameter Rz = 42.0 nm. The parameter Ra of the film after the plasma treatment was 2.3 ± 0.1 nm (inner side) and 3.7 ± 1.0 (outer side).

The range of the coefficient of friction (initial films) was 0.138-0.192 (1.5 mm/s), 0.127–0.171 (3 mm/s), 0.143–0.177 (5 mm/s) (fig. 2).

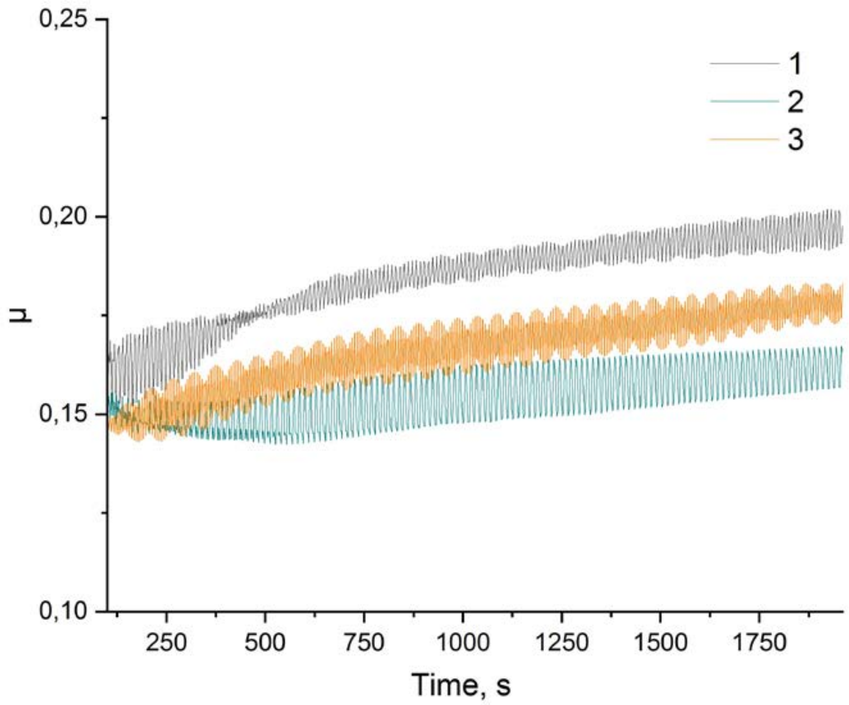

Figure 2 – The friction coefficient at sliding speed: 1 - 1.5 mm/s, 2 – 3 mm/s, 3 – 5 mm/s.

The friction coefficient of the films after plasma was in the range 0.122–0.203 (fig. 3). An increase in sliding speed contributes to a slight decrease in the friction coefficient for the initial samples and after exposure to plasma (~1.5 times). Changing the test duration does not lead to a significant change in the friction coefficient.

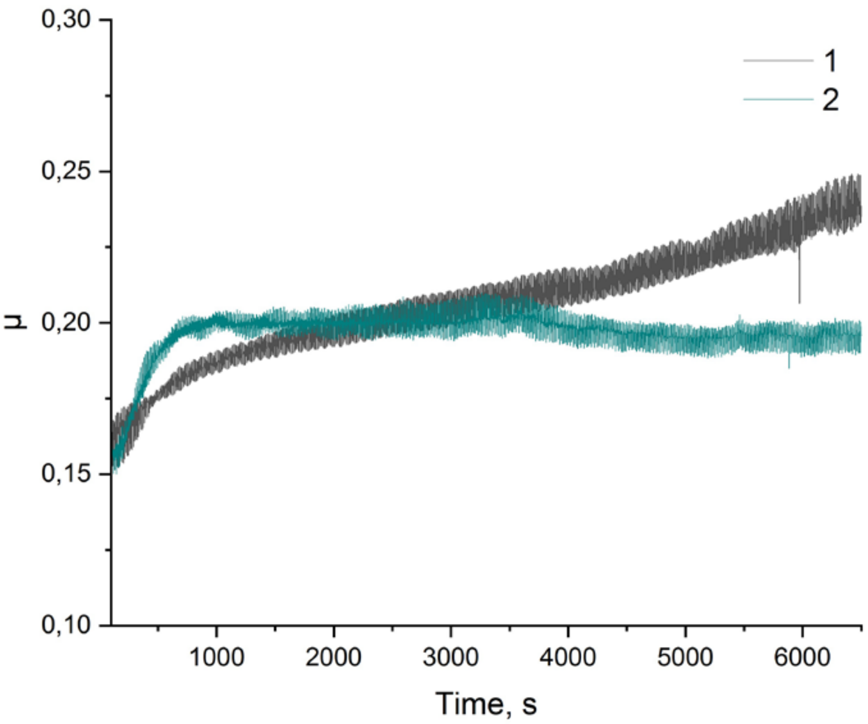

Figure 3 – The friction coefficient of the initial film (a) and the film after the plasma treatment (2) at sliding speed of 1.5 mm/s.

Thus, the results of the study showed that the plasma treatment decreases the values of roughness parameters and the friction coefficient. An increase in sliding speed contributes to a slight decrease in the friction coefficient for the initial samples and after exposure to plasma (~1.5 times). Changing the test duration does not lead to a significant change in the friction coefficient.

References

1. Lopes M.S., Jardini A.L., Maciel Filho R. Poly (lactic acid) production for tissue engineering applications // Procedia Engineering. – 2012. – Vol. 42. – P. 1402–1413.
2. Iesavand H., Rahmati M., Afzali D., Modir S. Investigation on absorption and release of mercaptopurine anticancer drug from modified polylactic acid as polymer carrier by molecular dynamic simulation // Materials Science and Engineering: C. – 2019. – Vol. 105. – P. 110010.
3. Pawar P.R, Tekale S.U., Shisodia S.U., Totre J.T., Domb A.J. Biomedical Applications of Poly(Lactic Acid) // Recent Patents on Regenerative Medicine. – 2014. – Vol. 4, № 1. – P. 40– 51.
4. Yasukawa T., Ogura Y., Sakurai E., Tabata Y., Kimura H. Intraocular sustained drug delivery using implantable polymeric devices // Advanced drug delivery reviews. – 2005. – Vol. 57, № 14. – P. 2033–2046.
5. Khoobehi B., Stradtmann M.O., Peyman G.A., Aly O.M. Clearance of fluorescein incorporated into microspheres from the cornea and aqueous after subconjunctival injection. Ophthalmic Surgery // Lasers and Imaging Retina. – 1990. – Vol. 21. – № 12. – P. 840–844.
6. Ivanova N.M., Filippova E.O., Karpov D.A., Pichugin V.F. Polylactic acid thin films properties after steam sterilization // Inorganic Materials: Applied Research. – 2020. – Vol. 11, № 2. – P. 377–384.