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ESTIMATION OF TRIBOLOGICAL PROPERTIES OF SELECTED PLASTICS MATERIALS MANUFACTURED BY EXTRUSION AND 3D PRINTING

OCENA WŁAŚCIWOŚCI TRIBOLOGICZNYCH WYBRANYCH TWORZYW SZTUCZNYCH WYTWORZONYCH METODĄ EKSTRUZJI ORAZ DRUKOWANIA 3D

Key words: wear, sliding contact, printing 3D, extrusion moulding.

Summary: The following work presents the results of research about the assessment of tribological properties of plastics used as components in modes of transport. For this purpose, the wear resistance of materials used in 3D printing (PA6CF and ABS), and extrusion moulding
(PA) were tested. The tribological research was carried out with the use of the T-05 tester in the roller-block system. The samples in the form of cuboids with a concave rounding of one wall were made on a 3D printer using the FDM method. The counter-sample was a ring made of aluminium alloy subjected to anodizing. The research was carried out under a variable loads, in reciprocating motion, under dry friction conditions. After that the tribological characteristics were assessed. The research and analysis of the results confirmed the possibility of using selected plastics in modes of transport.

Słowa kluczowe: zużycie, kontakt ślizgowy, drukowanie 3D, wytłaczanie.

Streszczenie: W poniższej pracy przedstawiono wyniki badań polegających na ocenie właściwości użytkowych tworzyw sztucznych, które mogą być wykorzystywane jako podzespoły w środkach transportu drogowego. W tym celu przebadano odporność na zużycie materiałów wykorzystywanych w druku 3D – PAGF i ABS. Zakres przeprowadzonych badań obejmował badania tribologiczne oraz badania makroskopowe. Badania tribologiczne zostały przeprowadzone przy użyciu testera T-05 w układzie rolka–klocek. Próbki w formie prostopadłościanów z wklęsłym zaokrągleniem jednej ścianki zostały wykonane na drukarce 3D przy zastosowaniu metody FDM oraz metodą ekstruzji. Przeciwpróbkę stanowił pierścień wykonany ze stopu aluminium. Badania przeprowadzono pod obciążeniem 100, 300 i 500 N, w ruchu posuwisto-zwrotnym w warunkach tarcia suchego. Na ich podstawie dokonano oceny charakterystyk tribologicznych. Wykonane badanie i analiza ich wyników potwierdziły możliwość wykorzystania wybranych tworzyw sztucznych w środkach transportu drogowego.

INTRODUCTION

In recent years, plastic materials have become increasingly important. It can be found in almost every area of life, including transport. Plastics are materials that are relatively cheap and easy to process, and they can guarantee safety, comfort, and reduce costs. Manufacturers from the automotive industry are increasingly deciding to use technology based on plastics **[L. 1]**.

3D printing is a technology made with the incremental FDM method. The material in the form of wire is wound on a spool, which is used to feed the material to the head of the device (**Fig. 1**). The head is responsible for dosing the working material, which is heated and pressed through the nozzle. The whole thing is completed by a movable base in the X, Y, and Z axes, moving relatively to the head. Currently, it is the most popular method of additive manufacturing. The material moves between the extruder rolls towards the

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hot extrusion head, which results in its plasticization. The head has the ability to change the speed of material feed. The heated material is laid linearly, layer by layer. Each subsequent one is adjacent to the preceding one. The speed of layer application affects the rate of the cooling of the material and its properties. Slower cooling increases wear resistance. When the layer is laid, the movable base or head moves away from the manufactured object by a predetermined thickness. The plasticized material bonds under the influence of high temperature, and after it solidifies, it forms a uniform structure **[L. 2]**.

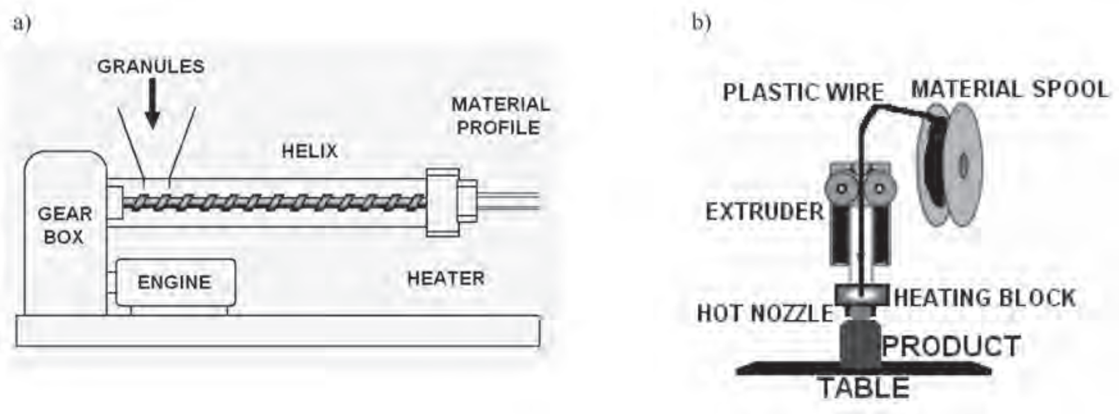

Fig. 1. Forming semi-finished or finished products of extrusion (a) and incremental (b) method
Rys. 1. Formowanie półproduktów lub gotowych wyrobów metodą wytłaczania (a) i przyrostową (b)

The evaluation of the functional properties of the tested materials was carried out in conditions that reflected the friction junction from the actual object of the selected combination, i.e. a sliding car roof, namely the AW-6062 alloy slider/profiled guide (**Fig. 2**). Sliders are made by extrusion from POM (polyacetal) or PA (polyamide), but it is not a rule **[L. 3–4]**.

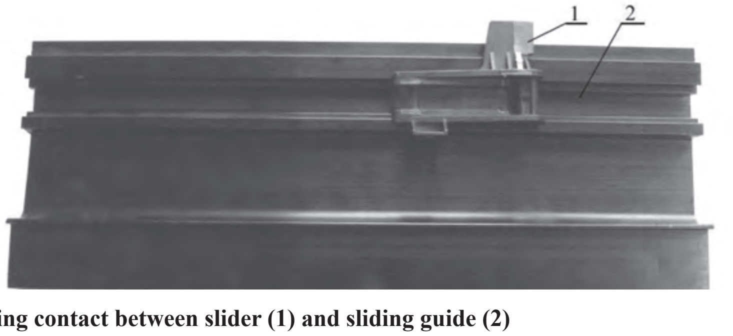

Fig. 2. Sunroof sliding contact between slider (1) and sliding guide (2)
Rys. 2. Widok skojarzenia ślizgacza (1) oraz prowadnicy (2) dachu przesuwnego

Taking into account the structure and principle of operation of a sliding car roof, the friction junction characterized by a distributed contact was mapped, which, in turn, was a decisive factor in the preparation of concave samples, and the type of movement (reciprocating) and parameters were set that will allow us to determine whether the tested materials are suitable for use as elements of the roof mechanism system. The friction path for the normal operation of the considered combination was determined.

This paper aims to answer the question of whether plastics, such as PA and ABS, can be used to produce parts of selected means of transport with 3D printing technology, based on the analysis of their wear.

TEST PROCEDURE

The paper presents the course of tribological tests of samples made of polyamide (PA6GF with glass fibres) and acrylonitrile-butadiene-styrene (ABS) produced by 3D printing with 90% filling – with the incremental method and with the extrusion method – PA12. The counter-sample was a ring made of an aluminium alloy (EN AW-2024), which was then, in the anodizing process, given the same properties over the entire surface as in the selected combination of the real object, i.e. the sliding car roof guide.

The T-05 tribological tester in the block-ring configuration was used for the tests. The measurements were carried out at room temperature, without the use of a lubricant. The system was characterized by a disassembled sliding contact, with a load Q amounting to 100, 300, and 500 N, respectively, which corresponds to the actual load in the tested system, and the speed was 24 rpm in reciprocating motion, which translates into 60 mm of friction path in one cycle and 500 m throughout the test cycle. The testing time of each individual sample was 3 hours. During the tests, the friction force was measured using a strain gauge force sensor with an accuracy of 2.5% of the measured value and the weight loss of the samples using an AS220 / C / 2 analytical balance with an inaccuracy of 0.2 mg. The wear of the anodized oxide coating was immeasurable. The wear mechanisms were assessed using macro photography.

The research association consists of a stationary sample (block) made of the tested material, pressed with a given load Q against a ring that performs an oscillating (rotational) motion with an appropriate frequency and amplitude (**Figs. 3, 4**). In the conducted tests, the counter-sample was an aluminium ring covered with an anodic oxide coating with a hardness of 450 μHV (**Fig. 5a**).

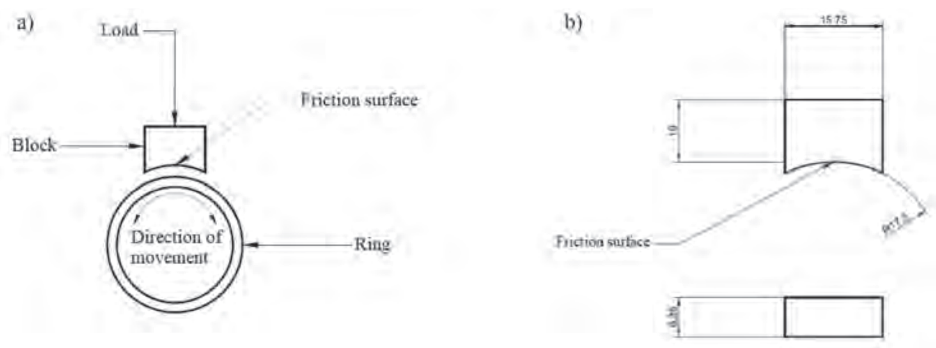

Fig. 3. Diagram of the tribological system of T-05 Tester (a) and dimensions of the tested samples (b)
Rys. 3. Schemat układu tribologicznego testera T-05 (a) oraz wymiary badanych próbek (b)

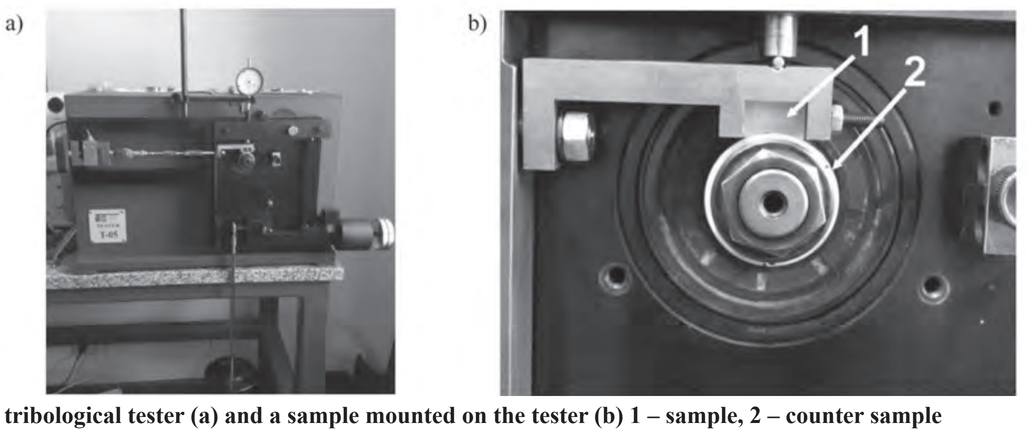

Fig. 4. T-05 tribological tester (a) and a sample mounted on the tester (b) 1 – sample, 2 – counter sample
Rys. 4. Tester tribologiczny T-05 (a) oraz próbka zamontowana na testerze (b) 1 – próbka, 2 – przeciwpróbka

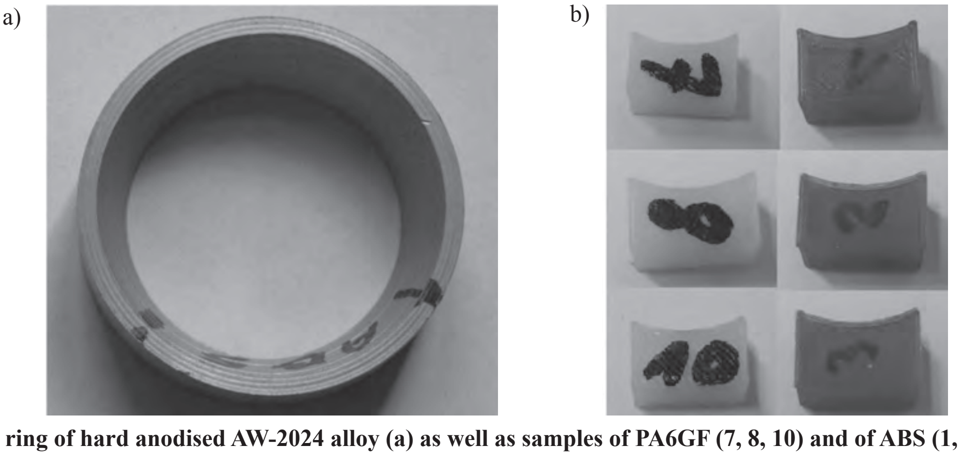

Fig. 5. Test ring of hard anodised AW-2024 alloy (a) as well as samples of PA6GF (7, 8, 10) and of ABS (1, 2, 3) – (b)
Rys. 5. Pierścień z anodowanego stopu AW-2024 (a) oraz próbki z PA6GF (7, 8, 10) i ABS (1, 2, 3) – (b)

RESULTS AND DISSCUSION

The influence of the manufacturing technique and loading on the weight loss of the samples made of the tested materials after cooperation with the anodized ring is shown in **Figure 6**. The dependence of the friction forces on the production technique, type of material, and load is shown in **Figure 7**. Photographs (8x magnification) of the friction surface of selected samples after cooperation is shown in **Figure 8**.

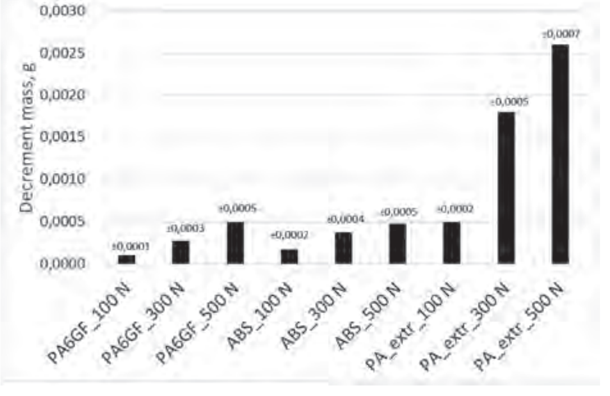

Fig. 6. Mass loss of materials at the given load

Rys. 6. Ubytek masy badanych materiałów przy zadanym obciążeniu Q

The analysis of **Figure 6** shows that the lowest wear was shown by samples made by 3D printing with PA6GF at a load of 100 N (unit pressure of 1 MPa). The increase in load increased the wear and friction force in combination with the PA. This is due to the high pressure that results in plasticising the polyamide. The presence of air in the sample (90% filling, for air λ = 0.025 – 0.045 $Wm^{-1}K^{-1}$, for PA λ_{20-100} = 0.42 – 0.38 $Wm^{-1}K^{-1}$) on the ring worsen the heat dissipation of friction. As the friction force increases, larger areas of the material heat up and deform. This is evidenced by the friction surfaces in **Figures 9a, 9c, and 9e**, which show the beginnings of material flow (1 in **Fig. 9a**), areas of deformed material (2 in **Fig. 9b**), and material flow along the entire width of the contact with the ring (3 in **Fig. 9e**). ABS behaves differently. Due to lower frictional forces, the amount of generated heat was lower, despite the fact that the thermal conductivity of ABS (λ = 0,157 W/(mK)) is half as much as that of PA. Therefore, slight changes were observed on the friction surface (1, 2, and 3 in **Figures 9b, d, f**). The friction force at the load of 300 N was the smallest, which resulted in the least changes on the ABS friction surface (2 in **Fig. 9d**). At this load value, abrasive wear was observed on the friction surface (2 in **Fig. 9d**). On the surface of the sample with a load of 500 N, the appearance of a plasticized layer (3 in

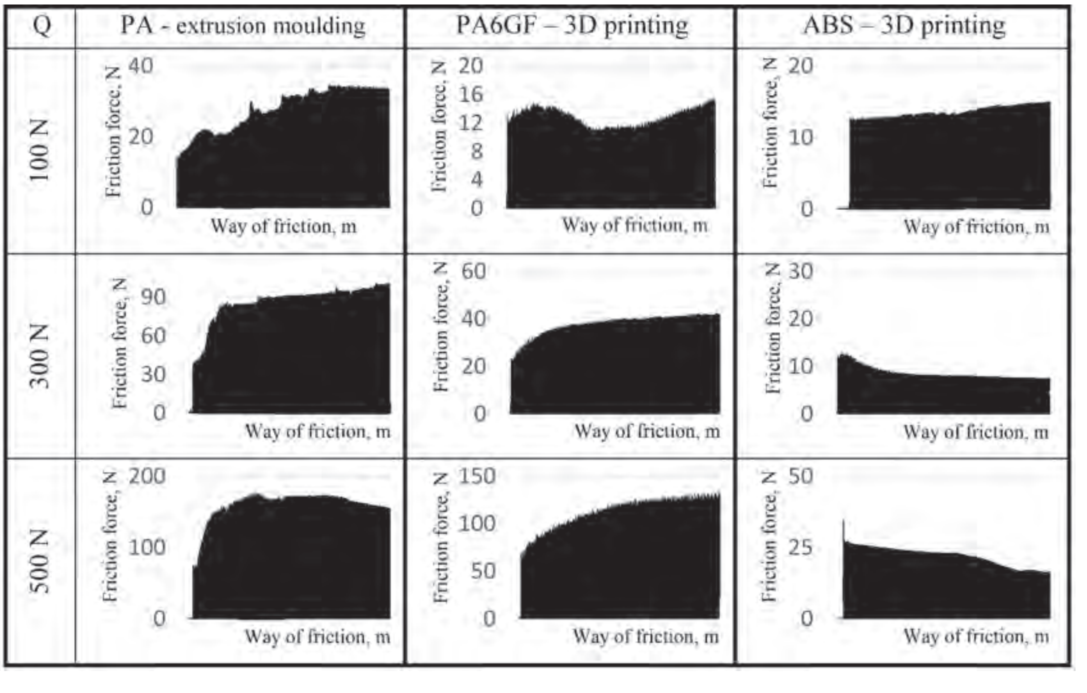

Fig. 7. Friction forces vs. sliding distance in examined contacts

Rys. 7. Siły tarcia w badanych skojarzeniach w funkcji drogi tarcia

Fig. 9f) was observed as a result of the impact of the highest values of frictional forces (2.5 times greater than the forces obtained at 300 N), which were recorded for samples made of ABS. During the sliding cooperation of samples made of PA12 by extrusion, abrasive wear of the material dominated. The micro-inequalities of the

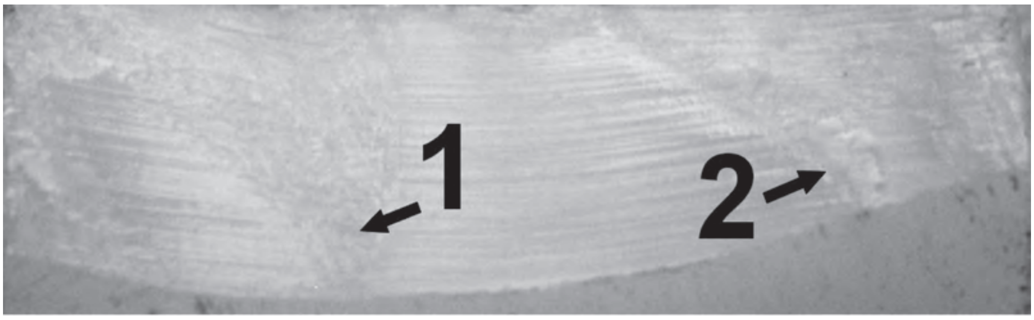

Fig. 8. Friction surface of a moulded sample made of PA12 after rubbing under a load of Q = 500 N (abrasive and adhesive wear tracks visible)

Rys. 8. Powierzchnia tarcia wytłaczanej próbki z PA12 po tarciu przy obciążeniu Q = 500 N (widoczne ślady zużywania ściernego i adhezyjnego)

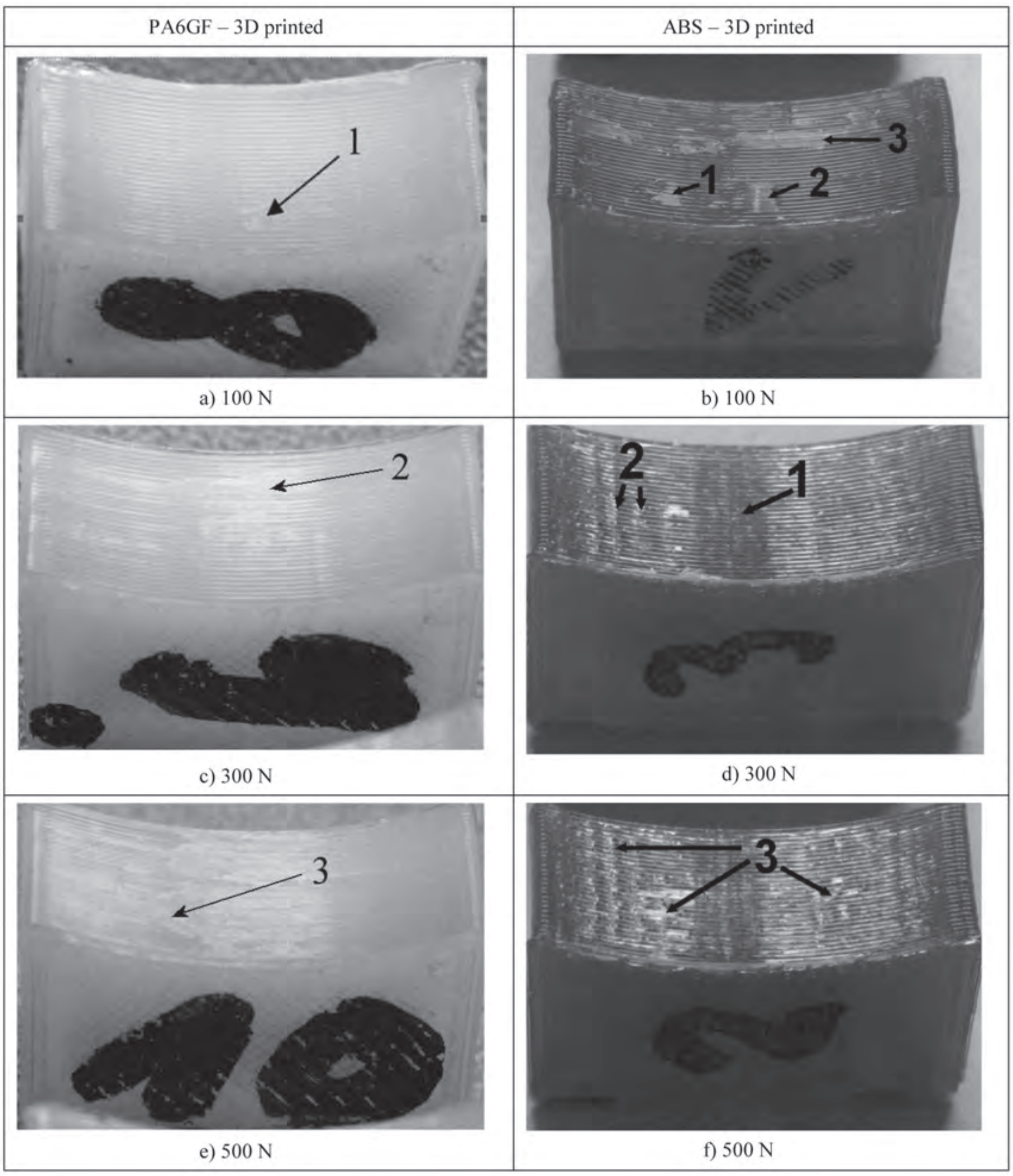

Fig. 9. Friction surface of samples in the block-ring contact

Rys. 9. Powierzchnia tarcia próbek w skojarzeniu klocek–pierścień przy obciążeniu oxide coating cut the PA12 surface, as evidenced by the scratches along the direction of the ring's movement (1) visible in the photography from **Figure 8**. The high value of friction forces caused an increase in temperature in the friction zone and plasticization of the material, which resulted in very high wear and deformation (2, 8). The higher consumption of samples made by PA12 extrusion than 3D printing with PA6GF is the presence of glass fibres in the PA6GF material. The high hardness of the fibres increases the wear resistance of the composite **[L. 6]**.

CONCLUSIONS

Based on the results of the research, the following can be concluded:

- With increasing load, the friction force increases in combination with polyamide.
- The presence of air in printed samples (10%) causes deterioration of heat dissipation conditions, which results in heating the surface layer of the material and leads to deformation and flow of the material.
- The wear resistance of samples produced by 3D printing from PA6GF is almost 5 times higher than for materials made by extrusion from PA12, which is the result of the presence of glass fibres in PA6GF.
- The wear resistance of the vehicle parts made of the tested materials is determined by the softening temperature, when exceeded, the material begins to deform plastically, which is essential in the case of slides in the sliding roof profile.
- Taking into account intermittent operation, the pair of slider / roof guide should be considered as sufficient tribological properties to ensure correct and failure-free operation of the device.

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