FUTURE SPACE EXPOSURE EXPERIMENT BEYOND 2011 -ITS PROBLEMS AND NEW CHALLENGES-

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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.

Keywords: MPAC&SEED, Space Exposure, Material, ISS, Space Environment, Low Earth Orbit

1. Introduction

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 is described in companion papers of this symposium. 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. This working group discussed the current problems of the material exposure program in Japan and proposed the future direction of the experimental methodologies. 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 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.

In this talk, the discussion in the "Advanced Material Exposure Test Working Group" regarding new material exposure testing method suitable for Japan is reported.

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 nine Japanese researchers on the space environmental effect on space materials. Five members are from JAXA and four from Universities.

Masahito Tagawa	(Kobe University, Chair)
Mengu Cho	(Kyushu Institute of Technology)
Mineo Suzuki	(JAXA)
Rikio Yokota	(JAXA)
Minoru Iwata	(Kyushu Institute of Technology)
Koji Matsumoto	(JAXA)
Eiji Miyazaki	(JAXA)
Hiroyuki Shimamura	(JAXA)
Kumiko Yokota	(Kobe University)

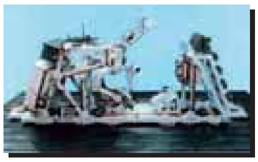
This working group is the first attempt in Japan to reflect on the past material exposure mission from the viewpoint of mission design and management including outside opinion of JAXA.

3. 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.,

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

Space Flyer Unit/ Exposed Facility Flyer Unit (SFU/EFFU) [1], Manipulator Flight Demonstration/Evaluation Space Environment and Effects on Materials (MFD/ESEM) [2] and SM/MPAC&SEED [3]. 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 were analyzed. Compared to the similar type of US mission (MISSE) [4], 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. The author believes this is the first official report in Japan 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 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 [5, 6]. 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 the major problem of

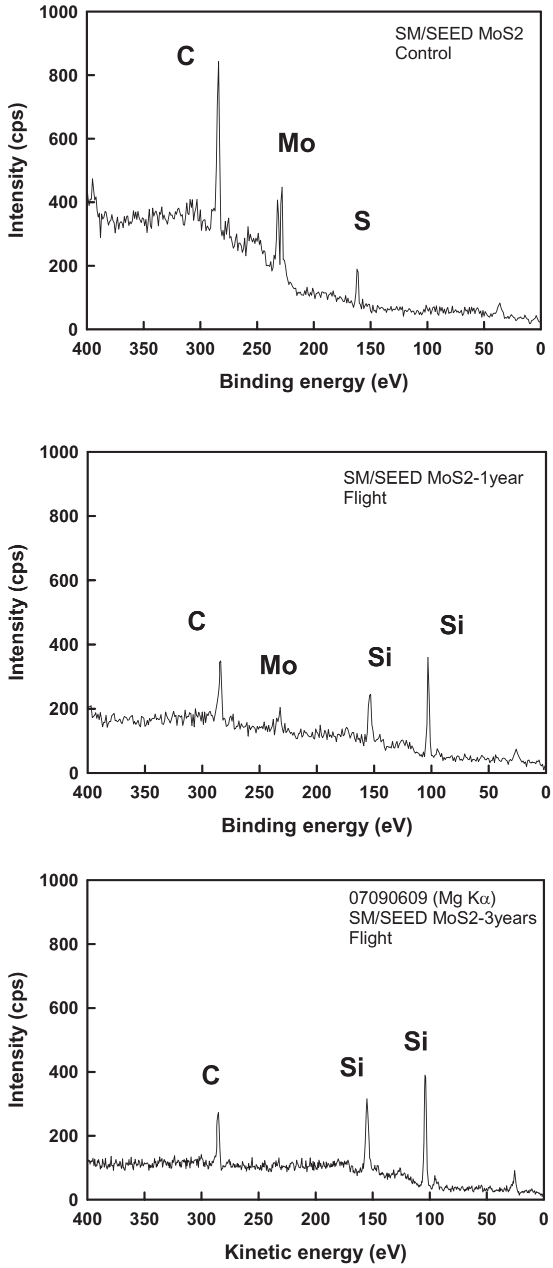


Fig.1 X-ray photoelectron spectra of control, 1-year and 3-year-exposed samples of MoS_2 aboard SM/MPAC&SEED.

material-related part 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. In this first Japanese material exposure mission, many samples were covered by SiO_2 contamination. However, effective countermeasures were not taken in the following material exposure missions, even though the presence of contamination is expected. At least, the witness samples should be protected from contaminations.

4. Current problems and solutions

4.1 Too small chances to send the samples in orbit, too long preparation period and rigidity of the program

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. Fast, cheap and better is the key for future material exposure mission. This is the same solution for the satellite system itself. The solution is also the same as satellite system, i.e., use of small, unmanned satellites for material exposure test. This will decrease 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 used for the material test. It will be useful especially for the radiation test in polar orbit. On the other hand, in-situ monitoring technology has to be developed for this type of application. This is a technological challenge compared to the current "passive" experiment.

4.2 Monitoring method of space environmental factors need to be reconstructed

Contamination control is a key for the passive material exposure test as described in Section 3. New monitoring methods (or device) for space environmental factors, including the methods for elimination of contamination, have to be developed. For the contamination control purpose, a hood or a skimmer system (Figure 2) would be effective, because atomic oxygen or UV in space is a directional beam but contamination is diffusive. Thus, a hood which restricts the field of view of the sample is a simple solution. Double skimmer system is the more appropriate but is weak for the misalignment from the velocity vector. These devices do not require any power and large mass attachment. It is worth trying in the future passive exposure test.

Witness samples of atomic oxygen, ultraviolet or radiation fluencies should be well-understood in its synergistic effect. For example, polyimide (or Kapton-H), which is widely used as

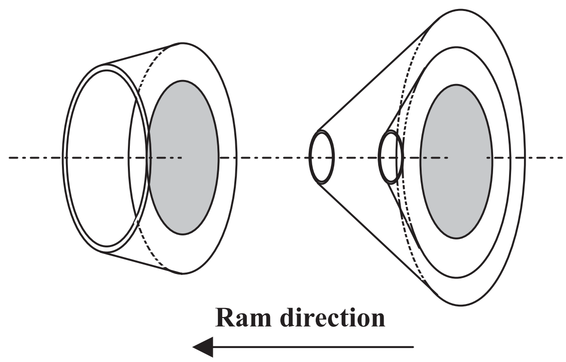


Fig.2 A hood (left) or a double skimmer system (right) for eliminating possible contamination.

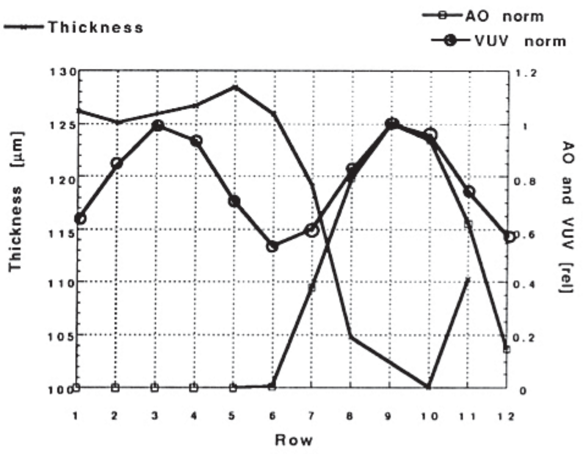


Fig.3 LDEF results regarding FEP Teflon degradation [8].

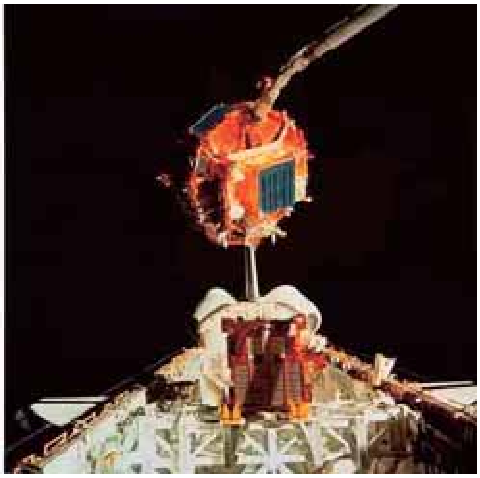


Fig.4 Retrieval of the SFU spacecraft by STS-72 mission.

an atomic oxygen witness sample, show increase in mass loss with a certain environment which includes atomic oxygen and ultraviolet simultaneous exposure [7]. This leads to the overestimation of the atomic oxygen fluence; i.e., underestimation of the atomic oxygen effect on targeted materials. All of the witness samples, which measure the experimental parameter, should be well analyzed for their responses in a complicated space environment.

4.3 Experimental data obtained by the past tests are not enough disclosed. A division that controls all of the material exposure programs must be established in Japan.

This might be a Japanese specific problem, but the results of the past material exposure test are not well disclosed even for the Japanese researchers. For improving the methods or materials for the next material exposure test, the past data should be disclosed for those who needed. At least, a division of JAXA should control all of the data and ready for the future requirement. According to the suggestion by the working group, the material group of JAXA will take this role.

4.4 Main purpose of exposure program is not clear; screening test of space materials or reference data?

As pointed out in 4.1, opportunity of material exposure test in LEO is limited. It is not realistic to send all of the materials to space to evaluate their survivability in space environment. Only selected materials can be flown on the material exposure test. This limitation comes mainly from the fact that Japan does not have method to retrieve the samples. This may also reflect the difference in mission design of MISSE and SM/MPAC&SEED as described earlier. In such a situation, how should the materials be selected for the flight experiment in Japan? Newly developed materials will not have a chance to evaluate their survivability in space environment. Survivability of the materials will have to be evaluated through the ground-based simulation test. In that case, accuracy of the ground-based simulation test is quite important. In order to increase the accuracy of the ground-based simulation test, flight test should provide the reference data for the ground-based simulations. In order to obtain the reference data, passive experiment has a problem; only integrated data can be analyzed over the exposure period. Figure 3 represents the erosion of FEP Teflon obtained by LDEF [8]. Erosion of the FEP Teflon at the leading edge of LDEF satellite (ram direction) is clearly observed. This data can be implied that the degradation of FEP Teflon occurs on by atomic oxygen exposure or by the simultaneous exposure of atomic oxygen and ultraviolet; not by ultraviolet alone. However, due to the difficulty for atomic oxygen testing on the ground, this problem has not been clarified yet. The real-time measurement of erosion in space provides direct evidence on these problems. A quartz crystal microbalance (QCM) is a promising technique to provide these 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].

4.5 Methods to retrieve the exposed samples after the retirement of Shuttle are in the dark. Freedom of the flight experiment is quite limited by the capacity of the Soyuz spacecraft.

The retrieval of the exposed samples to Earth is made by the Space Shuttle in two of three past flight experiments in Japan (Figure 4). However, Space Shuttle is scheduled to be retired 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. New exposure pallet should be designed to fit the capacity of Soyuz. It should be specially designed to maximize the spatial efficiency, i.e., sample density has to be increased significantly compared to SM/MPAC&SEED. However, due to the dimensional limitation, the complex equipment cannot be attached on the pallet. This restricts the freedom of the experimental design. For well-controlled exposure experiment, development of new transportation system with a large capacity is mandatory. With a marginal capacity of retrieval system, we can arrange some social experiments for next generation space scientists;

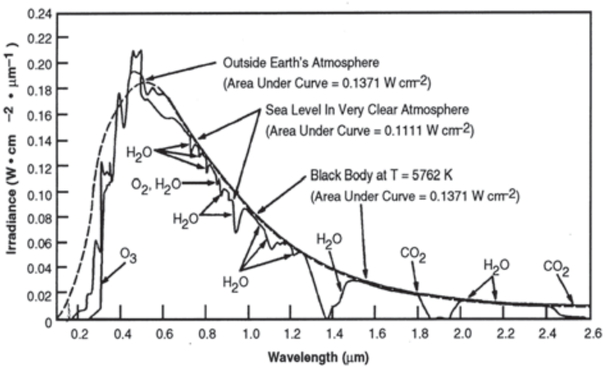


Fig.5 UV/VIS/IR spectrum in space [11].

for example, space-experienced rice seed distribution to all Japanese primary schools for growing experiment in biology.

5. 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 (Figure 5); (2) impact velocity of atomic oxygen both average and distribution, (Figure 6) and its peak flux; (3) energy spectrum and intensity of the 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 [14, 15]. 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.

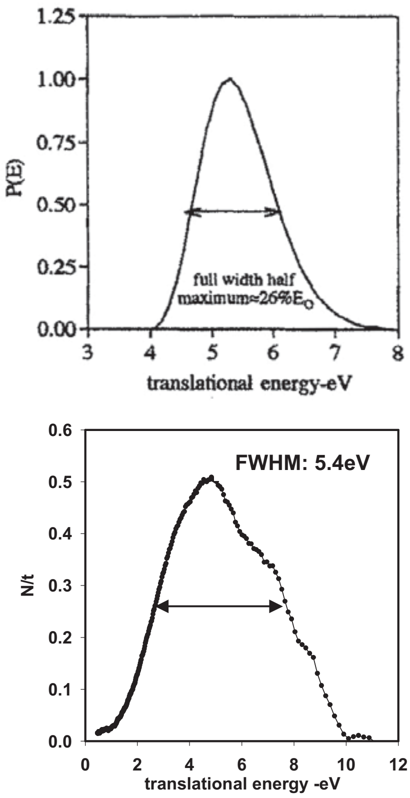


Fig.6 Translational energy distributions of atomic oxygen in LEO (upper panel) [12] and in the ground simulator (lower panel) [13].

6. 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, necessity of development new compact integrated pallet and new transportation system is also mandatory. Because of the limitation of the space exposure material test opportunity, increase in accuracy on the ground-based experiment has to be important.

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“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.

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