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Efficiency of Antifriction Solid Lubricant Coatings for Metal–Polymer Friction Pairs

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Abstract—Tribotechnical testing results for antifriction solid lubricant coatings in a metal–polymer friction pair are presented. The testing has been carried out according to an ASTMG99 standard with the use of a friction machine operating according to a sphere–disk pattern at sliding velocity $V = 0.8$ m/s, load $F = 23$ N, and rotation frequency $n = 310$ min^{-1}. While testing, the value of sliding friction force was permanently registered, and the value of the friction coefficient was automatically calculated. Testing was carried out until preset friction path $L = 2880$ m accumulated. After testing a level of linear wear was measured for the spherical counterbody. Antifriction solid lubricant coatings based on molybdenum disulfide and polytetrafluoroethylene deposited onto steel samples were tested. Polyoxymethylene spheres 10 mm in diameter were used as a counterbody. The testing was performed with the use of different greases based on mineral and synthetic oils with a complex of antifriction additives. It is revealed that the use of antifriction solid lubricant coatings together with greases makes it possible to provide a 5.9 to 10.1-fold decrease in the linear wear of counterbodies, as well as a 1.5 to 2.3-fold decrease in the friction coefficient depending on the grade of the coating under application. By selecting an optimum combination of antifriction solid lubricant coatings and plastic grease one can achieve a decrease in the linear wear of the counterbodies amounting up to 14.2 times, and an approximately 4.4-fold decrease in the friction coefficient.

Keywords: linear wear, wear resistance, friction coefficient, solid lubricant, antifriction coating, molybdenum disulfide, polytetrafluoroethylene

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INTRODUCTION

With the development of the modern world industry, there has been a tendency to make maintenance-free, high-resource, and high-temperature-resistant friction assemblies. When designing and operating such components, the use of solid lubricants is becoming increasingly popular. For some fields of modern industry, solid lubricants are of particular importance, for example, in robotics, aerospace, electric vehicles, and in the production of devices operating under vacuum or in the range of extreme temperature values. In the case of such systems, friction losses are of particular importance, since they directly affect autonomy and safety.

The main solid lubricants are represented by molybdenum disulfide, tungsten disulfide, graphite, polytetrafluoroethylene, and boron nitride. Most of these materials, owing to their layered crystalline structure, exhibit a low level of shear resistance between the layers of the structure [1–3].

Nowadays, solid lubricants are most often used in the form of special coatings [2, 3]. As a rule, such antifriction solid lubricant coatings (ASLCs) represent mixtures consisting of solid lubricants, binders, solvents, and functional additives [4–7]. Resulting from applying such ASLCs onto the surface of products, a thin composite layer with a thickness of 15–25 μm is formed, which represents a polymeric matrix that retains highly dispersed particles of solid lubricant in the structure thereof.

The type of solid lubrication filler in ASLCs determines their properties, their operating characteristics and the scope of application [7–9]. The ASLCs have a wide operating temperature range (from –210 to +730°C), they cannot be oxidized or evaporated, they exhibit good anticorrosion properties and a high load-bearing capacity (up to 3000 MPa) [2, 10, 11]. The fact that the coatings have small thickness makes it possible to use them with non-subsequent mechanical treatment.

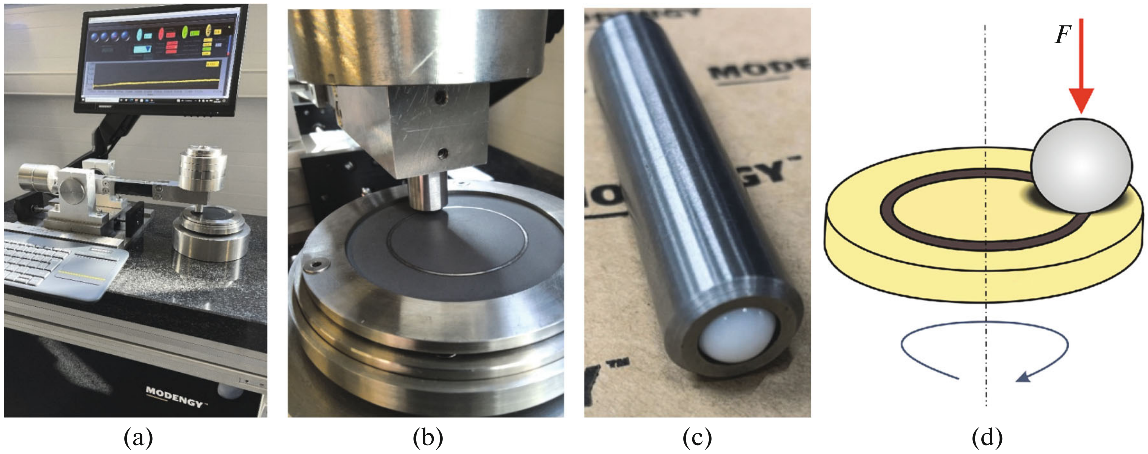

Fig. 1. Equipment for tribotechnical testing: (a) a general view of the friction machine; (b) general view of the friction pair; (c) a holder with installed spherical counterbody; and (d) friction pattern during testing.

There are many examples of the use of ASLCs in different industries [9–12]. For example, ASLCs are applied to the piston skirts of internal combustion engines, crankshaft liners, pneumatic drive parts, worm transmission pairs, lead screws, rack and pinion gears, ball joints, threaded joints, etc. A wide range of promising compositions for the formation of ASLCs are produced in European countries and the United States. In the Russian market, the Modeling and Engineering enterprise (Russia) is actively developing the field of ASLCs [3, 9, 12].

Thus, the use of ASLCs in metal–polymer friction pairs is of practical interest and is promising, in particular, for parts of spherical elements (fingers) working in conjunction with a plastic liner.

Objective—Revealing the effect of ASLCs and greases exerted on the tribological properties of a metal–polymer friction pair.

MATERIALS AND METHODS

Laboratory-scale testing was carried out according to the ASTM G99 standard with the use of a friction machine that operates according to a sphere-disk pattern at sliding velocity $V = 0.8$ m/s, load $F = 23$ N, and rotation frequency n = 310 min^{-1}. The friction machine (Fig. 1) is equipped with an NI LabVIEW automatic control and data registering system. During testing, the value of the sliding friction force was permanently registered, and the value of the friction coefficient was automatically calculated and graphically displayed on the screen. The testing was performed until the accumulation of preset friction path L = 2880 m. After testing, the linear wear level of the spherical counterbody was measured with the use of a MKTs 25 micrometric instrument (Russia) with an accuracy of 1 μm.

The samples for the experiments were made in the form of steel disks with a diameter of 80 mm and a thickness of 0.8 mm made of 40Kh grade steel, and spherical counterbodies 10 mm in diameter made of polyoxymethylene (POM). The working surfaces of the samples, having a roughness of $R_a = 0.5$ μm, were degreased after which three types of ASLCs, such as M-1014, M-1009, and M-A20 were deposited onto them with the use of spraying. After the coatings based on M-1014 and M-1009 were dried for 10 min at room temperature, hot curing (by means of polymerization) was carried out.

The M-A20 coating was cured at room temperature for 30 min. The characteristics of the ASLCs and polymerization modes under testing are presented in Table 1. The thickness of the deposited coatings has been determined by a Konstanta K5 electronic thickness gauge (Russia) to amount to 25 ± 5 μm. The testing was carried out with the use of different greases the characteristics of which are presented in Table 2. The weight of grease applied onto the disk amounted to 0.25 g.

Table 1. Characteristics of tested antifriction solid lubricating coatings

Coating	Polymerization mode	Film-forming agent	Solid lubricants	Working temperature, °C
M-1014	40 min at 180°C	Based on epoxy resin	PTFE, MoS_2	–75 to +255
M-1009	30 min at 120°C	Based on epoxy resin	PTFE	–100 to +250
M-A20	30 min at 20°C	Thermoplastic polymer	PTFE	–50 to +130

Table 2. Characteristics of the greases under testing

Grease	Base oil type	Base oil viscosity at 40°C, m^2/s	NLGI class	Thickener/ complex additives	Operating temperature range, °C
ShRB-4 (Russia)	I-20A	32	2	Barium soap/DPA	–30 to +130
Lublicant No. 1 (Germany)	Mineral	160	2	Lithium soap/MoS_2	–20 to +120 (140)
Lubricant No. 2 (Germany)	PAO	32	2	Lithium soap/PTFE	–50 to +140
Lubricant No. 3 (Russia)	PAO	25	2	Lithium soap/extreme pressure additives	–60 to +120

Table 3. Results of determining friction coefficient for MODENGY antifriction solid-lubricating coatings together with greases

Grease/coating	Friction coefficient			
	without coating	M-1014	M-1009	M-A20
Absent	0.38	0.19	0.16	0.10
ShRB-4	0.22	0.10	0.13	0.15
Lubricant No. 1	0.22	0.09	0.09	0.11
Lubricant No. 2	0.13	0.05	0.13	0.07
Lubricant No. 3	0.17	0.08	–	0.06

RESULTS AND DISCUSSION

The complex of tribotechnical investigations was in two stages. The first stage involved the studies on the samples with and without ASLCs in the absence of grease. The second stage involved studying the combined effect of ASLCs and different greases exerted on the wear processes occurring in the metal–polymer friction pairs under testing. At all stages of the investigation, we measured the linear wear level and the friction coefficient for the counterbodies. Figure 2 shows the results of ASLC testing in comparison with uncoated samples in the absence of a grease lubricant. The graphs plotting the change in the friction coefficient of the ASLCs over the entire testing period are presented in Fig. 3.

By analyzing the diagrams presented in Fig. 2, one can conclude that the use of all three ASLCs exerts a beneficial effect on the friction and wear processes. All ASLCs, regardless of the composition, provide a greater than sevenfold decrease in the linear wear and a twofold decrease in the friction coefficient. At the same time, samples with ASLC M-A20 based on polytetrafluoroethylene exhibit the lowest friction coefficient (0.10) and the lowest level of linear wear (80 μm). This coating reduced the friction coefficient by 3.8 times, and the linear wear level by more than 9 times as compared to the uncoated sample.

The combined application of greases and ASLCs has made it possible to reveal a synergistic effect that is exhibited by a decrease in the friction coefficient (see Table 3) and linear wear level of counterbodies (see Table 4) when the ASLCs are used together. Moreover, it can be argued that this effect is observed for all combinations of greases and ASLCs. The lowest friction coefficient (0.05) has been registered for the M-1014 coating in combination with lubricant No. 2 (Fig. 3, curve *4*).

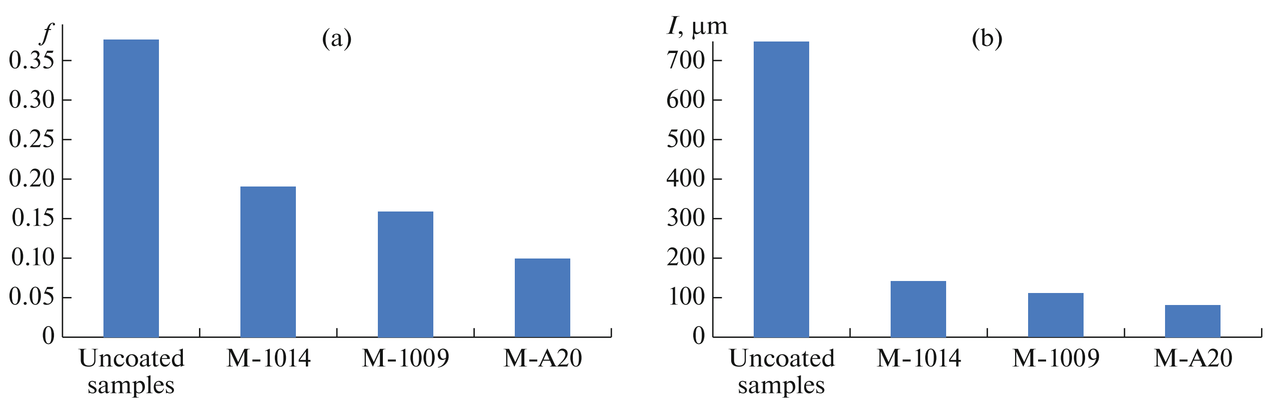

Fig. 2. Testing results for antifriction solid lubricant coatings: (a) friction coefficient; (b) linear wear of counterbodies.

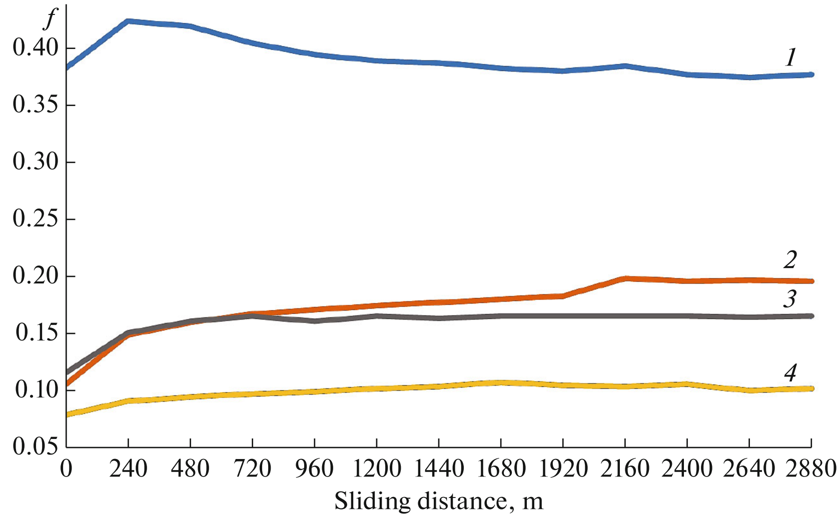

Fig. 3. Changes in friction coefficients under testing antifriction solid lubricant coatings: (*1*) uncoated samples; (*2*) M-1014; (*3*) M-1009; and (*4*) M-A20.

Fig. 4. Ball joint with antifriction solid lubricant coating M-1014.

The synergetic effect is achieved owing to the presence of PTFE in the lubricant and the coating. The smallest linear wear level of the counterbodies (50 μm) was observed in the case of the M-1014 coating in combination with lubricant No. 3 (Fig. 3, curve *2*) as well as when combining the M-A20 coating and lubricants No. 2 and No. 3 (Table 4). The presence of MoS_2 in the coating can significantly reduce wear level. The combination of ASLCs and grease can provide reducing the linear wear level by up to 14.2 times, and the friction coefficient, by up to 4.4 times.

Based on the analysis of the results of the investigations, it could be noted that ASLCs in general exert a more significant effect on the tribological parameters of the metal–polymer friction pair in comparison with greases. The ASLC coatings are under an active implementation at the enterprises of the Russian automotive industry. In particular, Fig. 4 shows a car steering ball joint.

CONCLUSIONS

Resulting from the series of conducted experiments, it has been established that:

— The application of modern ASLCs instead of grease makes it possible to provide a 5.1–8.9-fold decrease in the linear wear level of counterbodies, whereas the friction coefficient can be reduced by 1.2–2.2 times, depending on the used coating grade.

— The use of ASLCs studied in this work, makes it possible to provide, in combination with greases, a 5.9–10.1-fold decrease in the linear wear level of counterbodies, and a 1.5–2.3-fold decrease in the friction coefficient, depending on the used coating grade.

Table 4. Results of determining linear wear levels for counterbodies upon using antifriction solid-lubricating coatings together with greases

Grease/coating	Linear wear level, μm			
	without coating	M-1014	M-1009	M-A20
Absent	750	140	110	80
ShRB-4	710	100	120	70
Lubricant No. 1	590	80	100	100
Lubricant No. 2	260	60	110	50
Lubricant No. 3	330	50	–	50

— When used in combination with ShRB-4 grease, an M-A20 coating is the best ASLC from the standpoint of wear reduction, whereas an M-1014 coating is the best ASLC in terms of friction reduction.

— By selecting an optimal combination of ASLCs and grease, one can provide a 14.2-fold decrease in the linear wear level of counterbodies (for example, as it is in the case of coatings M-1014 and M-A20, as well as experimental lubricant No. 3), as well as provide a 4.4-fold decrease in the friction coefficient (for example, as it is in the case of coating M-1014 and experimental lubricant No. 2).

ABBREVIATION AND NOTATION

ASLC	antifriction solid lubricant coating
POM	polyoxymethylene
PTFE	polytetraflioroethylene

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflict of interest.

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