Tribotechnical characteristics of polyamide PA 6 with additives of molybdenum disulfide and graphite

Vladimir Biryukov1* and Anton Yakubovsky1

1Mechanical Engineering Research Institute of the Russian Academy of Sciences, 4 Maly Kharitonyevsky Pereulok, 101990 Moscow, Russia

Abstract. The paper presents the results of tribotechnical tests of polyamide PA 6 with additives of molybdenum disulfide and graphite in comparison with nitrile butadiene rubber, BNC rubber. The influence of the surface roughness of a 40X steel counter-tile on the friction coefficients from pressure is considered and the jamming loads from the sliding speed are determined. The tests were carried out on a friction machine with a vertical axis of rotation of the spindle according to the "plane-ring" scheme when the friction pair was lubricated with MGE-10A hydraulic oil. The test loads and sliding speeds were changed stepwise. It has been found that with a decrease in the surface roughness of samples of polymer materials, the friction coefficients decrease. Samples with graphite additives had the best indicators for reducing the coefficient of friction from pressure, followed by samples with molybdenum disulfide and PA 6 without additives. The bullying resistance of graphite samples is 2 times higher than that of BNC samples. The samples with molybdenum disulfide were slightly inferior to the samples with graphite, but were better than PA 6. Keywords: polyamide, coefficient of friction, jamming load

1 Introduction

Polyamide is one of the most commonly used materials for plain bearings due to its tribological properties. During dry sliding, it transfers microscopic amounts of material in the form of microfibers, which provide lubrication and reduce friction between the mating surfaces. Thus, the material has self-lubricating properties, which reduces the friction forces on the bearings. Moreover, polyamide can work in highly loaded friction contacts under dry friction conditions, which makes it a particularly interesting material [1]. Various micro-fillers in the form of fibers [1-3], powders [4, 5] or nanofillers [6-12] are used as reinforcing materials.

For the study [13], three engineering plastics and a bronze alloy TM 23, a natural polymer PA 6 (TECAST T), PA 6, MoS2 (commercial name: TECAST T MO), PA 6 filled with a special solid lubricant (TECAGLIDE) were used as samples Tribotechnical tests were performed on a tribometer according to the scheme "pin (polymer sample, bronze)-disc (SAE

* Corresponding author: laser-52@yandex.ru
1020 steel, diameter 159 mm, thickness 12 mm).

Before each test, the surface of the disc was sanded with sandpaper with a grain size of 280, 400, 500, 600 and 1200 until a roughness Ra of less than 0.20 microns was obtained. The K-type thermocouple was embedded at a distance of 1.5 mm below the disk surface at a radius of 40 mm, which corresponded to the center of the friction track. The tests were carried out at a sliding speed of 4.2 mm/s for 120 s at various loads of 200, 300, 400, 500 and 600 N. After each cycle (180 s), tests at fixed contact pressure levels, the rotation speed of the disc increased by 25 rpm (or 0.1 m/s). The speed increases were consistently repeated until the tested material reached jamming, which was recorded by a sharp increase in the coefficient of friction and temperature. The bronze alloy showed the highest degree of wear among the materials used in this work, and adhesive wear was the dominant type of wear. PA 6, filled with a special solid lubricant, demonstrated excellent tribological properties, since it had a relatively low and stable coefficient of friction, as well as the highest wear resistance and bulk resistance.

Polyamide PA 6 (Durethan BKV 30 H3.0) was used as a matrix [14], with the addition of 30% fiberglass. PA 6/GF composites with two types of graphite Thermophit GFG5 and GFG1000 HD with an average grain size (D50) ~5 microns (EG5) and ~1000 microns (EG1000) were prepared using a Dr. Collin ZK 25 T twin-screw extruder at a temperature of 250 °C and 60 revolutions per minute. EG5 concentrations in the composites were 2, 4, 6, 8 and 10 wt.%, and with EG1000, samples with a content of 6, 8 and 10 wt.% were made. Tribological tests were carried out with unidirectional sliding motion on a UMT-2 tribometer (Bruker, Campbell, California, USA) at room temperature of about 25 °C. Before the test, the samples were polished to achieve a final roughness of Ra = 0.30 microns. The tests were carried out at a double stroke frequency of 7,234 Hz and a normal load of 6 N. The size of the EG particles affected the tribological properties. The lowest coefficient of friction was obtained by adding 10 wt.% EG5. However, the wear was the highest for this composite. Wear also increased, but only slightly, with the introduction of the EG1000. All PA 6/GF with graphite had higher thermal conductivity, and no big difference was found between EG5 and EG1000.

Preparation of composites [15] PA 66 with additives, FG and GrF powders were dried at 65 °C for 24 hours in a vacuum furnace. The dried PA 66 granules were then treated with a melt with different concentrations of FG (5 microns) and GrF using a Haake Rheomix OS mixer at a temperature of 265 °C and 50 rpm for 15 minutes. The products were crushed and dried at a temperature of 65°C for 12 hours ready for injection molding. The samples were made of a cylindrical shape with a diameter of 6.16 mm and a length of 20 mm. Tribotectical tests were performed according to the "pin-disc" scheme according to ASTM D638 type V and ASTM G99 standards. The wear test results also showed that GrF and FG reduced adhesive wear and fatigue wear of the PA 66 matrix.

Laboratory-grade polyamide PA 6 (DuPont Zytel, 7300T) and molybdenum disulfide powder (MoS2) (Starplex) were used for the production of samples [16]. Graphite powder with particle sizes in the range of 50-60 microns was used as an additive. Carbon black powder (1 wt.%) was pre-mixed with 0.5, 1, 2 and 3 wt.% of MoS2 powder, and then mixed with polyamide 6 granules in a drum mixer for 15 minutes, after pre-drying in a hot air oven at 80 °C for 8 hours, and then melted by mixing with a twin-screw extruder with simultaneous rotation at a screw rotation speed of 175 min-1 and a temperature of cylinder in the range from 250 to 260 °C. Tribological properties of PA 6/CB/MoS2 composites were determined using a pin-disc wear testing machine of the Ducom LR20E model, India, in accordance with the ASTM G99-04 standard. The disc was made of stainless steel (AISI 314) with a diameter of 150 mm, a thickness of 8 mm, with a surface roughness of 25 microns and a hardness of 62 HRC. The tests were performed at sliding speeds of 5, 7 and 9 m/s, friction paths of 1000, 1500 and 2000 m and loads of 50, 100 and 150 N. The wear resistance of the obtained PA
6/CB/MoS₂ composites increased with an increase in the MoS₂ content, but decreased with an increase in the applied load or sliding distances.

Fine graphite powder in the ratio of 5, 10, 20, 30 and 40 wt.% was used as a reinforcing material [17] for PA 6 polymer composites. Tribological tests were carried out according to the pin-disc scheme on a DUCOM TR-20LE-PHM400 tribometer. Before the test, the test samples were cleaned with methanol to remove possible contamination from the surface. The test samples conformed to the ASTM G99 standard and were made of a cylindrical shape with a diameter of 12 mm and a length of 30 mm. The tests were carried out at a disk rotation speed of 1000, 1500 and 2000 min⁻¹ and applied load values of 5, 10, 20 and 30 N. The introduction of a small amount of graphite significantly improves the mechanical and tribological properties of PA 6 composites. It was found that composites containing 20 wt.% of graphite in the PA 6 matrix showed the best performance.

A cast matrix [18] of polyamide (PA 6G) and a composite filled with a solid lubricant made of polyethylene (PA 6G SL) allowed Ensinger GmbH to manufacture a semi-finished product supplied by Quattroplast Ltd, Hungary Docamid 6G and Docaglide. Tribological tests were performed according to the "pin-disc" scheme in accordance with the DIN 50322 standard. Plastic samples with a contact diameter of 5 mm and a height of 3 mm were used as pins. The surface of the disk made of S235 steel (average roughness Ra = 0.06–0.1 microns) slid along fixed pins located at radii of 17 and 27 mm. The surface energy of the composite (PA 6G SL) was slightly lower, which affected the adhesive component of the friction coefficient. With an increased load level, the tribological properties of the composites were significantly better than those of pure samples.

The powders PI and CF-MoS₂ were mixed mechanically [19] for 10 minutes, the mixture was poured into a mold and sintered at a temperature of 350 °C for 20 minutes. During the entire heating process, the pressure was maintained at 30 MPa. After natural cooling below 100 °C and extraction from the mold, a composite PI/CF-MoS₂ with a diameter of 30 mm and a thickness of 4 mm was obtained. In addition, pure PI, PI/CF and PI/MoS₂ were made for comparison. Tribological tests were performed on a UMT friction machine - according to the scheme "ball (GCr15 steel with a diameter of 4 mm) - disc (polymer sample)". The experiments were carried out with dry friction lasting 30 minutes, normal load of 1.5, 3 and 4.5 N, sliding speeds of 0.083 and 0.116 m/s. The hardness and heat resistance of the PI/CF-MoS₂ samples were much better than that of PI or PI/CF. More importantly, CF-MoS₂ has significantly improved the friction reduction and anti-wear properties of the PI. Its coefficient of friction and degree of wear were only 0.24, and $2.01 \times 10^{-6}$ mm³/N•m, respectively. This was mainly because the addition of CF-MoS₂ increased the bearing capacity and heat resistance of the polymer.

## 2 Materials and research methods

Experiments were performed on rectangular samples of polymers PA-6 (70×20×2 mm), PA-6, oil-filled with molybdenum disulfide (70×20×10 mm), PA-6 with graphite (Gr) (70×20×10 mm) and nitrile butadiene rubber, rubber (BNK) (70×20×2 mm). Plates of polymers and BNC rubber with a thickness of 2 mm were glued to a plywood substrate with dimensions of 70×20×10 mm. Tribotechnical tests were carried out on a friction machine with a vertical axis of rotation of the spindle according to the scheme: "the annular surface of the counter–plate sleeve (steel 40X) is a plane (the wide side of the polymer sample, BNC)". The moment of friction and the load on the samples were monitored using strain gauges mounted on 4 friction machines in continuous mode. The processing of the end face of the counter-tile was performed on silicon carbide sandpaper with a grain size of P180, P600, P 1200. Hydraulic oil MGE-10 was used as a lubricant.
3 Results

Fig. 1 shows the dependences of the friction coefficients on the pressure in the polymer (rubber) – steel 40X friction pair at a constant sliding speed. With increased roughness of the surface of the counter-tile treated with sandpaper P180, the values of the friction coefficients (Fig. 1, a) were for BNR, PA 6, PA 6+ MoS2 and PA 6 +Gr 0,1-0,13, 0,085-0,1, 0,07-0,082, 0,06-0,07 accordingly. With an average surface roughness (Fig. 1, b) (processing of the counter-sample P600) the values of the friction coefficients increased and amounted to BNR, PA 6, PA 6+ MoS2 and PA 6 +Gr 0,13-0,16, 0,1-0,11, 0,08-0,09, 0,075-0,085 accordingly. When sliding along the counter-tile after processing its friction surface with sandpaper P 1200 (Fig. 1, c), the values of the friction coefficients were for BNR, PA 6, PA 6+ MoS2 and PA 6 +Gr 0,11-0,13, 0,08-0,09, 0,06-0,07, 0,04-0,048 accordingly.
Fig. 1. Dependences of friction coefficients on pressure at constant sliding velocity a, P180, b, P600, c, P1200: 1 - BNR, 2 - 6, 3 - 6+ MoS$_2$, 4- 6 + Gr

Fig. 2 shows the patterns of changes in the jamming load from the sliding speed in a polymer (rubber) – 40X steel friction pair. PA 6 +Gr samples had the best properties according to the jamming criterion for all test modes. After processing the counter-tiles with sandpaper P180 (Fig. 2, a), the jamming loads and sliding speeds for BNK - 2MPa (1.4 m/s) - 5.5 MPa (0.25 m/s), PA 6 - 2.0 MPa (1.6 m/s), 6.5 MPa (0.25 m/s), PA 6+ MoS2 – 2 MPa (1.68 m/s) - 7.0 MPa (0.25 m/s) and PA 6 +Gr 2.0 – 2.0 MPa (1.95 m/s) – 8.0 MPa (0.25 m/s), respectively. When processing the counter-tile with P600 paper, the values of jamming pressures (Fig. 2, b) increased for all samples by about 1 MPa. With a decrease in surface roughness (Fig. 2, c) (processing P1200), the task load for BNC samples decreased by about 1 MPa over the entire speed range. The jamming loads and sliding speeds (at low pressures) of polymer samples increased, and amounted to PA 6 – 2.0 MPa (2.4 m/s) -7.5 MPa (0.25 m/s), PA 6+ MoS2 – 2.0 MPa (2.6 m/s) – 9.0 MPa (0.25 m/s) and PA 6 +Gr – 2.0 MPa (3.0 m/s) – 11.5 MPa (0.25 m/s), respectively.
4 Conclusion

1. The regularities of the friction coefficients change depending on the pressure and surface roughness at a constant sliding speed are determined.

2. A decrease in surface roughness when processing the counter-tile with sandpaper P1200 led to a decrease in the coefficient of friction of samples with graphite almost twice as compared with counter-tiles after processing with paper P180. Samples with PA 6+ MoS2 had higher coefficients of friction, followed by PA 6 and BNR.

3. Reducing the surface roughness of 40X steel increased the jamming load and sliding speed of samples with graphite by 2 times compared to BNR, further along the decreasing critical load, samples with molybdenum disulfide and PA 6 without additives. The BNR samples had the worst indicators of bullying resistance.

4. The technology of laser surfacing with multicomponent powder coating with additives of nano carbide TaC can be used for surfacing turbine necks, thrust discs, turbine blades of power and gas pumping equipment and other parts operating at high temperatures in corrosive environments.

References