# Friction and wear properties of oriented Polyamide 12 objects manufactured by SLS Technology

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**Abstract**

White Polyamide 12 (PA12) is the most usable material for additive manufacturing. PA12 parts manufactured by Selective Laser Sintering (SLS) process are chemically stable, environmentally friendly, and have reasonable mechanical properties. As a result, PA12 powder has been used for rapid prototyping purposes and manufacturing of end-user products. Although, the mechanical properties of PA12 manufactured by SLS technology have been the focus of many investigations, so far, the effect of build orientation on the tribological properties PA12 parts have not received sufficient attention in previous research. Therefore, this study is devoted to investigating the dry sliding friction and wear characteristics of PA12 parts manufactured by SLS technique at three different orientations (X, Y, and Z). For this purpose, the coefficient of friction (COF) and the approximate contact temperature of PA12 pins loaded against a stainless steel disc are measured using a Pin-on-disc test apparatus. The experimental results revealed that under dry sliding conditions, the COF, frictional heat, and specific wear rate of PA12 specimens oriented along the Y-axis are significantly smaller than those oriented along X and Z axes. Furthermore, the transfer film observed on the steel disc surface acts to decrease the COF and wear rate of Y-oriented test specimens. On the other hand, the results showed that at the steady-state wear stage, PA12 specimens oriented along X and Z axes experienced a combination of abrasive wear, adhesive wear, and sometimes surface fatigue wear. The results from this study can help designers to orient the active rubbing surface of PA12 during SLS process in the proper way to reduce the COF, frictional heat, and wear rates of PA12 objects.

**Keywords:**

Polyamide 12 (PA12); Selective Laser Sintering; Tribological properties, build orientation

## 1.Introduction

Polyamide 12 (PA12) is the most frequently used powder in selective laser sintering (SLS) process due to the resulting mechanical and functional properties of 3D printed objects. The particle size, melting temperature, surface energy, and fluidity make PA12 powder a suitable material for additive manufacturing which is a layer-by-layer object building technique. Hence, despite the recent developments in thermoplastic powders, around 95% of laser sintered objects are made of PA12 [1]. Hence, increasing research have been carried out in the last two decades to investigate the mechanical properties of PA12 parts manufactured by SLS process [2]. Also, the effects of SLS fabrication parameters (laser power, scanning speed, and scan spacing) on the geometry, density, tensile, compressive, and flexural properties of SLS parts were the focus of a reasonable number of researches [3-7]. Recently, a handful number of research works have addressed the effect of build orientation on the mechanical properties of PA12 composite objects manufactured by SLS [4,8,9]. Most recently, artificial intelligence technique was used to predict the mechanical properties of SLS objects in an attempt to produce objects with customized mechanical properties [10].

The drastic increase of using PA12 end-user products in application where it rubs against a metallic/polymeric counter surface calls for further research on the tripological properties of PA12 surfaces manufactured by SLS. As a result, the dry/lubricated sliding parameters that affect the tribological features of PA against other surfaces were analyzed [11], and several attempts were carried out to enhance the surface roughness of PA12 parts manufactured by SLS technique [12-14]. Since the SLS objects are known to exhibit anisotropic mechanical properties, the tribological properties of PA12 objects are expected to be orientation dependent. Despite the anticipated significant effect of build orientation on the tribological properties of laser sintered PA12, very few research studies were found in open literature on the anisotropic wear properties of PA12 [15,16].

Therefore, the present work is devoted to investigating the effect of build orientation of the friction and wear properties of laser sintered PA12 parts rubbing against a stainless steel disc. The study aims at measuring the COF, frictional heat, and the specific wear rates of PA12 pins manufactured by SLS technology at different build orientations (pins are oriented along X, Y, and Z axes). Furthermore, the PA12 tribosurfaces are to be examined by Scanning Electron Microscopy (SEM) to investigate the dominant wear pattern at each orientation.

## 2.Experimental Methods

### *2.1. Samples preparation*

The samples were fabricated from Polyamide 12 powder (PA 2200) on a commercial SLS machine. Each test specimen is a rod of 4 mm diameter and 25 mm length. During manufacturing, the rods are oriented along the X-axis, Y-axis, and Z-axis, and the build direction is along the positive Z-axis. A set of three test specimens was manufactured along each orientation. Once the fabrication process is completed, the parts are taken off the support and cleaned with sandblasting to remove any sticking powder. During manufacturing of the test specimens, scanning vector was along the X-axis of the SLS machine (parallel to the machine front face).

Fig.1 Orientations of manufactured test specimens

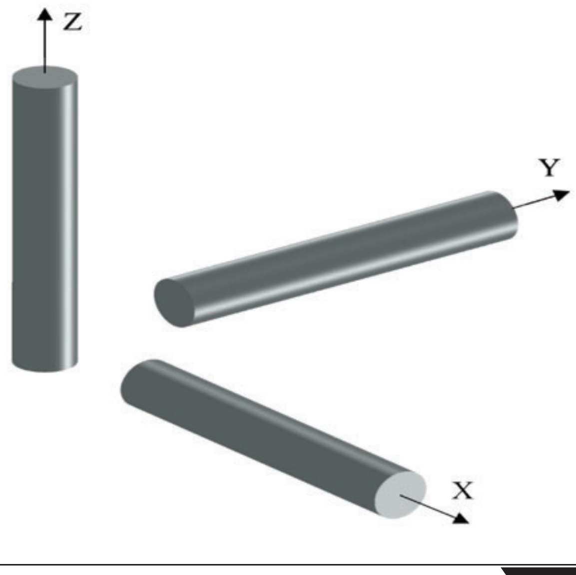
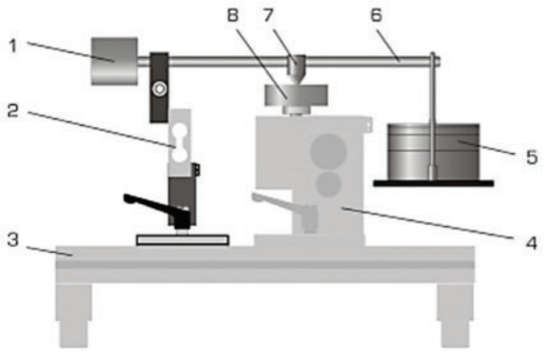


Fig.2 Pin-on-disc test apparatus




1. Counterweight 2. Force sensor,
3. Frame of TM 260 4. Drive unit
5. Applied Load 6. Load lever
7. Pin holder 8. Steel disc

*2.2. Pin-on-disc test apparatus*

Friction and wear properties of PA12 were examined using pin-on-disc test-rig, see Fig.2. The test specimen (in the form of rod) is inserted in the pin-holder and loaded against the rotating Stainless Steel disc by means of second-class lever. The pin-on-disc TM 260 apparatus is designed in such a way that the load on test specimen is twice the applied dead weight, and the friction force is measured by means of a double-bending beam force sensor. The rotation speed of the Stainless Steel disc is controlled by means of a drive unit with a gear reducer to give a maximum sliding speed of 0.5 m/sec. The experiments were carried out in dry sliding mode. The contact temperature was measured using infrared temperature sensor. The active tribosurfaces of pins are coated with a thin gold coating before investigation by the scanning electron microscopy (SEM).

**3.Results and Discussions**

The experiments were carried out in room temperature, and relative humidity was around 15%; thus, dry sliding condition was maintained. The circular end of the test specimen was loaded against the stainless steel rotating disc. In the following results, the disc is rotating at 120 rpm, the load on the pin (test specimen) is 50 N, and the experiment is run for 30 minutes. As the pin diameter is 4 mm and the diameter of the sliding track is 40 mm, the average pressure (P) on the pin is about 4 MPa and the sliding speed is 0.25 m/sec. With such levels of contact pressure and dry sliding speed, the test specimens are considered to be in a heavily loaded operating condition. The average value of surface roughness parameter (Ra) of the steel disc was 0.3m. The measured COF of PA12 test specimens built along the three different orientations is given in Fig.3. Several important remarks can be drawn from Fig.3: (1) at the running-in stage, the COF of X- and Z-oriented test specimens remains almost constant for about 6 minutes then increases rapidly toward the end of this stage, (2) at the steady-state wear stage, the COF of X- and Z-oriented specimens increases slowly where the COF of X-oriented specimen is always higher than that of Z-oriented specimen, (3) the parts built along the Y-axis exhibits a significantly lower COF compared with other orientations.

The behavior of the COF of X- and Z-oriented specimens suggests that abrasive wear dominates the first few minutes of dry sliding contact, then the real area of contact increases and, consequently, a combination of adhesive and abrasive wear exists; this results in the rapid increase of the COF at the end of running-in stage. On the other hand, the gradual increase of the COF for Y-oriented specimens may be attributed to a dominating adhesive wear throughout all stages of dry sliding condition.

The results from Fig. 3 are further explained when connected with the variations of approximate contact temperature at the different build orientations, shown in Fig. 4. It is noticeable from Fig.4 that the measured contact temperature of specimens built along the X- and Z- axes are higher than that of the specimen built along Y-axis (a difference of about 10 oC was noticed after 30 minutes of dry sliding). This result is in accordance with the fact of mutual effects of the COF and contact temperature; higher COF results in high flash temperature (manifested by the measured contact temperature) which in turn softens the substrate layer causing further increase in the COF.

As a result of the performance characteristics outlined in Figs 3 and 4, the specific wear rates are as shown in Fig.6. The specific wear rate (Ks) in (mm3/N.m) is calculated as [17];

$$K_s = \frac{\Delta V}{(P\times L)}$$

where ΔV is the wear volume (mm3), P the applied load (N), and L is the sliding distance (m).

Figure 5 shows clearly that the parts built along the Y-axis direction, which exhibits low COF and low contact temperature, has the lowest specific wear rates compared with those having high COF accompanied

Fig.3 Coefficient of friction of tested specimens

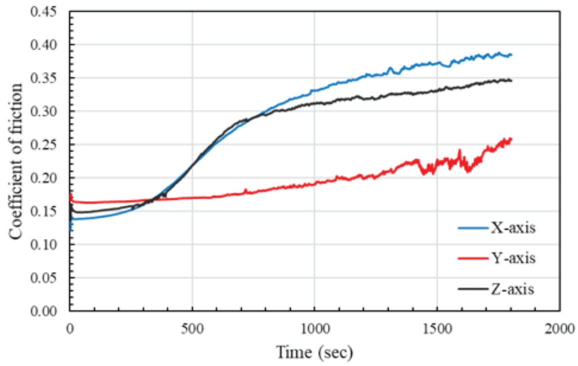



Fig.4 Average contact temperature of tested specimens

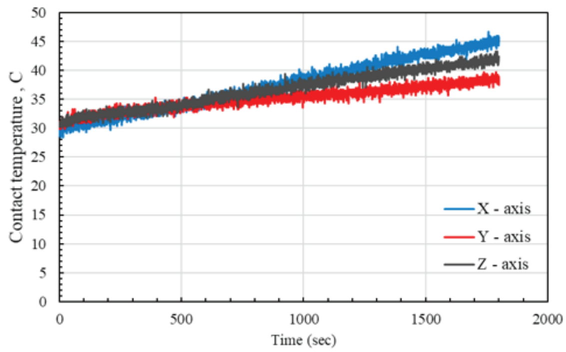
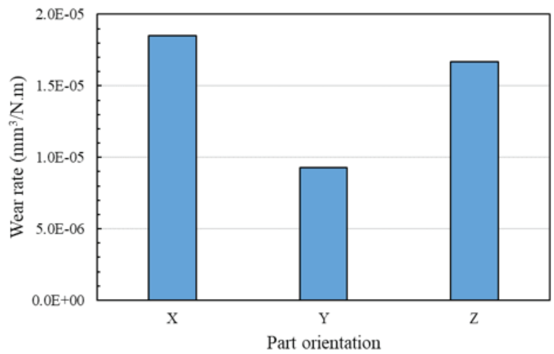



Fig.5 Average wear rate of PA12 after 30 minutes of dry sliding against steel disc




by high contact temperature (i.e., X- and Z- oriented PA12 specimens). The results from Fig.5 further emphasize the relationship between specific wear rate, the COF, and average contact temperature; higher coefficient of friction causes a corresponding increase in contact temperature which in turn increases the plastic deformation and shearing tendency of tribosurface layer resulting in an increase in wear specific wear and vice versa [18].

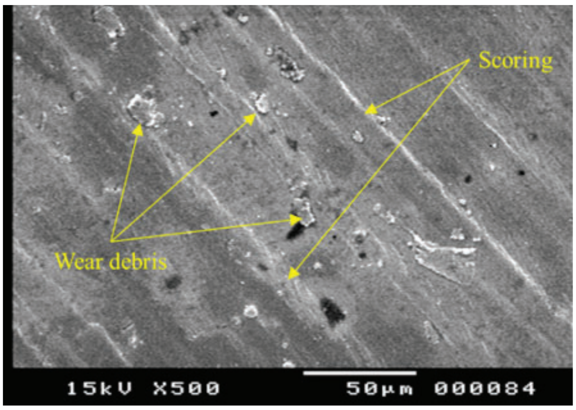
SEM (Scanning Electron Microscope) The active tribosurface of all PA12 pins was coated with a thin gold film so as to be suitable for investigation with the aid of SEM. The scanning electron micrograph of tribosurface of X-oriented PA12 specimens after 30 minutes of dry sliding wear test is shown in Fig.6. The scoring marks (groove/ridge pairs) shown clearly on the tribosurface along with free wear debris are an evidence of abrasive wear. Furthermore, the existence of embedded hard particles indicates a mutual material transfer between the counter surfaces; the hard embedded wear debris may roughen the counter surface causing further increase in wear rate of the soft PA12 surface. Moreover, PA12 flakes on the tribosurface are evidence of large plastic deformation (localized adhesive wear). Hence, interpretation of the tribosurface reveals that a combination of abrasive and adhesive wear dominates the steady state wear stages.

The SEM of wear surface of Y-oriented PA12 specimen is shown in Fig.7. As was predicted from Fig.3, the large plastic deformation of wear surface shown in Fig. 7 (b) is a clear evidence of sever adhesion which seems to be the dominating wear pattern throughout all stages of the interactions between mating surfaces. It is important to point out that other forms of dry sliding wear may exist side-by-side but, in case of Y-oriented PA12 specimens, sliding adhesive wear dominates.

Similarly, the SEM of wear surface of Z-oriented PA12 specimen after 30 minutes of dry sliding against the rotating steel disc is shown in Fig. 8. The wear pattern shown in Fig.8 suggests that a combination of abrasive wear, adhesive wear, and consequent surface fatigue wear may have occurred. The surface micrograph shown in Fig.8 may be explained as follows: the increase in PA12 real area of contact makes it prone to recurrent adhesion with steel counter surface, and hence large plastic deformation of PA12 surface layer accompanied by surface micro cracks may occur. The surface micro cracks propagate as the tangential shearing of surface layer continues and, eventually, flakes of PA12 are separated from the surface. Later, the separated flakes either stick to the PA12 face of transferred to the steel counter face forming a transfer film which may act to decrease the COF and subsequent wear rates, see Fig. 9. The transfer film shown in Fig.9 is partially continuous, however the hardened wear debris may detach from the disc face and then entrapped between the sliding surfaces causing a three-body abrasive wear pattern [19, 20].

Fig.6 SEM of tribosurface of the specimen aligned along X-axis (50 N and 0.25 m/s after 30 minutes).

(a) evidence of abrasive wear



(b) evidence of transfer film

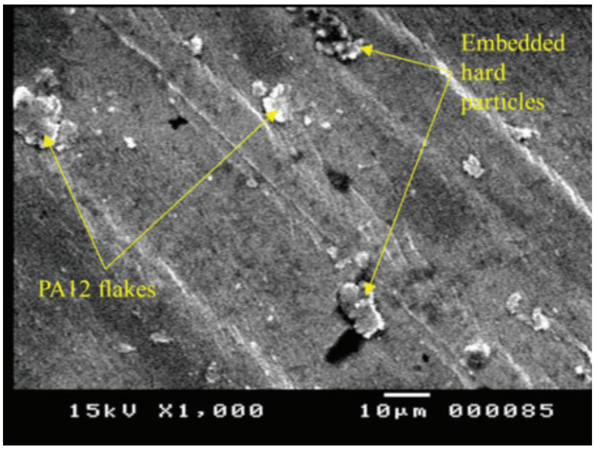
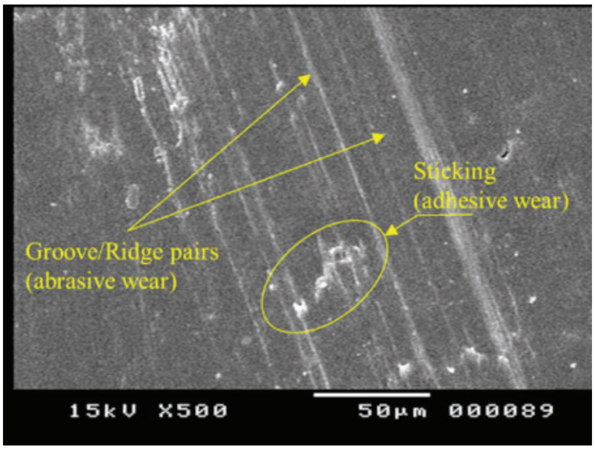



Fig.7 SEM of tribosurface of the specimen aligned along Y-axis (50 N and 0.25 m/s after 30 minutes).

(a) combination of adhesive and abrasive wear




(b) sever adhesion results in large plastic deformation

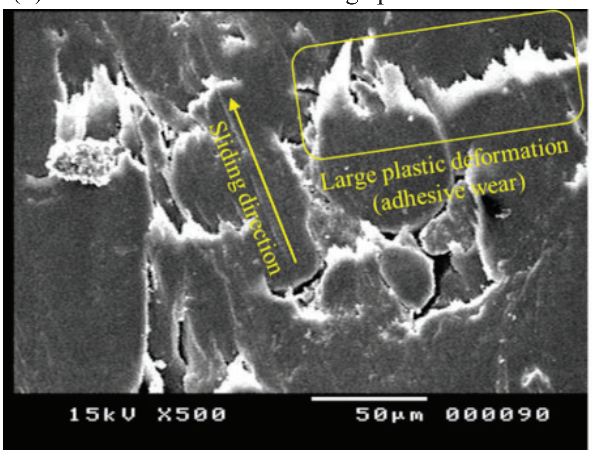
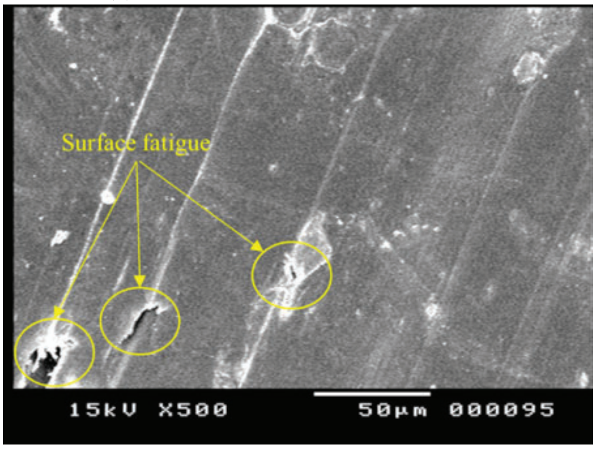



Fig.8 SEM of tribosurface of the specimen aligned along Z-axis (50 N and 0.25 m/s after 30 minutes).

(a) existence of surface microcracks




(b) adhesive and surface fatigue wear

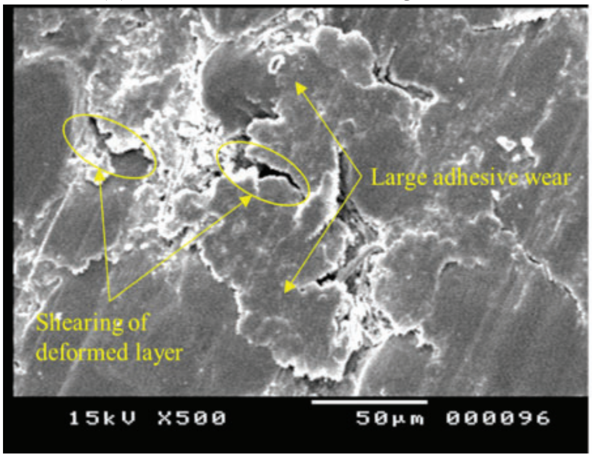
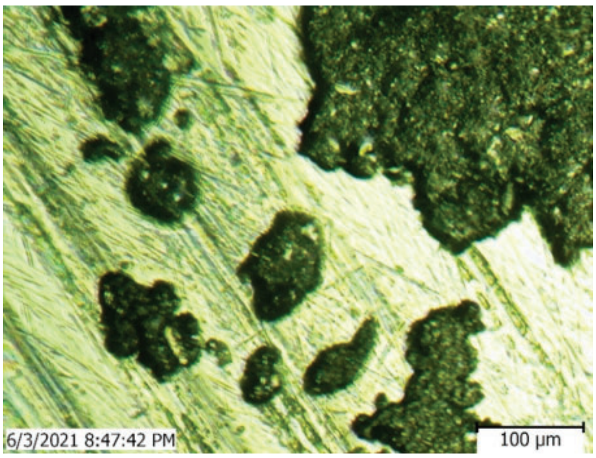



Fig.9 Microscopic picture showing wear debris and transfer film on rotating steel disc (after Y- axis specimen experiment)



## 4.Conclusions

In the present study, the dry sliding friction and wear characteristics of PA12 parts manufactured by SLS technology, considering the effect of object orientation in the build chamber, were investigated. The experiments were carried out to measure the coefficient of friction (COF) and the approximate contact temperature of PA12 pins loaded against a stainless steel rotating disc with the aid of Pin-on-disc test apparatus. The following important findings could be drawn out from the experimental results:

- The COF, contact temperature, and specific wear rate of PA12 specimens oriented along the Y-axis are significantly smaller than those oriented along X and Z axes.
- The transfer film observed on the steel disc surface acts to decrease the COF and wear rate of Y-oriented test specimens.
- For PA12 specimens oriented along X and Z axes, abrasive wear dominates the running-in stage while a combination of abrasive and adhesive wear prevails the subsequent steady-state wear stage.

The results from this study can help designers and manufacturers to properly align the active tribosurface during SLS process so as to minimize the COF, frictional heat, and wear rate. However, it should be pointed out that the application of introduced results is limited to the cases of dry sliding wear of PA12 against stainless steel at low sliding speed and heavy loads.

## Conflict of Interest

The author declare that there are no conflicts of interest regarding the publication of this paper.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## References


[1] R.D. Goodridge, C.J. Tuck, R.J.M. Hague, 2012. Laser sintering of polyamides and other polymers, Progress in Materials Science 57 (2), pp 229-267.

[2] Pande, Sarang, Tiwari, Sunil, Bobade, Santosh, Agrawal, Sanat. 2015. Selection of Selective Laser Sintering Materials for Different Applications. Rapid Prototyping Journal 21, pp 631-638.

[3] Abdelrasoul M. Gadelmoula and Saleh A. Aldahash, 2019. On the Effects of Fabrication parameters on the properties of parts manufactured with selective laser sintering: application on cement-filled PA12, Advances in Materials Science and Engineering, https://doi.org/10.1155/2019/8404857.

[4] Tyler Palma, Michael Munther, Praveen Damasus, Sepehr Salari, Ali Beheshti, Keivan Davami, 2019. Multiscale mechanical and tribological characterizations of additively manufactured polyamide 12 parts with different print orientations, Journal of Manufacturing Processes

40, pp 76-83.

[5] Stéphane Dupin, Olivier Lame, Claire Barrès, Jean-Yves Charmeau, 2012. Microstructural origin of physical and mechanical properties of polyamide 12 processed by laser sintering, European Polymer Journal 48 (9), pp 1611-1621.

[6] Magdalena Tomanik, Matylda Żmudzińska, and Magdalena Wojtków, 2021. Mechanical and Structural Evaluation of the PA12 Desktop Selective Laser Sintering Printed Parts Regarding Printing Strategy, 3D Printing and Additive Manufacturing 8 (4), pp 271-279.

[7] Alessandro Franco, Michele Lanzetta, Luca Romoli, 2010. Experimental analysis of selective laser sintering of polyamide powders: an energy perspective, Journal of Cleaner Production 18 (16–17), pp 1722-1730.

[8] K. Senthilkumaran, Pulak M. Pandey, P.V.M. Rao, 2009. Influence of building strategies on the accuracy of parts in selective laser sintering, Materials & Design 30 (8), pp 2946-2954.

[9] Aldahash, S.A., Gadelmoula, A.M., 2020. Orthotropic properties of cement-filled polyamide 12 manufactured by selective laser sintering. Rapid Prototyping Journal 26, pp 1103-1112.

[10] Saleh A. Aldahash, Shaaban A. Salman, Abdelrasoul M. Gadelmoula, 2020. Towards selective laser sintering of objects with customized mechanical properties based on ANFIS predictions, Journal of Mechanical Science and Technology 34 (12), pp 5075-5084.

[11] A. Pogačnik, M. Kalin, 2012. Parameters influencing the running-in and long-term tribological behaviour of polyamide (PA) against polyacetal (POM) and steel, Wear 290–291, pp 140-148.

[12] Jiang Guo, Jiaming Bai, Kui Liu, Jun Wei, 2018. Surface quality improvement of selective laser sintered polyamide 12 by precision grinding and magnetic field-assisted finishing, Materials & Design 138, pp 39-45.

[13] Petzold, Sean, Klett, James, Schauer, Andrew, Osswald, Tim, 2019. Surface roughness of polyamide 12 parts manufactured using selective laser sintering. Polymer Testing 80, 106094.

[14] Mahamood, Rasheedat & Okamoto, Yasuhiro & Maina, Martin Ruthandi & Akinlabi, Stephen & Pityana, Sisa & Tlotleng, Monnamme & Akinlabi, Esther, 2019. Wear Resistance Behaviour of Laser Additive Manufacture Materials: An Overview, 2019 International Conference on Engineering, Science, and Industrial Applications (ICESI), 10.1109/ICESI.2019.8863016

[15] Jiaming Bai, Shangqin Yuan, Wanlu Chow, Chee Kai Chua, Kun Zhou, Jun Wei, 2015. Effect of surface orientation on the tribological properties of laser sintered polyamide 12, Polymer Testing 48, pp 111-114.

[16] Andreas Wörz, Dietmar Drummer, 2018. Tribological anisotropy of selective laser sintered PA12 parts, Polymer Testing 70, pp 117-126.

[17] N.K. Myshkin, M.I. Petrokovets, A.V. Kovalev, 2005. Tribolo-

gy of polymers: Adhesion, friction, wear, and mass-transfer, Tribology International 38 (11–12), pp 910-921.

[18] Ziegler, Tobias & Marquez, Jhina & Jaeger, Raimund & Phommahavong, Somphong, 2018. Wear mechanisms and abrasion rates in selective laser sintering materials. Polymer Testing 67, pp 545-550.

[19] Shyam Bahadur, 2000. The development of transfer layers and their role in polymer tribology, Wear 245 (1–2), pp 92-99.

[20] Dewidar, M.A. (2002), "Direct and indirect laser sintering of metals", PhD Thesis, The University of Leeds.