CHANGES IN TRIBOLOGICAL PROPERTIES OF MOS$_2$ FILM EXPOSED TO LEO ON SM/SEED

Koji MATSUMOTO  
Japan Aerospace Exploration Agency  
Chofu, Japan

Masahito TAGAWA  
Kobe University  
Kobe, Japan

Masao AKIYAMA  
IHI Aerospace  
Tomioka, Japan

Kichiro IMAGAWA  
Japan Aerospace Exploration Agency  
Tsukuba, Japan

ABSTRACT

Service Module / Space Environment Exposure Device (SM/SEED) is experimental system aboard International Space Station (ISS) to evaluate the degradation of various materials for space application under the Low Earth orbit (LEO) space environment. Three sets of exposure pallets of SM/SEED with the same samples have been exposed to LEO since October 2001. One of the pallets returned to Earth after about one-year exposure. A bonded molybdenum disulfide (MoS$_2$) film was also exposed as a tested material of SM/SEED. The changes in tribological characteristics of the film were examined. And effects of ground-based irradiation with LEO environmental factors (e.g., Atomic Oxygen (AO) and Ultraviolet rays (UV)) were also evaluated.

At the beginning of the test, low friction coefficient was observed both in the flight and the AO-irradiated samples. MoO$_3$ was detected from the surface of these samples. A large amount of SiO$_2$ was recognized from the flight sample.

INTRODUCTION

Materials used for spacecraft in Low Earth Orbit (LEO) are affected by not only a vacuum but also Atomic Oxygen (AO) and/or Ultraviolet Rays (UV). Solid lubricants are also influenced by these factors, therefore evaluation of effect of the LEO environment (e.g., SFU/EFFU [1] and MFD/ESEM [2] experiments) have been carried out. However, the details of effects of the LEO environment on solid lubricants and changes in tribological properties by long duration exposure have not been clear.

Experimental project about effect of space environment on materials, the Space Environment Exposure Device on Service Module (SM/SEED), has been carried out in International Space Station (ISS). After exposure for 1, 2 or 3 years, set of exposure device has been returned one by one and the characteristics of materials have been evaluated. In this study, changes in tribological characteristics of solid lubricant after one-year exposure are reported.

TEST METHODS

Tested film

Tested lubricant was a bonded molybdenum disulfide (MoS$_2$) film with poly-amide-imide as a binder material. The film is commercially available and has been used for space applications. Substrate was Ti alloy disk with a diameter of 25.4 mm. The film thickness was approximately 10 µm.

Conditions of flight exposure and irradiation on Earth

Three sets of the pallets with tested specimens of SM/SEED were exposed to LEO from October 2001. First set was exposed for 315 days at altitude of 386.6 km and returned in August 2002. Conditions of the LEO environment calculated from monitor materials or altitude and posture of ISS are shown in table 1. Furthermore, the same materials were irradiated with AO, UV and Electron Beam (EB) on Earth to compare with the exposure to the LEO environment. Conditions of ground-based irradiation tests are also shown in table 1.

| Table 1 Condition of flight exposure and irradiation on Earth |
|-----------------|-----------------|-----------------|-----------------|
| Specimens       | Calculation     | AO [atoms/cm$^2$] | UV [ESD] | Radiation(EB) [Gy] |
| Flight exposure | method          |                 |       |         |         |
| to LEO          | Monitor         | 2.3 - 66.3      | 1 - 3  | 0.4 - 65 |
| Altitude, posture | 4.27 $\times$ 10$^{20}$ | 22.5            | 214    |
| Irradiation on Earth | 13.2 $\times$ 10$^{20}$ | 35.2            | (1.64 $\times$ 10$^{15}$) [e/m$^2$] |

Copyright © 2005 by ASME
Friction tests
Ball/disk type reciprocating friction tests were carried out in vacuum. An applied load was 2 N. A sliding speed and a stroke were 10 mm/sec and 10 mm respectively. Three times of friction tests were carried out for each specimen. The tests stopped at 2,000, 20,000 and 100,000 strokes. A 440C stainless steel ball with a diameter of 7.94 mm was used as the ball specimen.

RESULTS AND DISCUSSION

Tribological characteristics
Friction coefficient of the sample exposed to LEO (flight sample) and irradiated on Earth at the beginning of the tests were compared with non-exposed sample (controlled sample) in fig.1. Friction coefficient of the flight sample was similar to the controlled sample at the first sliding and then it showed obviously lower value after second sliding. The AO-irradiated sample showed similar friction behavior to the flight sample. At the beginning of the test, low friction coefficient was observed in also the UV-irradiated samples, whereas the friction coefficient of the EB-irradiated sample did not change.

Surface analyses
The XPS analysis confirmed a large mount of SiO₂ from the surface of the flight sample as a contamination. The increase in concentration of O and the decrease in concentration of C were observed on the surface of the AO-irradiated sample. In the Mo3d spectrum of these samples, spectral changes by the oxidation of Mo were obvious. Namely, Mo (IV) was converted to Mo (VI) by means of the formation of MoO₃. For the UV-irradiated sample, concentration of Mo and S showed some increases. A big change was not recognized from the EB-irradiated sample.

Table 2 and fig.2 show atomic concentration of rubbing surface by AES analysis and surface profile of rubbing tracks of the flight sample. The concentration of Mo and S increased and that of O decreased greatly as sliding strokes increased. The reason seems to be that MoO₂ was removed by friction and MoS₂ appeared. Relative concentration of C was lowered by adhesion of SiO₂ at the surface before friction. The concentration was recovered by removal of SiO₂ with increase of number of friction. However, it decreased again on the surface after sliding of 100,000 times. It is possible that transfer wear particles of SiO₂, which adhered on the counter part, returned and re-adhered on the rubbing surface of the sample.

Discussion on the effect of LEO environment
About environmental factor during one-year exposure to LEO in this study, AO fluence was more and UV fluence was less than SFU/EFFU or MFD/ESEM experiments. And a larger mount of SiO₂ was detected as a contamination. It may be that these differences in exposure environment caused difference in changes in tribological characteristics. More examination concerning influences of contamination, further long-term exposure and use in active condition may be necessary.

REFERENCES