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

M. ZAGORSKIa\*, M. KANDEVAa, T. GAVRILOVa, G. TODOROVa, B. DOCHEVb

*aFaculty of Industrial Technology, Technical University – Sofia, 8 Kl. Ohridski Blvd, 1000 Sofia, Bulgaria*

*E-mail:* [*mihail.zagorski.tu@gmail.com*](mailto:mihail.zagorski.tu@gmail.com)

*bTechnical University – Sofia, Plovdiv Branch, 25 Ts. Diustabanov Str.4000 Plovdiv, Bulgaria*

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 sources1. This polymer is becoming more and more popular in various fields2 – 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 conditions5,6,7,8. 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 ecosystems9,10.

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 particles11.

|  |  |
| --- | --- |
|  | 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 |  |  |  |  |  | = |

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°С |

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 х 10-6 | 0.49 х 106 | 1 |
| PLA-200TE | 1.7 | 0.34 | 1.90 х 10-6 | 0.53 х 106 | 1.08 |
| PLA-210TE | 1.5 | 0.30 | 1.70 х 10-6 | 0.59 х 106 | 1,2 |
| PLA-220TE | 0.7 | 0.14 | 0.80 х 10-6 | 1.25 х 106 | 2.6 |
| PLA-230TE | 0.5 | 0.10 | 0.57 х 10-6 | 1.75 х 106 | 3.6 |

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

|  |
| --- |
| **Intensity of erosion**  **Printing temperature, °C** |
| **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.

|  |  |
| --- | --- |
| **Wear resistance**  **Samples** | **Samples**  **Relative wear resistance** |
| **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.

REFERENCES

1. N. MSUYA, J.H. KATIMA, E. MASANJA, A. K. TEMU: Poly (lactic-acid) Production from Monomer to Polymer: A review. Sci.-Fed. J. Polym, 1, 1-15 (2017).

2. B. HAO, G. LIN, E. MASANJA: Poly (lactic-acid) 3D Printing Technology and Its Application in Industrial Manufacturing. IOP Conference Series: Materials Science and Engineering, 782. 022065. 10.1088/1757-899X/782/2/022065 (2020).

3. M. L. DI LORENZO, R. ANDROSCH: Industrial Applications of Poly(lactic acid). 10.1007/978-3-319-75459-8 (2018).

4. V. DESTEFANO, S. KHAN, A. TABADA: Applications of PLA in modern medicine. Engineered Regeneration. 1. 76-87. 10.1016/j.engreg.2020.08.002 (2020).

5. E. FLOYD, J. WANG, J. REGENS: Fume Emissions from a Low-Cost 3-D Printer with Various Filaments. Journal of occupational and environmental hygiene. 14. 10.1080/15459624.2017.1302587 (2017).

6. D. YOU: Optimal Printing Conditions of PLA Printing Material for 3D Printer. The Transactions of The Korean Institute of Electrical Engineers. 65. 825-830. 10.5370/KIEE.2016.65.5.825 (2016).

7. J. ANDRZEJEWSKI, J. CHENG, A. ANSTEY, A. MOHANTY, M. MISRA: Development of Toughened Blends of Poly(lactic acid) (PLA) and Poly(butylene adipate-co-terephthalate) (PBAT) for 3D Printing Applications: Compatibilization Methods and Material Performance Evaluation. ACS Sustainable Chemistry & Engineering. XXXX. 10.1021/acssuschemeng.9b04925 (2020).

8. D. MAGA, M. HIEBEL, N. THONEMANN: Life cycle assessment of recycling options for polylactic acid. Resources Conservation and Recycling. 149. 86–96. 10.1016/j.resconrec.2019.05.018 (2019).

9. A. ALBAGACHIEV, B. GURSKII, Y. LUZHNOV, A. ROMANOVA, A. CHICHINADZE: Economic and ecological issues in tribology. Russian Engineering Research. 28. 959-964. 10.3103/S1068798X08100092 (2008).

10. I. TZANAKIS, M. HADFIELD, B. THOMAS, S. NOYA, I. HENSHAW, S. AUSTEN: Future perspectives on sustainable tribology. 16. 4126–4140. 10.1016/j.rser.2012.02.064 (2012).

11. M. KANDEVA, Zh. KALITCHIN, Y. STOYANOVA: Influence of chromium concentration on the erosive wear of ni-cr-b-si coatings applied by supersonic flame jet (HVOF). Journal of the Balkan Tribological Association. 27 (6) (2021).