2. Savenko, V. S. Electroplastic deformation by twinning metals / V. S. Savenko // Actamechanicaet automatic. – 2018. – Vol. 12, N 4. – P. 6–12.
3. Троицкий, О. А. Фундаментальные и прикладные исследования электропластической деформации металлов : монография / О. А. Троицкий, В. С. Савенко. – Минск : ИВЦ Минфина, 2013. – 375 с.
4. Рощупкин, А. М. О влиянии электрического тока и магнитного поля на взаимодействие дислокаций с точечными дефектами в металлах / А. М. Рощупкин, И. Л. Батаронов // Физика твердого тела. – 1988. – Т. 30, № 11. – С. 3311.
5. Физические основы электроимпульсной и электропластической обработок и новые материалы / Ю. В. Баранов, О. А. Троицкий, Ю. С. Авраамов. – Москва : МГИУ, 2001. – 844 с.
6. Savenko, V. S. Electroplastic effect under the simultaneous superposition and magnetic fields / V. S. Savenko // Journal of applied physics. – 1999. – N 5. – P. 1–4.
7. Сташенко, В. И. Новые исследования вибрации металлов с помощью пьезометрических преобразователей под влиянием импульсов тока в статических и динамических условиях / В. И. Сташенко, О. А. Троицкий, О. Б. Скворцов, В. С. Савенко // Фундаментальные исследования и инновационные технологии в машиностроении : IV Междунар. науч. конф., Москва, 24–26 нояб. 2015 г. / Ин-т машиноведения им. А. А. Благонравова РАН. – Москва, 2015. – С. 242–244.

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MEDICAL AND BIOLOGICAL ASPECTS OF THE APPLICATION OF COMPOSITE MATERIALS BASED ON POLYLACTIDE FOR BIOPRINTING

S. A. Filatov[1], M. N. Dolgikh[1], O. S. Filatova[1], E. A. Paz Esteves[2], N. A. Gavrilenko[1], E. V. Batyrev[1]

[1]A. V. Luikov Heat and Mass Transfer Institute of NAS of Belarus, Minsk

[2]Center for the Study of Advanced and Sustainable Manufacturing, University of Matanzas, the Republic of Cuba

The paper presents the results of analysis of PLA structures based on gyroids. The possibilities of the development of more stable and durable structures are investigated.

Keywords: 3D-bioprinting, composite materials, polylactide, bioprinting, scaffolds, biodegradation.

МЕДИКО-БИОЛОГИЧЕСКИЕ АСПЕКТЫ ПРИМЕНЕНИЯ КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ НА ОСНОВЕ ПОЛИЛАКТИДА ДЛЯ БИОПЕЧАТИ

С. А. Филатов[1], М. Н. Долгих[1], О. С. Филатова[1], Э. А. Пас Эстевес[2], Н. А. Гавриленко[1], Е. В. Батырев[1]

[1]Государственное научное учреждение «Институт тепло- и массообмена имени А. В. Лыкова НАН Беларуси», г. Минск

[2]Центр изучения передового и устойчивого производства, Университет Матансаса «Камило Сьенфуэгос», Республика Куба

Представлены результаты анализа конструкций ПЛА на основе гироидов. Исследованы возможности создания более устойчивых и долговечных конструкций.

Ключевые слова: 3D-биопечать, композитные материалы, полилактид, биопечать, скаффолды, биодеградация.

The purpose of the work is to study the medical and biological aspects of creating implants with controlled biodegradation using 3D-bioprinting from biocompatible composite materials based on polylactide (*PLA*) with biocompatible nano-sized fillers.

Three-dimensional printing (3D-bioprinting) of implants using biocompatible PLA-based materials can be used to create porous three-dimensional scaffolds (matrices, cell scaffolds) to replace human tissue defects in regenerative surgery [1]. Biodegradable three-dimensional structures provide replacement mechanical and transport functions, including drug delivery with subsequent replacement of the scaffold with the body's own tissues.

To carry out the experiments, we used PLA, CAS No: 33135-50-1, from eSunMed, China with additives of hydroxyapatite (HAp) and calcium phosphate (CaP) (Figure 1). For 3D-printing (bioprinting) of samples, a specialized 3D machine was used FDM (Fused Deposition Modeling) bioprinter with an extruder temperature of 165–180 °C and a layer thickness of 0.2–0.4 mm.

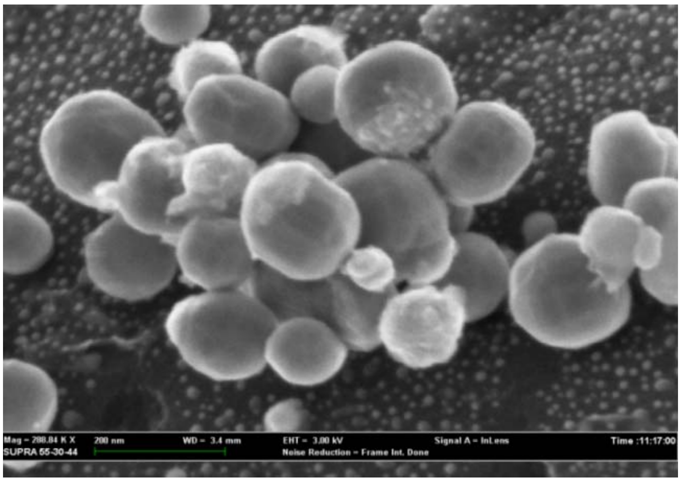
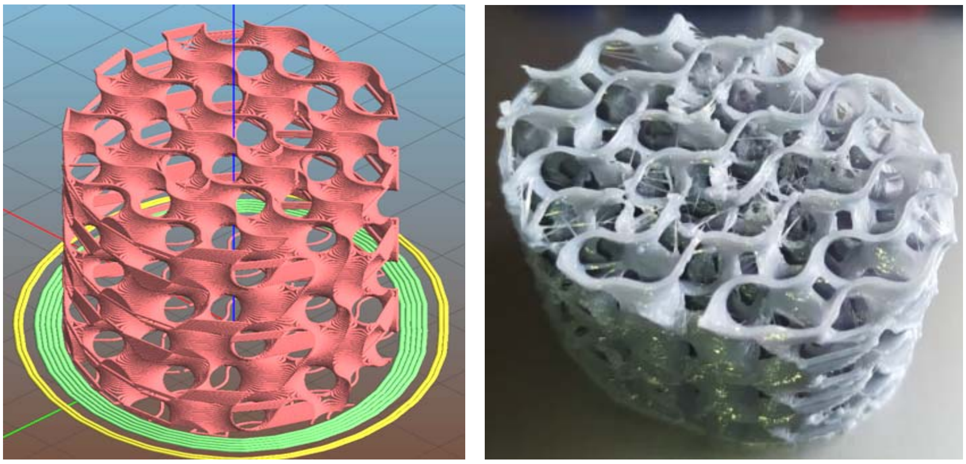


Figure 1. SEM image of nanoparticles HAp in PLA matrix

Tests to assess the fragility of scaffolds representing a three-dimensional composition of PLA thermoplastic filaments (with unidirectional or multidirectional strengthening components and cellular components) were carried out according to State Standard 4647–2015 for measuring impact strength using the Charpy method, which made it possible to determine the mechanical characteristics of the samples at high strain rates. The typical Charpy impact strength values for the samples with continuous filling are 4.6–4.8 kJ/m^2, for samples with gradient filling – 3.5–4.0 kJ/m^2, depending on the type of filling. Laboratory (accelerated) tests of biodegradation of PLA-based tissue-engineered matrices were carried out in a thermostated simulated body fluid (SBF) with a composition and concentration of ions close to the concentration of ions in human blood plasma. The testing regime included placing samples in SBF at a temperature of 37–40 °C for a period of 24 to 580 hours with periodic monitoring of the mass and structure of the tested samples.

It is established that the main mechanism of PLA matrices destruction from PLA formed by the FDM method is the hydrolysis of ester bonds. In this case, hydrolytic degradation is additionally catalyzed by the newly formed carboxyl groups of PLA, as a result the destruction of massive fragments of three-dimensional structures of tissue-engineered implants can occur faster, due to the accumulation of lactic acid and localized low pH values (3.2–3.4).

To reduce the volume of the polymer (PLA) framework, it is proposed to use the topology of gyroids with a periodic surface of minimum energy, trigonometrically approximated by the equation $\cos(x)\sin(y) + \cos(y)\sin(z) + \cos(z)\sin(x) = 0$, to fill the internal volume, that allows the formation of three-dimensional biocompatible structures with low density and high strength (Figure 2).



a) *b*)

Figure 2. PLA frame model (*a*) and test sample with a 3D-gyroid structure (*b*)

The surface of the gyroid with a constant average curvature allows dividing the volume of the tissue-engineered framework into two congruent labyrinths with the channels formed in the directions (100) and (111) and passages at an angle of 70.5 degrees to any channel. The formation of the implant framework filling with a gyroid structure was performed using Slik3 and Ultimaker Cura slicers. The obtained results made it possible to determine the characteristics of the degradation of three-dimensional PLA scaffold structures with a gradient density and a variable type of filling of the internal volumes of the frame (scaffold) and to create a computer model of the biodegradation of 3D-composite PLA structures (Figure 3).

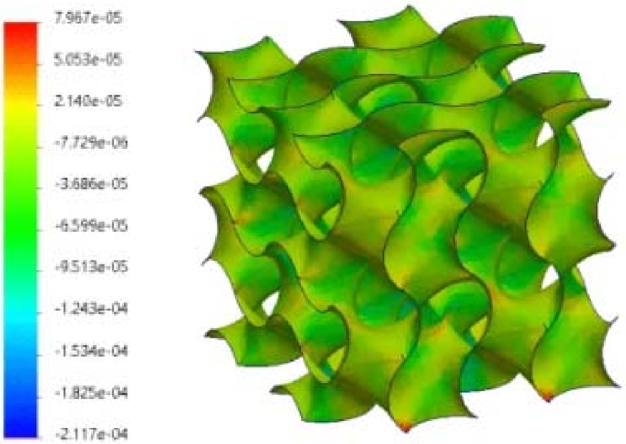


Figure 3. Localization of stress deformations in a gyroid structure under loading in the direction [0, 0, 1]

It was also found that the failure of the gyroid-type structures under mechanical load has several features related to their geometry and the materials they are made of. In particular, failure can occur in areas with the highest stress concentrations. In gyroids, such zones can occur at the points of connection of elements or near defects. In addition, gyroid structures can respond differently to static and dynamic loads. For example, fatigue cracks can be expected to form under dynamic loads.

Gyroid structures can exhibit fractal properties to the greatest extent, which affects the nature of crack propagation and failure. This can complicate the prediction of behavior under loads.

At the same time, modern gyroid structures can be made adaptive, changing their rigidity in response to changes in loads, which can help avoid failures.

Studying these features can help in the development of more stable and durable PLA structures based on gyroids, taking into account specific application conditions and the characteristics of materials with nanoscale fillers.This work was supported by the Belarusian Republican Foundation for Basic Research (Project No. T23KUB–007).

References

1. Calcium phosphate compositions with polyvinyl alcohol for 3D-printing in Inorganic Materials / O. N. Musskaya, V. K. Krut'ko, A. I. Kulak [et al.] // Applied Research. – 2020. – Vol. 11, N 1. – P. 192–197.
2. Composite materials and coatings based on polylactide and nanosized fillers for bioprinting / S. A. Filatov, M. N. Dolgikh, O. S. Filatova [et al.] // Heat and mass transfer–2023 : collection of scientific papers / ITMO named after A. V. Lykov of the National Academy of Sciences of Belarus. – Minsk, 2023. – P. 283–287.
3. Formation of tissue-engineering materials based on porous scaffolds from bioresorbable materials based on polylactide / S. A. Filatov, M. N. Dolgikh, E. A. Paz Esteves [et al.] // Actual problems of strength : materials of the LXVIII Int. scientific conferences, Vitebsk, May 27–31, 2024 / UP “IVC of the Ministry of Finance”. – Minsk, 2024. – P. 313–315.

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ФУНКЦИОНАЛИЗАЦИЯ КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ НА ОСНОВЕ PLA С ИСПОЛЬЗОВАНИЕМ УГЛЕРОДНЫХ ВОЛОКОН

С. А. Филатов[1], М. Н. Долгих[1], О. С. Филатова[1], Э. А. Пас Эстевес[2], Н. А. Гавриленко[1], Е. В. Батырев[1]

[1] Государственное научное учреждение «Институт тепло- и массообмена имени А. В. Лыкова Национальной академии наук Беларуси», г. Минск

[2]Центр изучения передового и устойчивого производства, Университет Матансаса «Камило Сьенфуэгос», Республика Куба

Возможность интерактивного внесения различных функциональных групп и компонентов на поверхность углеродных волокон позволяет адаптировать свойства в зависимости от планируемого применения. Добавление допированных углеродных волокон может быть сочетано с методами создания пористых структур, что улучшает прочность и проницаемость для биологических жидкостей, что, в свою очередь, способствует лучшей остеоинтеграции.

Ключевые слова: аддитивные технологии, послойный синтез, полимерные материалы, функционализация материалов, 3D-печать.