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Abrasive wear

INVESTIGATION OF ABRASIVE WEAR OF BIODEGRADABLE THERMOPLASTIC POLYMER SAMPLES PRODUCED BY 3D PRINTING

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ABSTRACT

The present paper represents the results of a study of tribological characteristics of biodegradable thermoplastic samples, produced by FFF/FDM 3D printing subjected to abrasive wear. The samples are printed at five different nozzle temperatures (190°C, 200°C, 210°C, 220°C and 230°C). Results on mass wear, wear intensity and wear resistance of the different types of samples in a condition of dry and lubricated abrasive wear are obtained.

Keywords: biodegradable polymers, abrasive wear, 3D printing, tribology.

AIMS AND BACKGROUND

FDM/FFF 3D printing is a powerful Rapid Prototyping instrument for various industries, research and development organizations, hobbyists, and small businesses. 3D printing is becoming more and more common in small-scale production and for the manufacturing of different spare parts – for example, gears, plain bearings, etc. This requires a better knowledge of the tribological properties of the materials used for 3D printing[1,2,3].

Polylactic acid (PLA) is a biodegradable thermoplastic polymer produced by condensation polymerization of lactic acid, which is derived by fermentation of sugars from carbohydrate sources[4]. PLA is one of the most often used materials in FDM/FFF 3D printing, because when it is printed no toxic fumes are emitted, the printing temperatures are relatively low compared to other 3D printing filaments, and it has a low thermal expansion that helps reduce the internal stresses caused during cooling down and it is biodegradable under specific conditions[,5,6,7,8]. Table 1 shows a comparison between PLA and other 3D printing filaments[9].

Table 1. Comparison between PLA and other 3D printing filaments

	PLA	ABS	PET	Nylon	TPU	PC
Ease of printing	highest	lower	higher	medium	lowest	lower
Visual quality	higher	medium	medium	medium	lower	medium
Max stress	higher	medium	lower	lower	lower	highest
Elongation at break	lowest	lowest	lowest	medium	highest	lowest
Impact resistance	lowest	medium	medium	higher	highest	medium
Layer adhesion	higher	lower	medium	lowest	medium	medium
Heat resistance	lowest	higher	lower	higher	lower	highest

The aim of the current study is to investigate and analyze mass wear, wear intensity and wear resistance of PLA samples 3D printed at different nozzle temperatures uncer conditions of abrasive wear with and without a lubricating agent.

EXPERIMENTAL

For the purposes of the study five types of PLA samples are printed using FDM/FFF technology. The geometric shape and dimensions of the samples are the same – 25x25x4 mm. The samples are printed on Anycubic Mega S 3D printer at five different nozzle temperatures 190°C (sample PLA-190T), 200°C (sample PLA-200T), 210°C (sample PLA-210T), 220°C (sample PLA-220T), 230°C (sample PLA-230T). In Table 2 some basic process parameters are represented.

The methodology for the study of abrasive wear consists in measuring the mass loss of the samples for a certain friction path length L (number of cycles) while maintaining constant conditions – normal load, sliding velocity, type of abrasive particles, and ambient temperature. The mass of the samples before and after a definite pathway of friction is measured by electronic balance WPS

Table 2. Basic process parameters

Parameter	Value	Unit
Layer Height	0.2	mm
Line Width	0.4	mm
Infill Density	100	%
Infill Pattern	Grid	–
Build Plate Temperature	60	°C
Print Speed	50	m/s
Initial Layer Print Speed	25	m/s
Fan Speed	100	%
Build Plate Adhesion Type	Skirt	–
Infill Overlap percentage	15	%
Skin Overlap percentage	5	%

180/C/2 with an accuracy of 0.1 mg. For each experiment with the corresponding sample the abrasive surface is replaced and before each measurement the sample is cleaned, removing mechanical and organic particles, thereafter it is dried up using ethyl alcohol interevent the electrostatic effect. The mass wear in mg is obtained as the difference between the initial mass of the sample m_o and its mass m_i after a definite number of cycles of friction. After measuring the wear process characteristics are calculated – wear intensity (i) and wear resistance (I). The corresponding formulas are represented in Table 3.

Table 3. Formulas

Parameter	Mass wear	Friction path length	Wear intensity	Wear resistance
Unit	mg	m	mg/m	m/mg
Formula	$m = m_0 - m_i$	$L = 2\pi RN$	$i = \frac{m}{L}$	$I = \frac{1}{im} = \frac{L}{}$

(R = 40 mm is the distance between the axis of rotation of the disc with the abrasive surface and the mass centre of the contact pad.)

The abrasive wear is studied using tribology pin-on-disc tribometer in case of plane-like contact applying the functional scheme, shown in Fig. 1. The studied sample 1 (pin) is firmly attached in the holder 2 of the loading head 8, in such a way that the frontal surface of the sample is in contact with the abrasive surface 3, fixed on a horizontal disc 4. Disc 4 is driven by the electric motor 6 and it is rotating around its central vertical axis at constant angular veocity. The normal loading pressure P is adjusted by the means of the lever system in the centre of the contact plate between the sample and the abrasive surface. The friction path as a number of cycles (N) is selected then measured by the turnover number metering device 7. The abrasive surface 3 is modelled by impregnated corundum P 320 of hardness 9.0 on the scale of Moos, whereupon the requirement of the standard for minimum 60% higher hardness of the abrasive material is observed with respect to that of the surface layer of the tested materials[10].

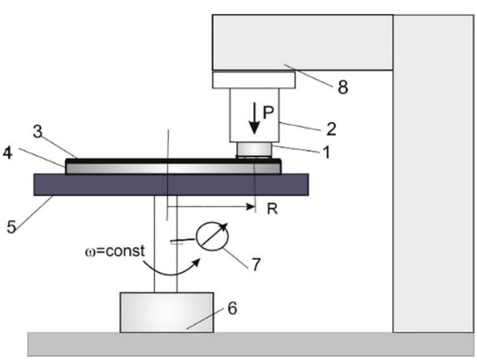

Fig. 1. Schematic diagram of abrasive wear testing on pin-disc tribometer

The investigation of all the samples has been carried out using a set of the following parameters of the regime of friction: loading P = 3.92 N, nominal contact surface area $A_x = 2.25 * 10^{-6}$ m^2; nominal contact pressure p_a = 1.74 N/cm2, sliding velocity of v = 0.16 m/s; type of the abrasive surface Corundum P 320, temperature of the environment 21 °C. For the experiments under lubricated conditions lubricant is introduced into the contact between the sample and the abrasive surface by means of wick lubrication, the abrasive surface being soaked with oil beforehand. 15W40 oil is used as a lubricant. Before each test, the sample is rubbed under the same conditions for 5 min.

RESULTS AND DISCUSSION

Results for abrasive mass wear in dry and in lubricated conditions depending on the friction path are represented in Table 3.

Table 3. Results for abrasive mass wear in dry and in lubricated conditions

		Number of cycles		
		50	100	150
		Friction path, m		
		12.55	25.1	37.65
Sample	Conditions	Mass wear, mg		
PLA-190T	dry	8.4	11.4	17.1
	lubricated	7.5	11.0	16.2
PLA-200T	dry	6.1	11.1	16.9
	lubricated	5.0	10.0	14.4
PLA-210T	dry	5.2	10.2	11.3
	lubricated	7.2	10.4	17.1
PLA-220T	dry	6.7	10.8	12.7
	lubricated	6.7	16.1	27.9
PLA-230T	dry	4.9	12.5	14.5
	lubricated	12.6	18.3	26.5

Table 4. Results for wear intensity in dry and in lubricated conditions

		Number of cycles		
		50	100	150
		Friction path, m		
		12.55	25.1	37.65
Sample	Conditions	Wear intensity, mg/m		
PLA-190T	dry	0.7	0.45	0.45
	lubricated	0.6	0.438	0.43
PLA-200T	dry	0.486	0.442	0.449
	lubricated	0.398	0.398	0.382
PLA-210T	dry	0.414	0.406	0.3
	lubricated	0.573	0.414	0.454
PLA-220T	dry	0.534	0.43	0.337
	lubricated	0.534	0.641	0.74
PLA-230T	dry	0.39	0.498	0.385
	lubricated	1.0	0.729	0.704

Results for wear intensity in dry and in lubricated conditions depending on the friction path length are represented in Table 4 and on Fig. 2, 3, 4, 5 and 6.

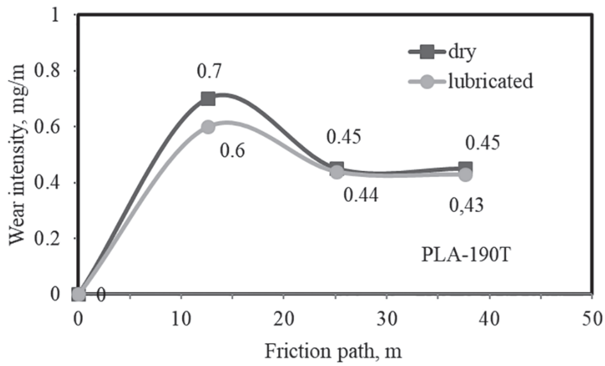

Fig. 2. Wear intensity – PLA-190T

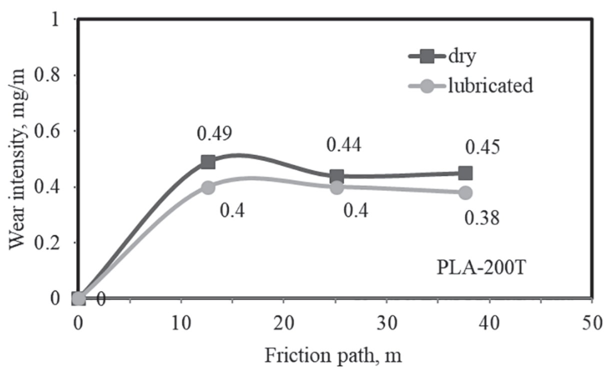

Fig. 3. Wear intensity – PLA-200T

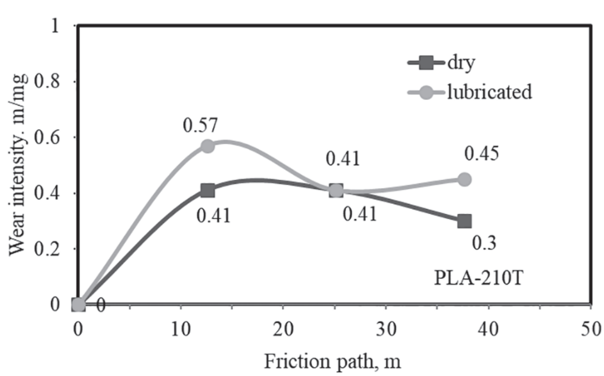

Fig. 4. Wear intensity – PLA-210T

Results for wear resistance in dry and in lubricated conditions depending on the friction path are presented in Table 5 and on Fig. 7.

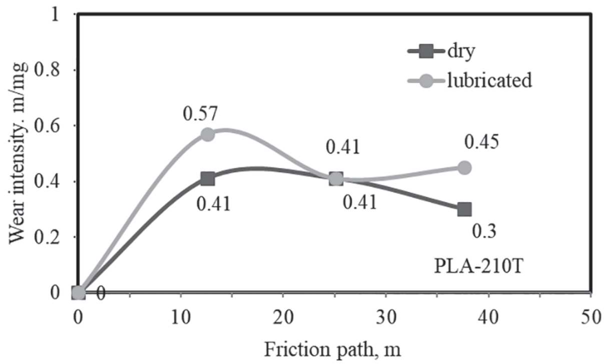

Fig. 5. Wear intensity – PLA-220T

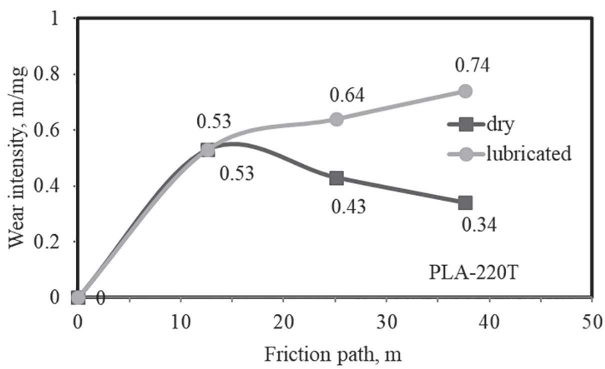

Fig. 6. Wear intensity – PLA-230T

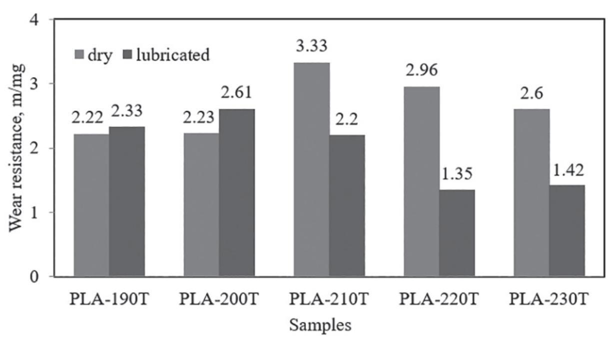

Fig. 7. Wear resistance at L = 37.65 m

Table 5. Results for wear resistance in dry and in lubricated conditions

		Number of cycles		
		50	100	150
		Friction path, m		
		12.55	25.1	37.65
Sample	Conditions	Wear resistance, mg/m		
PLA-190T	dry	1.43	2.22	2.22
	lubricated	1.67	2.28	2.33
PLA-200T	dry	2.05	2.26	2.23
	lubricated	2.51	2.51	2.61
PLA-210T	dry	2.41	2.46	3.33
	lubricated	1.74	2.41	2.2
PLA-220T	dry	1.87	2.32	2.96
	lubricated	1.87	1.55	1.35
PLA-230T	dry	2.56	2.01	2.6
	lubricated	1.00	1.37	1.42

The present results show that the PLA-210T sample has the greatest wear resistance $I = 3.3$ m/mg compared to the other samples in conditions of dry abrasive friction. When the printing temperature increases by 10°C, the wear resistance of samples PLA-220T and PLA-230T gradually decreases, but it remains higher than the wear resistance of samples PLA-190T and PLA-200T. The wear resistance of PLA-210T sample is 1.5 times higher than that of PLA-190T material. When the printing temperature changes from 190°C to 200°C in conditions of dry abrasive friction, the wear resistance remains constant. When the temperature increases by 10°C – at 210 °C, a jump occurs and a maximum of wear resistance is observed. With a subsequent increase in temperature, the wear resistance linearly decreases, but it remains 17% – 33% higher than that of the samples printed at lower temperatures.

In lubricated conditions wear intensity is lower, compared to that in dry abrasive wear conditions for samples PLA-190T and PLA-200T, but it is higher for samples PLA-210T, PLA-220T and PLA-230T. Furthermore, in that case wear resistance of PLA-200T is 18% higher than that of PLA-210T and the trend is reversed, compared to the wear resistance in conditions of dry abrasive wear – the wear resistance of samples PLA-220T and PLA-230T is lower than that of samples PLA-190T, PLA-200T and PLA-210T.

CONCLUSIONS

The present study demonstrates that the printing temperature has a strong impact on tribological characteristics of biodegradable thermoplastic polymer parts subjected to abrasive wear – a small change of this parameter leads to big changes of mass wear, wear intensity and respectively – wear resistance. Moreover, the presence of a lubricating agent leads to bigger wear intensity for the samples printed at temperatures above 200°C.

In view of the experiments performed and a thorough analysis of the data obtained, it can be concluded that it is impossible to find out a direct correlation between the results for PLA samples subjected to dry abrasive wear and the same ones subjected to lubricated abrasive wear. Nevertheless, the results from the study show that in the case of abrasive wear the biodegradable polymer parts show better tribological behaviour in conditions of dry friction.

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