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

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ABSTRACT

The present paper presents the results of a study of tribological characteristics of biodegradable thermoplastic samples produced by FFF/FDM 3D printing subjected to erosive wear. The samples are printed at five different nozzle temperatures (190 °C, 200 °C, 210 °C, 220 °C and 230 °C). Results about mass wear, wear intensity, wear resistance, roughness and microhardness of the different samples are obtained.

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

AIMS AND BACKGROUND

Polylactic acid (PLA) is a biodegradable thermoplastic polymer produced by condensation polymerisation of lactic acid, which is derived by fermentation of sugars from carbohydrate sources[1]. This polymer is becoming more and more popular in various fields[2] – industry, medicine, art, etc.[3,4], mainly because the material could be printed on budget 3D printers, it is not toxic, it has a low thermal expansion that helps reduce the internal stresses caused during cooling down and the polymer is biodegradable under specific conditions[5,6,7,8]. These applications require a better understanding of its mechanical and tribological properties.

The erosive wear of machine parts is a process of surface destruction under the impact of solid or liquid particles carried by a fluid flow - air, water, oil, etc. It is one of the most dangerous types of wear because it leads to a rapid deterioration of the functional characteristics of the machines in general and to a reduction of their resource. This is associated with huge costs for materials, spare parts, consumables and human resources for maintenance in the operation process. The other side of the problem is related to environmental pollution and the increasing extraction of raw materials from nature, which is directly related to the balance in the ecosystems[9,10].

The aim of the current study is to investigate and to analyse mass wear, wear intensity, wear resistance, microhardness and roughness of PLA samples 3D printed at different nozzle temperatures in condition of erosive wear.

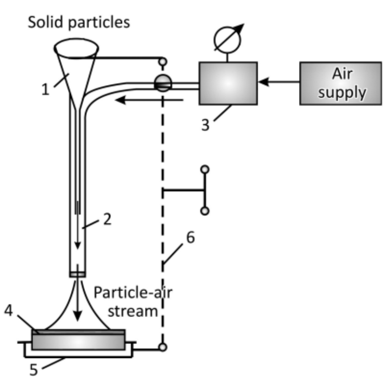
EXPERIMENTAL

For the purposes of the study five types of PLA samples are printed using FDM/FFF technology. The samples are printed on Anycubic Mega S 3D printer at five different nozzle temperatures: 190°C (sample PLA-190TE), 200°C (sample PLA-200TE), 210°C (sample PLA-210TE), 220°C (sample PLA-220TE) and 230°C (sample PLA-230TE). Some basic process parameters are presented in Table 1.

Table 1. Basic process parameters of 3D printing

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	mm/s
Initial Layer Print Speed	25	mm/s
Fan Speed	100	%
Build Plate Adhesion Type	Skirt	-
Infill Overlap percentage	15	%
Skin Overlap percentage	5	%

The erosion wear of the studied samples has been accomplished by means of air stream, carrying abrasive particles in atmospheric environment. The functional scheme of the device is represented on Fig. 1. The designation of this device is to produce bi-phase jet «air-abrasive particles» by independent setting and regulation of the parameters of the two separate stationary flows – air flow and abrasive mass flow and more specifically – the air pressure and the flow rate of the abrasive particles[11].



1 – chamber for solid particles

2 – mixing chamber

3 – chamber with manometer

4 – sample

5 – holder

6 – regulator

Fig.1. Scheme of erosive wear test device

The corresponding formulas are presented in Table 2.

Table 2. Formulas

Parameter	Mass flow rate	Mass erosion wear	Erosion rate	Erosion intensity	Erosion wear resistance	Relative wear resistance
Formula	$\dot{m}_a = \frac{m_a}{t_a}$	$m_e = m_e^0 - m_e^i$	$\dot{m}_e = \frac{m_e}{\Delta t}$	$i_e = \frac{\dot{m}_e}{\dot{m}_a}$	$I_e = \frac{1}{i_e}$	$R_{i,j}^e = \frac{I_i^e}{I_j^e}$

The parameters of the erosive wear experiment are presented in Table 3.

Table 3. Parameters of the erosive wear experiment

Parameter	Value
Solid particles material	silicon dioxide
Maximum size of the particles	600 μm
Air stream pressure	0.1 MPa
Particles flow	175.6 g/min
Impact angle of the particles	90°
Distance between the sample and the nozzle	10 mm
Duration of the test	5 minutes
Ambient temperature	22°C

The mass of the samples is measured with electronic scale WPS-180/C/ with accuracy of 0.1 mg. Before each measurement the sample is cleaned using a solution, neutralizing the static electric charge, and then it is dried up.

Microhardness and roughness are also investigated. The microhardness is measured before and after wear with HVS-1000 microhardness tester using Vickers hardness scale (Fig. 2). The load is set to 0.5 kg and the holding time is set to 10 s. The roughness is measured before and after wear with Tesa Rugosurf 20 roughness gauge (Fig. 3).

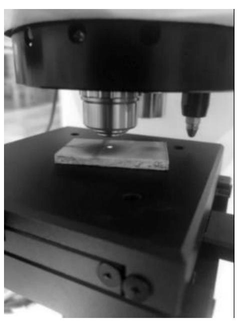


Fig. 2. Measuring of the microhardness after wear

Fig. 3. Measuring of the roughness after wear

RESULTS AND DISCUSSION

Results for various characteristics of erosive wear are presented in Table 4.

Table 4. Results for various characteristics of erosive wear

Sample	Mass wear, mg	Erosion rate, mg/min	Intensity of erosion	Erosion wear resistance	Relative erosion wear resistance
PLA-190TE	1.8	0.36	2.05×10^{-6}	0.49×10^{6}	1
PLA-200TE	1.7	0.34	1.90×10^{-6}	0.53×10^{6}	1.08
PLA-210TE	1.5	0.30	1.70×10^{-6}	0.59×10^{6}	1,2
PLA-220TE	0.7	0.14	0.80×10^{-6}	1.25×10^{6}	2.6
PLA-230TE	0.5	0.10	0.57×10^{-6}	1.75×10^{6}	3.6

A graphical representation of the dependence of the erosion intensity on the printing temperature is shown on Fig. 4.

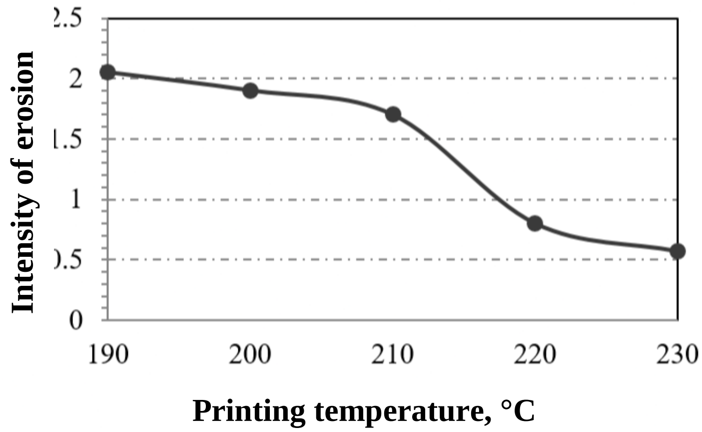
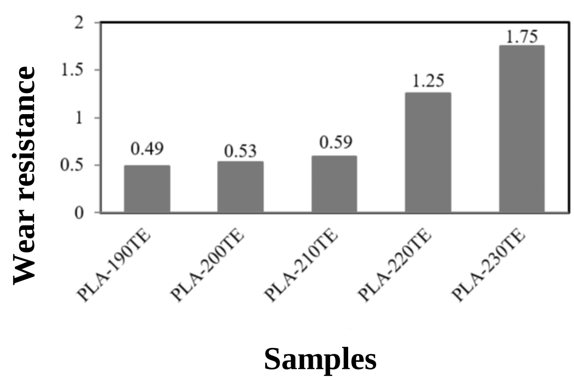


Fig. 4. Dependence of the erosion intensity on the printing temperature

Graphical representations of the erosion wear resistance and relative erosion wear resistance for the different samples are presented respectively on Fig. 5 and Fig. 6.



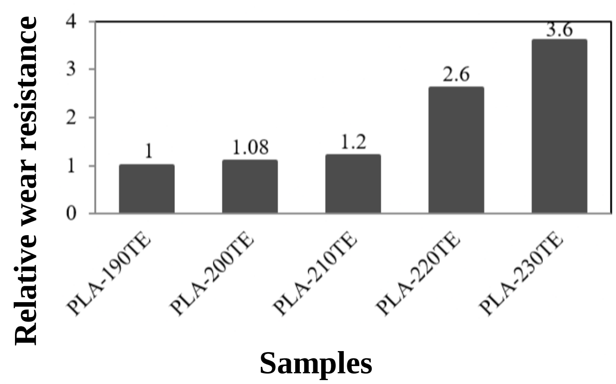


Fig. 5. Erosion wear resistance

Fig. 6. Relative erosion wear resistance

The microhardness values before and after erosive wear are presented in Table 5.

Table 5. Microhardness values before and after erosive wear

Sample	Initial hardness (HV)	Hardness after erosion (HV)
PLA-190TE	19.06	35.9
PLA-200TE	18.20	37.2
PLA-210TE	17.50	36.7
PLA-220TE	17.90	36.5
PLA-230TE	17.70	39.3

The roughness values before and after erosive wear are presented in Table 6.

Table 6. Roughness values before and after erosive wear

Sample	Initial roughness (Ra)	Roughness after erosion (Ra)
PLA-190TE	2.112	4.32
PLA-200TE	2.792	4.42
PLA-210TE	2.677	4.16
PLA-220TE	2.597	3.91
PLA-230TE	1.808	4.07

The present results that in case of producing parts such as fans, fins, etc. – elements that are subjected to erosive wear in the course of exploitation, it is important to choose the highest possible printing temperature.

CONCLUSIONS

The obtained results show that with increasing of the printing temperature, the intensity of erosion decreases non-linearly in the range from 210°C to 230°C. At lower printing temperatures (190°C and 200°C) the intensity of erosion changes slightly. It is found that the sample produced at the highest printing temperature (230°C) has the highest erosion wear resistance – 3.6 times higher than the wear resistance of the sample printed at 190°C. In summary, it can be stated that an increase in printing temperature by 40°C leads to an increase in wear resistance by 360%.

Microhardness studies show a definite tendency for a double increase in microhardness after erosion wear compared to the initial values of the parameter.

The roughness values after erosive wear show a two-fold increase compared to the initial values.

ACKNOWLEDGMENTS

The current research is funded by The Research and Development Sector (R&DS) of the Technical University-Sofia within a research project in aid of a doctoral student with contract No 222ПД0010-05.

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