TRIBOLAB: AN EXPERIMENT ON SPACE TRIBOLOGY. IN-ORBIT DATA AT THE ISS

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ABSTRACT

In February 2008, the Discovery Shuttle mission ST-122 brought the European Columbus Space Laboratory to the International Space Station (ISS). One of the Columbus External Payload Facilities (CEPA) is occupied by the European Technological Exposure Facility (EuTEF), a group of seven different scientific experiments, where the tribology experiment Tribolab is located.

The TriboLAB instrument is a space tribometer which performs tests with different lubricants and different devices at basic and component level respectively: pin-on-disk and ball bearing.

TriboLAB allows to investigate the tribological behavior of lubricants under conditions not possible to simulate simultaneously on earth: g-0, vacuum, microvibrations, LEO radiation, etc.

It is interesting to point out that previously obtained tribological data on Earth (friction coefficients, friction torques and long term durability of the lubricant thin layers) are going to be compared to the results obtained in the microgravity conditions of the LEO orbit of the ISS. In this way, a correlation between both data series is going to be done and the effect of the severe conditions that the lubricant has to withstand on the space is going to be evaluated. Up to now, these data are not available and the mechanisms designers will benefit from the knowledge obtained in this experiment for their future designs, as lubricants play a key role in the deployment of mechanisms and structures.

Previous works by the authors have shown that the WC alloyed MoS_x coating shows better tribological properties than conventional MoS_2 coating, both under vacuum and under air at higher humidity conditions [1,2].

This work reports on the results of the pin-on-disk tests on the alloyed MoS_x coatings in orbit in comparison with the results obtained under laboratory conditions on ground. These tests have shown that the solid lubricating film maintain very low friction levels of 0.04 and reach a maximum of 1,011,000 wear cycles demonstrating a similar behavior to that experienced on ground.

1. INTRODUCTION

TriboLAB is a scientific instrument to perform space tribology tests at the ISS [3,4]. This instrument has been located at the EuTEF module of the ESA Columbus Laboratory. A vacuum tribological model, hereinafter called VTM, was designed and developed to generate "on ground" tribological data of selected lubricants and compare these with results obtained at the environment of the ISS [5].

Thin films of MoS_2 alloyed with WC have been previously developed by the authors and have shown excellent vacuum tribology properties and a promising performance during atmospheric testing at various degrees of humidity [1]. The results obtained by the authors in commercial tribo-testers compare very favorably with similar metal alloyed solid lubricant films under air and also with unalloyed standard sputtered MoS_2 films under vacuum [6,7] . The WC modified MoS_2 presents - when tested under vacuum at 0,75 GPa contact pressure - the characteristic low friction under vacuum of these solid lubricants (μ of 0.01 to 0.03), an excellent endurance exceeding 1 million wear cycles and also acceptable friction and wear properties during atmospheric testing up to 50 – 60 % RH.

In this work, comparative tribological data are presented, using a developed "TriboLAB vacuum tribotester" and in orbit at TriboLAB flight model, in the International Space Station (ISS) .The main interest of this research is to compare "in orbit" wear test of this new solid lubricant with "on ground" tribological tests.

2. EXPERIMENTAL WORK

WC alloyed MoS_x films were deposited on hardened and tempered AISI 440C stainless steel discs (57 ± 1 HRc) of 55 mm diameter and 3 mm thick with a surface finish of 0.2 μm. A CemeCon CC800/8 magnetron sputtering PVD unit was used for the deposition work. Alloyed WC-MoS_x films were produced by magnetron sputtering from four targets (1 to 2 targets of MoS_2 and 1 to 2 targets of WC) in an Ar discharge at a pressure of 0.5 to 0.7 Pa. The thickness of deposited films was about 1.2 μm. Details of the experimental coating procedure and the composition of this lubricating film have been reported previously [8].

Tribology tests under vacuum ($<10^{-6}$ mbar) on ground have been carried out in the Vacuum Model of TriboLAB (VTM) on the WC-MoS_x coated disks and on commercial pure MoS_2 disks. The characteristics of this tribometer could be found in [5]. Test parameters were a constant angular speed of 75 rpm, the wear track was fixed to 25 mm radius and a 5N normal load applied by a torsional spring by a stainless steel ball of 6 mm diameter (0,75 GPa as contact pressure). The test criteria was to perform the test for each disk until reaching a mean friction coefficient higher than 0.2 for a time of 100 s. Monitorised parameters were the normal load, tangential force and friction coefficient, the data acquisition rate was 150 data/min.

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Finally, the WC alloyed MoSx films were evaluated in orbit in the TriboLAB flight model tribometer. An instrument for tribology experiments at the European Technology Exposure Facility (EuTEF) and externally located in the Columbus European Laboratory Module at the International Space Station (ISS). This equipment has been designed to accommodate two types of tribological tests: pin on disk and ball bearing tests. A general view of TriboLAB flight model (FM) can be seen in Fig. 1, and Fig. 2 shows the pin on disk and ball bearing lay out and the components. In this instrument there are four experimental cells and therefore the possibility of performing four pin on disk and four ball bearing tests.

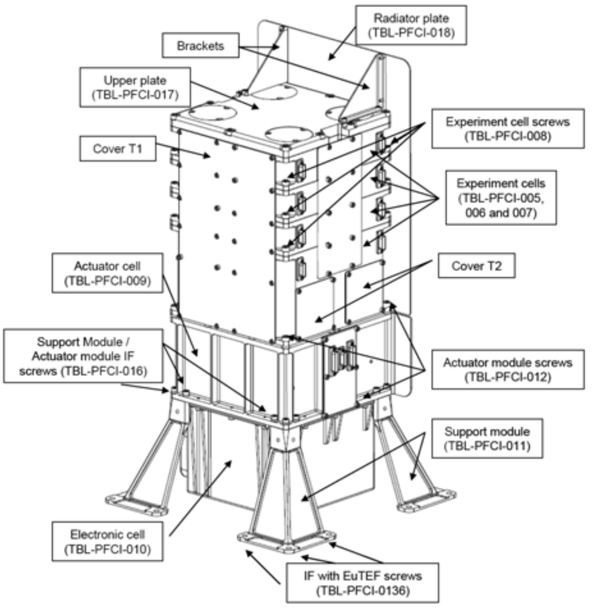


Figure 1: General view of TriboLAB FM.

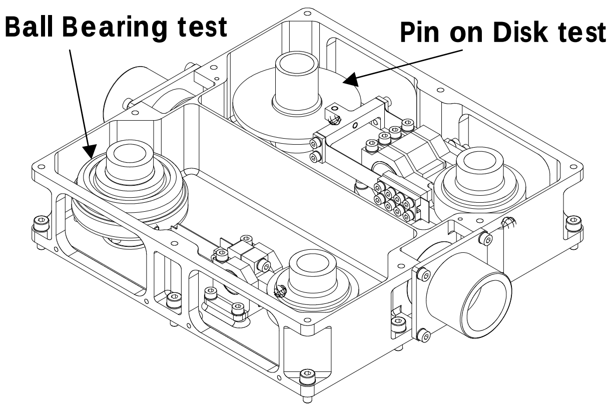


Figure 2: TriboLAB FM experiment cell view showing the pin on disk test (right) and the ball bearing test (left).

This paper only refers to the pin on disk experiments, and as a consequence only this part of the full experiment will be explained in more detail. The test set up shown in Figure 3 consists in a coated disk that rotates, attached to a main shaft that drives all experiments. The arm, that contains a ball or spherically ended pin at one extreme, is made with flexures and the ball at the end is set in contact with the disk by means of a pivot flexure (torsional spring) that applies the nominal contact force between ball and disk. The load that is applied by this method has been calibrated to 5 N +/- 10%.

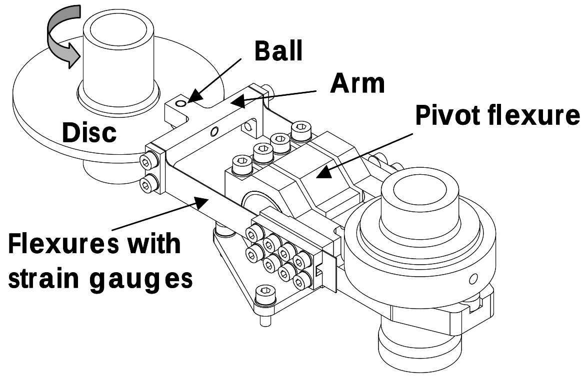


Figure 3: Pin on disk test lay-out and components

A cam controls the angular position of the torsional spring and the applied force. Its function is to select the disk to be tested, since only one pin-on-disk test is carried out at a time from a total of 4 positions that are made available. This cam rotates attached to a shaft that is shared for all experiments; a ball at one end of the arm is in contact with the cam. Friction and normal forces are measured by means of strain gauges bonded on the flexures. The test parameters for the in orbit tests were a constant normal load of 5 N, angular speed of 50 rpm and the 6 mm ball was placed at a fixed radius of 25 mm to perform the tests. The test criteria was to perform the test for each disk until reaching a mean friction coefficient higher than 0.2 for 60s. Monitorised parameters were the normal load, tangential force friction coefficient, angular speed and temperature; the data acquisition rate was 1 Hz.

3. RESULTS AND DISCUSSION

Table I presents tribology data obtained from the WC alloyed MoS_x film and from a commercial MoS_2 thin film used for space lubrication, both of them tested in the TriboLAB vacuum model, previously described [4]. Figures 4a and 4b depict respectively a typical friction curve from of a commercial unalloyed MoS_2 qualified for space mechanisms and from the WC alloyed MoS_x film.

Table I: Wear test results under vacuum obtained in the TriboLAB Vacuum Model of WC alloyed MoS_x (Film ref. M) and an unalloyed commercial MoS_2 film (Film ref. A).

Test conditions: nominal 5 N load. 75 rpm. 6 mm diameter ball of AISI 440C steel.

Disk Ref.	Normal Load (N)			Friction coefficient			Wear cycles
	Max	Mean	Min	Max	Mean	Min	
M27	7.17	5.68	4.37	0.16	0.04	0.00	69900
M14	7.15	5.61	4.14	0.17	0.06	0.00	347100
M5	6.34	5.27	4.23	0.28	0.07	0.00	59100
M1	5.89	5.13	4.51	0.14	0.05	0.01	241125
M17	5.57	4.96	4.24	0.17	0.07	0.01	249225
M553	6.02	5.09	4.31	0.09	0.05	0.01	500025
M4	6.55	5.51	4.59	0.32	0.08	0.00	108150
M3	5.94	5.03	4.18	0.22	0.07	0.01	197325
M18	6.32	5.55	4.62	0.13	0.06	0.01	492600
M28	5.81	5.02	4.29	0.09	0.02	0.00	109575
M29	6.33	5.45	4.38	0.13	0.04	0.00	196725
M2	6.96	5.72	4.65	0.12	0.04	0.01	190350
A1	6.11	5.35	4.69	0.10	0.06	0.03	22050
A2	6.99	5.74	4.52	0.47	0.01	0.00	227400
A3	8.45	4.84	3.70	0.50	0.04	0.00	179175

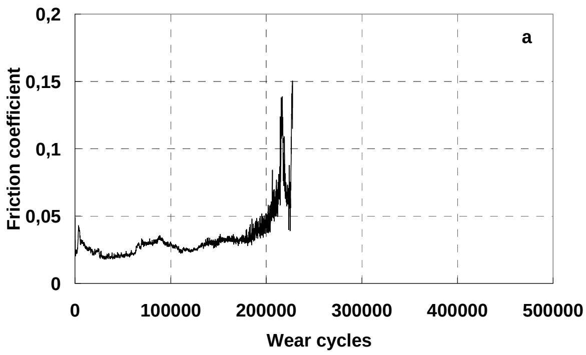
Mean friction coefficients of the WC alloyed MoS_x film measured under these testing conditions in the VTM TriboLAB during the steady-state period varied between 0.02 to 0.08 that means an average friction coefficient value of 0.05. These friction results of tests are in agreement with those obtained in these films using the commercial tribometer under vacuum [2,3]. The evolution of the friction coefficient for the WC-MoSx film in one of the tests performed is presented in figure 4b.

The variation in the WC-MoS_x coatings endurance among the different tests In the VTM was large, from 59,100 to 500,025 wear cycles in comparison with the one obtained in a commercial tribometer from 609,563 to 1,196,049 wear cycles [1].

The main difference between both tribometers is that while in the commercial one, the load is applied by a dead weight and is constant at 5 N, in the VTM TriboLAB it is applied by a torsional spring in which a deviation of 0.1 mm accounts for a 1 N variation. This causes during the test a measured variation in the normal load that ranges from 4 to 6 N (0.7 to 0.8 GPa), see Table I, since the perfect positioning of the sample does not guarantee a lower deviation of +/- 0.1 mm in flatness when rotating the disk, despite the flatness of disks is better than 0.01 mm.

To explain any differences in durability between VTM TriboLAB and other commercial tribotesters, it is known that the durability of sputtered MoS_2 is strongly dependent on load and contact stress [9]. Higher contact stresses and a cyclic loading behaviour conditions, such as those encountered in the VTM TriboLAB, would produce as a consequence a lower endurance life of the lubricating thin film. Furthermore, variation in endurance for pure MoS_2 film has also been reported by other authors using different tribometers or even among different tests [10,11].

A conventional MoS_2 thin film was deposited on the same disks, with a polished surface finish, and Table I also presents the results obtained with this film at the VTM TriboLAB. The friction coefficient is lower but the durability seems to be worse than in the case of the WC alloyed MoS_x film. Fig. 4a shows the evolution of the friction coefficient from one of these MoS_2 coated discs.



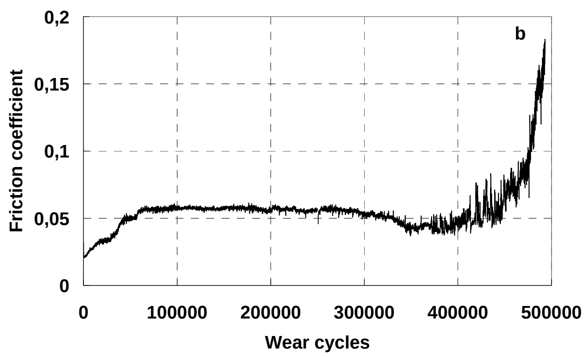


Figure 4: (a) Representative friction curve from an unalloyed commercial MoS2 thin film (disk ref A2) and (b) from a WC alloyed MoS_x thin film (disk ref. M18) tested under vacuum in VTM TriboLAB.

Table II shows the tribological data from the WC alloyed MoS_x films in orbit in the TriboLAB flight model. The mean friction coefficient showed in the four tests varied from 0.02 to 0.04 similar to the ones obtained on earth either in the TriboLAB vacuum model or on a commercial tribometer [2,3]. The maximum endurance of the film in orbit was 1,011,000 wear cycles, which over performed the results obtained on earth in the TriboLAB vacuum model and is similar to the results obtained on earth in a commercial tribometer.

Table II: Pin-on-disk test results in orbit obtained in the TriboLAB Flight Model of WC alloyed MoS_x.

Test conditions: nominal 5 N load. 50 rpm. 6 mm diameter ball of AISI 440C steel.

Test	**Normal Load (N)**			**Friction coefficient (µ)**			**Wear cycles**
	Max	Mean	Min	Max	Mean	Min	
PoD1	4.49	4.36	3.90	0.09	0.03	0.01	305008
PoD2	4.54	4.06	3.84	0.20	0.02	0.01	943454
PoD3	5.29	5.16	4.92	0.07	0.04	0.02	1011000
PoD4	5.22	4.99	4.80	0.20	0.04	0.01	123600

The evolution of the friction coefficient vs. wear cycles in one of the WC alloyed MoS_x film is depicted in Fig. 5. Similar to the data obtained on earth, after a running-in period were the friction coefficient slightly increases up to 0.045, the friction coefficient decreases to 0.033 in the steady-state period.

The good tribological response of the WC alloyed MoS_x films is thought to be mainly due to the Mo-S bonds and the low oxygen content of the film as it was reported before[12], therefore delaying the formation of the deleterious MoO3 phase as it was observed under vacuum in a commercial tribometer.

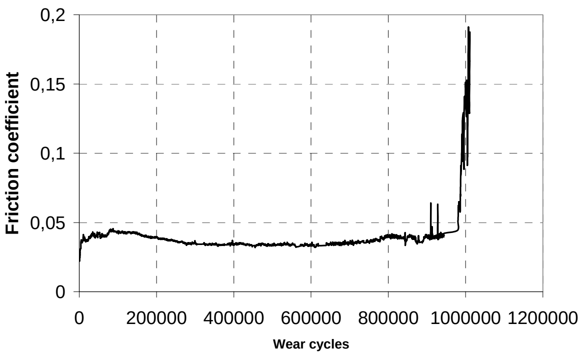


Figure 5: Evolution of friction coefficient for a WC alloyed MoS_x thin film when tested in orbit at the ISS in TriboLAB FM (position PoD3).

The variation in the coatings endurance among the different tests was large, from 123,300 to 1,100,000 wear cycles. Variations in loading sequences, start/stop intervals during testing and vibrations at the contacting interfaces were noted to vary among the tests, however there is not evidence to conclude that these changes contributed to the large spread in the films lifetimes.

Furthermore, this behaviour was also experience on ground and reported by other authors [10,11]. Anyway, further analysis should be done on the coated disks when the TriboLAB equipment will return to earth (time estimated: September 2009). Apart from the variability in the coatings endurance, the higher life-time obtained in the coatings in orbit compared to earth, is partly attributed to a lower variation in the load applied, with a maximum variation of 0.6 N in the worst case. Nevertheless, the results obtained in orbit show that the MoS_x-WC coating is a promising candidate for solid lubrication for LEO (low earth orbit) mechanisms.

4. CONCLUSIONS

The following summarized conclusions can be drawn:

- WC alloyed MoS_x thin films have been deposited by means of magnetron sputtering which have good tribological properties under vacuum and in a LEO environment.
- Vacuum tribology of these films tested in the VTM show that the endurance at 0.75 GPa can be as high as 500,000 wear cycles, which is significantly higher than the values obtained from unalloyed, conventional MoS_2 thin solid films. The extended endurance life of the films is not achieved at the expense of a low friction; the films exhibit an average friction coefficient in the steady state of 0.05.
- These novel WC-MoS_x coatings have been tested in orbit at TriboLAB, in the International Space Station (ISS). TriboLAB is a tribology laboratory installed in the EuTEF (European Technology Exposure Facility), fixed to Columbus laboratory from ESA. These tests have shown that the solid lubricating film maintain very low friction levels of 0.04 and reach a maximum of 1,011,000 wear cycles when tested on a ball on disk geometry at 0,75 GPa, demonstrating a similar behavior to that experienced on ground under laboratory conditions.
- The coated disks already tested in the ISS will be deeply studied when the TriboLAB equipment will return to earth (time estimated: September 2009).
- The WC alloyed MoS_x thin films compare very favorably with unalloyed conventional MoS_2 films.

5. ACKNOWLEDGEMENTS

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