Trans. JSASS Aerospace Tech. Japan
Vol. 8, No. ists27, pp. Th_1-Th_5, 2010

Topics

A Consideration of Future Flight Material Exposure Experiments in Japan: Advanced Material Exposure Test Working Group's Proposal

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(Received July 15th, 2009)

In Japan, the largest material exposure program "SM/MPAC&SEED (Service Module/ Micro-Particles Capturer and Space Environment Exposure Device) Experiment" has been completed. This program is quite ambitious among the other Japanese materials exposure tests; 3 sets of samples have been exposed for 1, 2 and 3 years in orbit in order to discover the fluence dependence of the material responses. We have learned a lot of lessons from this program. Based on the lessons learned, the "Advanced Material Exposure Test Working Group" has been established by the Committee on Space Utilization in 2007. This working group discussed the current problems of the material exposure program (flight tests) and proposed the future direction of the experimental methodologies. In this presentation, problems and new challenges discussed in this working group will be discussed.

Key Words: Exposure Test, Material, Space Environment, Low Earth Orbit

1. Introduction

It has been well-known that many space materials are eroded by space environment and thus space environmental effect on materials is one of the key technologies for long-term mission in space.[1] A number of flight experiments have been conducted in many countries. In Japan, the materials exposure program "SM/MPAC&SEED (Service Module/ Micro-Particles Capturer and Space Environment Exposure Device) Experiment" has been completed. This program is quite ambitious among the other materials exposure tests held in Japan; 3 sets of samples have been exposed for 1, 2 and 3 years in order to discover the fluence dependence of the material responses. Detail of the program was described elsewhere.[2] We have learned a lot of lessons from this program not only every material response, but also the methodology of a material test. Based on the lessons learned, the "Advanced Material Exposure Test Working Group" has been established with a permission of the Committee on Space Utilization in 2007. The purpose of this working group is to discuss the current problems of the material exposure program in Japan and proposed the future direction of the experimental methodologies. The methods for ground-based simulation studies are also discussed in this working group based on the surface physics and chemistry.

The environment surrounding the space exposure tests is greatly changing. Building of the International Space Station (ISS) is in the final stage, and the Japanese Experimental Module (JEM or Kibo) will soon be fully operational which equips Exposure Facility (EF) usable for material exposure testing. As well as Kibo, US module and EU module of ISS compartment also equip their own EF at the outside of the module. It is, therefore, stated that the infrastructures for the material testing at ISS will soon be established. However, due to the delay of the construction schedule of ISS, another problem arises; space shuttle will be retired after the accomplishment of ISS in 2010. The major transportation system will not be available for material testing beyond 2011. New methods for material testing have to be developed to match the new circumstances of the flight tests.

2. Advanced Material Exposure Test Working Group

2.1. Purpose

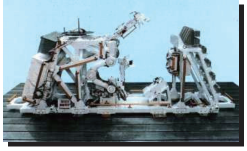
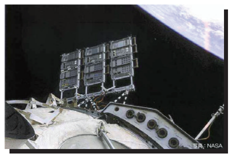
The purpose of "Advanced Material Exposure Test Working Group" is to discuss the problems of the current "passive" in-orbit material exposure tests and to propose the methodologies for advanced material exposure tests including in-situ or acceleration test capabilities. A new protocol for ground-based simulation considering the effect on differences in environmental factors in space and on ground tests will also be discussed in this working group. The goal of this working group is to establish the methodologies for space exposure tests to develop the advanced space materials suitable for Japan.

2.2. Member

The "Advanced Material Exposure Test Working Group" consists of ten Japanese researchers on the space environmental effect on space materials. Six members are from JAXA and four from Universities.

Masahito Tagawa	(Kobe University, Chair)
Kumiko Yokota	(Kobe University)
Mengu Cho	(Kyushu Institute of Technology)
Minoru Iwata	(Kyushu Institute of Technology)
Mineo Suzuki	(JAXA)

Table 1. Japanese material exposure missions.

			
Mission	SFU/EFFU	MFD/ESEM	SM/MPAC&SEED
Launch date	Mar. 18, 1995 H2	Aug. 7, 1997 STS-85	Oct. 1, 2001 Progress
Retrieval date	Jan. 13, 1996 STS-72	Aug. 12, 1997 STS-85	Aug. 18, 2005 Soyuz
Exposure time	10 month	54 hour	315-1403 days
Altitude & Inclination	482 km 28.5 deg.	315 km 57 deg.	400 km 51.6 deg.
Samples	22	21	23

Rikio Yokota (JAXA)
Koji Matsumoto (JAXA)
Yugo Kimoto (JAXA)
Eiji Miyazaki (JAXA)
Hiroyuki Shimamura (JAXA)

This working group is the first attempt in Japan to reflect on the past material exposure mission from the viewpoint of mission design and management including outside opinion of JAXA.[3]

3. Past Japanese Flight Missions

3.1. Overview of the past missions

Three flight experiments have been performed in Japan to study material responses in actual space environment, i.e., Space Flyer Unit/ Exposed Facility Flyer Unit (SFU/EFFU)[4], Manipulator Flight Demonstration / Evaluation Space Environment and Effects on Materials (MFD/ESEM)[5] and SM/MPAC&SEED[2]. SFU/EFFU experiment was flown by the Japanese satellite, and MFD/ESEM experiment was carried out in the cargo bay of the space shuttle orbiter. In contrast, SM/MPAC&SEED was done on ISS. Detail data of these flight experiments are summarized in Table 1. Exposure periods of these flight experiments are from 54 hours to 3 years.

Among these three missions, SM/MPAC&SEED is the most complicated mission, i.e., fluence dependence of the material responses to the space environmental factors such as atomic oxygen, radiation, and ultraviolet was attempted to analyze. Compared to the similar type of US mission (Materials International Space Station Experiment, MISSE)[6], difference in mission concept is obvious. Namely, MISSE pallet carries wide variety of samples (more than 2000 samples), however the exposure period is not a primary point of interest. In contrast, SM/MPAC&SEED exposed only selected samples (approximately 20 samples) for multiple fluence conditions. This is probably due to the fact that the US has their own method to transfer the samples to/from ISS, but Japan does not have their own such a transportation method.

3.2. Lessons learned

In these past "successful" missions, we still have had some problems. It should be recorded somewhere and have to be used to improve the next flight mission. Unfortunately, the former attempt is not enough to share the past experiences among the scientists of the following missions in Japan. The WG members believe this is a report in Japan accessible to non-classified personnel on the problems of material exposure mission including the mission designing point of view.

One of the most important issues to be addressed is the contamination effect on the passive space exposure test. SFU/EFFU and SM/MPAC&SEED missions, sample surfaces were severely contaminated by the silicone vapor. Figure 1(a) and 1(b) show the X-ray photoelectron spectroscopic (XPS) data of the control and the 1-year-exposed samples of MoS_2 aboard SM/MPAC&SEED. After one year of exposure at Service Module of ISS, Mo3d (228 eV) and S2p (168 eV) signal almost disappeared and Si2s (151 eV) and Si2p (103 eV) signals became obvious. Figure 1(c) shows the XPS spectrum of the 3-year-exposed

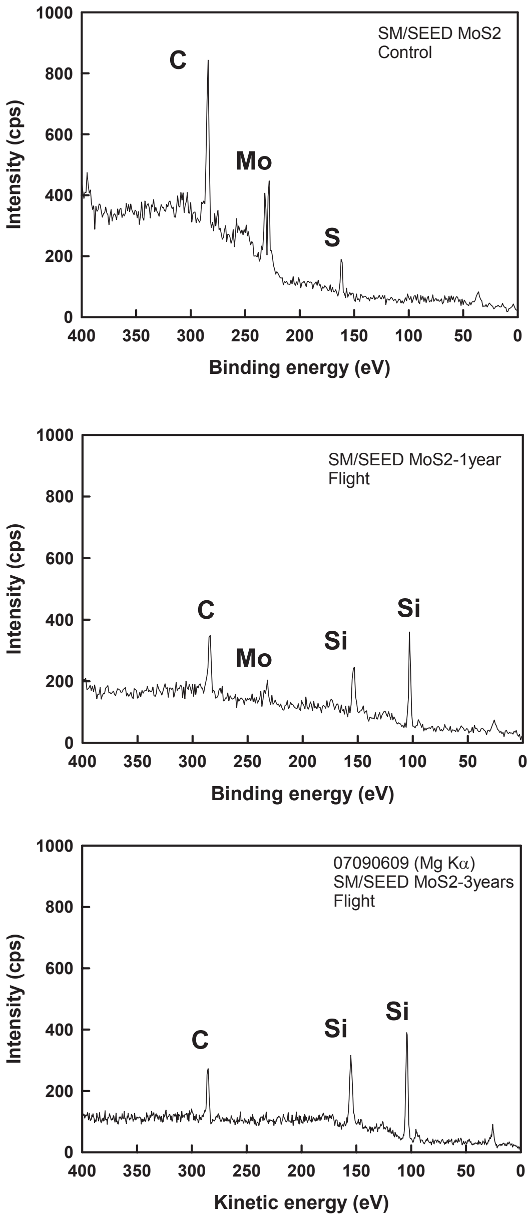


Fig.1. X-ray photoelectron spectra of control, 1-year and 3-year-exposed samples of MoS_2 aboard SM/MPAC& SEED.

sample. Mo3d signal disappears and MoS_2 surface is completely covered by silicone contamination. Since Mo reacts to atomic oxygen and formed MoO_3, which is not a volatile product, the MoS_2 surface could be covered by MoO_3 after atomic oxygen exposure. If this phenomenon is confirmed in this flight experiment, the predicted robustness of MoS_2 lubricant in an atomic oxygen environment could be proved in LEO.[7-8] It is, however, SiO_2 contamination layer interferes this atomic oxygen reaction with Mo, and made it difficult to confirm the protection effect.

SiO_2 contamination layer blocks the atomic oxygen reaction not only with Mo, but also with polyimide which is the witness sample to measure atomic oxygen fluence. This makes the evaluation of atomic oxygen fluence difficult. Accuracy of atomic oxygen fluence measurement in SM/MPAC&SEED mission became low due to the presence of SiO_2 contamination. This is a major problem of not only material-related part but also micrometeoroids capture-related of the SM/MPAC&SEED mission. The SiO_2 contamination may also influence UV and radiation monitor but has not been evaluated.

This contamination problem was not a new issue on SM/MPAC&SEED. Similar problem has been experienced in SFU/EFFU mission and the other flight missions. In this first Japanese material exposure mission, many samples were covered by SiO_2 contamination. ESA and US have also experienced sever contamination from Russian module of ISS. However, effective countermeasures were not taken in the following material exposure missions, even though the presence of contamination is expected. Insufficient disclosure and rigidity of the mission could cause such problem.

4. Current Problems on Flight Experiments

4.1. Too small chances to send the samples in orbit

This is the common problem for all space programs. Because new functional materials are being developed, the requirements of space qualification test for such new materials are always arising. Due to the high-speed of the development of materials, preparation period of the material exposure test is 2-3 years at maximum. Otherwise, feedback of the exposure results to the material development process becomes impossible.

4.2. Monitoring method of space environmental factors

Contamination control is a key for the passive material exposure test. New monitoring methods (or device) for space environmental factors, including the methods for elimination of contamination, have to be developed.

4.3. Retrieval methods of exposed samples beyond 2011

The retrieval of the exposed samples to Earth is made by the Space Shuttle in two of three past flight experiments in Japan. However, Space Shuttle is scheduled to retire in 2010. After 2011, sample retrieval from the orbit has to be carried out by Soyuz. The capacity of Soyuz is limited and only small pallet can be retrieved.

5. Possible Solution for Future Flight Tests

In order to solve the problems listed above, the following technical solutions are proposed: (1) use of small unmanned platform for material tests, (2) no sample retrieval by telemetry data transmission and (3) real-time measurement.

Use of small, unmanned satellites for material exposure test decreases the cost and time for material test and increase the chance to send samples to orbit as a piggyback mission. The unmanned mission can simplify the safety inspection process. It would solve the rigidity of the program. Also orbits other than ISS orbit can be realized for the material test. It will be useful especially for the radiation test in polar orbit. Due to the lack of reentry system, all measurements have to be performed in orbit and the samples cannot be retrieved. For this purpose, in-situ monitoring technology has to be developed for this type of application. This is a technological challenge compared to the current "passive" experiment. However, a trend for real-time data acquisition is a world technological trend. MISSE-6, -7 by US and MEDET by ESA are designed for partially or fully active experiments. They are preparing for the era beyond 2011. A quartz crystal microbalance (QCM) is one of the promising techniques to provide such data. QCM has been applied in space to measure a contamination on satellites during its operation.[9] On the other hand, it has also been used for material degradation research on the ground. Thus, integration of these two examples easily realizes the real-time mass loss of the samples during the flight test. The advantage of this method will be demonstrated by MISSE-6 in 2008.[10] One of the problems on QCM is its high cost and complication of the system. To overcome these shortcomings, the QCM system developed for contamination monitoring in Japan is applying the material study.

6. Role of Ground-Based Simulation

In order to evaluate the survivability of newly developed materials in space environment without sending the sample into space, the accuracy of the ground-based simulation test should be improved. Present technology of the ground-based space environmental simulation is not enough to predict the material response in real space environment. Absolute pressure and temperature in space can be simulated in the ground-based test. However, some other environmental factors are difficult to simulate in ground-based studies accurately. The inconsistency of the result of ground-based test with that of flight test is due mainly to the differences in experimental conditions between space and ground. Some examples of the experimental conditions which are difficult to simulate in ground-based experiments are listed below: (1) ultraviolet spectrum and intensity; (2) impact velocity of atomic oxygen both average and distribution and its peak flux; (3) energy spectrum and intensity of radiation; and (4) the synergistic effects of these environmental factors.

In order to increase the accuracy of the predictions, differences in experimental conditions between space and ground should be considered quantitatively. This should be applied to the reference materials first. For example, temperature, angular and impact energy dependences on the atomic oxygen-induced etching of polyimide should be made clear. These erosion properties are necessary to measure the atomic oxygen fluence both in space and in ground-based simulations. The same data set is required to calculate the erosion depth of any material with computer code. Well-controlled ground-based experiment can only provide such basic properties of atomic oxygen erosion phenomenon.[11-12] In the field of ground-based space environmental simulation, basic properties of material responses with space environmental factors have not been understand deeply. Sometimes, it is even difficult to judge whether the ground-based simulation is severer or milder compared to flight environment. Thus, improvement of the ground-based simulation technology is important even in the space-engineering field to assess the reliability of the materials.

7. Small Satellite Constellation Plan

In 2009, the Ministry of Education, Culture, Sports, Science and Technology, Japan, and Ministry of Economy, Trade and Industry announced that development of small satellite constellation is planned. Material testing by unmanned satellite, discussed in Section 5, shows very high applicability with small satellites system. As one of the missions for such small satellites, material testing without retrieving samples should be included. On the other hand, realization of small satellite constellation leads to the requirement for space environmental material and system testing for every satellite. Such great amount of ground-based testing has to be carried out by certain organizations in Japan, however, no organization has such capability in Japan. Establishment of an organization for ground-based test should also be included in the plan.

8. Conclusions

The "Advanced Material Exposure Test Working Group" was established to overlook the past Japanese material exposure missions and to propose the future material exposure tests. From the lessons learned by the past missions, importance of contamination control to the "passive" material exposure test is addressed. In order to increase the freedom of experiment in space, use of unmanned small satellites is proposed. Due to the retirement of space shuttle in 2011, development of unmanned small material exposure pallet with real-time data acquisition capability has to be developed.

Acknowledgments

"Advanced Material Exposure Test Working Group" has been established by the Committee on Space Utilization. Stimulated discussion in the Working Group is appreciated for preparing this manuscript. A ground-based experimental part was supported by the Grant-in-Aids for Scientific Research from JSPS.

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