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THE INFLUENCE OF MoS_2 ON THE TRIBOLOGICAL PROPERTIES OF POLYLACTIDE (PLA) APPLIED IN 3D PRINTING TECHNOLOGY

WPŁYW DODATKU MoS_2 NA WŁAŚCIWOŚCI TRIBOLOGICZNE POLILAKTYDU (PLA) STOSOWANEGO W TECHNOLOGII DRUKU 3D

Key words: PLA, polylactic, 3D printing, additive manufacturing, MoS_2, FFF, FDM, linear wear.

Abstract: The article presents the results of basic tribological research of polylactide enriched with MoS_2 powder. The research was conducted on a pin-on-disc station. Samples dimensions: 8 mm height, 8 mm diameter, printed in FFF/FDM method. Two mass percentages of addition were created: 1% and 2.5%. As counter-specimen steel (C45) disc was used. Ra roughness of counter-specimen was in the range of 0.3–0.4. The main purpose is to determine optimal, in the light of tribological properties, mass percentage values of additions in polylactide in the 3D printing application. The research has shown that materials with more MoS_2 addition would not be a good material for use in the production of prototype bearings, due to increased linear wear. It is also worth noting that the MoS_2 addition improves material properties in terms of the 3D printing process. Thanks to the addition, even up to 1%, the required temperature of the printing nozzle has been significantly reduced, as well as flow resistance in the nozzle.

Słowa kluczowe: PLA, polilaktyd, druk 3D, technologie przyrostowe, MoS_2, FFF, FDM, zużycie liniowe.

Streszczenie: Artykuł przedstawia wyniki podstawowych badań tribologicznych polilaktydu wzbogaconego proszkiem MoS_2. Badania zostały przeprowadzone na stanowisku pin-on-disc. Jako próbki zostały zastosowane walce o średnicy 8 mm, wytworzone w technologii FFF/FDM, stopnie wzbogacenia próbek to 1% oraz 2,5% wag. Jako przeciwpróbkę zastosowano dysk ze stali C45 o chropowatości Ra = 0,3–0,4. Badania mają charakter wstępny mają na celu ustalenie optymalnych pod kątem właściwości tribologicznych, wartości zawartości dodatków w polilaktydzie stosowanym w druku 3D. Badania wykazały, że materiały z większą ilością dodatku MoS_2 nie stanowiłyby dobrego materiału do zastosowania w produkcji prototypowych łożysk ślizgowych z powodu zwiększonego zużycia liniowego. Wartym odnotowania jest również fakt, iż dodatek MoS_2 powoduje polepszenie właściwości materiałowych pod kątem procesu druku 3D – dzięki dodatkowi już nawet w wysokości 1% znacznie obniżona została wymagana temperatura dyszy drukującej, a także obniżone opory przepływu w dyszy.

INTRODUCTION

The last decade brought rapid development into the 3D printing industry. In those years, researches and companies spent money and time on not only improving methods of printing and machines but also on researching properties of different materials that can be used in 3D printing. One of the biggest achievements in this field was engineering a PTFE material for 3D printing by the 3M Company **[L. 1]**.

Tribology in 3D printing is often a neglected issue. But in these properties provide a way to faster manufacturing and more durable ready components. Nowadays, speeds around 100 mm/s are very difficult

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to achieve on most 3D printers, and speeds around 60 mm/s are a standard value. Engineering materials with decreased friction will lead to shortening the time of manufacturing and, in consequence, lowering the cost, which still is one of the biggest issues with 3D printing technologies.

In this research, the author decided to determine the influence of MoS_2 addition on a PLA 3D printing material. Based on articles **[L. 2, 3],** MoS_2 should have an advantageous influence by lowering resisting force for sliding.

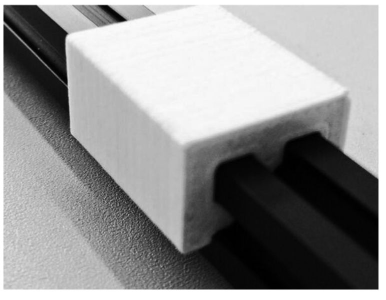

Fig. 1. Linear guide way block 3D-printed with Igus filament [L. 4]
Rys. 1. Wózek prowadnicy liniowej wydrukowany z użyciem filamentu Igus **[L. 4]**

RESEARCHED MATERIALS

These series of tests concerned 2 investigated materials and 2 reference materials. Researched materials were 3D printed samples of PLA with additions of MoS_2 in 1% and 2.5% of the weight of a whole batch. Reference materials: 3D printed plain PLA and injected plain PLA.

METHODOLOGY

All of the tests were conducted on a pin-on-disc station. Parameters of the research process are presented in **Tab. 1**. The general scheme of the test is presented in **Fig. 2** and testing apparatus in **Fig. 3**. Measurements of linear wear were conducted at a stable temperature before and after the tests.

SEM observations were made with a Phenom ProX aparature. Acceleration voltage was equal 15kV and the magnification was 400x and 1000x. Each sample was examined before and after pin-on-disc investigation.

In order to determine each sample's linear wear, it was measured with a micrometer before and after the research process. Before every measurement, there was a waiting period of 5 minutes to rule out the influence of a thermal expansion. For every material, 4 samples created in the same printing/injection process were tested. Based on four samples for each material, the average value and expanded uncertainty was calculated.

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

Parameter	**Value**
Time of the test	2h 27min
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%

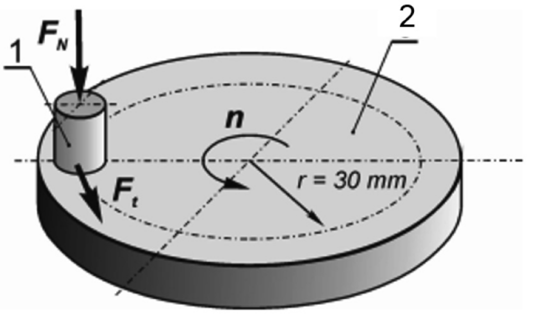

Fig. 2. Pin-on-disc scheme of research: F_N – the force of pressure, F_t – friction force, n – rotation speed, 1 – specimen, 2 – disc [L. 5]
Rys. 2. Schemat badania pin-on-disc: F_N – siła nacisku, F_t – siła tarcia, n – prędkość obrotowa, 1 – próbka, 2 – dysk **[L. 5]**

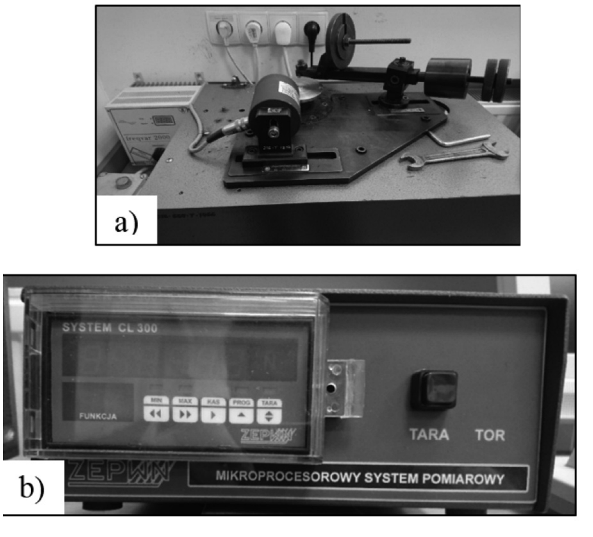

Fig. 3. Test apparatus – pin-on-disc station and force measurement system: a) Pin-on-disc station, b) Friction force measurement system
Rys. 3. Aparatura badawcza – stacja pin-on-disc wraz systemem pomiaru siły: a) stanowisko pin-on-disc, b) system pomiaru siły tarcia

All of the tests were conducted on a pin-on-disc station. Parameters of the research process are presented in **Tab. 1**. The general scheme of the test is presented in **Fig. 2** and testing apparatus in **Fig. 3**. Measurements of linear wear were conducted at a stable temperature before and after the tests.

RESULTS

Figure 4 presents images of all tested materials in 1000x magnification with the SEM aparature. In both plain PLA samples, there are clear signs of wear visible. In MoS_2 samples, with increasing addition percentage value, the signs of wear fade out. Moreover, in the sample with less MoS_2 addition, there are more visible rolled-up wear products.

Increasing the addition of MoS_2, as seen in **Fig. 5** and **Fig. 6**, causes higher and more frequent changes of friction force, which can indicate stick-slip behaviour. A lower addition of MoS_2, as seen in **Fig. 6**, in comparison to both PLA Natural samples, took shorter to achieve stable friction force, which can be seen as a positive feature.

Figures 9 and **10** present average values of linear wear and the kinetic friction coefficients. A higher addition of MoS_2 causes significantly higher rates of linear wear, although the coefficient of kinetic friction of both MoS_2 becomes slightly lower in comparison to printed PLA Natural samples. The lowest values of kinetic friction coefficient were observed in injected PLA Natural samples.

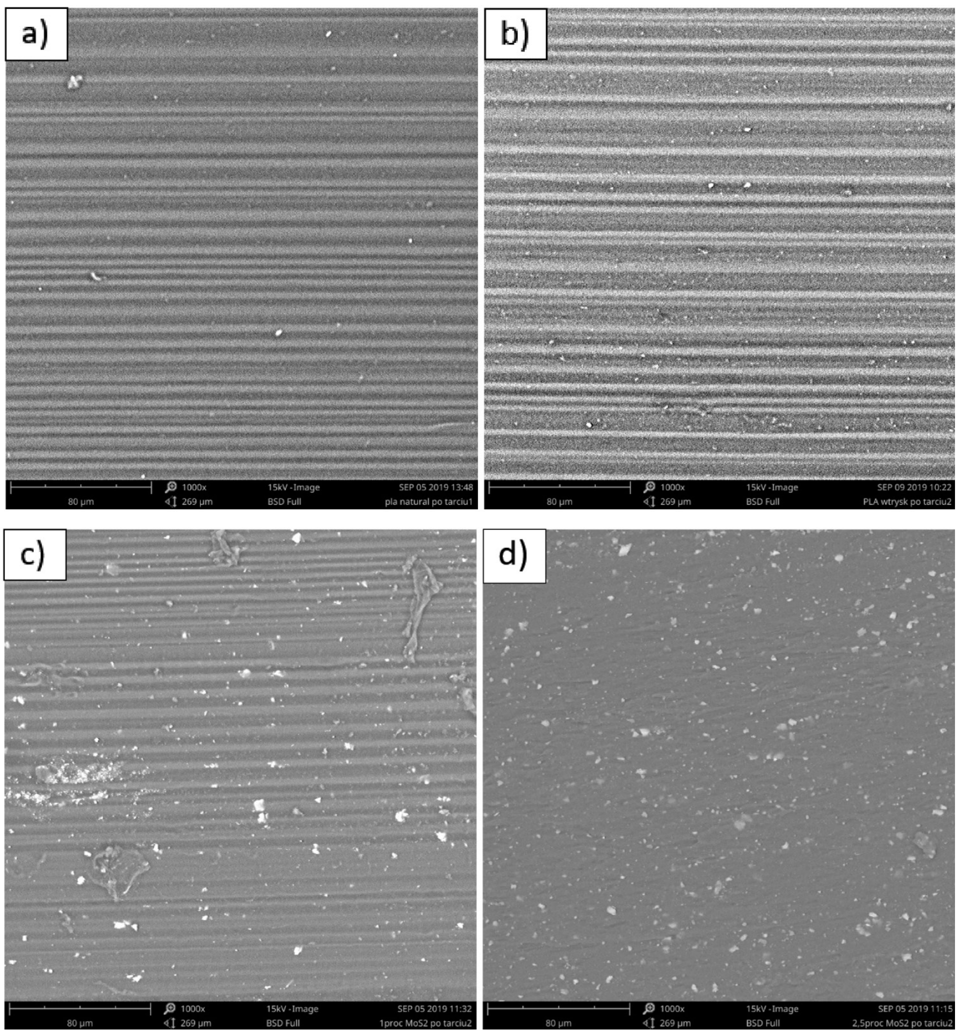

Fig. 4. Surfaces of examined filament specimens after tests: a) PLA Natural, b) PLA after injection, c) PLA + 1% MoS_2, d) PLA + 2.5% MoS_2 SEM x1000

Rys. 4. Powierzchnie testowanych próbek pod mikroskopem: a) PLA Natural, b) PLA po wtrysku, c) PLA + 1% MoS_2, d) PLA + 2.5% MoS_2 SEM x1000

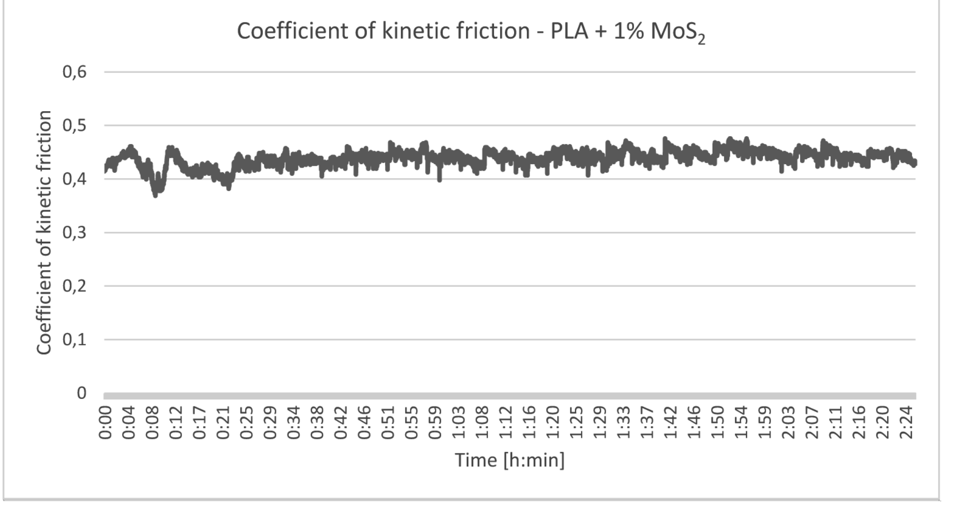

Fig. 5. Values of the kinetic friction coefficient during the whole test – PLA + 1% MoS_2
Rys. 5. Wartości współczynnika tarcia kinetycznego w trakcie całego badania – PLA + 1% MoS_2

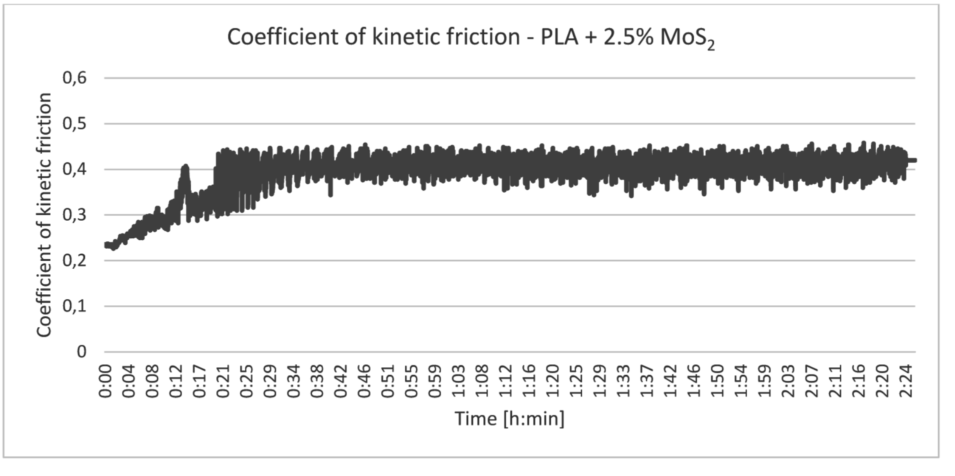

Fig. 6. Values of the kinetic friction coefficient during the whole test – PLA + 2.5% MoS_2
Rys. 6. Wartości współczynnika tarcia kinetycznego w trakcie całego badania – PLA + 2.5% MoS_2

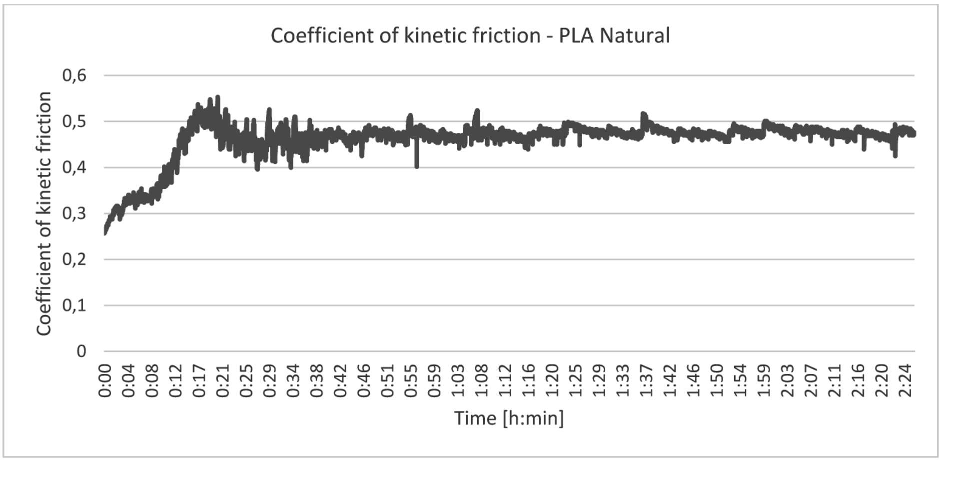

Fig. 7. Values of the kinetic friction coefficient during the whole test – PLA Natural printed
Rys. 7. Wartości współczynnika tarcia kinetycznego w trakcie całego badania – PLA Natural drukowane

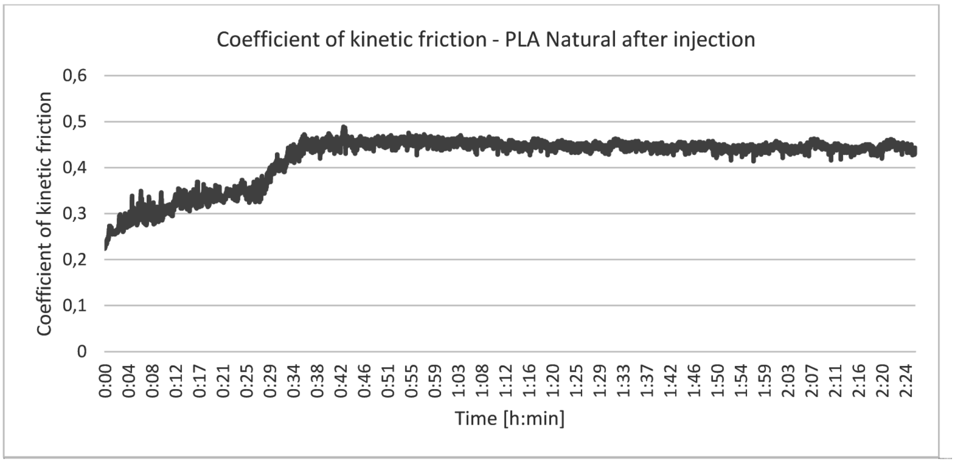

Fig. 8. Values of the kinetic friction coefficient during the whole test – PLA Natural after injection process
Rys. 8. Wartości współczynnika tarcia kinetycznego w trakcie całego badania – PLA Natural po procesie wtrysku

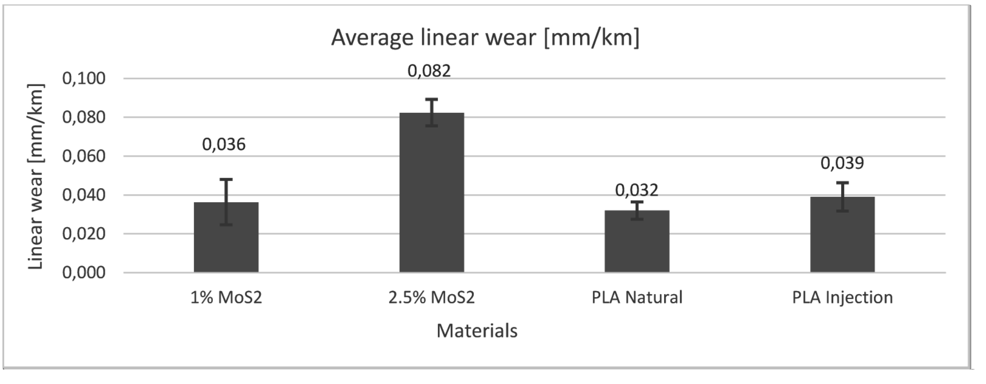

Fig. 9. Comparison of linear wear values for all materials
Rys. 9. Zestawienie porównawcze wartości zużycia liniowego wszystkich materiałów

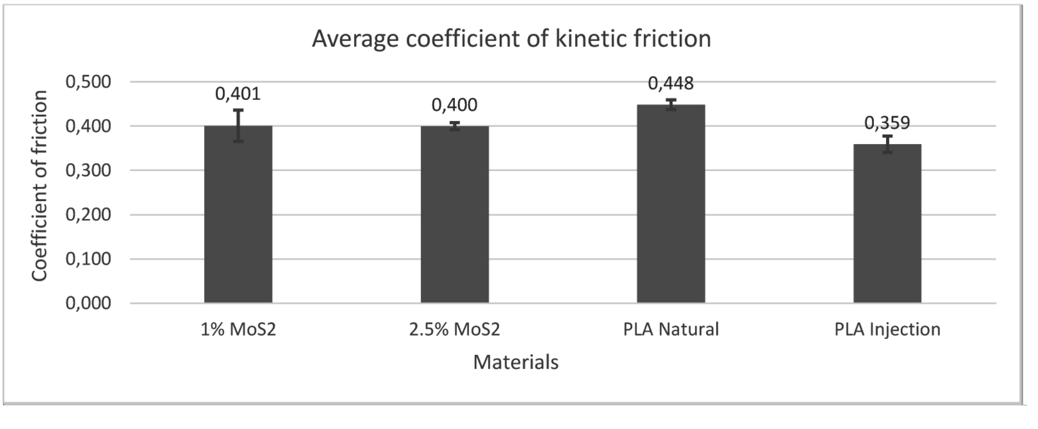

Fig. 10. Comparison of kinetic friction coefficient values for all materials
Rys. 10. Zestawienie porównawcze wartości współczynnika tarcia kinetycznego wszystkich materiałów

CONCLUSIONS

Material with 1% addition of MoS_2 powder presented similar results of linear wear to the reference material: printed PLA Natural, although higher uncertainty of measurement and a higher linear wear of 2.5% addition sample can indicate the negative influence of a MoS_2 addition on this property.

The coefficient of kinetic friction for both researched materials was slightly lower than the reference material.

The graph of the coefficient of kinetic friction for material with 2.5% addition of MoS_2 can indicate the possibility of stick-slip behaviour. Additionally, as SEM observation has shown, there are no visible clear signs of wear, as in other samples. There will be additional tests to determine this.

Significantly higher linear wear result for the 2.5% MoS_2 addition shows that the optimal value of addition has been exceeded.

ADDITIONAL OBSERVATIONS

The addition of MoS_2 has a positive influence on material behaviour during production and 3D printing processes. Even a 1% addition lowers the viscosity, which leads to improving lamination between layers during the 3D printing process.

Comparing results to previous research on 3D printing materials **[L. 6, 7]**, MoS_2 based composites presents worse tribological properties than some of the graphite-based composites. On the other hand, the bigger the graphite addition, the more brittle the material becomes.

Composites with higher percentage additions of MoS_2 are not suitable to use as bearing materials. Although the coefficient of friction was not higher than the basic material, wear and the course of friction force show that there is a high risk of stick-slip occurrence, which can lead to the unstable behaviour of bearing node.

On the other hand, MoS_2 addition improved the printing process by lowering the temperature needed to melt the material and decreasing flow resistance in the printing nozzle. Small additions (lower than 1%) can be desirable in 3D printing materials.

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