The influence of 3D printing layer height on frictional properties of ABS plastic

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Abstract. This work is devoted to the study of tribotechnical properties of 3D printed samples from ABS plastic. The results of determining the coefficient of friction and mass wear of the samples obtained by 3D-printing with different printing heights during the friction testing on machine II 5018 are presented. It is shown that in order to reduce the coefficient of friction and mass wear of the ABS plastic specimen, it is recommended to produce specimens with a higher print height. 3D printed parts with 0.3 mm layer height have shown the best results because of greater layer adhesion.

1. Introduction

A polymer is one of the best structural material in mechanical engineering. Polymers application expediency is primarily determined by the possibility of making the end product cheaper. This change can improve important technical and economic machine parameters: lower total weight, increase product reliability, etc. [1-4]. Poorly studied physical and mechanical properties and lack of information about behavior during friction processes are the main problems preventing polymer materials from becoming widely used in modern production and additive technology. Any finished sample has a ribbed surface due to the nature of 3D printing technology: the model is formed by sequentially applied layers of plastic. Ribs intensity on the surface is determined by the layer height which is set before printing (figure 1). The layer surface state determines the operational and tribotechnical properties and wear intensity of the workpiece [5-8]. Thus, the main goal of this article is to find the influence of 3D printing layer height on the tribotechnical characteristics of the ABS plastic parts. ABS is one of the most common materials used for 3D printing due to its high hardness, tensile strength, high impact toughness, low price and it is easy to print with. Products based on this material keep dimensions stable and have high chemical resistance [9-10].
2. Materials and methods

The ABS plastic pads samples (30 x 25 x 5 mm in size) for this study (figure 2) were printed with Picaso Designer XPro. The printing parameters for these samples are in table 1.

Table 1. 3D-printing parameters.

| Plastics | 3D printing layer height, mm | T_{printing}, °C | Fill percentage, % | k_{flow} |
|----------|------------------------------|-----------------|--------------------|---------|
| ABS      | 0.1                          | 230             | 100                | 0.94    |
|          | 0.2                          |                 |                    |         |
|          | 0.3                          |                 |                    |         |

To take into account the thermal expansion of the material and its elastic properties the flow coefficient \(k_{flow}\) is locked to 0.94. This coefficient links theoretical polymer volume extrusion with the actual one. For tribotechnical sample properties research the friction machine \(\text{II 5018}\) (figure 3) was used. Experiments were carried out with a disk-pad friction scheme (figure 4). A steel roller 50 mm in diameter and 12 mm in width acted as an opposite friction body.
Figure 3. Friction machine II 5018: 1 - specimen holder; 2 - steel disc (opposite friction body); 3 – the spring-loaded mechanism for creating pressure; 4 - handle for pressure adjusting.

Figure 4. Disk-pad friction scheme for II 5018 machine: 1 - stationary specimen (pad); 2 - steel disk (opposite friction body); P – pressure.

The operation principle of the machine is to conduct scuffing friction of pair of bodies pressed against each other with a given load. During the experiment, the values of friction force moment, friction coefficient, pressing force, and friction distance are recorded and displayed on the screen. To carry out tests, a polymer specimen was fixed (figure 3) in holder 1 over a steel counter body 2. The specimens are loaded with the help of a spring mechanism 3. The load value is tuned by knob 4.

The tests were conducted in the load range of 80 - 117 N and at a disk rotation speed of 150 rpm, the friction distance was set to 2000 m. The load values measured during the test were converted into contact pressure values using equation 1. The measured friction torque values were converted into friction coefficient values using equation 2.

\[ P = \frac{N}{S_k} \quad (1) \]

In equation 1: \( P \) - pressure, MPa; \( N \) - load, N; \( S_k \) - contact surface area of the pad (40 mm\(^2\)).

\[ F_r = \frac{F_p}{N} = \frac{M}{rN} \quad (2) \]

In equation 2: \( f_r \) - friction coefficient, \( F_p \) - friction force, N; \( M \) - friction torque, Nm; \( r \) - radius of the roller, mm; \( N \) – load, N.
3. Results and discussion

The obtained data from friction tests for ABS specimens with different print layer heights are presented in table 2.

Table 2. Result data gained with friction machine II 5018.

| Plastics | Sample | 3D printing layer height, mm | Average force, N | Average torque, N·m | Contact pressure | Friction coefficient | Average friction coefficient |
|----------|--------|-----------------------------|------------------|---------------------|-----------------|---------------------|---------------------------|
| ABS      | 1      | 0.1                         | 104.7            | 2.50                | 2.62            | 0.48                |                           |
|          | 2      | 0.2                         | 81.8             | 2.34                | 2.05            | 0.57                | 0.54                      |
|          | 3      | 0.3                         | 79.5             | 2.25                | 1.99            | 0.57                |                           |
|          | 1      | 0.1                         | 100.3            | 2.38                | 2.51            | 0.47                |                           |
|          | 2      | 0.2                         | 97.3             | 1.87                | 2.43            | 0.38                | 0.45                      |
|          | 3      | 0.3                         | 104.7            | 2.50                | 2.62            | 0.48                |                           |
|          | 1      | 0.3                         | 103.9            | 2.26                | 2.60            | 0.44                |                           |
|          | 2      | 0.3                         | 98.9             | 2.15                | 2.47            | 0.43                | 0.42                      |
|          | 3      | 0.3                         | 105.5            | 2.11                | 2.64            | 0.40                |                           |

Samples with a print height of 0.3 mm have the lowest friction coefficient. The difference between the maximum (for the sample with a print height of 0.1 mm) and the minimum (for the sample with a print height of 0.3 mm) obtained values of the friction coefficient is about 30%. The average values of the friction coefficient for each of the series of samples with different print heights are presented as a histogram in figure 5.

Figure 5. Average values of the friction coefficient of ABS plastic samples with different print heights.

The results of mass wear measurement are presented in table 3, the average mass wear of samples with different print heights are in figure 6.
Table 3. Result data gained with friction machine II 5018.

| Sample  | Sample mass, g | Mass wear, g | Average mass wear, g |
|---------|----------------|--------------|---------------------|
|         | Before         | After        |                     |
| ABS 0.1 | 5.74           | 5.26         | 0.48                |
|         | 5.71           | 5.41         | 0.3                 | 0.41               |
|         | 5.75           | 5.31         | 0.44                |
| ABS 0.2 | 5.63           | 5.13         | 0.5                 |
|         | 5.64           | 5.63         | 0.01                | 0.31               |
|         | 5.63           | 5.21         | 0.42                |
| ABS 0.3 | 5.84           | 5.67         | 0.17                |
|         | 5.57           | 5.27         | 0.3                 | 0.23               |
|         | 5.55           | 5.33         | 0.22                |

Figure 6. Average values of ABS plastic samples mass wear with different print heights.

The value of mass wear is in inverse dependence on the height of the print layer: the higher the printing layer – the less wear occurs. In all shown cases, the mass loss of the sample is less than 7% of the total mass. The change of wear with layer height is the same as the change of friction coefficient with layer height. Which proves that received influence data is reliable.

4. Conclusions
Experiments have shown that samples with a print height of 0.3 mm have a 30% lower coefficient of friction than samples with a print height of 0.1 mm. Samples with a print height of 0.3 mm have the least mass wear, the mass loss of these samples is about 40% less than 0.1 mm ones. The reason for this pattern probably is better adhesion between layers when printing at 0.3 mm height. This leads to better surface friction properties. The higher the temperature of the melted polymer and the slower it cools down, the better the adhesion between the layers. More polymer is going of the printer nozzle
per second with a higher printing layer height, so a larger volume of material can retain heat better and cool down slower. It should also be noted that when the layer height is increased, the printing time decreases drastically. Required time to print samples with a print height of 0.3 mm is 2-3 times less than the required time to print samples with a height of 0.1 mm.

Thus, 3D printing with a 0.3 mm layer height is the best option for the production of friction parts, as it succeeds in manufacturing speed and can deliver better friction properties of the finished workpiece.

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