MoS_2-Filled PEEK Composite as a Self-Lubricating Material for Aerospace Applications

Géraldine Theiler* and Thomas Gradt*

Abstract

At BAM, several projects were conducted in the past years dealing with the tribological properties of friction couples at cryogenic temperature and in vacuum environment. Promising candidates for vacuum application are MoS_2-filled PEEK/PTFE composites, which showed a friction coefficient as low as 0.03 in high vacuum. To complete the tribological profile of these composites, further tests were performed in ultra-high vacuum (UHV) at room temperature. In this paper, friction and stick slip behavior, as well as outgassing characteristics during the test are presented.

Introduction

Ultra-high vacuum, a wide temperature range, presence of atomic oxygen, and limited applicability of liquid lubricants, make open space an extremely hostile environment for tribologically stressed components in satellites. In most of these systems, self-lubricating materials must be employed. These include lamellar solids, soft metals, and polymers. Solid lubricants usually are applied as thin film (sputtering), bonded film (with organic binder), or mixed in a polymer matrix (Polyimide and PTFE) [1]. MoS_2 is the most widely used solid lubricant in vacuum environment and has been successfully used in space applications for many years. In vacuum, MoS_2 films exhibit extremely low friction, but in the presence of humid air, friction and wear rate increase significantly.

Since many space mechanisms must be ground tested before launch, sometimes in atmospheric air, there has been much research performed to improve the performance of MoS_2 under atmospheric conditions [2]. One method is the co-deposition of MoS_2 with metal [2] or DLC [3]. Good performance was obtained with WC/DLC/WS_2 coatings in vacuum and air [4]. Another approach is to optimize MoS_2-filled polymer composites.

At BAM, the tribological behavior of MoS_2-filled PEEK composites was investigated in the temperature range between -80°C and +160°C in high vacuum [5, 6]. Particularly in the lower temperature range and at higher loads, the composites showed high wear resistance and friction coefficients as low as PVD coatings. To complete the tribological profile of these composites, further tests were performed in ultra-high vacuum at lower sliding speed. In this paper, friction and stick slip behavior, as well as outgassing characteristics during tests are presented.

Experimental

Tests were performed with a pin-on-flat configuration in oscillating sliding at room temperature in a UHV tribometer [Fig. 1]. The spherical polymer pins used in these experiments were made of PEEK composite filled with 10% by volume carbon fibers, 10% by volume PTFE and 10% by volume MoS_2. The counterface material was X5CrNi1810 steel (similar to AISI 304), with a roughness $R_a \cong 0.2$ µm. Test parameters are summarized in Table 1.

* Federal Institute for Materials Research and Testing (BAM), Berlin, Germany

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During the friction experiment, a mass spectrometer was used to measure the outgassing of the materials. After the experiments, SEM and EDX were performed at the surface of the samples as well as XPS analyses.

Technical data - UHV Tribometer:

Sliding mode: reciprocating
Load: 5 mN to 5 N
Stroke: 3 mm
Frequency: ca. 0.5 – 1.5 Hz
Temperature: Room temperature
Residual pressure: 10^{-10} - 10^{-4} hPa

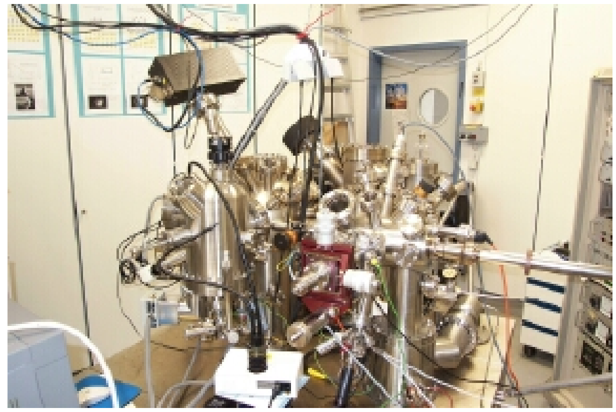

Figure 1. Ultra high vacuum tribometer (UHVT)

Table 1. Test parameters in UHV

residual pressure (hPa)	stroke (mm)	velocity (m/s)	Load (N)	cycles
10^{-9}	3	0.01	5; 10	500

Results

Figure 2 indicates an average friction coefficient of 0.12 – 0.15 with a maximum at 0.25 and accompanied by stick-slip behavior under these conditions. The influence of load on the friction coefficient is not as significant in UHV as in high vacuum (Fig. 3), but the values are somewhat smaller at 10 N than at 5 N. The relatively higher friction coefficient in UHV at v = 0.01 m/s compared to the one obtained in high vacuum at v = 0.1 m/s could be due to the lower sliding velocity or to the fact that the end of the running-in phase in UHV was not yet achieved.

SEM images of the friction surface of the pin and flat after the experiment in UHV at 5 N are presented in Figure 4. EDX analyses of the steel flat indicate that polymer was transferred to it, especially in the grooves present on the surface (Fig. 5). Since the F-map could not be distinguished from the Fe one (of the flat), it is not shown here. MoS_2 is homogeneously transferred, but does not form a closed transfer film on the steel flat. In this case, the very low friction coefficient obtained by MoS_2 film at higher sliding speed in high vacuum cannot be reached.

Furthermore, EDX analyses of the polymer pin indicate a MoS_2 rich surface, intermittent due to carbon fibres (Fig. 6). The analyses revealed also that some Fe has been transferred from the steel to the polymer pin. In addition, XPS analyses were performed after the experiment in UHV. Figure 7 shows the measured binding energy with the corresponding components. Beside MoS_2, the formation of molybdenum oxides was observed, which could be formed with the oxide layer of the steel disc. The presence of molybdenum oxides could also explain the higher coefficient of friction, as reported in [7].

A preliminary measurement was performed to characterize the outgassing during the friction experiment. Figure 8 indicates that the outgassing increases during sliding, especially for hydrogen and nitrogen compounds. Indeed, due to frictional heat, desorbed hydrogen and trapped gas are released during the test.

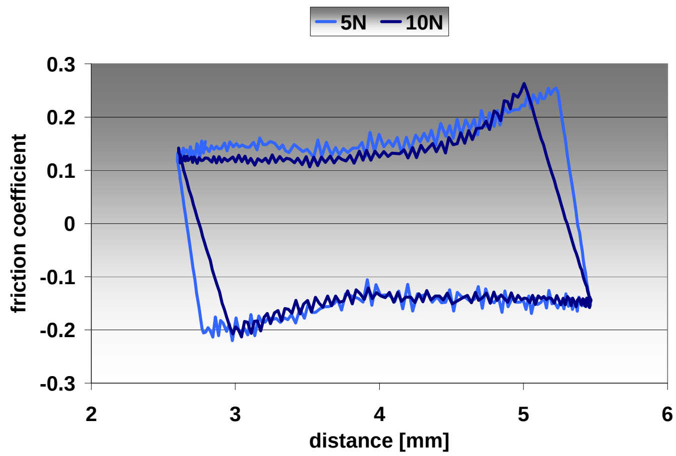

Figure 2. Friction behavior in oscillating motion in ultra-high vacuum

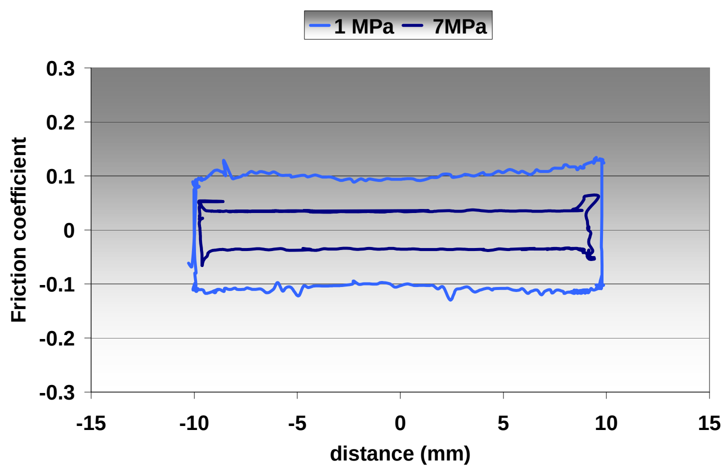

Figure 3. Friction behavior in oscillating motion in high vacuum

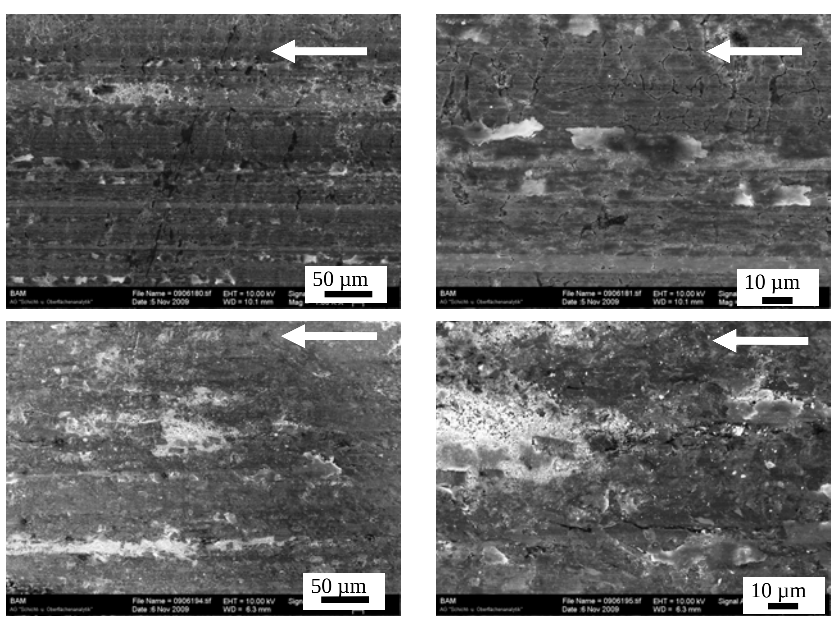

Figure 4. SEM Analyses after the test in UHV at

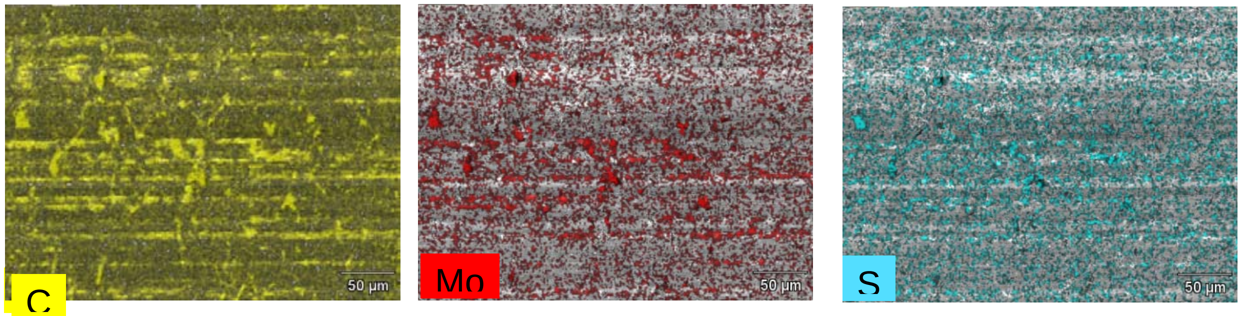

Figure 5. EDX Analyses of the polymer transfer on the steel counterface after the test in UHV at room temperature, 5 N

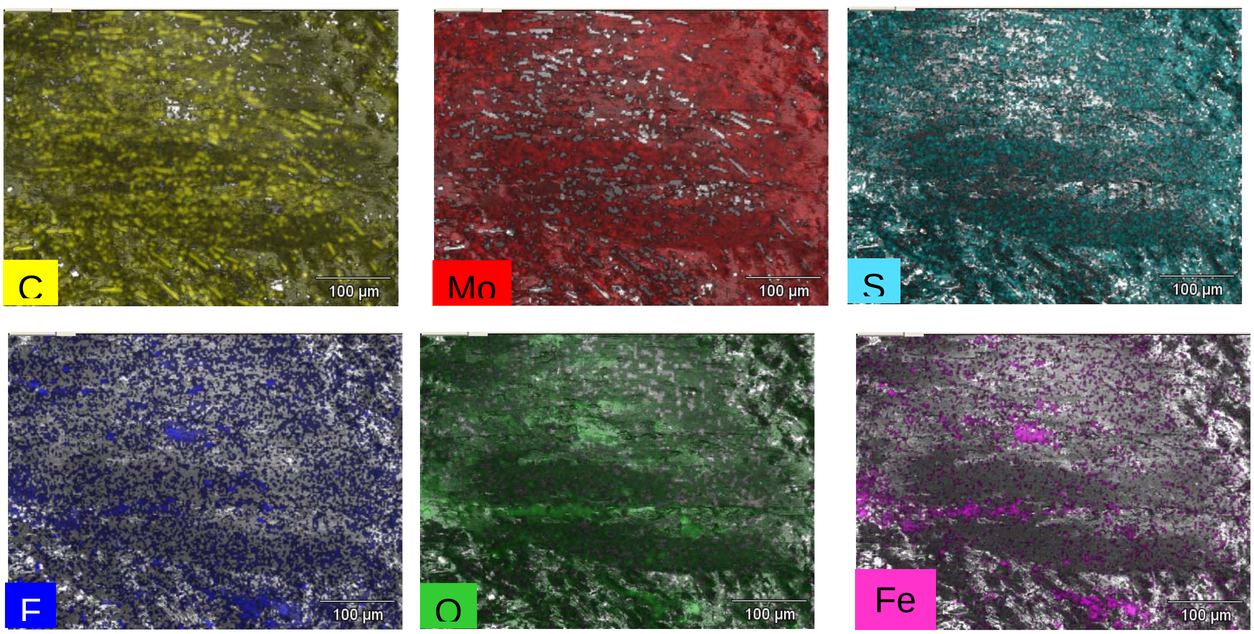

Figure 6. EDX Analyses of the polymer pin after the test in UHV at room temperature, 5 N

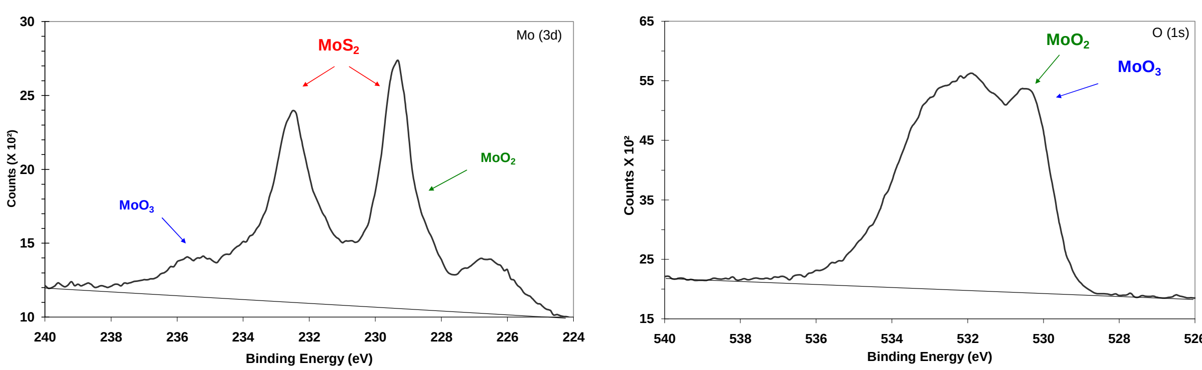

Figure 7. Mo(3d) and O(1s) spectra after the test in UHV at room temperature, 5 N

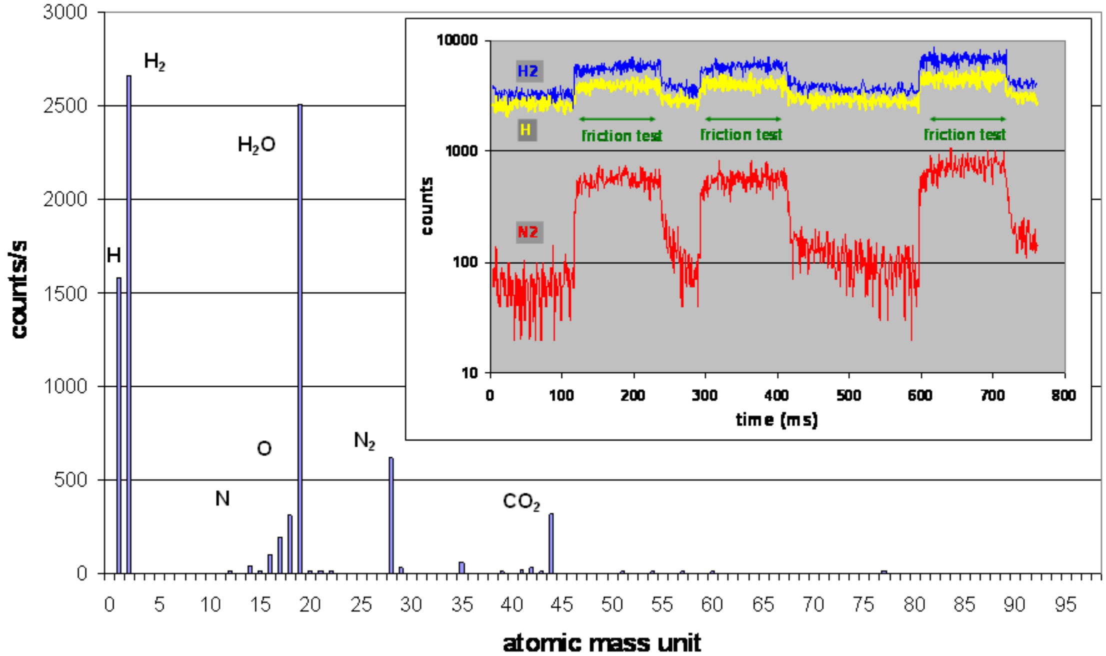

Figure 8. Mass spectroscopy during friction test in UHV

Conclusion

This subsidiary study gives additional information concerning the tribological behavior of MoS2-filled PEEK in vacuum environment. The outstanding performance of this composite found in high vacuum at v = 0.1 m/s [5, 6] is limited in UHV at low sliding speed (v = 0.01 m/s), where some static friction as well as increased outgassing are observed. However, since the sliding velocity is an influencing factor on the tribological behavior of polymer composite, further tests in UHV should be performed at higher speed and during a longer period of time to verify the potential of these PEEK composites.

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