Study of tribotechnical characteristics of 3D printed abs plastic samples

V Slavkina¹ and Yu Lopatina¹,²,³

¹Federal State Budgetary Scientific Institution "Federal Scientific Agricultural Engineering Center VIM", 1st Institutskyproezd 5, Moscow, Russia
²Bauman Moscow State Technical University, 5 Second Baumanskaya Street, Moscow, 105005, Russian Federation
³E-mail: lopatina.julia@yandex.ru

Abstract. This work is devoted to research of tribotechnical characteristics of 3D printed samples from ABS plastic. The results of determination of friction coefficient and depth of counterbody introduction into the sample surface on Tribometer TRB-S-DE-0000 are presented. The article also presents the advantages of using 3D printing for repairing machine parts and describes the causes of gear failure.

Introduction

The profitability of expensive equipment is largely determined by the useful life of components of nodes and machine parts which often quickly become unusable. Due to systematic breaks for the replacement of faulty parts decreases productivity and the quality of goods produced by this technique. At the same time, the costs of producing new parts and paying for repair workers will increase. All this slows down the work of the enterprise, destroys key elements necessary for automation of production and operational processes. With such dynamics, the losses of the enterprise will be very large [1]–[3].

The fact that nowadays a lot of manufacturers have to buy spare parts abroad also leads to certain difficulties: shortage of spare parts, their high price, long delivery times. Many manufacturers of machinery to reduce the cost of parts and metal consumption for their production replace the material with plastic. Such parts fail much faster which again leads to downtime in production [4],[5].

The majority of machine parts fail due to wear and tear [6],[7]. Wear leads to destruction and separation of solids from the surface, as well as accumulation of deformation during friction. Friction can be defined as a process that occurs when objects interact with each other in their relative motion. The causes of friction are the attraction of molecules of mutual nature in the contacting surfaces at the point of their contact as well as mechanical interaction of irregularities of friction surfaces [8].

The key indicator of friction is the coefficient of friction, which varies depending on the material of the interacting objects. But this is not the only indicator that should be taken into account it is equally important to measure material wear. When estimating the wear, it is necessary to take into account the changes in mass, parameters of the surface and shape of the original part resulting from the destruction of the upper layers during friction [9],[10].

Gear which in operation are subjected to dynamic and cyclic loads leading to surface destruction, are an example of parts that often fail due to friction wear. The extremely constant gear ratio determines the smooth running of the gears. However operating and technical errors (deformation)
exclude the possibility of a constant gear ratio. Dynamic loads such as shocks also have an undesirable effect. The above-mentioned errors do not allow the load to be distributed evenly over the width of the toothed rim which leads to the appearance of the angle of misalignment as a result of which the tension in some points will increase [11]–[13]. As a result, a defect such as wear of the working profile of teeth can often be found on gears of any kind. It is not accepted to correct such a defect and usually it is replaced with a new part. The exception is if the defect does not exceed the permissible limits. The permissible wear of gear teeth is given in Table 1 [14],[15]. If there is a need to replace one gear wheel it is also necessary to replace the conjugated one the defect of which is still acceptable because the necessary contact can only be achieved in this way. Usually gear wheels working in a pair are produced on the same machine to achieve better meshing effect. Also, it is necessary to consider that at replacement only one defective wheel can increase noise level [16]–[18].

Table 1. Permissible wear of gear teeth

| Working Mode                                | Circular speed, m/s | Limit wear to nominal tooth thickness along initial circle, % |
|---------------------------------------------|---------------------|---------------------------------------------------------------|
|                                             |                     | Type of repair                                              |
|                                             | Small   | Medium | Capital | Small   | Medium | Capital |
| Power transmission in one direction with shockless load | under 2  | 20     | 15  | 10  |                     |
|                                             | 2…5     | 15     | 10  | 6   |                     |
|                                             | Over 5   | 10     | 7   | 5   |                     |
| Reverse gear with impact load              | under 2  | 15     | 10  | 5   |                     |
|                                             | 2…5     | 10     | 5   | 5   |                     |

Reducing material and time costs in manufacturing spare parts in particular plastic gears can be achieved by using 3D printing technology. The most commonly used 3D printing technology today is fusion deposition modeling (FDM). Fusion deposition modeling is shown in Figure 1.

![Figure 1. Melting method simulation: 1 — controlled mobile extruder feeding molten plastic through a nozzle; 2 — molten material; 3 — controlled mobile platform.](image)

The FDM printing method uses a polymer thread called filament to produce the part. The extruder melts the incoming filament forming a layer of the part on the desktop. The layer is formed according to the contour of the part and the scheme specified by the special program. As the heat dissipates the molten polymer layer solidifies and then goes down together with the worktable under the next layer. Then the actions are repeated [19]–[23]. The main problem for wide application of additive technologies is a weak study of physical and mechanical characteristics of used materials in particular their friction characteristics. It should also be noted that tribotechnical characteristics of a part depend
to a large extent on the quality of its surface and at 3D-printing roughness of formed surfaces can vary in very wide limits.

**Materials and methods**

A tribometer TRB-S-DE-0000 for measuring the sliding friction coefficient in contact between two mutually movable surfaces has been used to carry out the research. The device is a desktop unit consisting of a friction machine with a measuring device and a computer (figure 2, a). The investigated sample in the form of a flat disk is established on a platform in a 6-cam holder. The counterbody is a ball of 6 mm diameter made of steel 100Cr6 fixed immovably in the rod holder (figure 2, b). The counterbody was placed on the sample at a distance of 1–2 mm from the axis of rotation of the platform.

The tests were carried out at a load of 20 N, the speed of relative sliding — 0.20 m/s, at a distance of 4500 m and ambient air temperature — 23–25 °C, the path of friction was 500 m. During the test the friction coefficient and the depth of penetration of the control sample into the body were continuously measured. The sliding of the counterbody relative to the sample is ensured by rotation of the platform with the sample.

Acrylonitrile butadiene styrene (ABS) is one of the most common materials used for 3D printing due to its high tensile strength and hardness [24] as well as its high impact toughness. At the same time products based on it have stable dimensions and chemical resistance. The main advantages also include ease of processing and low cost. In order to exclude shrinkage of the obtained parts it is necessary to observe the temperature regime during printing [25],[26]. In the Table 2 characteristics of ABS plastic used for 3D printing on FDM technology are presented.

| Table 2.ABS plastic characteristics for 3D printing |
|-----------------------------------------------|
| Extrusion temperature, °C | 210–245 |
| Operating temperature of products, °C | -40 ÷ +80 |
| Tensile strength, MPa | 26–47 |
| Rockwell hardness | R118 |

In this study, the samples were flat discs with a diameter of 30 mm and a thickness of 5 mm printed on a Picasso 3D Designer XPro printer. The printing parameters are presented in Table 3. The coefficient of friction was measured on two different surfaces of the sample: the ribbed one and the opposite smooth one which was pressed to the desktop surface during printing.
Table 3. Options for printing ABS plastic samples on the Picasso 3D Designer XPro 3D printer

| Parameter                  | Value  |
|----------------------------|--------|
| Nozzle diameter, mm        | 0.3    |
| Print speed, mm/s          | 100    |
| Height of print layer, mm  | 0.2    |
| Thickness of printing, mm  | 0.15   |
| Print temperature, °C      | 250    |

Results and discussion

The data obtained from the tests have been processed and presented in graphs. During the tests two indicators were recorded: the coefficient of friction and the depth of penetration of the counterbody into the surface of the analyzed sample. The data obtained from the tests of ribbed and smooth samples presented in graphs (figure 3). In both cases a similar character of friction coefficient behavior is observed: at the beginning of the test the coefficient of friction is reduced, then there is area where the value is practically unchanged. The first section is called the run-in section. After running in, the coefficient of friction corresponds to the minimum possible for a given pair of friction.

![Graphs showing friction coefficient and depth of penetration](image)

**Figure 3.** Dependence of the friction coefficient and the depth of counterbody penetration into sample surface from the friction path: a) a sample with a ribbed surface (№ 2); b) a sample with a smooth surface (№ 4)
The tribotechnical parameters of the specimens determined as a result of the test are given in Table 4. The running-in distance varied in the range from 234 to 412 m, and the coefficient of friction during the tests ranged from 0.11 to 0.37. After running-in, the average coefficient of friction for samples with a ribbed and smooth surface practically does not differ (0.20 and 0.24, respectively).

Table 4. Values of coefficients of friction of ABS plastic obtained on tribometer TRB-S-DE-0000

| Way of friction | Surface | Sample № | Run-in distance, m | Coefficient of friction | Medium in normal operating mode | Medium value |
|-----------------|---------|-----------|--------------------|-------------------------|---------------------------------|--------------|
|                 |         |           |                    | min | max |                           |              |
| 500 m           | Ribbed  | 1         | 412                | 0.11 | 0.27 | 0.19                      |               |
|                 |         | 2         | 234                | 0.16 | 0.25 | 0.20                      | 0.20          |
|                 |         | 3         | 257                | 0.17 | 0.29 | 0.23                      |               |
| Smooth          |         | 4         | 387                | 0.24 | 0.37 | 0.30                      | 0.24          |
|                 |         | 5         | 400                | 0.11 | 0.29 | 0.18                      |               |

Conclusion
The study showed that the surface quality does not significantly affect the coefficient of friction of 3D-printed samples from ABS. In all cases, the coefficient of friction in normal operation (after running in) was on average about 0.2. Thus, studies have shown that spare parts for friction machines can be produced using FDM 3D printing technology. The frictional characteristics of these parts will be close to those for the molded plastic with a smooth surface.

References
[1] Kandeva M., Kalitcin Z.H., Kornic P. Ecology for Renovation of Automotive Air Filters / Journal of Environmental Protection and Ecology. 2017. V.18. №2. 641–651 pp.
[2] Reznic S.V., Prosuntsov P.V., Michailovskii K.V. Prediction of Thermophysical and Thermomechanical Characteristics of Porous Carbon-Ceramic Composite Materials of the Heat Shield of Aerospace Craft / Journal of Engineering Physics and Thermophysics. 2015. V.88. №3. 594–601 pp.
[3] Eitherton J.R., Myers J.R. Agricultural Machine-Related Death / American Journal of Public Health. 1991. V.81. №6. 766–768 pp.
[4] Buyanov I.A., Vdovin D.S. Development of a Design Procedure and Preform Piercing Technology for Carbon-Composite Manufacturing / Polymer Science: Series D. 2017. V.10. №2. 103–105 pp.
[5] Signhal N., Levchenko I., Huang S., Xu L., Potrivitu G.S., Cherkun O., Bazaka K., Xu S., Fang J.
[6] Denisenko N.I., Maslyuk V.A., Yakovenko R.V. Reinforced Powder Chromium Steels and their Use for Hardening of Feed Mill Hammers / Powder Metallurgy and Metal Ceramics. 2019. V. 57. № 11–12. 740–746 pp.
[7] Lavrov N.A., Kiemov S.N., Kryzhanovskii V.K. Tribotechnical Properties of Composite Materials Based on Epoxy Polymers / Polymer Science: Series D. 2019. V.12. №2. 182–185 pp.
[8] Kobernic N.V., Mikheev R.S., Kalashnikov I.E., Kobeleva L.I., Bolotova L.K. Tribological Properties of Babbitt Alloy Coating Modified with Carbon Nanotubes / Inorganic Materials: Applied Research. 2017. V.8. №3. 428–433 pp.
[9] Fernandes C.M., Martins R.C., Seabra J.H. Coefficient of Friction Equation for Gears Based on a Modified Hersey Parameter / Tribology International. 2016. V.101. 204–217 pp.
[10] Li S., Chu Y. Application Research of Automatic Control Technology in Agriculture Machinery / Revista De La Facultad De Agronomía. 2019. V.36. №4. 1106–1115 pp.
[11] Medelyaev, I. A. Wear of Machine Parts with Mixed Lubrication / Russian Engineering Research. 2018. V. 38. 956–61 p.

[12] Gorodetskii, M. A., Nelyub, V. A., Malysheva, G. V., Shaulov, A. Y., Berlin, A. A. Technology of Forming and the Properties of Reinforced Composites Based on an Inorganic Binder // Russian Metallurgy (Metally). 2018. Volume 2018, Issue 13. 21–25 pp.

[13] Borodulin, A. S., Kalinnikov, A. N., Beshtoev, B. Z., Kharaev, A. M., Bazheva, R. C., Kvashin, V. A. Synthesis and Performance Characteristics of Superstructure Polyethers / Key Engineering Materials. 2019. V. 816. 307–311 pp.

[14] Polyakov, S. A., Kuksenova, L. I., Alekseeva, M. S. Methodological Foundations for Choosing the Materials for Gears According to Wear Resistance Criteria / Journal of Machinery Manufacture and Reliability. 2019. V. 48. № 4. 328–335 pp.

[15] Polezhaev, Yu. V., Reznik, S. V. Advanced Thermal Technologies and Materials / High Temperature. 1998. V. 36. №3. 503–506 pp.

[16] Stepashkin, A., Chukov, D. I., Senatov, F. S., Salimon, A. I., Korsunsky, A. M., Kaloshkin, S. D. 3D-printed PEEK-carbon fiber (CF) composites: Structure and thermal properties // Composites Science and Technology. 2018. Volume 164. pp. 319–326.

[17] Trifonova, O. M., Panova, Y. A., Akhmetov, I. G. A Study of the Effect of Maleic Anhydride on the Properties of Acrylonitrile Butadiene Sterene Plastic / International Polymer Science and Technology. 2018. V. 45. № 4. 251–256 pp.

[18] Lifton, V., Lifton, G., Simon, S. Options for additive rapid prototyping methods (3D printing) in MEMS / Rapid Prototyping Journal. 2014. V. 20. № 5. 403–412 pp.

[19] Zukas, V., Zukas, J. An Introduction to 3D Printing / Published and Distributed by First Edition Design Publishing. 2015. 41 pp.

[20] Stansbury, J., Idacavage, M. 3D Printing with polymers: Challenges among expending options and opportunities / Dental Materials. 2016. V. 32. 54–64 pp.

[21] Rinaldi, M., Ghidini, T., Cecchini, F., Brandao, A., Nanni, F. Additive layer manufacturing of poly (ether ether ketone) via FDM // Composites Part B: Engineering. 2018. Volume 145. pp. 162–172

[22] Hoskins, T. J., Dearn, K. D., Kukureka, S. N. Mechanical performance of PEEK produced by additive manufacturing // Polymer Testing. 2018. Volume 70. pp. 511–519

[23] Tuan, D., Kashani, A., Imbalzano, G., Nguyen, K., Hui, D. Additive manufacturing (3D printing): A review of materials, methods, application and challenges // Composites Part B: Engineering. 2018. V. 143. P. 172–196

[24] Oliveira, S., Muralidhara, H., Venkatesh, K., Gopalakrishna, K., Vivek, C. Plating on acrylonitrile-butadiene-styrene (ABS) plastic: a review / Journal of Materials Science. 2016. V. 51. P. 3657–3674

[25] Letcher, T., Rankouhi, B., Javadpour, S. Experimental Study of Mechanical Properties of Additively Manufactured ABS Plastic as a Function of Layer Parameters // Proceedings Paper. 2016. V. 5. 14–22 pp.

[26] Armilotta, A. Tolerance Analysis of Gear by Static Analogy / Mechanism and Machine Theory. 2019. V. 135. 65–80 pp.