Influence of the composition of polymeric materials on the tribological characteristics under abrasive wear

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Abstract. The paper presents the results of tribological tests of thermoplastic polyurethanes (TPU), UHMWPE, polypropylene and rubber based on nitrile butadiene rubber (BNR) on fixed silicon carbide and free abrasive. The influence of pressure and sliding speed on the coefficients of friction is shown. For PP2015 polypropylene, the coefficient of friction and mass loss were 0.3-0.35 and 0.003 g, which is 4 - 10 times lower than for BNR.

1. Introduction
Currently, rubber materials are used in the friction units of railway rolling stock. These include oil seals, cuffs, various seals, corrugations, shock absorbers, etc. Until now, the issue of wear of free and fixed abrasive parts made of rubber, and the possibility of replacing them with other polymer materials, has not been sufficiently studied.

In [1], polymer samples of polyamide and polypropylene PA6/PP composites filled with GR PA66/PP graphite and a polymer composite with the introduction of solid particles of nano-clay NC - PA66/PP with shore hardness of 64, 66 and 71, respectively, were made for testing for abrasive wear according to the US ASTM G-65 standard. Quartz sand and quartz with a particle size of 200 – 250 µm were used as an abrasive. The tests were carried out at a constant load of 36 N, the friction path was 150 - 600 m. The greatest wear is observed in samples with graphite filler PA66/PP – 0.0105·10^{-9} m^{3}·N^{-1}·m^{-1}, and the lowest wear is 0.0055·10^{-9} m^{3}·N^{-1}·m^{-1} for the PA66 / PP mixture when tested with quartz abrasive. When using quartz sand as an abrasive, the relative wear rate is lower. Wear for graphite-filled PA66/PP and unfilled PA66/PP is 0.0085·10^{-9} m^{3}·N^{-1}·m^{-1} and 0.004·10^{-9} m^{3}·N^{-1}·m^{-1}, respectively. For samples of NC-PA66/PP and GR PA66/PP composites, the specific wear rate increases with increasing friction path and decreases for the PA66 / PP mixture. There is an increase in the wear of GR - PA66/PP samples by 196% and 167% compared to NC - PA66/PP and PA66/PP composites, respectively.

In [2], the effect of white soot (colloidal silicon dioxide and precipitated silicon dioxide) on the tribological properties of silicone rubber was studied. Friction and wear tests were carried out according to the scheme disk (silicone rubber with a diameter of 29 mm, height of 12.5 mm) - ball (GCr15 steel with a diameter of 6 mm, hardness 59-61 HRC) on a universal tribotester with a CFT-1 microcontroller, China. During the test, the upper steel ball GCr15 remained stationary, and the silicone rubber disk rotated at a frequency of 500 min^{-1}. The rubbing surface of each silicone sample was sanded with sandpaper to ensure even contact. All experiments were performed with a load of 10 N, three times to ensure repeatability of the results. The coefficient of friction of rubber with...
colloidal silicon dioxide constantly increased and reached a maximum value of 0.633, with further testing it stabilized at a value of 0.54. Silicone rubber with deposited silicon dioxide had a maximum coefficient of friction of 0.89, then it decreased and stabilized at a value of 0.65.

The wear value was 0.00190 g of samples with colloidal silicon dioxide, which is 1.5 times less than for samples with deposited silicon dioxide.

In [3], samples from thermoplastic polyurethane (TPU) and a mixture of TPU and ultra-high-molecular polyethylene (UHMWPE) were used 95/5, 90/10, 85/15, 80/20, 75/25 and 70/30%. The friction and wear test was performed on the MRH-3 installation, China using the disk (steel with a diameter of 49.22 mm) - a finger (a sample of TPU or TPU/UHMWPE with a thickness of 4 mm) glued to a steel rod with a thickness of 8 mm. Dry friction tests were performed at a normal load of 150 N, with a rotation speed of 100 min⁻¹ at room temperature with a relative humidity of 20-50%. In addition, water in the amount of 55-65 drops fed to the friction zone was used as a lubricant under similar test conditions. The coefficient of friction and the rate of wear of samples under dry friction conditions decreased sharply, with the addition of 15% UHMWPE. The coefficient of friction decreased from 1.2 for TPU to 0.45 for TPU/UHMWPE 85/15%, and the wear rate decreased by 15%.

For mixtures of TPU/UHMWPE with a higher UHMWPE content, the wear rate during water lubrication is comparable or even slightly higher than for dry friction.

The aim of this work is to determine the tribological characteristics of polymers for replacing rubber products in the friction units of rolling stock.

2. Research materials and methods
For friction and wear tests, thermoplastic polyurethanes (TPU), UHMWPE, and polypropylene (PP) were selected. The technical characteristics are shown in table 1 for comparison with the polyurethanes of the selected rubber based on butadiene-nitrile rubber (BNR). Each of the 5 materials studied was a plate with dimensions of 20×70×2 mm, which was glued to plywood with dimensions of 20×70×12 mm.

| Material brand | Hardness, Shor | Density, g·cm⁻³ | Ultimate strength, MPa | Elongation at break, % |
|----------------|----------------|-----------------|-----------------------|-----------------------|
| TPU 50D2S10    | 52 D           | 1.18            | 45.0                  | 450                   |
| TPU 60D2S10    | 60 D           | 1.18            | 55.0                  | 320                   |
| UHMWPE         | 64 D           | 0.93            | 25                    | 50                    |
| PP 02015       | 70 D           | 0.9             | 29                    | 400                   |
| 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 with a fixed abrasive 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. The weight loss of the samples was determined on a vibra HT-220CE analytical balance. The wear value was determined as the arithmetic mean 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 increases, the coefficients of friction decrease for all types of polymers and BNR. The obtained values of the friction coefficients can be arranged as they increase in the following order: 0.3 – 0.36 PP2015, 0.33 – 0.44 UHMWPE, 0.38 – 0.55 50D2S10, 0.4 – 0.58 60D2S10 and 0.85 – 0.98 BNR. An increase in the sliding speed from 0.12 to 0.23 m·s\(^{-1}\) led to a slight increase in the friction coefficients for the studied polymers. So for PP2015 and UHMWPE, it increased from 0.32 to 0.36. With a further increase in speed to 0.3 m·s\(^{-1}\), the coefficient of friction was 0.5 and 0.49 for PP2015 and UHMWPE, respectively. The coefficient of friction of BNR - 0.8 - 0.9 increased proportionally over the entire range of sliding speeds.

![Figure 1](image1.png)

**Figure 1.** Dependence of polymer friction coefficients on pressure (a) and sliding speed (b): 1 – PP2015, 2 – UHMWPE, 3 – 50D2S10, 4 – 60D2S10, 5 – BNR.

Figure 2 shows the mass loss of samples from pressure.

![Figure 2](image2.png)

**Figure 2.** Dependence of polymer mass loss on pressure: 1 – PP2015, 2 – UHMWPE, 3 – 50D2S10, 4 – 60D2S10, 5 – BNR.
For BNR, the mass loss increased in proportion to the pressure. The wear of TPU samples at low pressures up to 0.34 MPa is insignificant, with a further increase in pressure up to 0.54 MPa for 50D2S10, 60D2S10 increases from 0.01 to 0.04 g. The minimum mass loss was obtained for PP2015 polypropylene. Figure 3 shows the morphology of the friction surfaces of the samples.

Figure 3. Morphology of the friction surfaces of polymers and BNC rubber: (a) - PP2015, (b) – UHMWPE, (c) - 50DS210, (d) - 60DS2010, (e) – BNR.

The friction surfaces of PP02015 and UHMWPE polypropylene with a minimum wear value of 0.003 and 0.004 g, respectively, did not have deep ridges or grooves in the sliding direction of the fixed abrasive grain. The undulation of the surface indicates a gradual accumulation of damage and
separation of wear particles by the fatigue mechanism. The friction surfaces of the 50DS210 samples and the BNR throughout had risks in the sliding direction. It can be assumed that the prevailing mode of wear was micro-cutting. For the 60DS2010 samples, the wave height was minimal, and the wear pattern can be attributed to fatigue when friction occurs on a fixed abrasive grain.

Figure 4 shows the profiles of wear holes of polymer materials and BNR when tested with loose abrasive.

![Figure 4](image1.png)

**Figure 4.** Profiles of material wear holes: 1 – 50DS210, 2 – 60DS2010, 3 – UHMWPE, 4 – PP2015, 5 – BNR.

In contrast to the tests with fixed abrasive, the samples TPU50DS210 and 60DS2010 showed minimal weight loss. Samples of UHMWPE has moved into third place. PP2015 and BNR samples showed the greatest weight loss, respectively. Figure 5 shows fragments of wear holes of materials during friction on a free abrasive.

![Figure 5](image2.png)

**Figure 5.** Morphology of the friction surfaces of polymers and BNC rubber when tested for free abrasive: (a) – 50DS210, (b) – 60DS2010, (c) – UHMWPE, (d) – PP2015, (e) – BNR.
The friction surfaces of 50DS210, 60DS2010 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 UHMWPE and PP2015 SAMPLES indicates a gradual accumulation of damage and separation of wear particles by the fatigue mechanism. Various results of friction tests with free and fixed abrasive grain indicate that the sandpaper was coated with polymer particles due to adhesion during the testing of TPU PP2015, and the wear rate and coefficient of friction were reduced. For polymers 50DS210, 60DS2010, the minimum mass loss due to friction with a free abrasive indicated that their hardness is higher than that of a rubber disk and some of the abrasive particles were simply pressed into the forming surface of the disk. 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
Regularities of changes in the coefficients of friction and mass loss of samples from pressure are obtained. The coefficient of friction of PP 2015 polypropylene had values of 0.3-0.36, while for BNR was 2.5 times higher and was 0.85-1.0 when friction on the fixed abrasive. A stable result in relative weight loss was shown by PTFE samples when tested with a free and fixed abrasive. The samples PP2015 and 50DS210 and 60DS2010 had the least wear during friction on the fixed abrasive and free abrasive, respectively. Materials such as TPU 50DS210, 60DS2010 and UHMWPE can be used in the future in friction units as a replacement for rubber products for the manufacture of cuffs, seals, gaskets and corrugations. PP 2015 polypropylene can be used instead of rubber in control panels, rotary mechanisms and devices inside the rolling stock.

References
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