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THE INFLUENCE OF SELECTIVE LASER SINTERING PARAMETERS ON TRIBOLOGICAL PROPERTIES OF PA 3200 GF POLYAMIDE

WPŁYW PARAMETRÓW SELEKTYWNEGO SPIEKANIA LASEROWEGO NA WŁAŚCIWOŚCI TRIBOLOGICZNE POLIAMIDU PA 3200GF

Key words: SLS, PA 3200 GF, Additive Technologies, Formiga P100.

Abstract The paper presents the preliminary results of tribological research on the material used in the selective laser sintering technology, SLS. The samples in the shape of rings were manufactured of PA 3200 GF polyamide powder additionally reinforced with glass fibre, which is based on pure PA 2200 polyamide. The tests were carried out on a tribological T-15 tester, ring-on-disc type imitating the cooperation conditions of elements, e.g., the rings of the contact active seal. The main objective of the research was to determine the influence of the direction of the positioning of the models on the construction platform on the coefficient of friction and the wear of the cooperating friction pair components.

Słowa kluczowe: SLS, PA 3200 GF, Technologie Przyrostowe, Formiga P100.

Streszczenie W pracy przedstawiono wstępne wyniki badań tribologicznych materiału stosowanego w technologii selektywnego spiekania laserowego SLS. Próbki w kształcie pierścieni wykonane zostały z poliamidowego proszku PA 3200 GF dodatkowo wzmacnianego włóknem szklanym na bazie poliamidu PA 2200. Badania przeprowadzono na testerze tribologicznym T-15 typu pierścień–tarcza odwzorowującym warunki współpracy elementów takich jak np. pierścienie czołowego uszczelnienia stykowego. Głównym celem badań było wyznaczenie wpływu kierunku usytuowania modeli na platformie budowania na współczynnik tarcia oraz zużycie współpracujących elementów pary ciernej.

INTODUCTION

Additive, unconventional manufacturing technologies allowing the immediate construction of physical models directly from 3D models are more and more often used to build fully functional elements of machines and mechanisms. Currently, layered technologies are used in many areas of industry, e.g., prototype production **[L. 5, 12]** or the construction of tools used in the production of conventional manufacturing technologies (foundry, machining, injection moulding). The mechanical properties of the materials used are so good that they are also used to build components exposed to the wear process **[L. 7]**. Tribological processes occurring in the friction pair often determine the reliability and durability of such devices and have a direct impact on their proper functioning **[L. 1, 2]**. Due to the layered nature of model construction, most of the models produced using additive technologies using materials based on plastics have anisotropic mechanical properties and dimensional-shape accuracy **[L. 3, 4]** depending on the orientation of the models on the building platform **[L. 8]**. Due to this fact, during the research, an attempt was made to determine the impact of the positioning of the models on the construction platform on the tribological properties of the polyamide samples. The phenomenon of anisotropy is so unfavourable that it significantly impedes the determination of the mechanical and tribological properties of the examined materials **[L. 14]**.

Due to the high degree of complexity in the construction of models using SLS technology, the current bibliography describing the impact of

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technological parameters on tribological properties does not sufficiently describe the presented subject. Selected tribological properties of materials used for construction in SLS technology have been described in several works, among others **[L. 6, 9, 13]**.

In **[L. 6]**, the basic tribological characteristics of two types of materials used in the technology of selective laser sintering, SLS (polyamide PA 2200) and photo-curing of liquid polymer resins, PJM (VeroWhite resin) were determined. The authors used the T-15 test stand (ring-on-disc type) to determine the influence of two parameters, i.e. the printing direction on the building platform and the layer thickness on the value of the friction force and the total linear wear of the friction pair.

In **[L. 9]**, the authors used the tribological pin-on-ring type tester to determine the basic tribological parameters of the friction pair. The samples were manufactured of EOSINT M Cu 3201 material based on bronze. Counter-samples were produced of glass fibre reinforced polyamide. The tests were carried out in a controlled heating chamber.

This work describes the preliminary research describing the friction process in the face contact of a fixed ring with a rotating disk. Rings (samples) for testing were made of glass fibre reinforced polyamide PA 3200 GF, based on pure PA 2200 polyamide, and the analysis of application results was compared with the results obtained for pure PA 2200 polyamide **[L. 6]**. The aim of the research was to determine the influence of the technological parameter, i.e. the direction of "print", on the total linear wear of the tribological pair and the coefficient of friction.

SLS TECHNOLOGY

Selective Laser Sintering SLS is one of the oldest additive technologies. The technology developed in the 1980s is also one of the most complex layered methods. A number of technological parameters **[L. 11]** that have a direct impact on the manufacturing process and functional properties is one of the largest in relation to other generative technologies, in particular, those based on plastics. An unquestionable advantage of SLS technology is the ability to build models with complex internal shapes, without having to carry out further removal of the supporting material. The powder in the cleaning process is removed using compressed air without using any force. In this method, a polyamide powder with a grain diameter of 0.056 mm is convey on the machine working platform over the mechanical shoulder, and then a focused CO_2 laser beam scanning the selected cross section sinter the currently built layer combining it with the previously created one. The construction and cooling process takes place in an atmosphere of inert gas (nitrogen), which prevents oxidation and ignition. After the sintering process is completed, the working platform is lowered by the value corresponding to the set layer thickness, which, in SLS technology, is at least 0.1 mm in the case of the materials used **[L. 10]**. During the tests, a Formiga P100 machine from EOS was used to produce the sample models. The mechanical properties of materials used for the construction of samples are presented in Table 1. The process of "printing" of samples and tribological tests were carried out at the Kielce University of Technology in the Laboratory of Unconventional Manufacturing Technologies.

Table 1. Mechanical properties of material: PA 2200/PA 3200 GF [L. 10]
Tabela 1. Właściwości mechaniczne materiałów: PA 2200/PA 3200 GF **[L. 10]**

Mechanical properties	Value	Unit	Standard
Young's modulus	1700/3200	MPa	EN ISO 527
Impact strength (23°C)	4.4/5.4	kJ/m^2	ISO 180/1A
Shore'a hardness (15s)	75/80	Scale D	ISO 868
Density	0.930/1.22	g/cm^3	EOS
Water absorption	1/1.5	%	D-570-98 24hr

SAMPLES

The samples for testing were designed using the CAD SolidWorks 2016 program according to the manual **[L. 15]**. The approximation of solid models with a triangle mesh was carried out for 0.01 mm linear and 10° deviation tolerances. The model saved in this way was approximated with 1220 triangles. Samples were produce in the amount of 3 pieces for each of the three variants, which is a total of 9 samples. The angles of the samples between the building platform and the working plane (friction) were 0°, 45°, and 90°. For all sample models, the layer thickness was 0.1 mm. Geometric dimensions of the samples, technological parameters, and their location on the machine platform are shown in **Figures 1** and **2** and in **Table 2**.

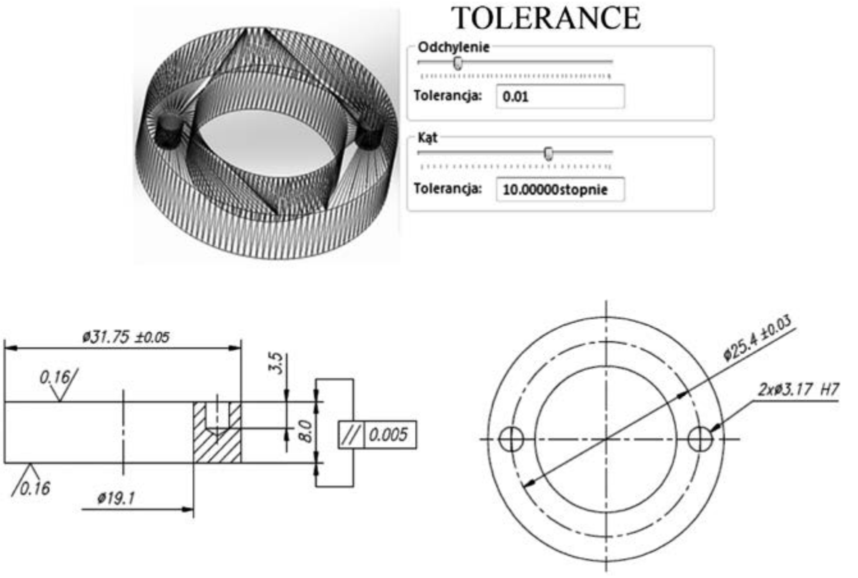

Fig. 1. Samples dimensions
Rys. 1. Wymiary próbek do badań tribologicznych

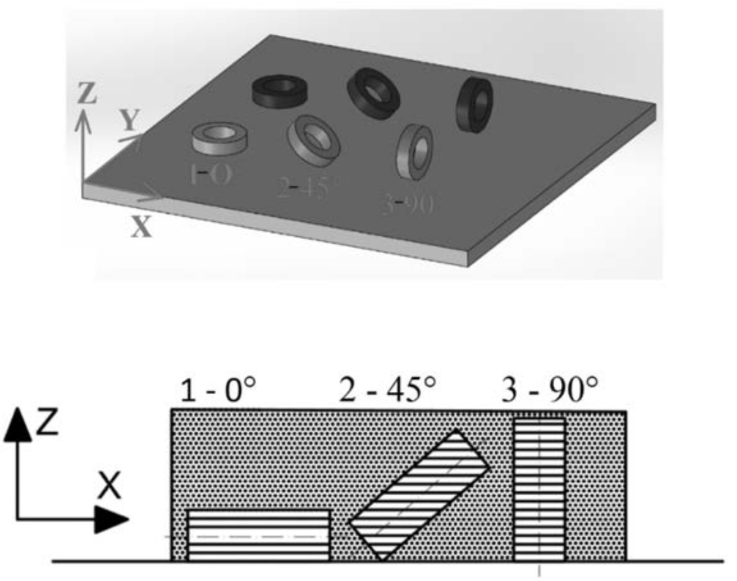

Fig. 2. Placement samples on the building platform
Rys. 2. Rozmieszczenie próbek na platformie maszyny

Table 2. Technological parameters
Tabela 2. Parametry technologiczne wytwarzania

No.	Angle, °	Layer thickness, mm
1-3	0	
4-6	45	0.1
7-9	90	

RESEARCH METHODOLOGY

Tribological tests were carried out using a T-15 tester consisting of a test machine, a measurement and control system, and a computer with software for testing and recording results. The ring-on-disc tribological tester enables both the registration of test results and the smooth regulation of conditions, i.e. the rotation speed. The principle of the operation of the station is shown in **Figure 3**. The turning disc made of C45 steel contacts the face with a fixed, ring-shaped sample, which is pressed by the lever with a given force of 150N. The device allows one to measure the total wear of the tribological pair measured linearly and the friction force. Due to the use of a closed chamber and two separate sensors, it is possible to measure the temperature both in the test chamber and near the place of contact between the sample and the counter-sample. The test chamber is equipped with a heating system with the possibility to regulate the temperature in the range from ambient temperature up to 200°C. Taking into account the layered construction and composition (the addition of fiberglass) of sample models in the case of the above-mentioned research, the main type of wear will be abrasive wear.

The parameters of the research cycles were determined based on maximum surface pressures and previously conducted experimental research **[L. 6]**. The rotational speed of the disc was set at 150 rotations/minute, the test cycle time was extended to 3600 seconds, and the sample load was 75 N. During the tests, the friction force, the total abrasive wear, and the temperature near the contact of the surfaces were measured. In addition, each completed research process was extended by analysing the total wear after the cooling of the friction pair to the initial temperature of the test.

Based on the calculated contact area of the sample with the counter-sample of – 505.21 mm^2 and the loading force – 75 N, the pressure at the contact surface is 0.148 MPa. This is a very low value with respect to the strength of polyamide compressive materials at 30–70 MPa.

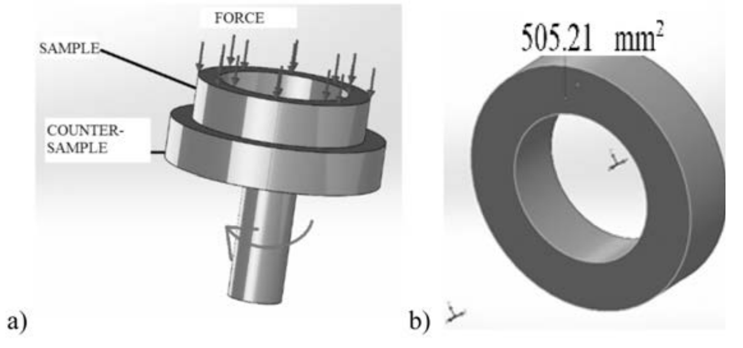

Fig. 3. Testing stand: a) tribological model, b) friction surface [L. 6]
Rys. 3. Stanowisko badawcze: a) uproszczony model układu tribologicznego, b) powierzchnia styku **[L. 6]**

RESEARCH RESULTS

The measurement of the surface texture before the test cycle, to adapt the surface of the sample to the requirements of the test stand, was carried out using a Talysurf CCI Lite optical profilometer by Taylor Hobson.

The test results are presented in **Figures 4–6** and in **Table 3**, where t1 and t2 are respectively the result after 1 hour (test cycle) and the result after cooling to the initial temperature. In the case of SLS technology, the friction forces increase their value at the beginning of the test, and then its stabilization can be noticed. **Figures 4–6** show the results of tests obtained directly from the T-15 tester software.

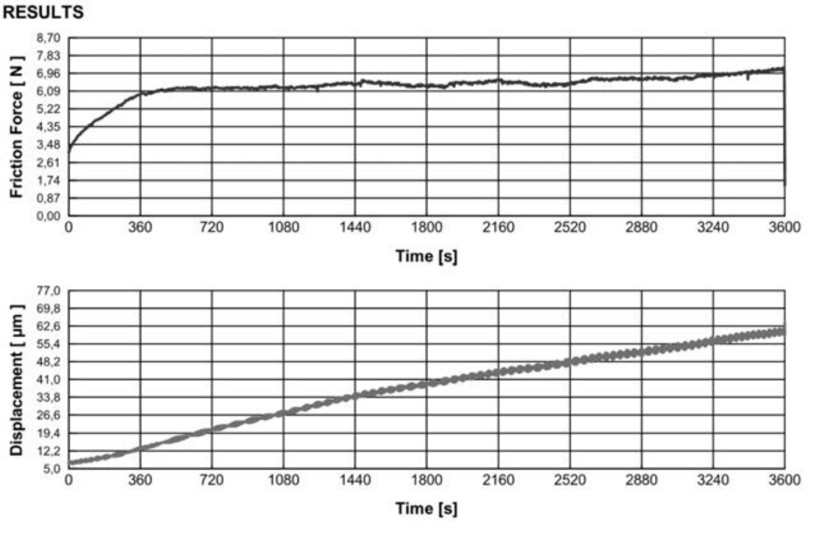

Fig. 4. Research results, angle 0°
Rys. 4. Wyniki badań, kąt 0°

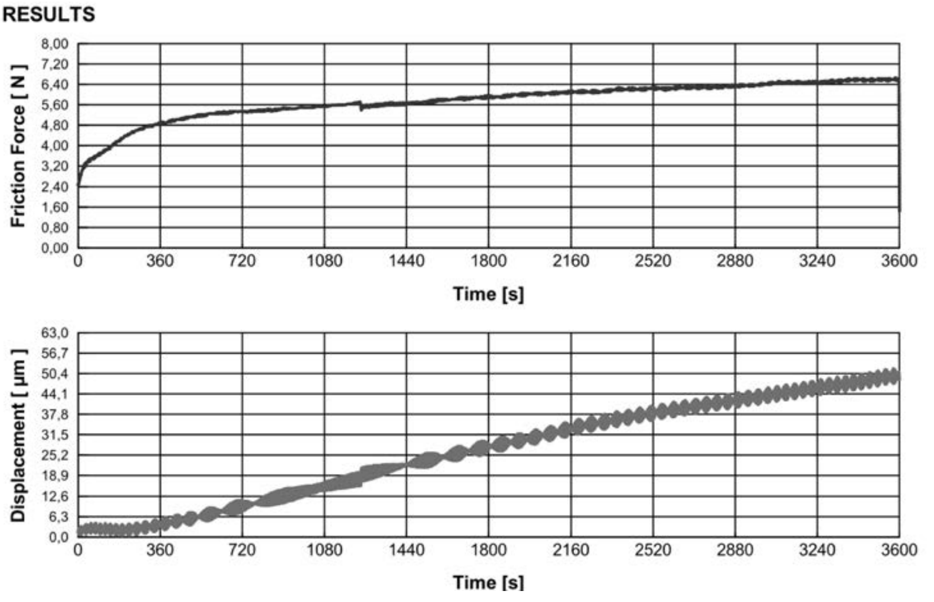

Fig 5. Research results, angle 45°
Rys 5. Wyniki badań, kąt 45°

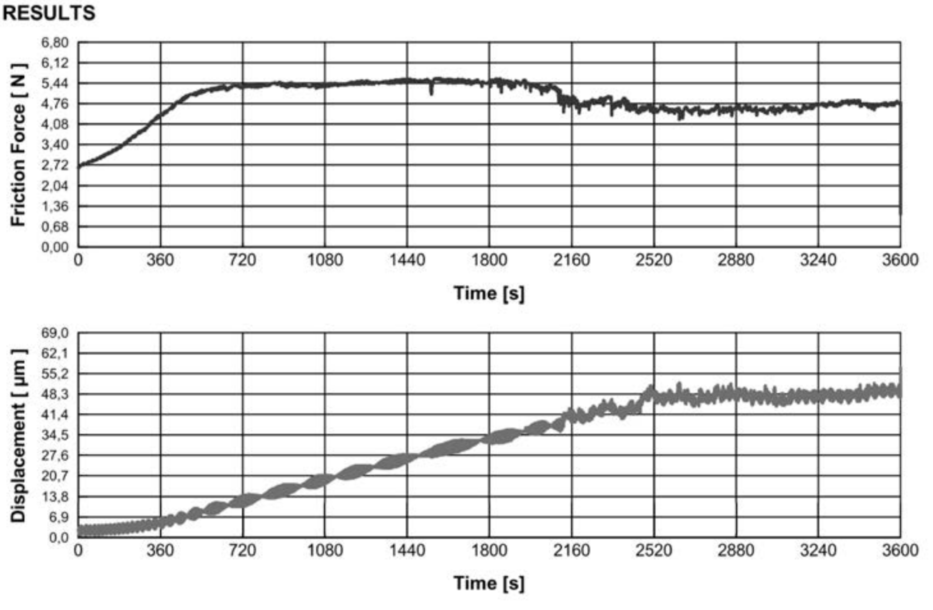

Fig 6. Research results, angle 90°
Rys 6. Wyniki badań, kąt 90°

Analysing the presented research results and comparing them with the previous ones regarding pure PA 2200 **[L. 6]** polyamide, it can be stated that the positioning of models on the machine (printer) platform in SLS technology has a significant influence on the process of producing models.

In the case of glass fibre reinforced polyamide samples, the linear wear of samples during the test cycle is noticeable. This applies to all types of model orientation on the build platform (**Figures 4–6**). A deeper analysis, which is based on the re-measurement of wear after cooling of friction pair to the initial temperature of the process, shows different characteristics. It is clearly visible that the linear increase in temperature in the friction zone directly affects the analysis of test results. The thermal expansion of the elements of friction is at a high level, which somewhat misleads the image of the preliminary results. The re-measurement reveals that, despite imperceptible initial differences in wear, the direction of the location plays a key role. The wear is respectively equal 15.43 µm – 0°, 24.1 – 45°, and 6.17 – 90°. This indicates that the glass fibre reinforced polyamide behaves in a similar way to the case of pure polyamide PA 2200, where wear at 45° was the largest. The presented conclusions confirm the value of wear intensity presented in **Table 3**.

It is noticeable that the products of the wear process from the counter sample are absorbed by samples. The frictional force, as shown by the results of the tests presented in **Figures 4–6**, reduces the value according to the increase in the printing angle from the level of 6.49 N to 5.44 N. In the same way, it related to the value of the coefficient of friction, whose value is below 0.1.

Table 3. Tribological research results
Tabela 3. Wyniki pomiarów tribologicznych

No.		Coefficient of friction	Temperature after t_1	Linear wear t_1, µm	Linear wear t_2, µm	Intensity of wear, µm/km
1	0°	0.08	63,250	63.25	13.30	18.54
2		0.10	61,125	61.13	13.10	18.26
3		0.08	71,250	71.25	19.90	27.74
mean		0.09	65,208	65.21	15.43	21.51
4	45°	0.07	75,375	75.38	45.40	63.28
5		0.09	50,875	50.88	22.00	30.66
6		0.09	48,100	72.20	4.90	6.83
mean		0.08	58,117	66.15	24.10	33.59
7	90°	0.06	50,625	50.63	18.50	25.79
8		0.07	41,444	53.60	0	0
9		0.08	45,760	72.13	0	0
mean		0.07	45,943	58.79	6.17	8.60

CONSLUSIONS

When analysing the results of tribological tests of samples manufactured in SLS technology, the following general conclusions can be formulated:

For polyamide samples (PA 3200 GF) with fiberglass-reinforced SLS technology, the highest wear occurs for samples at an angle of 45°, which is also typical for pure polyamide (PA 2200).

The direction of model positioning clearly influences the value of the coefficient of friction. The most advantageous variant showing the lowest value of the above parameter is placing the samples at an angle of 90°.

For all types of samples, a linear increase in temperature in the friction zone is noticeable. In the presented studies, after a time t_1 of 3600 seconds, the temperature increased from 25°C to about 56°C, on average.

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