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THE INFLUENCE OF THE ADDITION OF GRAPHITE ON THE TRIBOLOGICAL PROPERTIES OF POLYLACTIC (PLA) APPLIED IN 3D PRINTING TECHNOLOGY

WPŁYW DODATKU GRAFITU NA WŁAŚCIWOŚCI TRIBOLOGICZNE POLILAKTYDU (PLA) STOSOWANEGO W TECHNOLOGII DRUKU 3D

Key words: PLA, polylactic, 3D printing, additive manufacturing, graphite, FFF, linear wear.

Abstract The article presents the results of studies on the influence of the addition of graphite to a PLA filament on linear wear and the coefficient of friction. A cylinder of 8 millimetre diameter manufactured in *Fused Filament Fabrication* process, popularly called 3D printing was used as a specimen. Studies were conducted on *pin-on-disc* testing machine, in which the cylinders mentioned above were paired with a steel disc – the counter-specimen. Specimens used in research were enriched by 5%, 10%, 20%, and 30% of graphite in comparison to the base filament – Natural PLA, which were not enriched with any additions that could improve its tribological properties. The experiment was conducted as a preliminary research. The gained results create a basis to select the optimal composition of additions to the PLA to create a filament with better tribological properties.

Słowa kluczowe: PLA, polilaktyd, druk 3D, technologie przyrostowe, grafit, FFF, zużycie liniowe.

Streszczenie W niniejszej pracy przedstawiono wyniki badań wpływu dodatku grafitu do PLA na zużycie liniowe oraz współczynnik tarcia. Jako próbkę zastosowano walec o średnicy 8 milimetrów wytworzony w procesie *Fused Filament Fabrication*, popularnie zwanym drukiem 3D. Badania zostały przeprowadzone na stanowisku typu *pin-on-disc*, w którym wykorzystano wyżej wspomnianą próbkę, współpracującą ślizgowo ze stalową tarczą – przeciwpróbką. Próbki użyte w badaniu wzbogacone były kolejno o 5%, 10%, 20% oraz 30% grafitu względem filamentu bazowego, tzw. Natural PLA, niewzbogaconego żadnymi dodatkami polepszającymi właściwości tribologiczne. Przeprowadzony eksperyment ma charakter badań wstępnych, a uzyskane wyniki stanowią podstawę do opracowania optymalnego składu filamentu o polepszonych właściwościach tribologicznych.

INTRODUCTION

3D printing technology has rapidly grown over the last decade. In addition to cheaper and cheaper machines, the needs for cheaper filaments and for filaments for special applications have emerged **[L. 1]**. Today, it is possible to buy a filament with electric conductivity, a glow in the dark effect, strengthen with carbon fibre or even filaments that look like wood. **Fig. 1** presents 3D-printed gears and a laminating mould.

Usually, 3D printed objects are used as prototypes, but more and more often, people use this technology to create products, spare parts, and even fully functional machines. With these new applications, there was created another need – need for filaments with a low wear rate. First to answer those needs was Igus with its Iglidur series. These filaments are characterized with a low wear rate, as well as a low coefficient of friction, compared to standard filaments. **Fig. 2** presents a 3D-printed linear guideway block **[L. 3]**.

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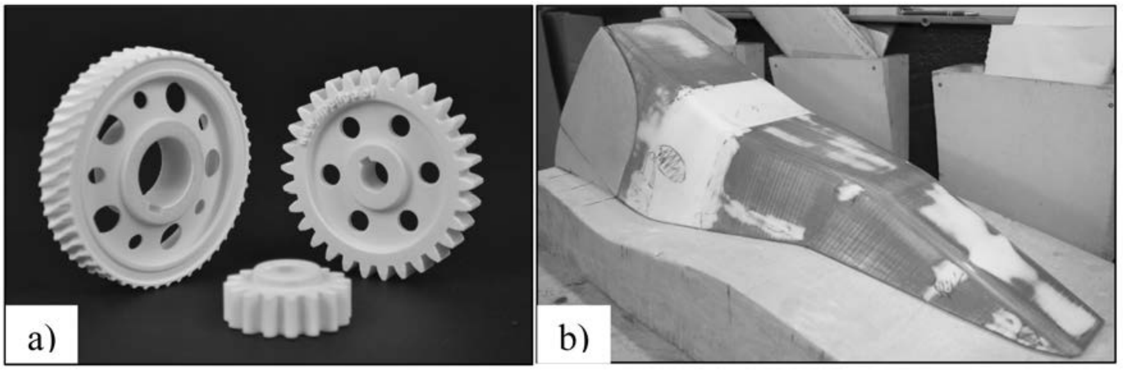

Fig. 1. Possible applications of 3D-printed objects: a) Gears, b) Laminating mould [L. 2]
Rys. 1. Przykładowe zastosowania wydruków 3D: a) koła zębate, b) forma do laminowania **[L. 2]**

Fig. 2. Linear guideway block 3D-printed with Igus filament [L. 4]
Rys. 2. Wózek prowadnicy liniowej wydrukowany z użyciem filamentu Igus **[L. 4]**

RESEARCHED MATERIALS

As test objects, 4 different types of enriched PLA filaments were selected: 5%, 10%, 20%, and 30% of graphite addition. As standard samples, PLA Natural (no additions) and tribo-filament Igus Iglidur I180 was selected. PLA Natural allowed establishing the improvement or deterioration of tribological properties, and Iglidur allowed establishing proper test parameters and comparing results to the official data of the producer.

RESEARCH METHOD

As a research method, a pin-on-disc tribometer station was used in order to establish linear wear and the coefficient of the kinetic friction of the researched material. The general scheme of pin-on-disc research is presented in **Fig. 3**. **Fig. 4** presents the specific apparatus used during the test **[L. 5]**. Parameters of the process are described in **Tab. 1**. All measurements, before and after the test, were conducted in the stable temperature of the specimen.

Table 1. Parameters of the research process
Tabela 1. Parametry procesu badawczego

Parameter	Value
Time of the test	2 h 27 min
Load	5.49 N
Pin pressure on the disc	0.11 MPa
Roughness of the disc	Ra (0.35–0.45)
Velocity of the disc	0.34 m/s
Length of the pin path	3 km
Friction	Dry
Temperature of environment	23.8ºC
Humidity	26%

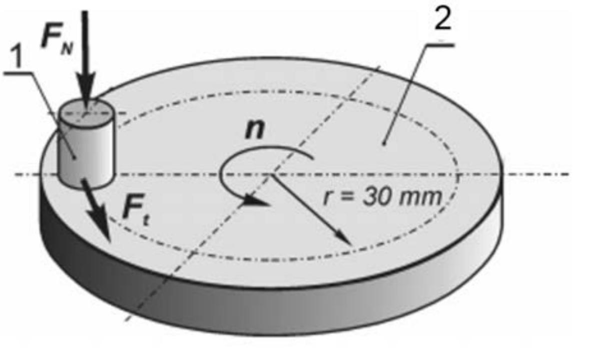

Fig. 3. Pin-on-disc scheme of research, F_N – force of pressure, F_t – friction force, n – rotation speed, 1 – specimen, 2 – disc
Rys. 3. Schemat badania pin-on-disc, F_N – siła nacisku, F_t – siła tarcia, n – prędkość obrotowa, 1 – próbka, 2 – dysk

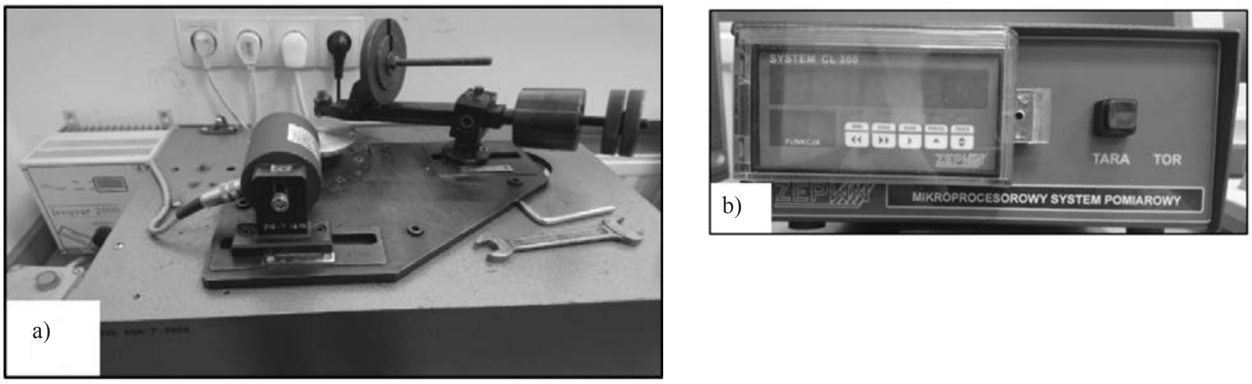

Fig. 4. Test apparatus – pin-on-disc station and force measurement system: a) pin-on-disc station, b) friction force measurement system

Rys. 4. Aparatura badawcza – stacja pin-on-disc wraz systemem pomiaru siły: a) stanowisko pin-on-disc, b) system pomiaru siły tarcia

RESULTS

In the plan of study, we determined to use 3 samples of each material created in separate processes. Each of these samples was tested on a pin-on-disc station for 3 kilometres each, detailed in **Tab. 1**. **Fig. 5a–f** presents SEM images of the surfaces of the specimens after the tests. As can be seen in the pictures, the most regular surface can be observed for image (a) Igus Iglidur I180. Due to the PTFE dust that separated from the specimen during the test, most of the unevenness on the disc was covered by a film layer, which protected the specimen from excessive wear and caused a lower coefficient of friction. **Figure 6** presents the friction forces for each type of specimen during the whole time of the test.

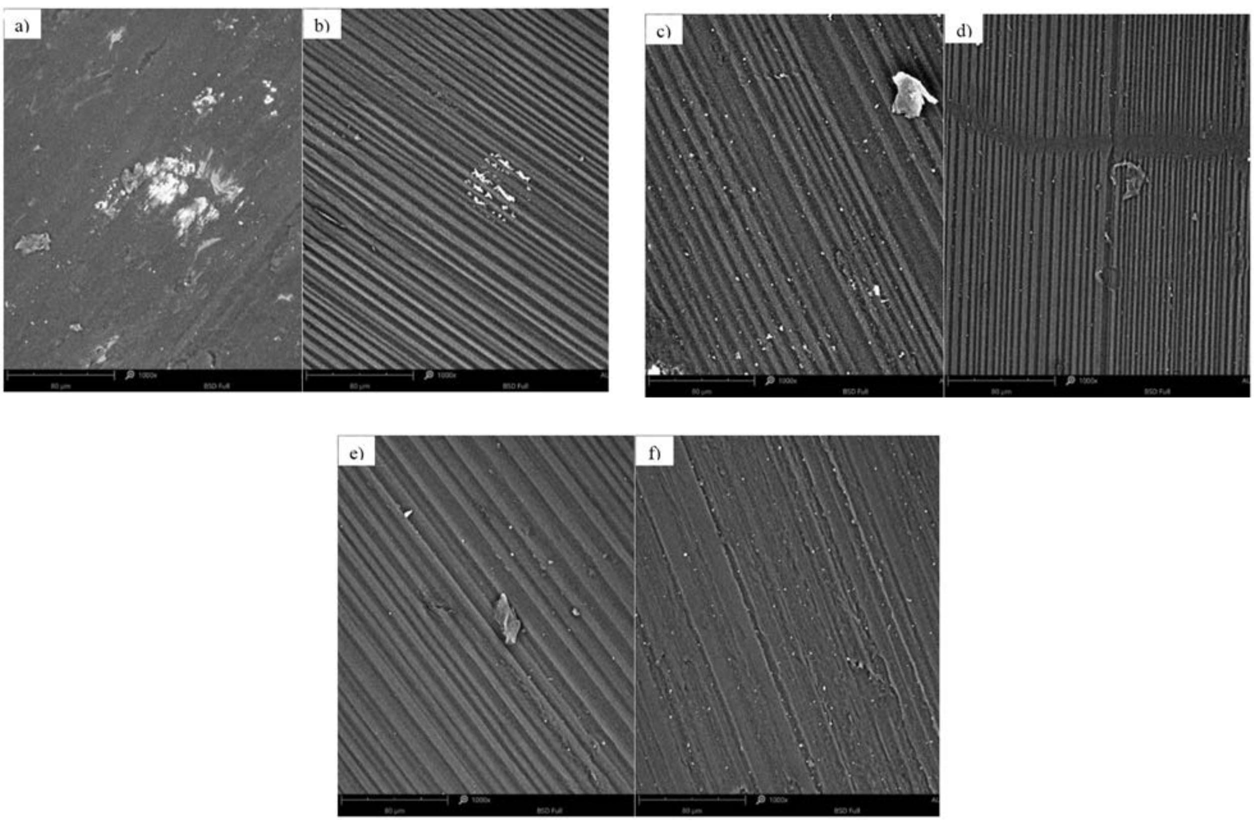

Fig. 5. Surface of examined filament specimens after tests: a) Iglidur I180, b) PLA Natural, c) PLA + 5% graphite, d) PLA + 10% graphite, e) PLA + 20% graphite, f) PLA + 30% graphite, SEM x1000

Rys. 5. Powierzchnia próbek po testach: a) Iglidur I180, b) PLA Natural, c) PLA + 5% grafit, d) PLA + 10% grafit, e) PLA + 20% grafit, f) PLA + 30% grafit, SEM x1000

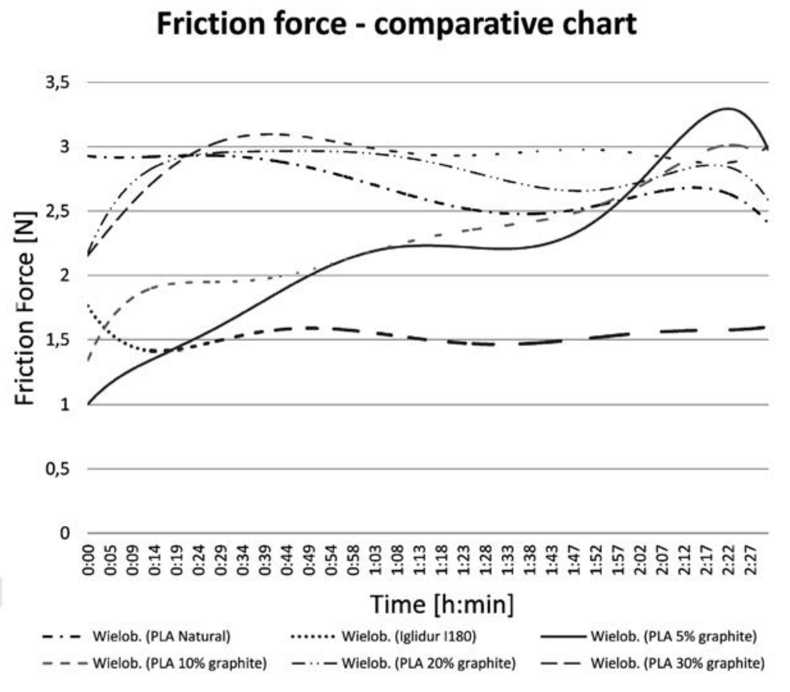

Fig. 6. Graph of friction force for samples: Iglidur I180, PLA Natural, PLA + 5% graphite, PLA + 10% graphite, PLA + 20% graphite, PLA + 30% graphite

Rys. 6. Wykresy siły tarcia dla próbek: Iglidur I180, PLA Natural, PLA + 5% grafit, PLA + 10% grafit, PLA + 20% grafit, PLA + 30% grafit

The specific results are presented in **Tab. 2**. The lowest values of wear and the coefficient of friction occurred for Iglidur I180. Significant improvement for samples enriched with graphite appeared in samples with 5% graphite. However, low linear wear and a high coefficient of friction occurred for the sample with the addition of 30% graphite and a high linear wear and low coefficient of friction for the sample with the addition of 10% graphite.

Tab. 2. Results of a study

Tab. 2. Wyniki badań

Material	Average linear wear [μm/km]	Average coefficient of friction
Iglidur I180	Immeasurable	0.278
PLA Natural	15.2	0.492
PLA + 5% graphite	6.2	0.397
PLA + 10% graphite	45.8	0.419
PLA + 20% graphite	15.2	0.512
PLA + 30% graphite	9.6	0.531

CONCLUSIONS

The best results with Iglidur I180 are caused by PTFE powder precipitating from the sample and creating a film layer on the steel disc (**Fig. 5a**). This layer significantly affected the test conditions, lowering the real roughness of the disc. Additionally, at the beginning of the test, a significant drop of the friction force, which represents the stage of creating PTFE film, can be observed (**Fig. 6**).

The lowest wear and coefficient of friction values were obtained for the sample with the addition of 5% graphite (**Tab. 2**). Nevertheless, the value of the coefficient of friction significantly increased with the duration of the test (possibly in higher temperatures) (**Fig. 6**). This leads to conclusion that, in short time of working (and in low temperatures), this composition can be competitive to Iglidur I180.

The sample with the addition of 30% graphite gained a considerably low linear wear rate and high coefficient of friction, which was stable throughout the whole test (**Fig. 6**).

Samples with 0%, 10% and 20% of graphite addition presented higher linear wear rate and coefficient of friction (**Tab. 2**).

In the future tests should be repeated with use of planned experiment methodology.

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