CULTIVATION OF RESEARCH AND PROJECT-SUPPORT NETWORK FOR DEGRADATION OF SPACE-USE MATERIALS — CONCEPT OF CLUSTER TYPE IN-SITU TEST FACILITIES NETWORK

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ABSTRACT

The space-use materials would degrade in harsh space environments. To provide assurance of safety reliability on satellite, we must evaluate the degradation of space-use materials by using ground-simulation tests. However, the ground-simulation-test facilities and engineers to evaluate the degradation of materials are not enough to support satellite projects in Japan. We have started to organize the network named 'Cultivation of Research and project-support network for Degradation of space-use materials (CRED)' that would make possible the in-situ ground simulation test, measurement, and analysis.

If we want to construct new ground simulation test facility integrated in one 'massive' system, we must spend enormous budget. In addition to this, it could be difficult to expand the function of system and to use each equipment integrated in the system, simultaneously. Therefore, we have suggested the concept of cluster type in-situ test facilities system achieved by connecting various facilities and equipment existing dispersedly in Japan due to a portable vacuum transfer vessel and glove box filled with an inert gas.

In this paper, we described the concept of cluster type in-situ test facilities system in CRED.

Key words : in-situ test, vacuum transfer, ground simulation test

1. INTRODUCTION

The materials used for spacecraft would be degraded by harsh space environments exposure and would lose functionality sooner or later. In a scientific observation satellite executing progressive and innovative missions, various materials are used for unique devices and applications. In the unique devices and applications, the non-conventional properties would be required for these materials. These would not be the flight-proven materials, because the flight data on non-conventional properties in space environment would not be enough. Therefore, to provide assurance of safety reliability on satellite project, we must confirm the durability of materials after harsh space environments exposure by using ground simulation tests.

On ground simulation test, we should perform the all of environmental exposure tests and material properties measurements in a vacuum — that is, in-situ test is recommended. Since we should simulate harsh space environments including vacuum, it is proper course to take in-situ tests. To achieve in-situ test on ground, we must finish the material property measurements without air exposure after environmental exposure tests. Although the environmental exposure tests would be conducted in a vacuum, transportation of exposed samples from exposure test facility to measurement equipment of material property and material property measurements are usually conducted in air atmosphere. To support a satellite project planning progressive and innovative missions, we should ideally make clear the degradation mechanisms in space environments by using in-situ ground test facilities. Then we should improve and construct the test methodology based on academic knowledge of degradation mechanisms to simulate degradation equivalent to space on ground.

To conduct in-situ test on the all of environmental exposure tests and material properties measurements, many space agencies would concentrate the various beam sources (electron, proton, ultra-violet ray, and etc), equipment of material property measurements (mechanical, optical, electrical, and etc.), and analysis equipment in one place and would construct a 'massive' in-situ ground test facility by connecting these sources and equipment with vacuum conveyor line each other. However, the enormous budget must be spent to construct a 'massive' in-situ facility and it is not easy construct the facility except for space agency in each country. In addition to this, it might be difficult to conduct plural ground tests, simultaneously. Because the 'massive' in-situ facility is one system in which many apparatuses are dependently combined, it might be difficult to use each apparatus, independently and simultaneously. The massive in-situ facility is rare and is useful for the ground simulation test required for satellite project. Since the machine time would be spent to the ground simulation test for satellite project, it might be difficult to conduct the academic research on degradation mechanism. The massive in-situ facility would be a complex-controlled system. Since it is not easy to add and extend the function of massive in-situ facility, it might be difficult to satisfy increasingly diverse and complex evaluation requirements on materials degradation. From the reasons described above, the ground-simulation-test facilities evaluating the degradation of materials are not enough to support satellite projects in Japan.

We have started to organize the network named 'Cultivation of Research and project-support network for Degradation of space-use materials (CRED)'. In CRED network, we have suggested the concept of cluster type in-situ test facilities system achieved by connecting various facilities and equipment existing dispersedly in Japan with a portable vacuum transfer vessel and glove box filled with an inert gas. The cluster type in-situ test facilities system would be constructed in low budget and would have extendibility compared with the massive in-situ test facility.

2. CONCEPT OF CLUSTER TYPE IN-SITU TEST FACILITIES SYSTEM

On ground simulation tests, in-situ condition is recommended during the all of test processes. If the test sample irradiated to charged particle radiation is exposed to air atmosphere, we may observe the variation on degradation of sample with increasing of air exposure time. For example, radiation-induced coloration of polymer materials fade with increasing of air exposure time.

On cluster type in-situ test facilities system in CRED network, we mainly utilize the facilities dispersedly existing in Japan. In the configuration, since each facility is far apart, it would be impossible to keep the in-situ condition to prevent the aging or recovering in air. In CRED network, we have, however, achieved in-situ condition during transporting test sample between test facility by using a portable vacuum transfer vessel (VTV) unit. In VTV, test sample is stored under low pressure (high vacuum) condition. The concept for achieving in-situ condition in CRED network is as follows.

The test samples are usually irradiated in vacuum or inert gas condition with a beam source (electron, proton, ultraviolet-ray, atomic oxygen, and etc.) to simulate a space radiation environment. Therefore, the condition during irradiation would be not matter. The matter is to transport a test sample. To achieve the in-situ test, we must transfer a test sample between irradiation test facility and VTV before and after irradiation without air exposure. In CRED network, we plan to attach a specified connection port on each irradiation test facility. The VTV is connected on the specified connection port. The in-situ condition before and after irradiation would be kept by using VTV.

The VTV with irradiated test sample is transported to apparatus to measure material properties. Next matter is how to secure in-situ condition during material property measurements. In many case, it would be difficult to measure material properties in a vacuum, because measurement apparatus for material properties is not usually specified for a vacuum. If we strongly adhere to measure material properties in a vacuum, we must place many kinds of measurement apparatuses having the specification for vacuum usage. Since a large budget must be spent, we cannot take care the many kinds of material properties required for a satellite project within the usual framework of budget. In the CRED network, the material property equivalent to that in a vacuum would be evaluated by using measurement apparatus mounted inside an inert atmosphere grove box. The test sample would be transferred without air exposure between measurement apparatus mounted in inert atmosphere and VTV through the pass box attached on a grove box.

Above mentioned, irradiation test facilities and measurement apparatuses dispersedly existing in Japan would be connected each other by using vacuum transfer system (VTV and TP) and inert atmosphere grove box. We would achieve the cluster type in-situ test facilities system in CRED network. The detail of these facilities is as follows.

3. TEST FACILITY

3.1 Vacuum transfer system

To achieve cluster type in-situ test facilities system, we must prepare the vacuum transfer vessel (VTV). The exposed test sample is stored in VTV under low pressure (high vacuum) condition and is transferred between the apparatus for material property measurement and exposure test facility that are far apart each other. As a material analysis tool, there is a growing need for in-situ analysis of anaerobic materials. In fact, the optional tool to transfer an anaerobic sample stored in a hermetically sealed container have been prepared for a electron spectroscopy for chemical analysis (ESCA) analysis facility, for example. In CRED network, the facilities are far apart more than 1,000 km each other. Since we would domestically transport the VTV, the pressure inside VTV should be kept for a few days taken to transport the VTV. The VTV should be man-portable weight and size, and it should be acceptable that VTV is transported between facilities by package-delivery company. We have constructed the VTV that meets the above-mentioned requirements.

Figure 1 shows VTV for one test specimen. The VTV is composed of a vacuum container with gate valve, a portable vacuum pump, and linear motion manipulator to transfer a test sample between VTV and a facility. The VTV is connected with the specified connection port on facility, and then the test sample is transferred into facility. The performance of VTV and in-situ measurement results by using VTV are shown in reference [1].

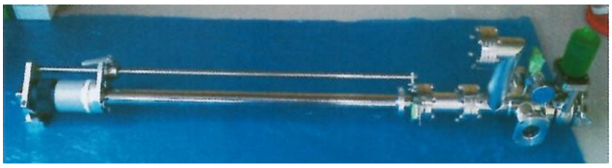
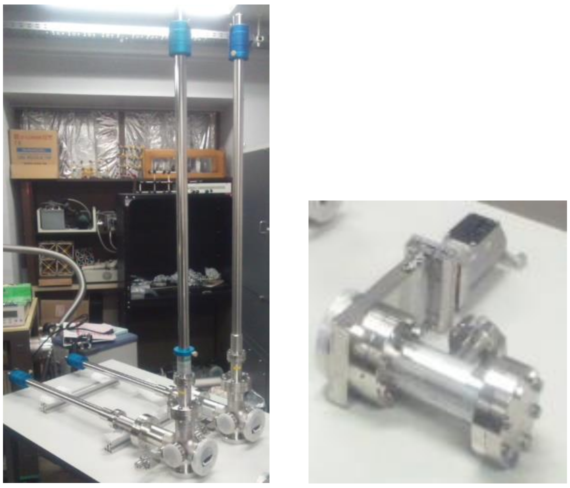


Fig. 1. Vacuum transfer vessel (VTV).



(a) transfer port (b) vacuum transfer case

Fig. 2. Vacuum transfer for plural samples.

If there is a need to transport plural test samples simultaneously, a vacuum transfer case (VTC) as shown in Fig. 2 is used. The VTC and transfer port (TP) to transfer the exposed test sample in VTC are shown in Fig. 2 (a) and 2 (b), respectively. The mechanism of VTC would become complex compared with VTV. Since it may be difficult to transport VTC with TP with the objective of man-portable weight and size, the only VTC as shown in Fig. 2 (a) is transported and the TP as shown in Fig. 2 (b) is left on the facility. The VTC is designed to store 4 piece of test samples, but the more piece of test samples is accepted with design change.

To transfer the exposed test sample under in-situ condition, we must attach the specified connection port and TP for connecting VTV and VTC, respectively. These improvement is, however, cheaper than the specified newly purchased facility.

3.2 Irradiation test facility

To evaluate the material degradation in space, we must expose test samples to following various space environment factors.

- electron, proton, and heavy ion
- X rays and gamma rays
- ultra-violet ray (near, middle, vacuum, and etc.)
- atomic oxygen
- thermal cycling etc.

The independent or combined environment exposure would be conducted on a ground simulation test. In this section, the concept and performance of irradiation facilities in CRED network are described as follows.

(1) Charged particle radiation

To simulate the material degradation due to charged particle radiation in space environment, the depth-dose profile in space should be reproduced on ground [2]. To reproduce the depth-dose profile, it is necessary to perform the proton and electron irradiation on ground. Since a test sample should be irradiated with the proton having the energy from several tens to several hundreds of keV, we must use the accelerator for proton irradiation. But it would be difficult to place a 'huge' accelerator due to the limitation of budget, human resource, installation site, management, and etc. Therefore, we utilized proton accelerator in an external institution. The TP was attached on proton accelerator facility, and then we had transported a exposed test sample by using VTV and had evaluated the degradation due to proton irradiation with in-situ condition [1].

On the other hand, to establish the ground simulation methodology, we must promote academic research on radiation degradation. To promote academic research, we should prepare the network's own radiation beam source and should spend much time to investigate the radiation degradation mechanisms. Therefore, a low-energy electron irradiation test facility, that was relatively easy to maintain in comparison with the proton accelerator, was placed in Kyushu Institute of

Technology. The low-energy electron irradiation test facility (EB-ENGINE, Hamamatsu Photonics K. K.) is shown in Fig. 3. The electron irradiation facility is composed of an electron beam source with vacuum pump, an irradiation container, a mounting plate of test sample, and XY motorized stages. The electron beam source is attached on the top plate of irradiation container. The mounting plate attached on XY motorized stages are mounted inside of irradiation container. The electron beam source with acceleration voltages from 40 to 110 kV and with irradiation current of 200 μA at maximum emit the spot-shape beam without scanning. The mounting plate with test samples move back and forth with shift of some intervals under the spot-shape electron beam due to control the XY motorized stages. In this manner, the electrons are uniformly irradiated on the large area of test sample. The irradiation container, in which oxygen concentration is kept around 10 ppm, is purged with nitrogen gas at the flow rate of 30 L/min during electron irradiation. If we attach a vacuum pump to the irradiation container, the container can be kept in a vacuum. The dose rate on the electron irradiation facility depends on acceleration voltage, irradiation current, distance from irradiation window to sample, and traverse speed of sample. The depth-dose profile and in-plane distribution of absorbed dose were measured by using a film dosimeter (FWT-60, Far West Technology). The dose rate with one scan process is 445 kGy/scan at the distance from irradiation window to sample of 15 mm and at the scan interval of 4 mm under the conditions shown in Table 1. The irradiation area with 10% dose uniformity is the length of 100 mm and the width of 80 mm. There was no significant temperature increase, although the samples were mounted on the plate without temperature control. As a result of depth-dose profile, electron beam affected materials within about 100 μm in depth in terms of a film dosimeter. Therefore, the low-energy electron irradiation test facility in CRED network would be effective for the research of material degradation on thin material or material surface.

(2) Ultra-violet rays

In the CRED network, there are two kinds of ultra-violet ray (UV) irradiation test facilities to simulate solar UV radiation. One is a UV irradiation test facility equipped with Xenon lamp source, another is that with Deuterium lamp source.

The UV irradiation test facility with Xenon lamp is composed of Xenon lamp, vacuum chamber, vacuum pump, temperature-controlled plate for mounting test sample, and UV irradiance meter. The vacuum chamber has a cylindrical shape of 400 mm in diameter and 385 mm in length, which is evacuated by a turbo molecular pump to achieve a pressure of less than 1×10^{-3} Pa. The UV source is a 1-kW Xenon Lamp with dichroic mirror, and its intensity is 1.5 times solar constant in the wavelength region of 200-400 nm. The uniformity of UV source is within 2% on an area of 10 cm in diameter.

The UV irradiation test facility with Deuterium lamp is composed of Deuterium lamp, vacuum chamber, vacuum pump, plate for mounting test sample, and UV irradiance meter. The vacuum chamber has a cylindrical shape of 310 mm in diameter and 375 mm in height, which is evacuated by a turbo molecular pump to achieve a pressure of less than 1×10^{-4} Pa. The UV source is a 35-W deuterium Lamp with dichroic mirror, and its intensity is 7 times solar constant in the wavelength region of 120-200 nm. The uniformity of UV source is within 15% on an area of 6 cm in diameter.

Fig. 3. Low-energy electron irradiation test facility.

Tabel 1. Irradiation condition

Acceleration voltage	110 kV
Irradiation current	50 μA
Scan speed	20 mm/sec

(3) Atomic oxygen

The CRED network is co-organized with Prof. Tagawa in Kobe University. The atomic oxygen (AO) test facility in Kobe is used to simulate low Earth orbit (LEO) environment. The detail of AO facility is described in reference [3] and [4].

3.3 Material properties and analysis

The progressive and innovative satellite projects may require the in-situ measurements of various material properties before and after environmental exposure. However, the measurement apparatuses are not designed for use in vacuum except for specified apparatuses.

In the CRED network, an inert atmosphere grove box (UL-1300A, Unico) as shown in Fig. 4 was placed in Kyushu Institute of Technology, and permitted in-situ measurement in an inert atmosphere equivalent to in a vacuum. We would achieve the in-situ measurement by placing the measurement apparatus in a glove box and transferring a exposed test sample through the pass box with the specified connection port to connect VTV.

The oxygen and moisture would cause a difference between a material property in air atmosphere and that in a vacuum. For example, the oxygen would induce the color fading of irradiated test sample [5)], and the moisture would induce the variation on electrical resistivity [6)] and mass [7, 8)]. The oxygen and moisture level in the grove box are kept at a concentration of less than 1 ppm and at a dew point of about −76°C, respectively. The dimension of grove box is 1300 mm in width, 1000 mm in hight, and 570 mm in depth. We could place the small universal mechanical test apparatus inside of the grove box. In the grove box, the oxygen concentration of 1 ppm and the dew point of moisture at −76°C are achieved due to the purging of nitrogen gas for 2 weeks.

Fig. 4. Inert atmosphere grove box.

4. SUMMARY

The cluster type in-situ test facilities system that dispersedly existing facilities are connected each other by using a portable vacuum transfer vessel is non-conventional system. The advantage of the cluster type in-situ test facilities system are that it is able to construct in-situ test facilities in low budget, to utilize each facility constituting the cluster type in-situ test facilities system simultaneously, and to flexibly incorporate various facilities into the cluster type in-situ test facilities system. By using this concept, many institutes or companies would easily invested into in-situ ground simulation test facility system. For massive in-situ facility in space agency, it would be also easy to add and extend the function of facility.

By taking the advantage in CRED network, we promote academic research by using in-situ test facility and the evaluation of material degradation required in a progressive and innovative satellite project, simultaneously.

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