ISSN 0208-7774 TRIBOLOGIA 6/2020 p. 65–70
DOI: 10.5604/01.3001.0014.8338

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INFLUENCE OF 3D PRINTING TECHNOLOGY OF AUTOMOTIVE PARTS MADE OF PLASTICS ON THEIR TRIBOLOGICAL PROPERTIES

WPŁYW TECHNOLOGII DRUKOWANIA 3D SAMOCHODOWYCH CZĘŚCI Z TWORZYW SZTUCZNYCH NA ICH WŁAŚCIWOŚCI TRIBOLOGICZNE

Key words: 3D printing, sunroof slider, tribological properties, sliding contact.

Abstract: This paper presents results of tribological examinations of chosen automotive subassemblies made of plastics by using of 3D-printing. The influence of chosen technological parameters, i.e. plastic temperature, the velocity of printing head, and the height of deposited simple layer on wear of samples produced of PA 12 polymer rubbing against hard anodised sliding guide of car sunroof is defined. It was found that samples printed at minimal temperature (t = 240°C), a minimal height of deposited simple layer (h = 0,1 mm), and a minimal (40 mm/s) and maximal (v = 60 mm/s) deposition velocity show the minimal wear. Examining under similar conditions (p = 0.4 MPa, v = 2.5 m/s, reciprocating movement) of samples made by using press moulding cut out from car sub-assemblies for a comparison were carried out. As a result of experiments, it was concluded that the wear intensity of roller stretching drive belt made from composite (PA15GF) and the wear intensity of the belt itself during sliding, caused by seizure of bearing, is so high that menaces engine with damage.

Słowa kluczowe: druk 3D, ślizgacz rozsuwanego dachu, właściwości tribologiczne, skojarzenie ślizgowe.

Streszczenie: W artykule przedstawiono wyniki badań tribologicznych wybranych podzespołów samochodowych z tworzyw sztucznych wykonanych metodą drukowania 3D. Określono wpływ wybranych parametrów technologicznych drukowania, tj. temperatury tworzywa, prędkości ruchu głowicy oraz wysokości osadzanej warstwy na zużycie próbek wykonanych z tworzywa PA 12 współpracującego z anodowaną prowadnicą odsuwanego dachu samochodu. Stwierdzono, że najmniejsze zużycie wykazują próbki drukowane w minimalnej temperaturze (t = 240°C) i przy najmniejszej wysokości osadzanej warstwy (h = 0,1 mm) oraz przy minimalnej (40 mm/s) i maksymalnej prędkości osadzania (v = 60 mm/s). Dla porównania wykonano w podobnych warunkach (p = 0,4 MPa, v = 2,5 m/s, ruch posuwisto-zwrotny) badania próbek wykonanych techniką prasowania wyciętych z podzespołów pojazdów. W wyniku badań stwierdzono, że intensywność zużywania termicznego adhezyjnego wykonanej z kompozytu (PA+15%GF) rolki napinacza paska osprzętu i samego paska podczas poślizgu, np. spowodowanego zacieraniem łożyska, jest tak duża, że zagraża uszkodzeniem silnika.

INTRODUCTION

Sub-assemblies made of plastics occupy more and more place in automotive vehicles. Thanks to chosen properties of plastics, like a density less than of steel, resistance against corrosion, and many chemical reactants, a low friction coefficient when rubbing against many engineering materials, it is possible to reduce the weight of vehicles and its fuel consumption **[L. 1]**. Lower fuel consumption means lower harmfulness for the environment. Concealed sub-assemblies include the sliders of sunroofs (**Fig. 1**) and the sliders of crank-operated car windows. A visible contact with a plastic element is a tension roller of an engine accessories

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belt (a tension roller, **Fig. 2**). The sliders of a sunroof rub against made of an anodised and sealed AW-6062 aluminium alloy. The sliders of a crank-operated car window rub against the AW-6062 aluminium alloy with paint coating.

The above mentioned plastic parts have complicated spatial forms. Nowadays, they are produced by using press moulding. During rapid prototyping and production of machine parts which have complicated forms, a new technique FDM (Fused Deposition Modelling), which is 3D-printing, takes place **[L. 1–4]**. This technique allows one to produce parts that have advanced forms. Technological parameters of printing give the possibility to program the chosen properties of parts, including tribological properties **[L. 3–5]**. The slider of sunroof is made of two joined together thermoplastic polymer polyphtalamide (PPA+45%GF) joined with polyoxymethylene (POM). The sliding partner for it is a slide guide made of the AW-6062 aluminium alloy coated with 20 µm anodic aluminium oxide layer **[L. 6]**. In the automotive industry praxis, during robotised montage of roofs, there is too much friction resistance between a slider and a slide guide. It is possible to simplify the production technique and to reduce friction by using another plastic and 3D printing technique. A composite tension roller used in cars rolls with minimal slip on the composite (a rubber with a reinforcing material) belt. This roller has a small ball bearing. In the case of pitting wear of bearing, the roller will rub against a drive belt. This causes a high temperature accompanied by catastrophic thermal wear with thermal destruction of resin and damage of the belt and the roller itself (**Fig. 2c**). A damaged belt causes the destruction of accessories and motor failure.

Tribology research with a slider made of PA12 by using of 3D-printing was carried out in the Faculty of Transport and Aviation Engineering at the Silesian University of Technology. The possibility of using 3D-printing for tension roller and for a sunroof slider was also checked. The influences of 3D-printing parameters on the wear resistance of printed automotive parts are described in this paper.

MATERIALS AND METHODS

For checking of influence of 3D printing technology parameters on tribological properties of printed automotive parts, tribological examination was carried out. Because of the complex form of the slider and excessive friction by a sunroof montage into the car, an attempt to replace the currently used material for the slider was done. PA12 filament as a slider material was chosen, because of its lower price and the ability for 3D printing. Additionally, for comparison, samples cut out from the tension roller (PA+15GF) produced through moulding were examined.

On the base of the authors' experiences **[L. 6]**, literature research **[L. 1–5]**, chosen material's properties **[L. 7]**, and the capabilities of 3D printer **[L. 8]**, the following parameters were selected:

– The temperature of printer head, t, °C;
– The velocity of printing, v, mm/s; and,
– The height of the printed single layer, h, mm.

The experiment was based on multi-sectional, D-optimal, partial experiment's plan. The plan provides three levels of steering parameters, i.e. minimal (-1), average (0), and maximal (1). The border values were determined after physical analysis of material properties and 3D printer capabilities. The minimal temperature is defined by the samples and machine parts formability during printing. Viscosity of melted polymer has to ensure obtainment of a required form of products. For PA 12, the minimum temperature is 240°C. The maximum temperature is limited by the thermal destruction of polymer. At excessive filament temperatures, some gaps can be initiated in the samples **[L. 3]** and some problems with a tolerance of dimensions occur. For PA 12 plastic, the maximum printing temperature is 260°C.

Printing velocity depends on the material's viscosity at a given temperature and also depends on printer's heating device efficiency, as well as depends on the form of the product and its fillings ratio. For the selected material and the printer, the minimum velocity was 40 mm/s and the maximum velocity was 60 mm/s.

a) b) c)

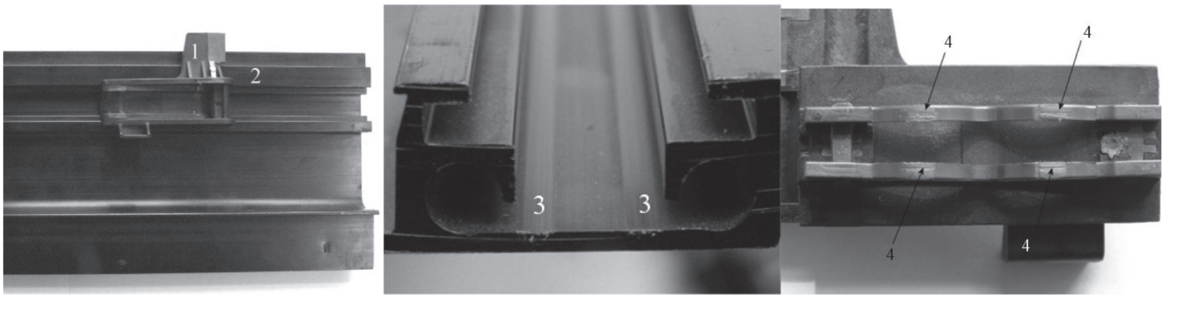


Fig. 1. Slider (1) and guide bars (2) of sunroof (a–b) and sliders with abrasive wear trucks (marked with 3 in Fig. b and 4 in Fig. c)

Rys. 1. Ślizgacz i prowadnice rozsuwanego dachu (a–b) i ślizgacz ze śladami zużycia ściernego (zaznaczone 3 na rys. b i 4 na rys. c)

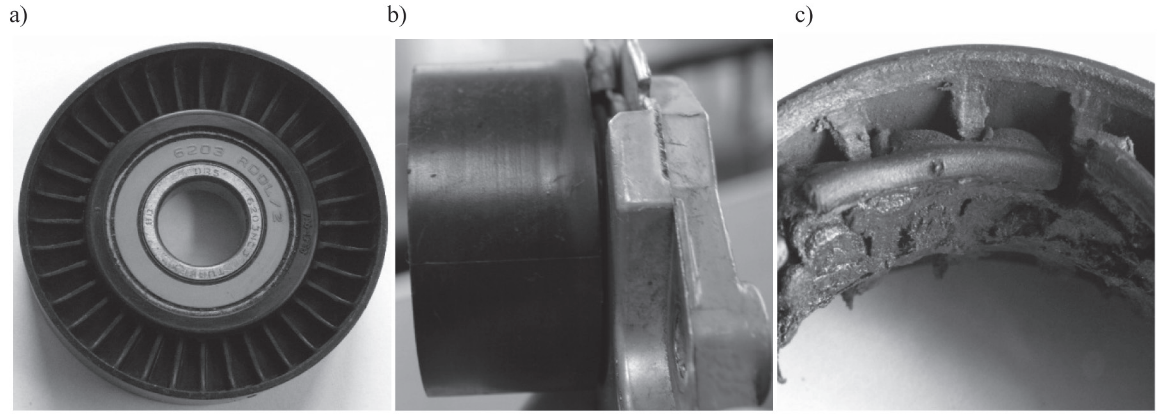


Fig. 2. Roller with complicated form putting tension on the belt (a), wear trucks on the rubbing surface (b) and roller failure as a result of thermal destruction in case of seizure of bearing (c)

Rys. 2. Rolka napinacza paska o skomplikowanych kształcie (a) i jej powierzchnia robocza ze śladami zużycia (b) oraz rolka uszkodzona cieplnie w wyniku zatarcia łożyska (c)

The height of the printed layer depends on the velocity of heat transfer away from the product to the ambient air. For the described experiment, it was assumed h_{min} = 0.2 mm and h_{max} = 0.3 mm.

From the tribological and ecological point of view, the volumetric distribution filling of a material is important. For example, 80% volumetric filing reduces the mass of automotive parts and environment pollution, but it lowers the load which the part is able to withstand. According to **[L. 3]**, a 40% hexagonal filling of PLA polymer allows the product to reach a repeatable tensile strength.

For tribological examination, the samples in a form of a cube (a = 10 mm) and the counter-samples in a form of a prism (120x14x2 mm) were used. The samples were produced using PA12 polymer (3D printed), POM (moulded), and PA+15GF (moulded). The counter-samples were cut from a sunroof slide guide made of anodised AW-6062aluminium alloy.

TRIBOLOGICAL EXAMINATION AND RESULTS

Two stages of examination were carried out, i.e. a preliminary and a basic. During the preliminary tests, the influence of filling rate (20%, 60%, 100%) was tested. The printed samples had a special form for tribological application (**Figs. 3b** and **4c**). The surface designed for friction contact consists of 5 single layers. Additionally, for comparison, the samples cut out from a moulded tension roller (PA15GF, **Figs. 4a**, **b**) and from a POM block (**Fig. 6c**) were examined. On the base of the preliminary examination results, the conditions for the basic stage were determined. Because of too high wear of the roller material rubbing against belt material, as the counter-sample, the sliding guide of sunroof was selected.

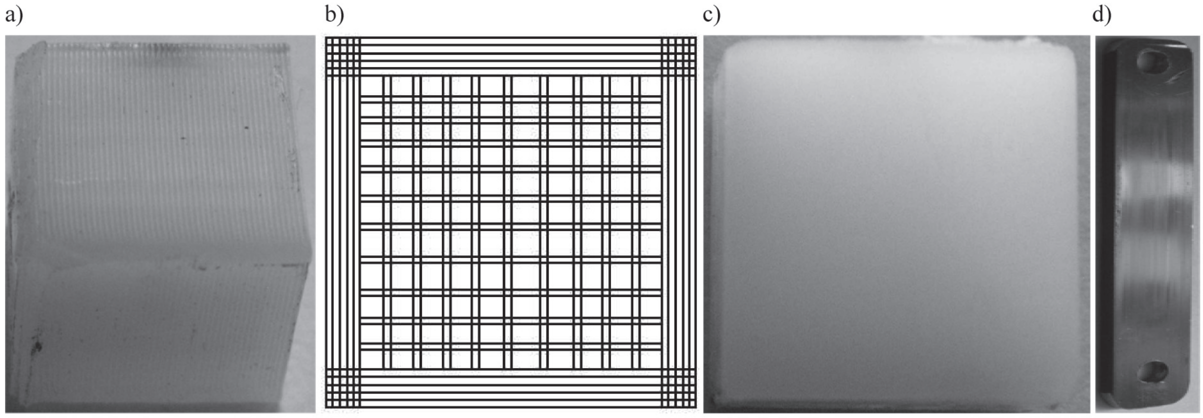


Fig. 3. Printed cube (sample) of PA12 (a), inside filling (b), moulded cube of POM (c) and prism of AW-6062 aluminium alloy with AHC (counter-sample, d)

Rys. 3. Drukowana kostka (próbka) z PA12 (a), wypełnienie wnętrza (b), prasowana kostka z POM (b) i prostopadłościan ze stopu AW-6062 pokrytego APT (przeciwpróbka, d)

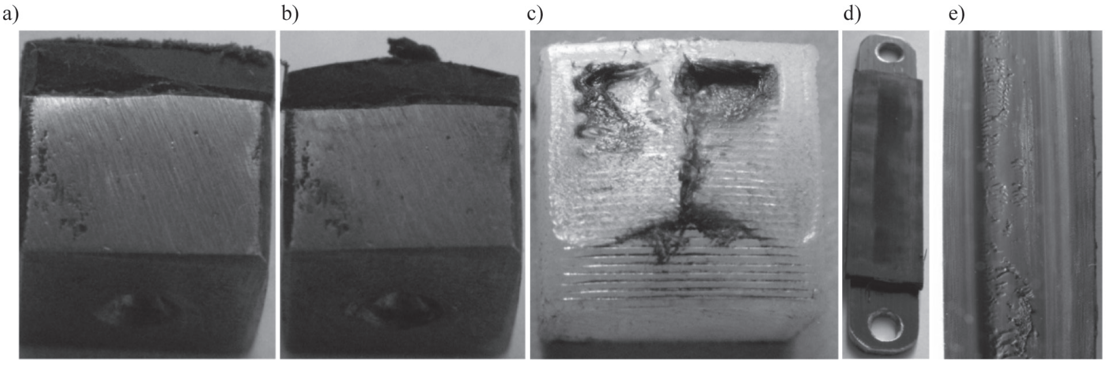


Fig. 4. Sample cut out from a tension roller (PA15GF) before (a) and after tests (b), 3D printed of PA 12 with 20% filling ratio (c) and counter-samples from drive belt after preliminary test (d, e)

Rys. 4. Próbka wycięta z rolki napinacza (PA15GF) przed badaniami (a) i po badaniach (b), drukowana z PA 12 z 20% wypełnienia oraz przeciwpróbka z paska rozrządu (d, e) po badaniach wstępnych

During the basic stage, the influence of a filament temperature (t), a printing velocity (v), and the height of printed layer (h) on wear of PA 12 were examined. The experiment plan is presented in **Tab. 1**.

Tribological examination of printed and moulded samples rubbing against slide guides made of anodised AW-6062 aluminium alloy was carried out by using a tribological testing apparatus with friction contact type

Table 1. Matrix and results of experiment

Table 1. Matryca i wyniki eksperymentu

Nr	Process parameter in standardised scale			Process parameter in real scale			Average wear	
	t	v	h	t, °C	v, mm/s	h, mm	m mg	Δm %
01.	-1	-1	1	240	40	0.3	7.04	0.85
02.	1	-1	-1	260	40	0.1	33.5	3.79
03.	-1	1	-1	240	60	0.1	**3.**7	0.43
04.	1	1	1	260	60	0.3	51.0	5.81
05.	-1	0	0	240	50	0.2	7.2	0.85
06.	1	0	0	260	50	0.2	103.6	12.11
07.	0	-1	0	250	40	0.2	6.6	0.79
08.	0	1	0	250	60	0.2	74.65	8.78
09.	0	0	-1	250	50	0.1	52.9	5.91
10.	0	0	1	250	50	0.3	**140**	17.1
11.	0	0	0	250	50	0.2	38.9	4.47
12.	PA15GF moulded						17.25	-[1)]
13.	POM moulded						2.05	0.16

[1)] Not applicable because of samples structure (PPA45GF prism joined with cast iron one, **Fig. 4**)

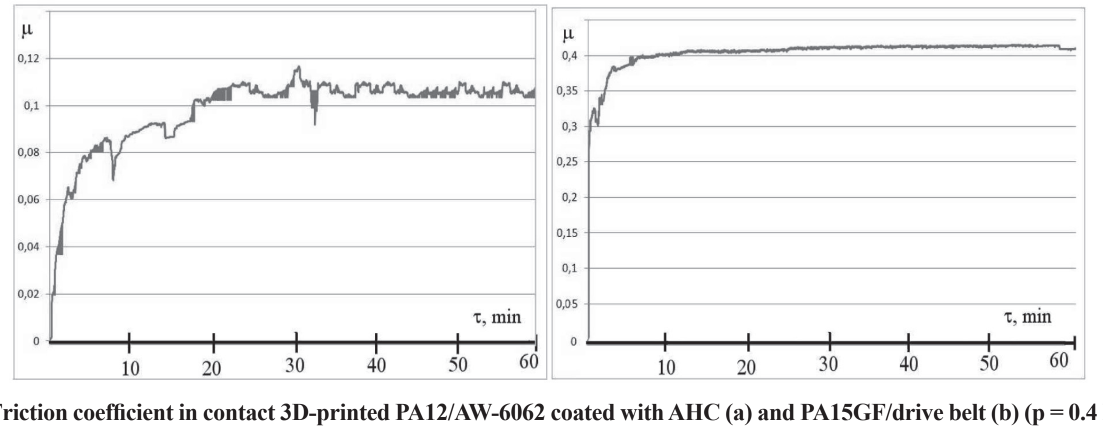
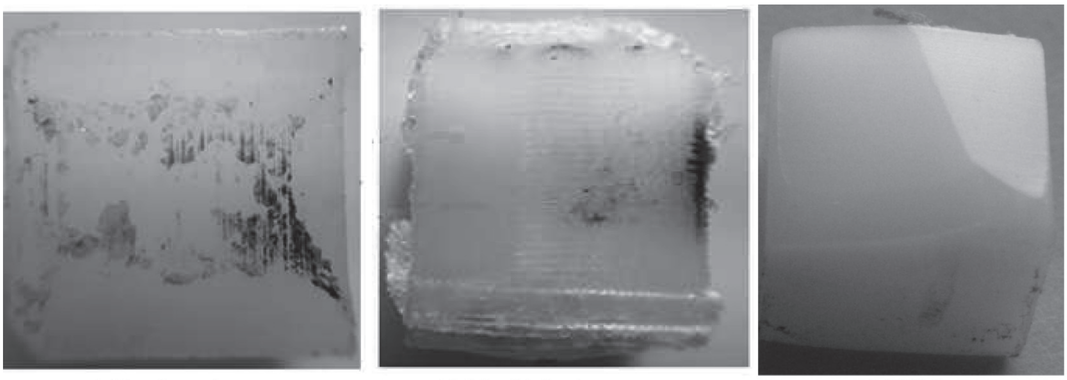


Fig. 5. Friction coefficient in contact 3D-printed PA12/AW-6062 coated with AHC (a) and PA15GF/drive belt (b) (p = 0.4 MPa, v = 2.5 m/s)

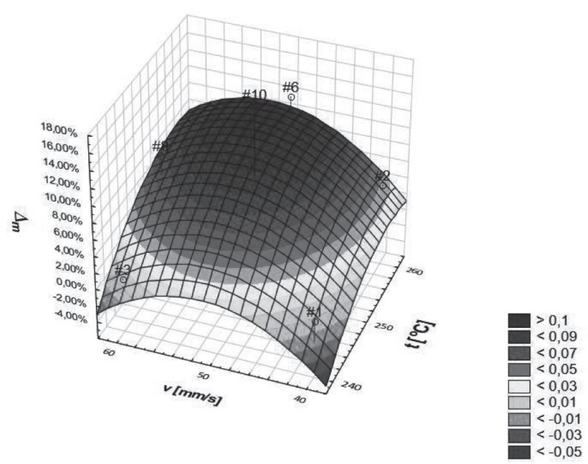
Rys. 5. Współczynnik tarcia w skojarzeniu drukowany PA12/AW-6062 pokryty APT (a) i PA15GF/pasek rozrządu (b) (p = 0,4 MPa, v = 2,5 m/s) cube-prism. A friction contact velocity by reciprocating movement was 2.5 m/s, and unit pressure was 0.4 MPa. In a real object (a sunroof in a car), such hard conditions do not exist. The higher pressure and the velocity have a goal to shorten the duration of the experiment. During the tests, the mass loss of samples was measured by using of a laboratory balance with an inaccuracy of 0.2 mg. The results are presented in **Table 1** and in **Figs. 4–7**.



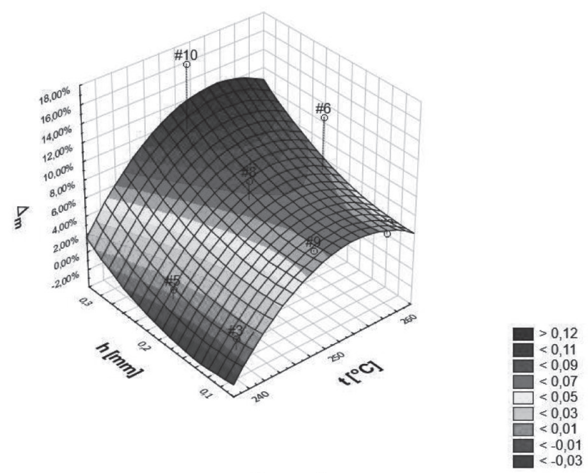
a) 03 – lowest wear b) 10 – highest wear c) POM

Fig. 6. 3D-printed samples of PA12 (100% filling ratio) after friction contact against AW-6062 coated with AHC with lowest wear (a) and highest wear (b)and POM sample (c)

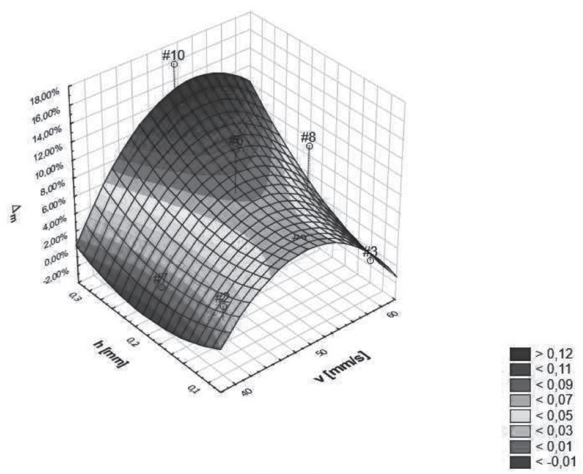
Rys. 6. Próbki drukowane z PA12 (100% wypełnienia) po współpracy z AW-6062 pokrytego APT z najmniejszym (a) i największym (b) zużyciem oraz z POM (c)



a) h = 0



b) v = 0



c) t = 0

Fig. 7. Mass loss of PA12 samples vs. 3D-printing parameters (for central levels of third parameter)

Rys. 7. Ubytek masy próbek z PA12 w funkcji parametrów drukowania 3D (dla centralnej wartości trzeciego parametru)

RESULTS DISCUSSION AND CONCLUSIONS

The results of the primary test indicated that the filling rate of printed samples must be 100%, because of the low strength of used PA 12 polymer (Rm = 50 MPa, A = 200%). Under a unit pressure p = 0.4 MPa and a velocity v = 2.5 m/s, thermal softening and plastic deformation of polymer and intensive wear are caused. Because of the low specific heat (1.7 $kJkg^{-1}K^{-1}$) and the thermal conductivity (0.3 $Wm^{-1}K^{-1}$) of PA 12, the temperature rises in the friction zone, which causes softening, deformation and wear of the plastic. The presence of air inside the skeleton of samples decreases thermal conductivity.

Rubbing a composite roller made of PA15GF against a composite with a rubber matrix drive belt is accompanied by a very high friction coefficient (μ>0.4) and conducts intensive thermal and adhesive wear of both partners (**Fig. 4**). The functional temperature for POM is about 115°C. The border product (pv) for POM is 1.2 MPa·m/s at v = 1 m/s and an ambient temperature **[L. 9]**. This is a main reason for the intensive wear of the POM sample by p = 0.4 MPa and v = 2.5 m/s.

It is a warnings indicator for car users. The technical state of a bearing in a tension roller of the belt should be regularly examined. Every pitting or seizure of a bearing can cause friction contact of a roller against the belt with a very high coefficient of friction (**Fig. 5b**), which causes thermal and adhesion wear of the roller and the belt (**Fig. 4**).

The results of basic tribological examining have shown that the technological parameters of 3D-printing were correctly chosen. According to **Tab. 1** and **Fig. 7b**, it can been stated that the samples printed at the minimum temperature (t = 240°C) and the minimum height of the deposited single layer (h = 0.1 mm) as well as by the minimum (v = 40 mm/s) and maximum (v = 60 mm/s) deposition velocity (Experiment No 3) show the minimal wear. The samples printed at the central temperature (t = 250°C) and the central deposition velocity (v = 60 mm/s) and the maximum (h = 0.3 mm) height of the deposited single layer (Experiment No 10) show the maximal wear. The reason for that is a superposition of the temperature, the depositing velocity, and the height of the single layer. The values of the parameters cause worse heat abstraction between single layers and the samples, causing higher temperatures, which results in a worse crystallisation of a polymer.

A wear resistance of polymers depends on a solidification temperature. At lower temperatures, the polymer crystallization ratio is higher, which results in a higher hardness **[L. 10]** and a higher wear resistance. A lower filament temperature during 3D-printing allows one to produce harder samples, which have a higher wear resistance.

The results of carried out experiments let us to form the following conclusions:

1. Pitting or seizure of a bearing composite tension roller on the drive belt in a car leads to friction contact of the roller against a belt with a high coefficient of friction (>0.4), resulting in intensive thermal and adhesive wear of both partners, which can cause damage to the motor.
2. Technological parameters of 3D printing of a sunroof slider made from PA 16 have significant influence on its wear. The samples printed at a minimum temperature (t = 240°C) and a minimum height of a deposited single layer (h = 0.1 mm) as well as by a minimum (v = 40 mm/s) and a maximum (v = 60 mm/s) deposition velocity show the minimal wear.

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