ISSN 0208-7774 TRIBOLOGIA 1/2019 p. 25–28

Wojciech PAWLAK*, Wojciech WIELEBA*, Roman WRÓBLEWSKI*

RESEARCH OF TRIBOLOGICAL PROPERTIES OF POLYLACTIDE (PLA) IN THE 3D PRINTING PROCESS IN COMPARISON TO THE INJECTION PROCESS

PORÓWNANIE WPŁYWU PROCESU DRUKU 3D ORAZ PROCESU WTRYSKIWANIA NA WŁAŚCIWOŚCI TRIBOLOGICZNE POLILAKTYD (PLA)

Key words: PLA, polylactic, polylactide, 3D printing, additive manufacturing, FFF, FDM, linear wear, injection, wear, friction.

Abstract This article presents the results of studies on the tribological properties of linear wear and kinetic friction of polylactide processed by 3D printing (FFF) and injection moulding. Research was conducted on a *pin on disc* apparatus, and the test specimens used were polylactide cylinders with the counter specimen of C45 steel disc. Research was planned and executed with the planned experiment method for two variables: velocity of the counter specimen and pressure. The range of specified values was in the following sections: $p = \langle 0.2;0.6 \rangle MPa$ and $v = \langle 0.2;1.0 \rangle \frac{m}{s}$. The conducted experiment had a target of defining the influence of a somewhat new method of 3D printing on the tribological properties of materials that might find application in prototyping plain bearings.

Słowa kluczowe: PLA, polilaktyd, druk 3D, wytwarzanie przyrostowe, FFF, FDM, zużycie liniowe, wtryskiwanie, zużycie, tarcie.

Streszczenie W niniejszej pracy przedstawiono wyniki badań właściwości tribologicznych: zużycia liniowego oraz tarcia kinetycznego dla polilaktydu przetworzonego w procesie druku 3D (FFF) oraz w procesie wtryskiwania. Badania przeprowadzone zostały na aparaturze *pin on disc*, próbkę stanowił materiał badany, przeciwpróbkę – tarcza stalowa C45. Badania zostały zaplanowane i przeprowadzone przy pomocy eksperymentu rotalnego dla dwóch zmiennych – prędkości obrotowej tarczy stalowej oraz nacisku. Zakres określonych wartości zawierał się w przedziałach: $p = \langle 0.2;0.6 \rangle MPa$ oraz $v = \langle 0.2;1.0 \rangle \frac{m}{s}$. Przeprowadzony eksperyment miał na celu przedstawienie wpływu stosunkowo nowej metody druku 3D na właściwości tworzyw sztucznych, mogących znaleźć zastosowanie w wytwarzaniu prototypowych lub krótkobieżnych łożysk ślizgowych.

INTRODUCTION

Further research **[L. 1]** of the author towards tribology in 3D printed elements led to the conclusion that, beside modifying plastics, it is also important to determine how big of a change in tribological properties the process itself makes. Over the last couple of years, development in new 3D printing materials has advanced more than the previous 40 years of the slow growth of the whole 3D printing industry. Machines used for the least expensive method (*Fused Filament Fabrication*) can now operate on temperatures of manufacturing process up to 450°C **[L. 2]**. This range of temperatures allows one to print with PEEK and ULTEM and achieve much better tribological, thermal, and mechanical properties than in previous material's groups such as ABS **[L. 3]**. So far, polylactide is considered to be the easiest material to print, with considerably good mechanical, thermal,

* Wrocław University of Science and Technology, Faculty of Mechanical Engineering, ul. Łukasiewicza 7/9, 50-371 Wrocław, Poland, e-mail: wojciech.pawlak@pwr.edu.pl, wojciech.wieleba@pwr.edu.pl, roman.wróblewski@pwr.edu.pl.

and tribological properties, than can be improved by crystallization. Those good properties were the reason to choose PLA as a material of the studies. This article presents the differences in tribological properties of PLA samples produced of the same granulate through two different processes: *Fused Filament Fabrication (FFF)* and conventional injection moulding.

RESEARCHED MATERIALS

As a test object, samples prepared of Ingeo PLA 2003d were prepared. All of the data of production process is presented in **Tab. 1**. The external fill pattern was set to be concentric to ensure the isotropy of the sample.

Table 1. Parameters of samples' manufacturing process
Tabela 1. Parametry procesu wytwarzania próbek

Parameter	Value
Pin diameter	8 mm
Pin height	8 mm
3D printed sample:	
Layer height	0.1 mm
Infill percentage	16%
Printing speed	30 mm/s
Heat bed temperature	75–70°C
Extruder temperature	200°C
Amount of full layers top-bottom	16
Nozzle diameter	0.3 mm
Internal fill pattern	Rectilinear
External fill pattern	Concentric
Injection moulding	
Injection temperature	220°C

RESEARCH METHOD

To plan the experiment, the multidimensional functions of regression were used, with is called the rotational experiment plan for two independent variables **[L. 4]**. As variables, the pin pressure on the disc and linear velocity were selected. All of the parameters and values of the research process are presented in the **Tab. 2**. As research equipment, the *pin on disc* station was used. **Fig. 1** illustrates the course of the study. The equipment is presented in **Figs. 1, 2a** and **2b**.

Table 2. Parameters of the research process
Tabela 2. Parametry procesu badawczego

Parameter	Value
Load	10.05–30.14 N
Pin pressure on the disc	0.2–0.6 MPa
Roughness of the disc	Ra (0.3–0.4)
Velocity of the disc	0.2–1.0 m/s
Length of the pin path	1 km
Friction	Dry
Temperature of environment	24.3ºC
Humidity	39%

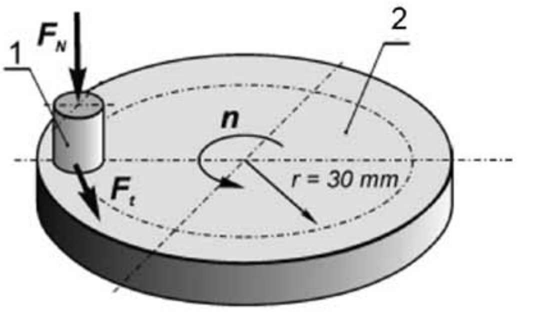

Fig. 1. Pin-on-disc scheme of research, FN – force of pressure, Ft – friction force, n – rotation speed, 1 – specimen, 2 – disc [L. 5]
Rys. 1. Schemat badania pin-on-disc, FN – siła nacisku, Ft – siła tarcia, n – prędkość obrotowa, 1 – próbka, 2 – dysk **[L. 5]**

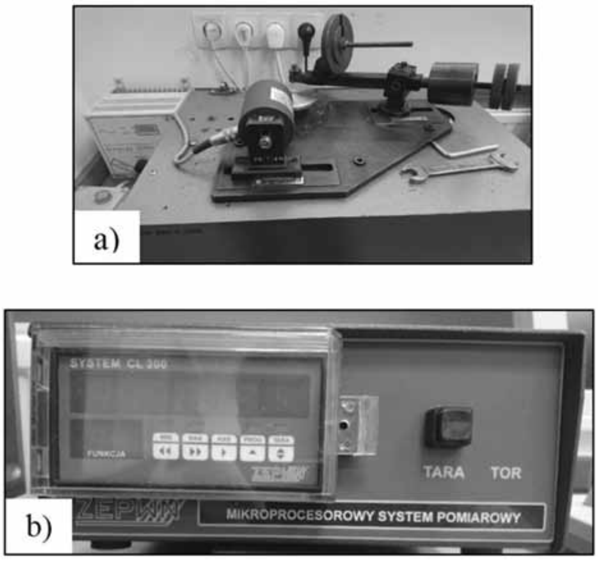

Fig. 2. Test apparatus – pin-on-disc station and force measurement system: a) Pin-on-disc station, b) Friction force measurement system [L. 5]
Rys. 2. Aparatura badawcza – stacja pin-on-disc wraz systemem pomiaru siły: a) stanowisko pin-on-disc, b) system pomiaru siły tarcia **[L. 5]**

RESULTS

Result are presented in 3D graphs in **Figs. 3–7**. First two figures present the values of the coefficient of kinetic friction for samples produced in traditional injection moulding technology and in relatively new 3D printing technology. As both samples contains kinetic friction values in the range between 0.35 and 0.55 values, there is clear trend in the injection moulding sample to decrease the value of the coefficient of kinetic friction with the increase of rotational speed and pressure. However, for the 3D printed sample, the trend is reversed. In the case of linear wear, both types of samples present similar responses in the tests.

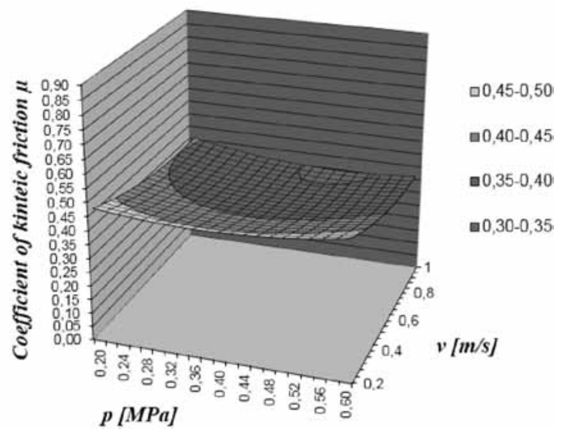

Fig. 3. Coefficient of kinetic friction in function of velocity and pressure for sample produced in injection moulding technology

Rys. 3. Współczynnik tarcia kinetycznego w funkcji prędkości i nacisku dla próbki wykonanej w technologii wtryskiwania

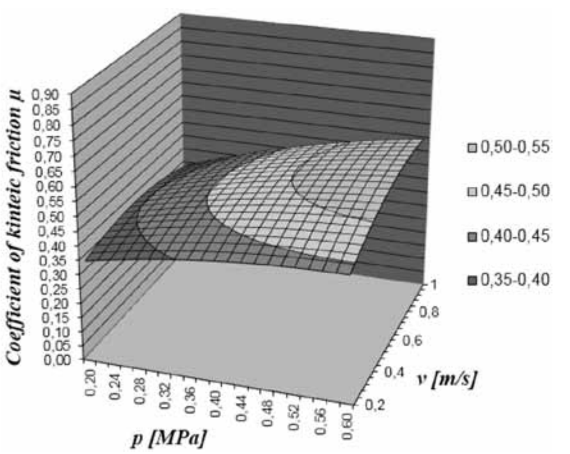

Fig. 4. Coefficient of kinetic friction in function of velocity and pressure for sample produced in 3D printing technology

Rys. 4. Współczynnik tarcia kinetycznego w funkcji prędkości i nacisku dla próbki wykonanej w technologii druku 3D

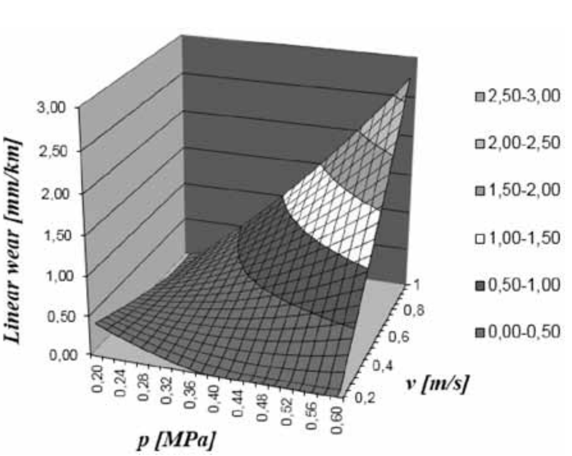

Fig. 5. Linear wear in function of velocity and pressure for sample produced in injection moulding technology

Rys. 5. Zużycie liniowe w funkcji prędkości i nacisku dla próbki wykonanej w technologii wtryskiwania

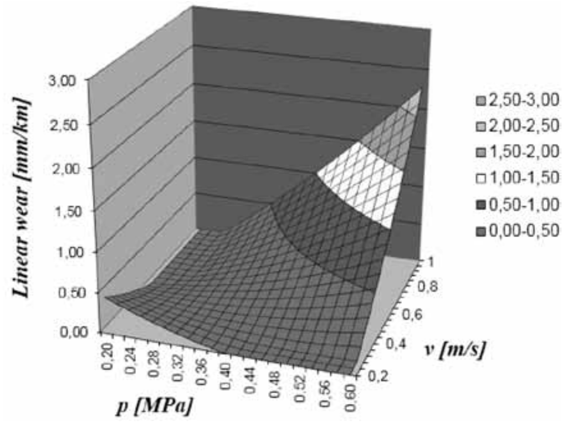

Fig. 6. Linear wear in function of velocity and pressure for sample produced in 3D printing technology

Rys. 6. Zużycie liniowe w funkcji prędkości i nacisku dla próbki wykonanej w technologii druku 3D

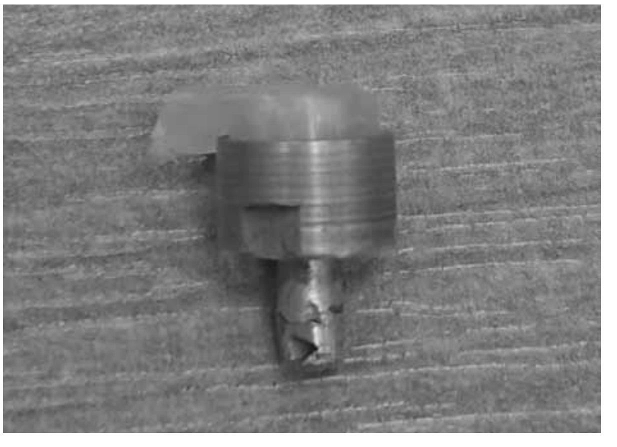

Fig. 7. Sample destroyed due to thermal degradation.

Rys. 7. Zniszczona próbka w wyniku zużycia cieplnego.

DISCUSSION

The research presented above proved that 3D printed parts can be an eligible substitute for parts produced in the injection moulding process. However, the pressure and a speed values selected for this research were significantly too high for this material, causing the destruction of samples in the highest ratio of speed and pressure. Previous research results conducted on PLA with the addition of graphite are presented in **Tab. 3**. Those research results were presented in article **[L. 6]**. In the future, similar tests are planned for PLA-graphite and PLA-MoS_2 composites. The key target is to determine the optimal, in the case of the coefficient of kinetic friction and linear wear, composition for tribological composite, suitable for 3D printing technology in the *fused filament fabrication* field. The relatively easy process and manufacturing possibilities of PLA can open a new segment of prototype sliding bearings in the future, and it may be possible to design and manufacture sliding bearings just in couple of hours.

Table 3. Results of previous studies for values $p = 0.1$ MPa, $v = 0.34 \frac{m}{s}$

Tabela 3. Wyniki badań $p = 0{,}1$ MPa, $v = 0{,}34 \frac{m}{s}$

Material	Average linear wear [µm/km]	Average kinetic 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

1. For the tests of the highest values of the *pv* ratio, much bigger role was played by thermal degradation. **Fig. 7** presents a completely destroyed sample. It leads to the conclusion that, in the next series of tests of PLA Natural, it is necessary to correct both maximum velocity and maximum pressure values.
2. 3D printed samples were characterized with a lower wear rate and higher kinetic coefficient of friction than injected samples.
3. **Table 3** presents a previous series of tests for several materials after processing with a 3D printer. Results for PLA Natural concerning the kinetic coefficient of friction correspond with result obtained in the current research.

REFERENCES

1. Pawlak W.: Wear and coefficient of friction of PLA-graphite composite in 3D printing technology, Engineering Mechanics 2018.
2. https://tractus3d.com/our-industrial-3d-printers/t650p-peek-3d-printer/
3. Wenzheng Wu, Peng Geng, Guiwei Li, Di Zhao, Haibo Zhang, Ji Zhao: Influence of layer thickness and raster angle on the mechanical properties of 3D-Printed PEEK and a comparative mechanical study between PEEK and ABS. In Materials 2015, 09.2015, 5834–5846.
4. Capanidis D.: Tribological research of multicomponent composite on a polyoxymethylene base during friction with steel, Tribologia 03/2009, 19–30.
5. Capanidis D., Wieleba W.: Badanie tarcia i zużycia kompozytów polimerowych. Laboratory instruction, Mechanical Department, Wrocław University of Science and Technology (in Polish).
6. Pawlak W., Wieleba W., Kluczyński J., Śnieżek L.: The influence of the addition of graphite on the tribological properties of polylactic (PLA) applied in 3D printing technology, Tribologia 01/2018, 89–93.