Determination of tribological characteristics of polymer materials

V P Biryukov and A N Prince
Mechanical Engineering Research Institute of the Russian Academy of Sciences, 4 Maly Kharitonyevskiy Pereulok, Moscow, 101990, Russia
Laser-52@yandex.ru

Abstract. The paper presents the results of tribological tests of thermoplastic polyurethanes (TPU) and rubber based on nitrile butadiene rubber (BNR) on rigidly fixed silicon carbide and free abrasive. The influence of pressure and sliding speed on the coefficients of friction is shown. For Elastollan 1164, the coefficient of friction and mass loss were 0.2 -0.3 and 0.028 g, which is 5-7 times lower than for BNR.

1. Introduction
TPU samples (Elastolan ET870-11V, BASF, Germany) were obtained by injection molding a sheet with a thickness of 4 mm [1]. In addition, samples of BR butadiene rubber and SBR styrene-butadiene rubber were used. The sheets were cut into blocks with dimensions of 5×5×3 mm. During the test, the sample slid along the abrasive paper unidirectionally at a length of 0.07 m. The sample was then lifted up and returned to its original position. This process was repeated 100 times. The friction path of the sample was 7.0 m. Sheets of silicon carbide SiC abrasive paper with different grain sizes 3000, 1000, 500, 240, and 80 with roughness Ra 1.94, 4.02, 8.64, 17.8, and 45.7 µm, respectively, were glued to the fixed base. For three repeated measurements of the friction coefficient f of the TPU samples, there was no noticeable effect of the grain size of the abrasive paper (1.05 ≤ f ≤ 1.12). In contrast, the coefficient of friction for BC samples decreased from 0.96 to 0.69 with an increase in Ra at Ra ≤ 8.64 µm, and then it increased from 0.69 to 0.96 at Ra ≥ 8.64 µm. For SBC samples, the coefficient of friction decreased slightly from 0.91 to 0.84 with increasing Ra at Ra ≤ 17.8 µm and then increased from 0.84 to 0.98 at Ra≥17.8 µm. The values of the friction coefficient for TPU exceeded 1.0 in comparison with the samples of BC and SBK, regardless of the Ra of the abrasive paper. The specific wear rate for all materials generally increased with increasing Ra. The wear rate for TPU was higher than for BC, but samples made of thermoplastic polyurethane had a higher wear resistance compared to SBC samples.

For testing, a thermoplastic polyurethane TPU (UT-74D) from Bayer, Germany, which has good wear resistance, mechanical strength and is widely used for sealing, in the automotive and footwear industry [2]. The height and diameter of the samples were 10 ± 0.05 mm and 30 ± 0.05 mm, respectively. Copper balls (H65, with Ra ≤ 0.2 µm, 10 ±0.03 mm in diameter) were used as a counter-sample. The friction pair simulated the actual operating conditions of the aft bearings lubricated by sea water. Tribological tests were performed according to the disk - ball scheme and using a multifunctional Tribometer (MFT5000, USA). The applied loads were 2, 6, 10 and 14 N, providing an initial average contact pressure of 14.34, 20.68, 24.52, 27.44 MPa in Hertz. The speed of rotation of
the disk was 70 min⁻¹ (0.04 m·s⁻¹), the Ball glided along a circle with a radius of 6 mm. The TPU samples were irradiated with 60 Co radiation source, EL PONT Inc. China, with increasing absorbed radiation energy for each batch of 50, 150 and 250 kGf. Unirradiated samples were designated 0K.

The coefficient of friction of TPU samples under various loads and the degree of irradiation of 0K and 50K TPU remained relatively stable, compared with samples 150K and 250K, at which it increased to 0.17-0.35 and 0.35 and 0.42, respectively, with increasing pressure.

To determine the tribological characteristics, mixtures of polypropylene and thermoplastic polyurethane (PP/TPU) were used in various weight ratios (25/75 and 75/25) with the addition of maleic anhydride PP-g-MA as a binder grafted to polypropylene. in quantity 0, 3, 5, 7, 9, 11 wt.h. per 100 wt.h. PP/TPU [3]. Friction and wear tests were performed according to the US standard ASTM G99 according to the scheme disk (a sample of a composite with a diameter of 29 mm and a thickness of 8 mm) - ball (Al₂O₃ with a diameter of 5 mm). The test load was 2.5 N, the sliding speed was 0.576 m·s⁻¹ (1100 min⁻¹), the friction path was 345 m, and the duration was 10 min. Samples of PP25/TPU75 composites had a coefficient of friction of 0.39 - 0.6 and a wear RATE 1200 – 1800 × 10⁻⁶ mm³·N⁻¹·m⁻¹ with their maximum values at 5 wt.h. PP-g-MA. For the PP75/TPU25 mixture, the coefficient of friction was 0.39 - 0.4 and the wear rate 1000 - 1600 × 10⁻⁶ mm³·N⁻¹·m⁻¹ according to the results of wear tests, it was found that the PP75/TPU25 mixture with a content of 11 wt.h. PP-g-MA is superior to other mixtures.

2. Research materials and methods
For testing for friction and wear, thermoplastic polyurethanes (TPU) were selected, the technical characteristics of which are shown in table 1 for comparison with the polyurethanes of the selected rubber based on butadiene-nitrile rubber (BNR). Each of the 7 materials studied was a plate with dimensions of 20×70×2 mm, which was glued to plywood with dimensions of 20×70×12 mm.

Table 1. Technical characteristics of TPU.

| Material brand       | Hardness, Shore | Density, g·cm⁻³ | Ultimate strength, MPa | Elongation at break, % |
|----------------------|-----------------|-----------------|------------------------|------------------------|
| Elastollan 560 A     | 60 D            | 1.22            | 24                     | 850                    |
| KOPEL KP 3340        | 40 D            | 1.15            | 24.5                   | 850                    |
| Elastollan 1164 D 11 | 69 A            | 1.18            | 50                     | 350                    |
| Elastollan 1154 D 10 | 53 A            | 1.17            | 50                     | 450                    |
| Elastollan 1175 A 10 W| 75 A            | 1.14            | 40                     | 700                    |
| Elastollan 1185 A 10 W| 83 A            | 1.16            | 40                     | 700                    |
| BNR                  | 75 A            | 1.3             | 25                     | 425                    |

A steel ring mandrel with sandpaper made of silicon carbide with a grain size of 120 µm pasted on its end was used as a counter-tile. Tests for friction and wear were performed according to the "plane (test sample) - ring" scheme. The sliding speed and pressure on the sample varied discretely in the range of 0.1–0.3 m·s⁻¹ and 0.1–0.5 MPa, respectively. Wear tests with a free abrasive were performed when a flat sample was rubbed against the forming surface of a rubber disk. Quartz sand with a particle size of 0.2-0.6 mm was fed into the friction zone. The tests were performed at normal atmospheric pressure and temperature. The test load was 15 N, and the time was 5 minutes. Three samples of each material were tested. The amount of wear was determined as the average arithmetic weight loss for three samples.

3. Results of experimental studies
Figure 1 (a, b) shows the results in the form of dependences of the coefficient of friction on the normal pressure and sliding speed when tested on a fixed abrasive.
As the pressure increased, the values of the friction coefficients decreased for TPU 1164, 1154, 1175A and BNR over the entire pressure range. The values of the friction coefficients of 0.6 and 0.61 remained constant for the TPU 3340 and 1185A, independent of pressure. For polymer 560, the coefficient of friction increased from 0.4 to 0.43 at a pressure of 0.34 MPa, and then decreased to 0.38 at a pressure of 0.5 MPa. An increase in the sliding speed from 0.12 to 0.24 m·s⁻¹ led to a slight decrease in the friction coefficients for TPU 1164, 1154, 1175A. With a further increase in the speed to 0.3 m·s⁻¹, the coefficient of friction increased for all types of polymer materials. The BNR coefficient of friction increased proportionally over the entire range of sliding speeds.

Figure 2 shows the mass loss of samples from pressure.

**Figure 1.** Dependence of polymer friction coefficients on pressure (a) and sliding speed (b): 1 – 1164, 2 – 1154, 3 – 560, 4 – 3340, 5 – 1185A, 6 – 1175A, 7 – BNR.

**Figure 2.** Dependence of the mass loss of the TPU sample on the pressure when testing on a fixed abrasive: 1 – 1164, 2 – 1154, 3 – 3340, 4 – 560, 5 – 1185A, 6 -1175A, 7 – BNR.
For the BNR, the mass loss increased in proportion to the pressure. The wear of TPU samples at low pressures up to 0.3 MPa is insignificant, with a further increase in pressure up to 0.52 MPa for Elastollan 1175 A and 1185 A increases to 0.078 and 0.087 g, respectively. The minimum mass loss was obtained for TPU 1164 0.004 g. At a pressure of 0.52 MPa, the minimum wear of 0.037 g was recorded in the Elastollan 1164 and 1154 samples. Figure 3 shows the morphology of the friction surfaces of the samples. The friction surface of the TPU560 (figure 3 (a)) has swells and rough delamination of the material, apparently as a result of repeated elastic and plastic deformation and fatigue separation of wear particles. On the surface of samples 3340, 1175A, 1185A (figure 3 (b), (d), (e)), risks are visible in the direction of sliding of the fixed abrasive grain. The undulation of the surface of the TPU 1164 and 1154 samples (figure 3 (c), (d)) indicates a gradual accumulation of damage and separation of wear particles by the fatigue mechanism. The friction surfaces of the BNR samples (figure 3 (g)) throughout had risks in the direction of sliding. It can be assumed that the prevailing mode of wear was micro-cutting with friction on the fixed abrasive grain. Figure 4 shows the profiles of wear holes of polymer materials and BNR rubber when tested with loose abrasive. Similar test results with minimal weight loss were shown by samples of TPU 1164 and 1154 with free and fixed abrasive. Samples of polymers 3340 and 560 when rubbed with free abrasive grain showed worse results than BNR. Samples 1185A and 1175A retained less weight loss compared to rubber.

Figure 3. Morphology of the friction surface of TPU and BNR when tested with a fixed abrasive: (a) - 560, (b) – 3340, (c) - 1164, (d) - 1154, (e) – 1175A, (f) – 1185A, (g) – BNR.
Figure 4. Hole profiles export of materials: 1 – 1164, 2 – 1154, 3 – 1185A, 4 – 1175A, 5 – BNR, 6 – 3340, 7 – 560.

Figure 5 shows fragments of wear holes of materials during friction on a free abrasive.

Figure 5. Morphology of the reunion of polymers and BNR in the free abrasive confession: (a) – 1164, (b) – 1154, (c)-1185A, (d) – 1175A, (e) – BNR, (f) – 3340, (g) – 560.
The friction surfaces of TPU 1164, 1154, 1185A, 1175A and BNR had longitudinal risks in the direction of sliding of the abrasive grain and the wear mechanism can be attributed to micro-cutting. The undulation of the surface of samples 3340, 560 indicates a gradual accumulation of damage and separation of wear particles by the fatigue mechanism. These materials are significantly inferior to the wear resistance of BNR when friction is not fixed with an abrasive, and can not be used to replace rubber products. Despite the different results, both test methods complemented each other and gave a complete description of polymer materials used in natural conditions during the operation of machines and mechanisms, when it is possible to affect the friction surface with fixed and free abrasive grain.

4. Conclusions
The regularities of changes in the coefficients of friction and mass loss of samples from pressure during friction on the fixed abrasive are obtained. Coefficient of friction for TPU 1164 – 0.2-0.3 and for BNR 0.8-1.0. The minimum weight loss was shown by TPU 1164 and 1154 when testing for wear with a free and fixed abrasive. Samples 3340, 560 had a greater mass loss than BNR when tested with free abrasive and cannot be used to replace it.

References
[1] Sato S, Yamaguchi T, Shibata K, Nishi T, Moriyasu K, Harano K and Hokkirigawa K 2020 Biotribology 23 p 100130
[2] Jiang S, Yuan C, Guo Z and Bai X 2019 Tribology International 136 pp 276–84
[3] Savaş S and Al-Obaidi AY 2018 Tribology Transactions 61 p 754–64