MOS_2(TI, W) COATINGS AS SURFACE MODIFICATION OF FRICTION PAIRS OPERATING IN SPACE AND DUSTY LUNAR ATMOSPHERE

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ABSTRACT

The aim of the study was to investigate properties of bearing steel coated with MoS_2 and MoS_2(Ti, W) coating, dedicated to work in lunar environment. Tribological tests were carried out on two different tribometers. CSM THT for tests in low humidity (up to 1% RH) and in environment dusted with lunar regolith analogue, and TR-1 prepared to operate in vacuum environment and at varying temperatures. The tests showed that the deposited coatings made it possible to obtain a very low friction coefficient $\mu < 0.04$ in friction pair with uncoated bearing steel counterbody, with good resistance to wear, k_v of the order of 10^{-16} $m^3N^{-1}m^{-1}$, both under low humidity conditions and vacuum, and there was no drastic coating wear caused by the presence of regolith in the friction contact zone.

1 INTRODUCTION

The Moon's surface is covered with lunar regolith, the thickness of which varies from a few to several meters, depending on its regions [1]. The Moon's residual atmosphere makes its surface vulnerable to bombardment by micrometeorites, as well as to direct solar wind. Bombardment causes pulverization of the soil (a process called grinding) and diffusion bonding of regolith particles [2]. In turn, the action of solar wind plasma causes the surface of regolith particles to be charged, the appearance of significant electrostatic forces, resulting in their levitation, and electrostatic adhesion to the surface [3,4]. In addition to its abrasive properties, regolith is highly volatile due to its low gravity and its charge, and is highly adhesive, both mechanically and electrostatically [4,5]. The surfaces of equipment operating on the Moon can be covered with a significant amount of fine regolith dust, leading to increased friction on mechanical surfaces. Because of its aforementioned properties, regolith creates an unfriendly environment for mechanical components. Surface modifications of components working in friction couples by vacuum and plasma techniques are successfully used to give them a sufficiently low coefficient of friction and high wear resistance resulting from friction. Particularly noteworthy are modifications by deposition of thin coatings of such materials as amorphous hydrogenated carbon or molybdenum disulfide. This also applies to components operating in space [6-8]. The present study attempts to determine whether MoS_2-based coatings could also find application in the modification of components operating in lunar regolith dust conditions.

2 SCOPE OF WORK

This article presents the results of work aimed at investigation of technological solutions in the form of surface modification of AISI 52100 bearing steel components with MoS_2 and MoS_2(Ti, W) coatings and to determine which solution performs better in a friction pair with non-coated AISI 52100 counterbody, operating under conditions simulating the lunar surface (which coating will achieve a lower coefficient of friction and high resistance to wear). The work plan included:

- Deposition of coating of pure MoS_2 and MoS_2 with Ti and W additions onto prepared samples of AISI52100 bearing steel. Coatings were deposited in a B-90 vacuum chamber (from Hoch-Vacuum, Dresden) by magnetron sputtering. Four independent planar magnetrons WK100 (from Dora POWER SYSTEMS) fitted with circular targets Ø100 × 10 mm were used for coating deposition. Two targets were made from pure MoS2 (4 N) and one from pure W and one Ti (both 4N). Magnetrons were fixed in the vacuum chamber every 90° in horizontal plane and their axes were intersecting in one point. Targets were sputtered in pure Ar (5N) atmosphere.

- Adaptation of the tribometer to conduct friction tests under low humidity conditions (LH). This effect was achieved by using an hood that restricts air access to the test specimen area while introducing a continuous stream of dry nitrogen (5N) flowing around the specimen holder, sample and counterbody during testing. This solution made it possible to achieve a relative humidity of the atmosphere of about 1% RH, with a temperature of about 20 ^{0}C;

- Conducting tribological tests of coated samples under various conditions (in reduced humidity conditions with clean surfaces of specimens and covered with regolith (up to 1% RH) and vacuum conditions with varying temperatures) to determine the properties of MoS_2 and MoS_2(Ti, W) coatings.

- Compare the properties and determine which technological solution performs better under conditions simulating the surface of a Moon.

3 TEST PROGRAMME

Tribological properties were determined in friction couple with AISI 52100 steel, i.e. the coefficient of dry sliding friction by the pin-on-disc method. Wear was calculated from profiles of the wear tracks on the coatings surfaces after tribological tests. Tribological tests were carried out on two different tribometers. CSM THT high-temperature tribometer equipped with a module that allows to control the atmosphere adjacent to specimens and reducing the humidity, and TR-1 tribometer (developed by Space Research Centre of the Polish Academy of Sciences) prepared to operate in vacuum environment.

3.1 TRIBOLOGICAL TESTS - REDUCED HUMIDITY AND TEST WITH LUNAR REGOLITH ADDITION

These tests were carried out on a THT CSM high-temperature tribometer using the ball-on-disc method with a module mounted to control humidity in the sample area. AISI52100 bearing steel balls with a diameter of 6.35 mm were used as counterbodies, the total friction path was 1000 m, the load was 10 N, the friction radius was 10 mm, and the linear velocity was 0.1 m/s. During the dust tests, 50 mg of JSC-1A [9] powder with a composition and morphology similar to lunar regolith was applied uniformly to the surface of the coated samples. The relative humidity in the area of the samples at a temperature of about 20 ^{0}C was reduced to a value of 1%. Fig. 1 shows schematically the idea of ball-on-disc measurement, while Fig. 2 shows the distribution of regolith analogue on the surface of specimens before measurement. Fig. 3 shows surface of specimen after tribological test in dusted conditions.

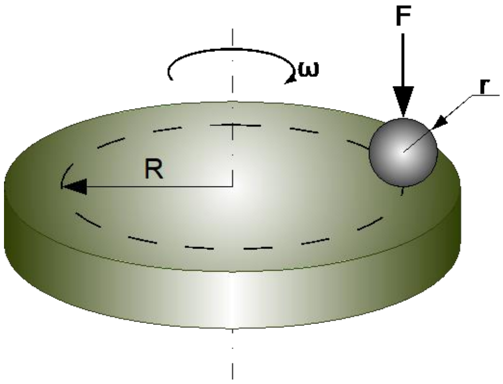

Figure 1. Ball-on-disk method - measurement scheme.

Figure 2. Surface of regolith-dusted MoS_2-coated sample. Before testing.

Figure 3. Surface of the sample with MoS_2 coating applied. After tribological test with JSC-1A powder.

3.2 TRIBOLOGICAL TESTS - VACUUM AND VARIABLE TEMPERATURE

Tribological tests in vacuum were carried out on a TR-1 tribometer mounted in a vacuum chamber with a pumping system equipped with a turbomolecular pump (Spacive Sp. Z o. o.). Fig. 4 shows the interior of the vacuum chamber with the tribometer mounted ready to run the tribological test. The measurement on this equipment was also carried out using the ball-on-disc method, with the friction radius changed to 18 mm due to the size of the samples. The other parameters remained unchanged: friction path 1000 m, load 10 N, linear velocity 0.1 m/s. The test was started when the pressure in the vacuum chamber reached value about $5{\cdot}10^{-3}$ Pa. For temperature tests, simulating both daytime and lunar night conditions (operating temperature of friction couples in range from -30 ^{0}C to over 100 ^{0}C), liquid nitrogen circuits on the holder in the sample area and resistance heating of a heating tape of the same element were used for cooling and heating of the samples.

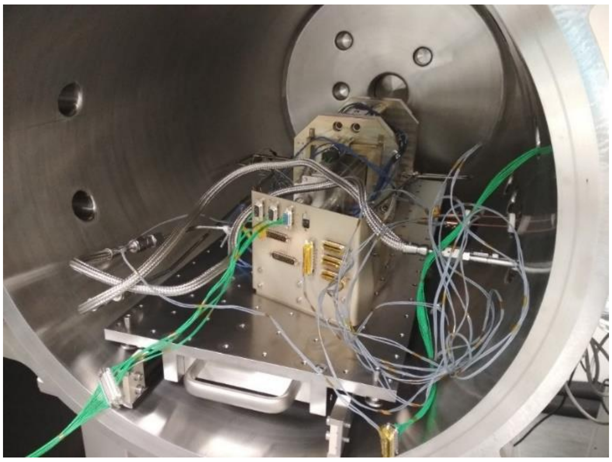

Figure 4. Vacuum chamber with mounted TR-1 tribometer.

4 RESULTS

The collected results of changes of friction coefficients of samples coated with MoS_2 and MoS_2(Ti, W) coatings in a function of friction path for tests carried out at reduced humidity with lunar regolith dusting and in vacuum are shown in fig. 5 and fig. 6, respectively. The calculated mean values of friction coefficients and wear with theirs standard deviations are shown in Fig. 7 and 8, respectively.

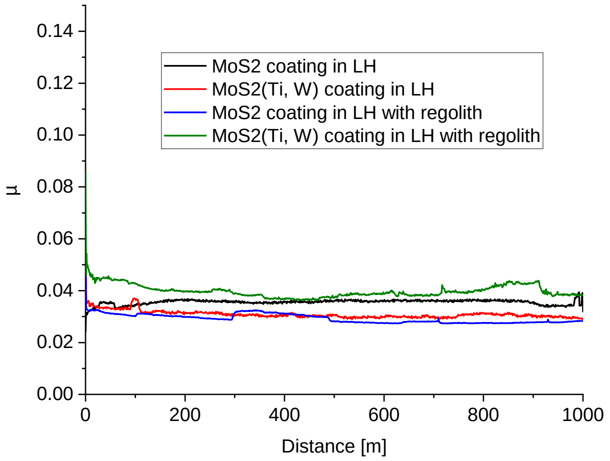

Figure 5. Changes in friction coefficients as a function of friction path for MoS_2 and MoS_2(Ti, W) coatings. Conditions: low humidity (LH) and with regolith dusting.

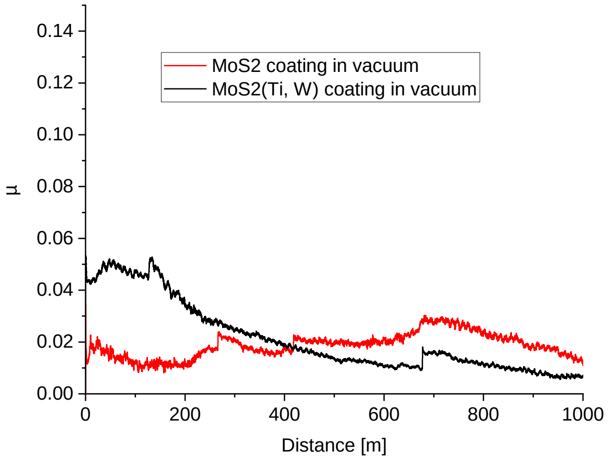

Figure 6. Changes in friction coefficients as a function of friction path for MoS_2 and MoS_2(Ti, W) coatings. Conditions: tests conducted in vacuum.

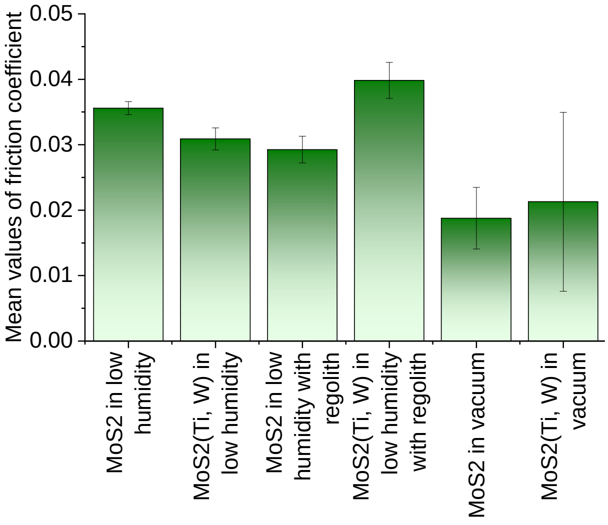

Figure 7. Calculated mean values of friction coefficient.

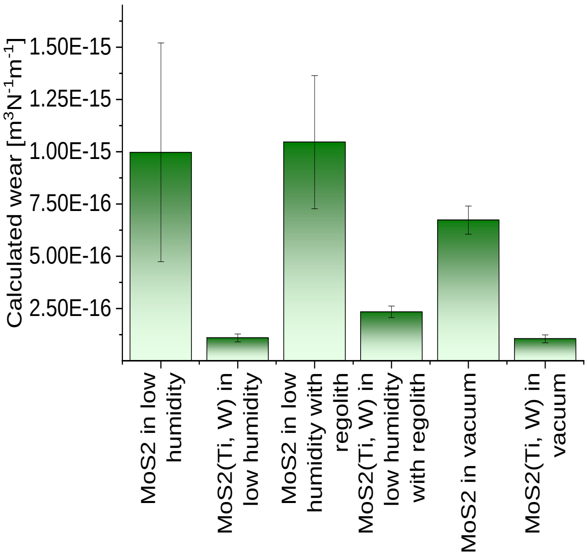

Figure 7. Calculated mean values of wear.

5 SUMMARY AND DISCUSSION

The coefficients of friction of MoS_2 and MoS_2(Ti, W) coatings tested in low humidity conditions have very low, similar values of about 0.03-0.04. The coefficients of friction are very stable and there are no apparent abrupt changes, suggesting abrasion of the coating during the tribological test. The changes in friction coefficient values caused by the addition of Ti and W to the coating material composition are subtle and still indicate very good low-friction properties of the coating. Dusting the surface of the samples with lunar regolith analogue also did not affect the course of the friction test, there was no destruction of the coating, the friction coefficient value had a similar value to the results of the tests without regolith. The lunar regolith was scattered by the moving counterbody on the surface of the coated samples.

In the case of tests in a vacuum, values of friction coefficients reached even lower values, approx. 0.01. Comparing the tests for MoS_2 and MoS_2(Ti, W) coating, it is noticeable that there is a lapping effect in the initial 200-300 m of the friction test for the coating with the addition of Ti and W.

The results of wear resistance calculations indicate that both MoS_2 and MoS_2(Ti, W) coatings shows a low wear coefficient, but the coating with the addition of Ti and W is more resistant. The addition of these metals strengthens the coating material, which in turn reduces wear. Dusting the surface with lunar regolith had no significant effect on the wear of the coatings. In all cases studied, there was no coating failure.

6 CONCLUSIONS

Taking into account that both coatings have similar tribological properties, i.e. comparing the values of friction coefficients under the same conditions, a nanocomposite coating with the addition of Ti and W metals is a better option. Both coatings were not damaged during the test conducted under dusty conditions with lunar regolith. It should be noted that the coating with the addition of Ti and W obtained a lower value of wear. Deposition of MoS_2(Ti, W) coating onto surfaces of elements of friction couples operating in lunar surface conditions is a promising solution to protect surfaces from wear and overload resulting from friction.

7 ACKNOWLEDGEMENTS

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