*A. G. KOSTORNOV, O. I. FUSHCHICH, T. M. CHEVICHELOVA,
Y. M. SIMEONOVA, G. S. SOTIROV*

RESEARCH

Self-Lubricating Composite Materials for Dry Friction

In certain applications under dry friction, the composites, containing small amount of solid lubricant, work very effectively. The copper matrix composite alloyed with metals and phosphorous and containing globular inclusions of lead is among these. During the friction process, the lead acts as solid lubricant.. Shortcoming of these materials is that lead's high toxicity makes them inapplicable according to ecological requirements. This necessitates replace lead by other solid lubricants and in particular by molybdenum disulfide (MoS_2). The results of tribological study of this material show his antifrictional efficiency. The received experimental data for friction coefficient in vacuum were significantly smaller that the friction coefficient of materials, containing lead as lubricant. The measured values for friction coefficient in vacuum were 0,050 – 0,062 and for wear were smaller of 1.10^{-6} mm^3 / Nm. The good frictional properties of the materials are a result of the self-lubricating effect.

Key words: *self-lubricating effect, antifrictional composite materials, MoS_2.*

1. INTRODUCTION

The processes of friction, wear and lubrication by the contact interaction of materials in vacuum differ significantly from the similar ones in air, which is due to the specific particularity of vacuum as operating environment characterized by:

- high degree of rarefaction,
- absence of oxygen, humidity and lubricant,
- higher temperature in contact,
- increasing plastic deformation in the surface layer, along with significantly increasing adhesion.

All that leads to growth of wear and formation of seizure centers and cold welding blocking the movement in the tribosystem.

The studied materials of type IPM are copper matrix composite materials alloyed with P and Mn, Sn or Ni, containing globular inclusions of Pb, which acts as a solid lubricant [1, 2, 3].

Due to increased temperature in the tribo-contact, to plastic deformation of the surface layer and to differences in the coefficients of diffusion and thermal expansion of components, the friction surface is enriched with Pb in the friction process [4, 5], as it can be seen from its distribution on the friction track on Fig.1 and Fig.2.

A. G. Kostornov[1], O. I. Fushchich[1], T. M. Chevichelova[1], Y. M. Simeonova[2], G. S. Sotirov[2]
[1] Institute for Problems of Materials Science at the National Academy of Sciences, Kiev, Ukraine
[2] Space Research Institute at the Bulgarian Academy of Sciences, Sofia, Bulgaria

2. EXPERIMENTS AND RESULTS

The gathered experience shows convincingly that Pb in composite materials IPM represents an effective solid lubricant under dry friction vacuum conditions, including in space conditions [6].

The materials possess small friction coefficient (0,12 – 0,23) – Fig. 3 and Fig.4, and also small values of the wear intensity (5.10^{-6} – 5.10^{-5}) mm^3/Nm under dry friction vacuum conditions of 1.10^{-5} mbar with load in contact of 2 to 20 N and velocity of 0,2 and 1 m/s [4].

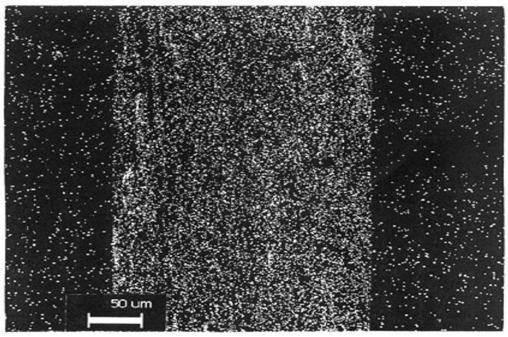

Figure1. Distribution of Pb in the surface layer of self-lubricating composite materials IPM after dry friction vacuum conditions.

Figure 2. Micrograph of the friction surface of materials IPM under dry friction in vacuum /x 1000/.

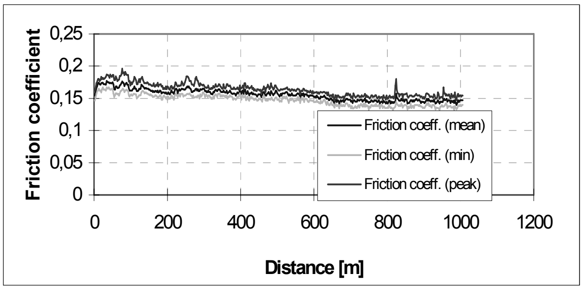

Figure 3. Friction coefficient dependence of sliding distance under dry friction in vacuum (load 2 N, velocity 1 m/s, distance 1000 m), material IPM-304.

The results are related to the effect of self-lubrication of the friction surface in vacuum with metallic Pb, which improves the wear-resistance of the materials and assures the ability to adapt of the friction surface to the friction regime [4, 5].

Main shortage of lead is its **toxicity,** which makes it inapplicable as regard of ecology. This is the reason for the expected interdiction of its usage of worldwide validity after 2010. Therefore the general ambition is directed to replacement of lead by other effective solid lubricants.

The self-lubricating copper matrix composite material, alloyed with Sn and P, containing small amount of MoS_2 has been created and studied.

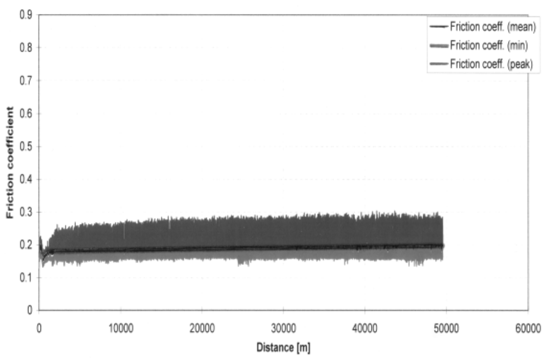

Figure 4. Friction coefficient dependence of sliding distance under dry friction in vacuum (load 20 N, velocity 0,2 m/s, distance 50000 m), IPM-304

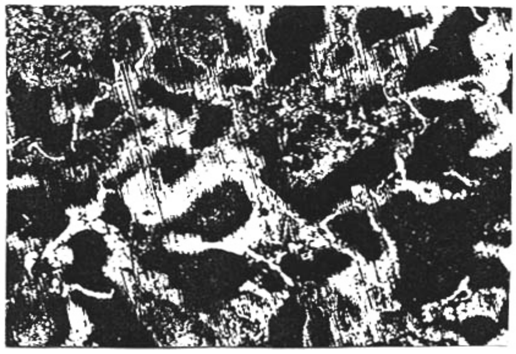

Figure 5. Micrograph of the microstructure of self-lubricating composite materials IPM /x 500/.

The material is characterized by a highly heterogeneous microstructure, which is responsible for their improved frictional properties and for the protection of the friction surface against adhesion during dry friction under vacuum conditions.

Aiming improvement of antifrictional properties, presence of the chalcogenide MoS_2 is important. It has layered structure (Fig. 6) [7], which determines its lubricating properties under dry friction in air [8, 9] and especially under dry friction vacuum conditions.

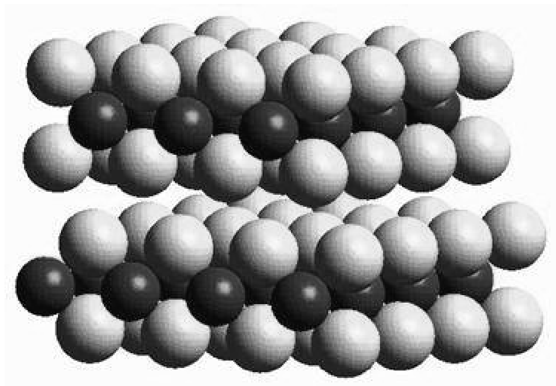

Figure 6. Model of the structure of the molybdenum disulfide (MoS_2)

To fulfill the present-day ecological requirements, new self-lubricating composite materials were synthesized and investigated. They consist of a copper matrix alloyed with P, Sn and contains as a solid lubricant instead of lead small amounts of MoS_2.

The microstructure of the new composite materials can be seen in Fig.7. The brighter phase is the copper matrix, while the darker inclusions are the MoS_2. According to the investigations carried out, the copper matrix has eutectic composition and represents **α**-solid solution of Sn in Cu. During the synthesis, Cu_3P solid phase is segregated on the grain boundaries of the copper matrix, forming in this way a scattered mesh. In the course of friction, this mesh limits the plastic deformation, lowers the contact temperature and increases the wear-resistance of the materials.

Figure 7. Micrograph of the structure of self-lubricating composite material IPM-306

Alloying with Sn improves mechanical properties of the materials, forming solid solution with Cu, increasing the strength. The solid phase Cu_3P limits the formation of intensive plastic deformation in the tribo-contact zone and restricts the creation of seizure centers under dry friction vacuum conditions. MoS_2 realized practically no interaction with Cu plays the role of solid lubricant decreasing friction coefficient and wear, and increasing the reliability of the tribo-couple.

By adding sulfur to the composite, copper sulphide layers were formed on the MoS_2 inclusions during the synthesis. In this way, a smooth transition between the MoS_2 phase and the matrix was realized.

Molybdenum disulphide and copper sulphide form during friction a thin layer on the working surface, which improves the antifrictional properties of the material and prevents seizure.

This specific microstructure of the composite material is responsible for the improved antifrictional properties and for the protection of the friction surface against adhesion during dry friction under vacuum conditions.

Table 1. Triboparameters of the composite materials IPM-306 and IPM-304 in vacuum.

Materials	Friction coefficient	Wear intensity [mm^3/Nm]
IPM - 306 (MoS_2)	0,050 - 0,062	$< 1.10^{-6}$
IPM - 304 (Pb)	0,150 - 0,180	6.10^{-6} - 1.10^{-5}

Table 1 summarizes the results of tribological study of two self-lubricating composite materials**:** IPM-304 and IPM-306. The latter resembles in its composition the composite IPM-304 but instead of Pb it contains MoS_2. The tribological measurements were carried out under one and the same conditions of dry friction at vacuum of1.10^{-5} mbar, under load of 2N, sliding velocity of 0.1 m/s and distance of 1000 m, with counter-body made of bearing steel SHX - 15 /GOST/.

Moreover, good operation results were also obtained for the friction couple - composite material IPM-306 and counter-body of Steel 45 /GOST/ under regime of friction in air with load of 0,1 MPa and sliding velocity of 1,2–2,0 m/s. Under these conditions, the friction coefficient and the wear intensity measured were from 0,5 to 0,1, and 8.10^{-3} μm/km, respectively. For rotation speed 1,2 – 2,0 m/s, operating life of 480 - 1520 hours was achieved [10].

3. CONCLUSION

As seen, the triboparameters of the composite IPM-306 are much better than those of IPM-304. Hence, it should be expected that the material IPM-306 is suitable for application in vacuum techniques and technologies, both in Space and on Earth.

The general technological principle by the creation of this type of composite materials is the formation of a highly heterogeneous structure, procuring good antifrictional properties and characteristics (small friction coefficient, wear-resistance and enhanced loading level). Therefore stability of this composite structure, exposed on long influence of space environment is with important meaning [6, 11].

REFERENCES

[1] Patent No 73217 / 29.05.2003, Ukraine.

[2] Patent No 108727 / 29.05.2003, Bulgaria

[3] Patent No 77601 / 15.12.2006, Ukraine

[4] Y. Simeonova, G. Sotirov, Study of the Parameters of New Antifrictional Materials under Dry Friction Vacuum Conditions, BAS, ARC - Seibersdorf, Austria, ARC-W-0136, pp. 2-30, 2002 (Data Bank of the AMTT), http: //www2.arcs.ac.at/amtt.

[5] Y. M. Simeonova, G. S. Sotirov, Peculiarity of the Friction Surface of Antifrictional Composite Materials under Dry Friction Vacuum Conditions, Proceedings of Conference "TRIBOLOGY: Science and Applications", April 2003, Vienna, Austria, 277-283, 2004.

[6] A. I. Yuga, T. M. Chevichelova, Y. M. Simeonova, T. G. Nazarsky, Application of a New Antifrictional Material at Tribological Junctions of Space Research Equipment, 2-nd World Tribology Congress, Sept. 2001, Vienna, Austria, Session "Tribology in Extreme Environments", 734.

[7] M. E. Bussel, Chemistry Department at Western, Washington University; http: //chem.wwu.edu/dept.shtm

[8] R. H. Savage R.H., Jour. Appl. Phys., v. 19, No 1, 1948.

[9] B. Marchon, D.F. Ogletree et al, Journal Microscopy, 152, 427, 1988.

[10] A. G. Kostornov, O. I. Fushchich, T. M. Chevichelova, Y. M. Simeonova, A. D. Kostenko, Relationships at friction, wear and synthesis of the friction surface of composite self-lubricating materials, ISSN 0032-4795, Powder Metallurgy, No 3/4, pp. 11-19, 2007 /In Russian/.

[11] Y. M. Simeonova, Study of new materials and coatings with improved antifrictional properties for space applications, Work of Habilitation, SRI at the BAS, Sofia, 2004.