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SURFACE ROUGHNESS QUALITY, FRICTION AND WEAR OF PARTS OBTAINED ON 3D PRINTER

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Abstract: *The achievement of the required roughness of the surface (today known as surface texture) is of great importance in obtaining the required characteristics of the parts from the aspect of reduction of friction and wear. The most common methods for obtaining the required roughness, or surface texture, are laser treatment and micro-processing by milling. 3D printing is increasingly being used to produce parts of wide range of applications. In order to obtain the necessary surface texture, the use of 3D printing technology compared to traditional technologies is faster, more flexible and cheaper. So far, a small number of studies have been related to the surface characteristics of parts produced by 3D printing. Therefore, all the researches in this field in order to improve the friction and wear characteristics have significant role. This work provides an insight into the research of tribological characteristics of surface of samples made from polymers which are most commonly used materials in 3D printing technologies. The surface roughness, friction and wear are measured using tribometer and experimental method „Block-on-Disk“. The results shows significant differences in measured values in the tested materials, which demand further researches in order to.*

Keywords: 3D printing tribology, friction, wear, surface roughness quality

1. INTRODUCTION

Roughness determines the performance of the part because it plays a significant role in determining how the parts interact with the environment. In terms of the surfaces of the engineering materials, roughness is thought to be detrimental to the performance of the part. In tribology, rough surfaces commonly have higher friction coefficients than smooth surfaces and wear faster. For this reason, the surface structure is closely related to the friction and wear properties of the surface [1].

Kovan et al. pointed out that the strength of the adhesive bond connection between the 3D printed parts is affected by the surface roughness. It has been determined that layer thickness and printing orientation in 3D

printed parts have significant effects on adhesion strength. In the case of low layer thicknesses, the layer produced on the side edge has the highest adhesive strength, whereas in the high layer thickness, the horizontal layer has the highest adhesive strength [3].

Three-dimensional printing is a production method that uses only digital technology to produce pieces, as opposed to machining methods such as turning, milling, drilling, etc., in which the material is cut out. Although the focus of 3D printing technologies has been developed primarily for prototype purposes, it has become possible to fabricate metallic structures and a much wider variety of functional parts, with increased emphasis on mechanical properties [2, 3].

Fused Deposition Modelling (FDM) is the most widely used technology in this production method which is also called additive manufacturing. FDM has many advantages, such as the use of cheap materials, the lack of expensive equipment, and the ability to create complex geometry. However, FDM has limitations, such as roughness on the surfaces. Methods that will remove these constraints and achieve better surface quality have been studied by many researchers [7, 8, 10].

Griguras and Kramar examined the hybrid production process of 3D printing and milling. To enhance the surface quality of the part, the outer surface of the parts produced by 3D printing is milled. By using a larger nozzle size, the production time is shortened and obtained the same surface quality [3].

Dewey and Ulutan researched the use of CO₂ laser polishing as an adjunct post-treatment to FDM-produced PLA parts to improve the surface features of the products. In their study, instead of reducing the layer thickness in 3D printing, the total processing time could be reduced without sacrificing surface quality. In addition, larger layer thicknesses and lasers have shown that the surface could be processed rapidly [3, 5].

Maidin et al. have tried to improve the surface characteristics of the FDM specimen by applying ultrasonic vibration in their work. As a result of the study, it was found that the best surface quality was obtained with a 21 kHz frequency applied during FDM production [3].

These hybrid processes, which combine machining, laser and ultrasonic processes with FDM processes, result in better surface quality. However, in all of these methods, machinery and production costs significantly increase. For this reason, the effect of the printing parameters on the surface properties of the different printing parameters has been investigated by many researchers, as it is known that the printing parameters affect the surface properties of the 3D printed parts.

Many authors are searching the surface roughness and wear of PLA models fabricated

by 3D printing technique. It is found that surface roughness decreased with increasing material melting temperature and wear increases [3 - 6].

2. EXPERIMENTAL METHODOLOGY

In this work, surface roughness measurement specimens were manufactured using a WANHAO Duplicator i3 plus printer by two samples from the PLA, ABS+ and PETG material of 1.75 mm diameter produced by Devil Design, Poland. The 3D printer is capable of producing a model with dimensions of 200x200x180 mm with a positioning accuracy of 12 µm for X and Y axes and 0,4 µm for Z axis.



Figure 1. WANHAO 3D printer

Conditions of the experiment are presented in Table 1. The dimensions of the samples were 11 x 6.3 x 15 mm and that is shown on Figure 2.

Table 1. Conditions of the experiment

| Materials | PLA | ABS+ | PETG |
|--------------------------|------|------|------|
| Layer thicknesses, mm | 0.15 | 0.15 | 0.15 |
| Fill density, % | 100 | 100 | 100 |
| Print speed, mm/s | 35 | 35 | 35 |
| Printing temperature, °C | 220 | 200 | 230 |
| Bed temperature, °C | 70 | 50 | 90 |

With specially prepared 3D printing codes, for all samples; 3 shells were used around the sample and on the upper and lower surface,

and the inside of the sample was printed using the specified printing angles ($-45^{\circ}/+45^{\circ}$) and 100% infill ratio. In this paper, all samples were manufactured in the same printing orientation (upright position). Investigating the effect of other printing orientations (flatwise and edgewise) on surface roughness will be extremely useful for engineering applications.

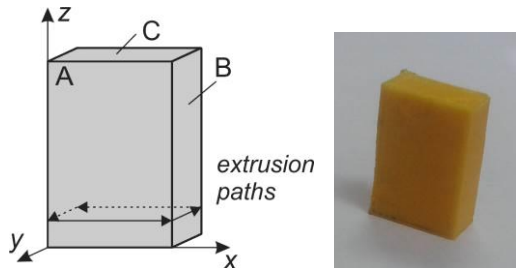


Figure 2. Sample

Surface roughness R_a and other parameters surfaces roughness are measures by device computerized measuring device Talysurf-6, which allows complex monitoring of the contact surfaces, figure 3.



Figure 3. Talysurf-6

Figure 4 shows the rectangular sample details and the measuring direction. Measuring direction the is perpendicular 90° to the building direction for all samples identical.

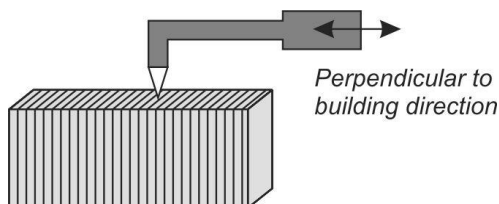


Figure 4. Sample area B and measuring direction surfaces roughness R_a

Research was carried out with materials of PLA, ABS+ and PETG [11].

PLA material is a biodegradable thermo-plastic which is derived from renewable resources, such as cornstarch, sugar cane. This makes PLA the most environmentally friendly material in the domain of 3D printing. PLA is tough, though it has the feature of a little brittle. When printing, PLA is odorless, low shrinkage, good rigidity, excellent gloss of printed object, no heated print bed necessary, high printing speed, available in rich colors [11].

PLA Filament is normally extruded at around $190-220^{\circ}\text{C}$, with printing speed as 50-60 mm/s. Opening the fan near the extruding nozzle is usually recommended to speed up the cooling down.

ABS+ material is generally very durable and strong, slightly flexible and quite resistant to heat. It has good shock absorbing properties and great plastic properties. It solidifies quickly, durable and difficult to break, ideal for mechanical parts.

ABS Filament is generally operated at the temperature around $210-250^{\circ}\text{C}$. Because of the feature of ABS material, ABS Filament cools down quickly, so 3D Printer need a heated print bed (around 110°C) to process ABS filament, in order to prevent warping or cracking of the printed object. ABS filament is better printed in a well ventilated area.

PETG filament is a close to PET (Polyethylene terephthalate) filament. PETG is a new updated version that has enhanced properties. It has minimal shrinkage and warping.

PETG filament has good flexible strength more than ABS filament. The filament is super transparent with a glossy finish. PETG filament is also environmentally friendly and recyclable. PETG is known for its transparency and clarity. It has great chemical resistance with good acidic and alkalic resistance.

The ideal print temperature is between $220^{\circ}\text{C} - 250^{\circ}\text{C}$. The filament has easy adhesion, so it can be printed on acrylic, glass, polyimide (Kapton) tape, blue tape, and others. A heated bed is not required.

Tribological investigations of the friction coefficient and wear surface layer were performed on the TPD-93 tribometer "Block-

on-disc", with contact at a line with disc made of 50CrMo4 of hardness 240 HB, Figure 5.

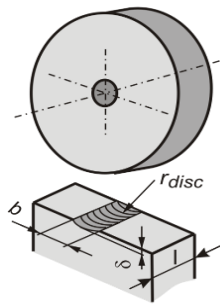


Figure 5. Contact elements "Block-on-disk"

The tribometer TR-95 perform contact condition variations in terms of shape, dimension and material of the contact elements, the normal load contact and sliding speed. Normal load was 20, 50 and 80 N and the sliding speed 0.25 m/s and 0.75 m/s. Total slip route was 150 m.

3. EXPERIMENTAL RESULTS

After finishing the production of samples (from all materials) on 3D printer, roughness measurement is done in the middle of surface B (with repeated measurement). Figures 6, 7 and 8 show the results of the foughness parameter Ra, the appearance of the obtained surface and the surface profile. Figure 9 shows a histogram with values of Ra of all samples.

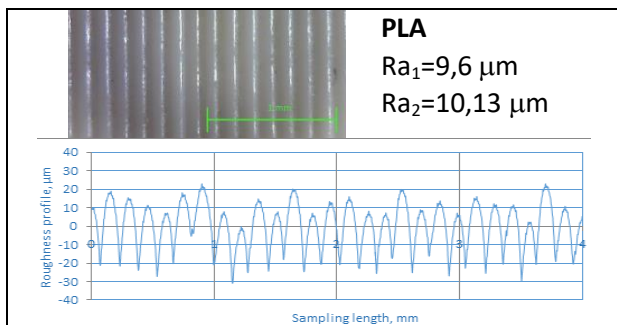


Figure 6. Surface profile of sample PLA

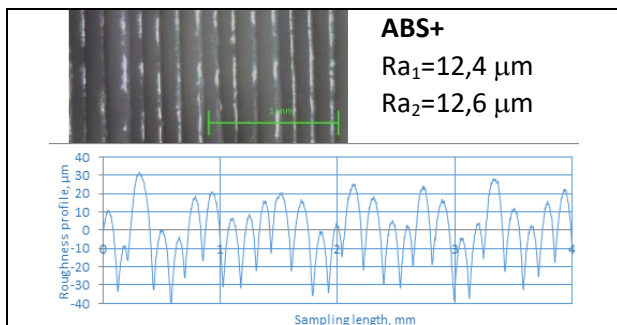


Figure 7. Surface profile of sample ABS+

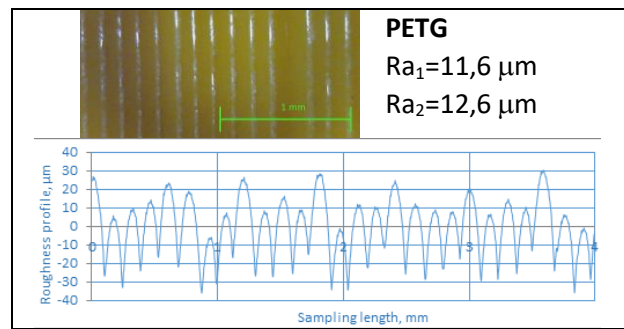


Figure 8. Surface profile of sample PETG

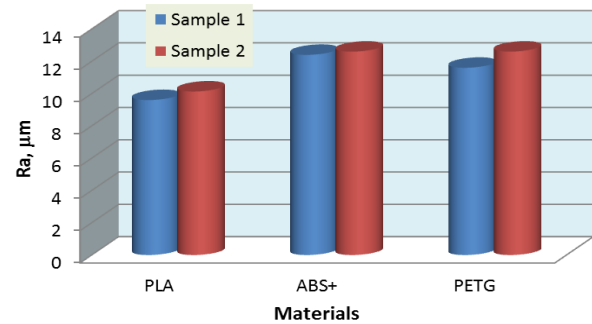


Figure 9. Surface roughness

By analysing the shape of the surfaces obtained by 3D printing, the unevenness profiles and values of Ra, it can be concluded that there are differences between the samples and that the smallest roughness has samples of PLA material. Furthermore, it can be noticed that in the samples of ABS+ and PETG materials, there is an unequal distribution of the material with the occurrence of local increase and decrease in the height of unevenness.

Measurement of tribological properties, both coefficient of friction and wear of samples was performed on the tribometer TPD-95 and the results are shown in Tables 2 and 3. The experiment was performed with two slip speeds and three normal loads.

Table 2. Friction coefficient

| Fn, N | v=0.25 m/s | | | v=0.75 m/s | | |
|-------|------------|------|------|------------|------|------|
| | PLA | ABS+ | PETG | PLA | ABS+ | PETG |
| 20 | 0.26 | 0.43 | 0.24 | 0.30 | 0.44 | 0.26 |
| 50 | 0.16 | 0.33 | 0.19 | 0.19 | 0.30 | 0.20 |
| 80 | 0.14 | 0.28 | 0.15 | 0.12 | 0.25 | 0.17 |

During the experiment the coefficient quickly reached a value that was approximately constant. Figure 10 shows the change in the friction coefficient over time for all three measured materials at a speed of 25 m/s and with a normal load of 50 N.

Figures 11 and 12 show the values of the friction coefficient depending on the type of material, the slip speed and the normal load. It can be concluded that with increasing normal load in all materials there is a significant reduction in the coefficient of friction. That coefficient it almost does not depend on the slip speed. The highest coefficient of friction is for ABS+, while PETG is slightly higher than PLA.

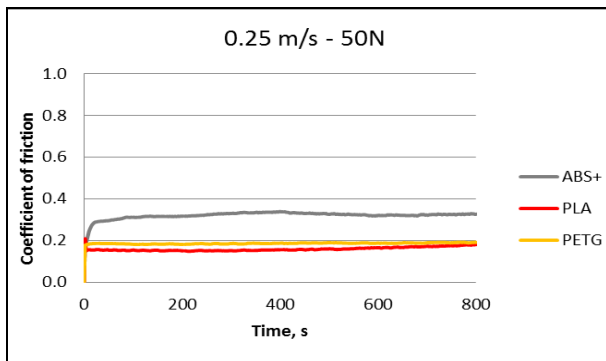


Figure 10. Change friction coefficient for materijals

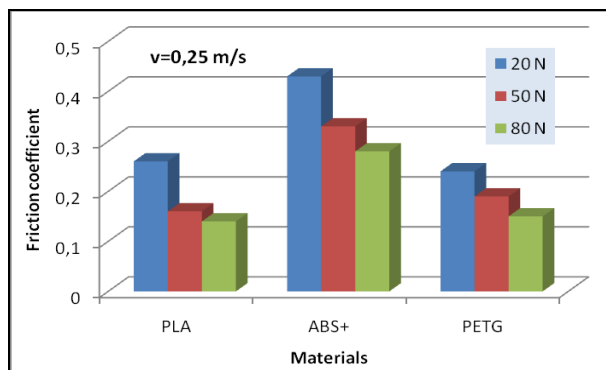


Figure 11. Friction coefficient for v=0,25 m/s

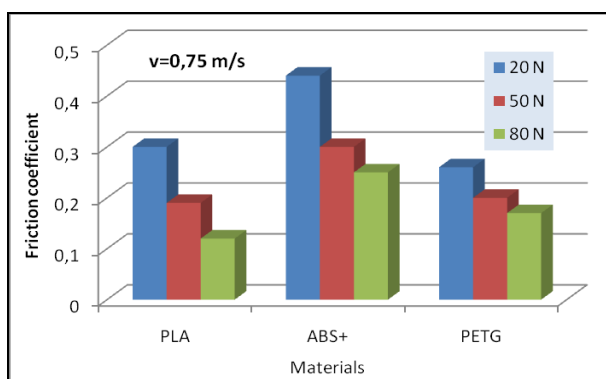


Figure 12. Friction coefficient for v=0,75 m/s

Measurement of the width of wear on the blocks after testing was performed on UIM-21 microscope. Tables 3, 4 and 5 show worn surfaces of tested blocks for different materials and different normal loads, tested at speed of 0.75 m/s. Table 6 shows all the values of the width of the wear on the blocks.

Table 3. Wear sample PLA, v=0,75 m/s

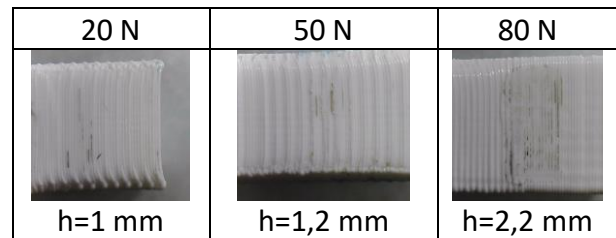


Table 4. Wear sample ABS+, v=0,75 m/s

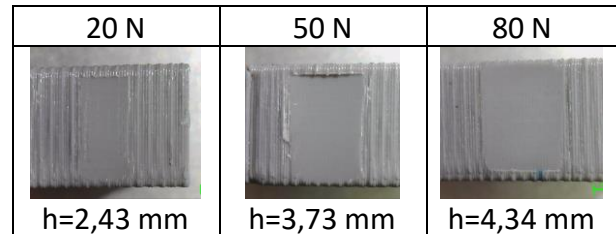


Table 5. Wear sample PETG, v=0,75 m/s

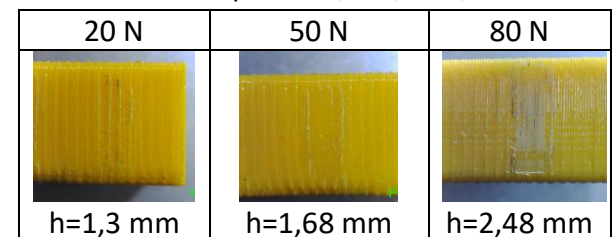


Table 6. Wear samples, mm

| Fn, N | v=0.25 m/s | | | v=0.75 m/s | | |
|-------|------------|------|------|------------|------|------|
| | PLA | ABS+ | PETG | PLA | ABS+ | PETG |
| 20 | 0,8 | 1,45 | 1,19 | 1 | 2,43 | 1,3 |
| 50 | 1 | 2,88 | 1,41 | 1,2 | 3,73 | 1,68 |
| 80 | 1,3 | 3,62 | 2,1 | 2,2 | 4,34 | 2,48 |

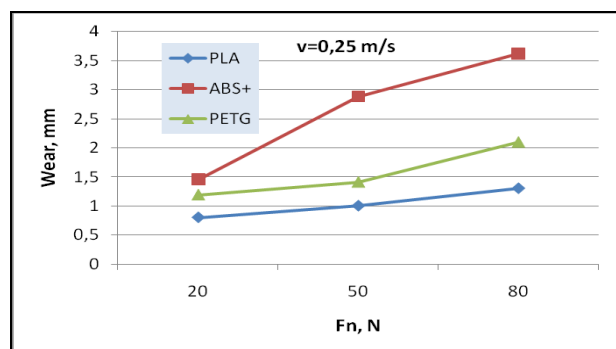


Figure 13. Wear block for v=0,25 m/s

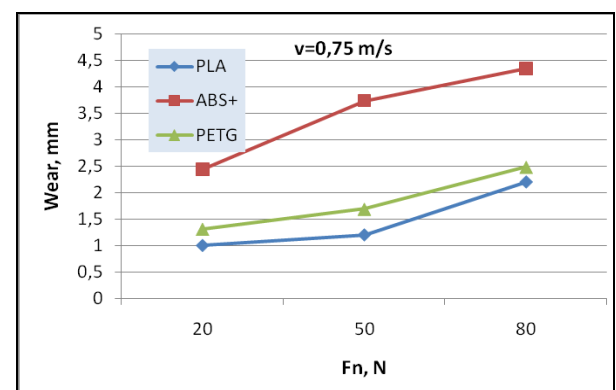


Figure 14. Wear block for v=0,75 m/s

Figures 13 and 14 show dependence of the wear width on the tested samples from the normal load, slip speed and material. It can be seen that the wear of the samples increases with increasing load as well as with increasing speed. The highest wear has ABS+ then PETG and PLA has the lowest wear.

4. CONCLUSION

The analysis of the obtained results of testing the tribological characteristics of the tested materials which are used as filament for 3D printing indicates that there are significant differences. This means material selection for 3D printing technology plays an important role from the aspects of surface roughness (topography), friction and wear and attention should be paid for it. The development and application of tribo-materials [9] significantly contributes to the expansion of the 3D printing area and its intensive development.

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