The Komplast Experiment: Space Environmental Effects after 12 Years in LEO (and Counting)

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ABSTRACT

The Komplast materials experiment was designed by the Khrunichev Space Center, together with other Russian scientific institutes, and has been carried out by Mission Control Moscow since 1998. The purpose is to study the effect of the low earth orbit (LEO) environment on exposed samples of various spacecraft materials. The Komplast experiment began with the launch of the first International Space Station (ISS) module on November 20, 1998. Two of eight experiment panels were retrieved during Russian extravehicular activity in February 2011 after 12 years of LEO exposure, and were subsequently returned to Earth by Space Shuttle "Discovery" on the STS-133/ULF-5 mission. The retrieved panels contained an experiment to detect micrometeoroid and orbital debris (MMOD) impacts, a temperature sensor, several pieces of electrical cable, both carbon composite and adhesive-bonded samples, fluoroplastic samples, and many samples made from elastomeric materials. Our investigation is complete and a summary of the results obtained from this uniquely long-duration exposure experiment will be presented.

1. INTRODUCTION

The Komplast experiment has been conducted on the ISS by Khrunichev Space Center in collaboration with other Russian scientific centers since 1998. In this experiment, space environmental effects (SEE) on exposed specimens of various materials were studied in low earth orbit (LEO) as part of the International Space Station (ISS) program.

To execute this experiment, Komplast panels outfitted with specimens of materials and sensors were located on the outer surface of the Functional Cargo Block (or FGB; the first ISS flight element). The panels were delivered on orbit together with the FGB on 20 November 1998. In March 2011, two of the eight Komplast panels were returned from the ISS on the Space Shuttle Discovery after 12 years of LEO exposure.

Figure 1 shows the FGB with Komplast panels Nos. 2 and 10 mounted (marked with arrows) immediately after launch in 1998. Note that Panel No. 10 (left) had a cover installed prior to launch and during early flight. This cover was removed during the ISS-2A mission, extravehicular activity (EVA) 3 on 12 December 1998. The approximately three week period during which Panel No. 10 was covered had an insignificant impact on the SEE analysis.

Figure 2 shows closer views of Komplast panels Nos. 2 and 10 on the surface of the FGB in flight.

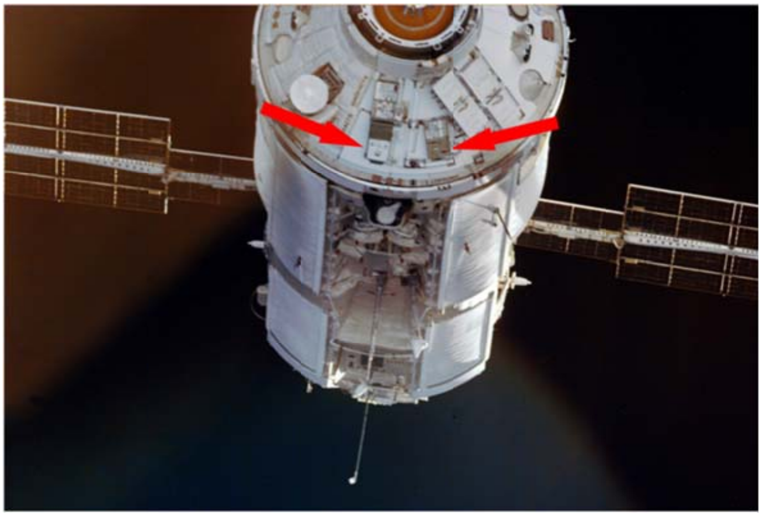

Figure 1. FGB with mounted Komplast panels Nos. 2 and 10, 1998.

a

b

Figure 2. Komplast panels Nos. 2 (a) and 10 (b) on the surface of the FGB.

SEE experiments similar to the Komplast experiment, in which specimens of space system materials are exposed for a given period of time in space on the surfaces of orbital stations, have been conducted on many occasions [1]. These experiments make it possible to obtain information on changes in material properties under the overall impact of the sum total of spaceflight factors in a given orbit. The uniqueness of the Komplast experiment lies in its long duration of in-situ exposure of material specimens (12 years) on the surface of the FGB, significantly exceeding the exposure time of specimens in previous similar experiments.

The goal of this work was to determine the effects of spaceflight factors on the properties of FGB materials following LEO exposure for 12 years, based on analyzing the results of the in-situ experiment and subsequent laboratory investigations, and to contribute to ISS service life extension assessment activities.

2. SPACE ENVIRONMENT FACTORS

2.1 The "Natural" Environment

Temperature dynamics during exposure to space were determined from sensors located on both panels. On Panel 2, the maximum temperature recorded was +85°C; the minimum, minus 80°C. On Panel 10, the maximum temperature recorded was +107°C; the minimum, minus 80°C. The most extreme temperatures recorded on panels by year of operations are presented in Table . The maximum values by year are on top; the minimum values, on the bottom.

Table 1 Temperature Extremes, in °C, on Komplast panels 2 and 10 From January 1999 to December 2010

Panel	1999	2000	01	02	03	04	05	06	07	08	09	2010
2	83 -50	85 -45	80 -35	85 -40	65 -45	85 -40	80 -45	75 -40	85 -40	80 -65	60 -80	55 -40
10	103 -80	102 -60	107 -55	105 -70	95 -75	105 -65	101 -75	95 -70	106 -65	102 -75	80 -80	84 -61

The average temperature of panels Nos. 2 and 10 over the entire period of exposure was 20±10°C.

Total exposure to solar ultraviolet radiation was determined by analysis of the temperature dynamics. The total exposure on the FGB at the locations of Panels 2 and 10 for 12 years was 960±200 kJ/cm^2 or 21,100±4,400 ESH (equivalent sun hours). Ionizing radiation dose was not determined.

Atomic oxygen (AO) fluence was determined. An analysis of the condition of several specimens which have been utilized on previous SEE experiments enabled the atomic oxygen fluence to be evaluated, estimated at approximately 1.5×10^{21} atoms/cm^2. This fluence was evaluated for the entire 12-year period of panel exposure on the FGB and accounts for both the initial (differently oriented) period of flight and the modern flight period, during which the FGB end cone (on which removed Komplast Panels 2 and 10 were mounted) was not directly exposed to the ram atomic oxygen.

The micrometeoroid and orbital debris (MMOD) environment was also evaluated, using a test device specifically for this purpose on Panel 2. The distribution of craters and low-velocity particles so obtained in the range of 5-50 µm per m^2 of surface area was ~2-3 orders of magnitude high as compared to NASA model expectations.

2.2 The Contamination Environment

Visible traces of contamination on the surfaces of panels and material specimens were studied (Figure).

By using X-ray microanalysis, the chemical composition of contamination was determined. It was found that the contamination occurred in the form of deposition of the substances emitted from some the test specimens placed on the panels, primarily from rubber (elastomeric) specimens.

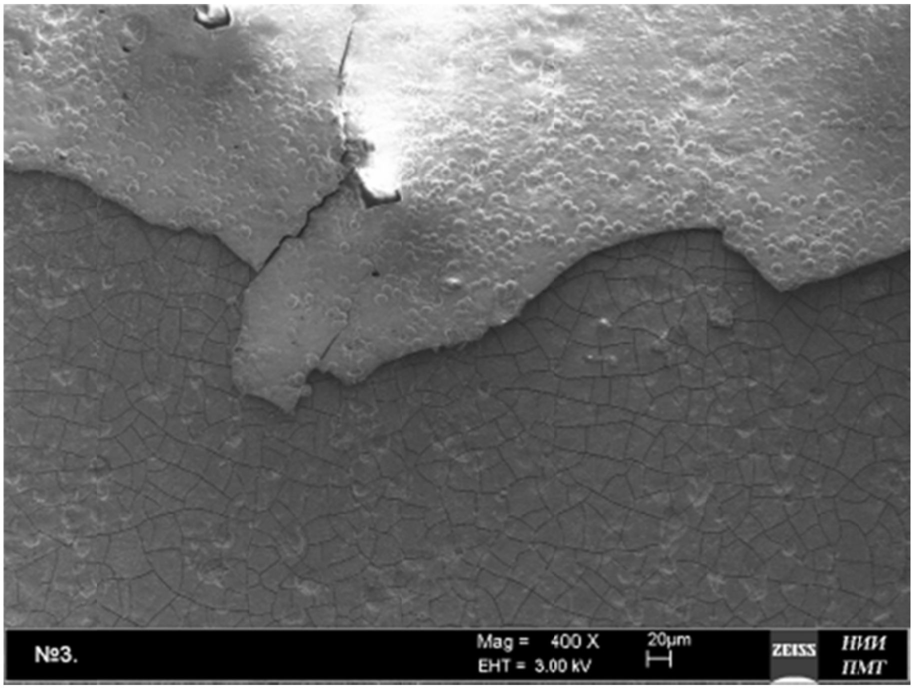

Figure 3. Contamination film (top) on the Komplast panel surface.

3. RESULTS

A highly detailed report on the methods used, results obtained, and analysis conducted has been prepared and document through the ISS program. What follows here is a summary of the very extensive work conducted to evaluate the Komplast test specimens from Panels 2 and 10.

3.1 Rubber (Elastomeric) Specimens

Rubber specimens exposed to LEO environmental factors for 12 years on Komplast Panel 2 were studied. Six types of rubber materials underwent exposure.

The deformation, strength, and relaxation properties of rubber specimens were studied, and the sealing capability of rubber seal replicas was assessed. After exposure in space, some of the rubber specimens underwent additional (post-flight exposure) radiation with a stream of atomic oxygen at a dose equivalent to a total duration of 30 years in a low-Earth orbit similar to the orbit of the ISS.

During investigations, it was determined that:

- After long-term exposure, exposed specimens retain their volume deformation and relaxation properties.
- When exposed rubber specimens are stretched by up to 50%, structural failure and partial separation occurs in the surface layer (films forming on specimens under SEE) without volume failure for all exposed rubber types.
- When studying sealing capability, a change was noted in the sealing mechanism of the forward-facing surface of seals: a transition occurs from diffuse-type leakage mode to contact one. In other words, the sealing capability of seals deteriorates after long-duration space exposure. In these same studies, the retention of the sealing capability of shielded surfaces, protected from direct contact with the ambient environment, was observed.

The principal significant conclusion of the Komplast experiment regarding rubber material specimens is the localization of structural changes in the thin surface layer of exposed materials on surfaces with a direct view of space. The localization of aging on a surface leads to the development of a lack of uniformity in exposed materials, the formation of surface films, their deformation, and failure.

The formation of rigid surface films explains the deceleration of processes in the volume of exposed materials; i.e. it causes rubber stabilization. Simultaneously, because of the rigid surface films, the sealing capability of openly exposed rubber deteriorates.

Another important conclusion from the experiment is the identification of the protective effect of different types of shielding (such as with specimen fasteners – see Figure).

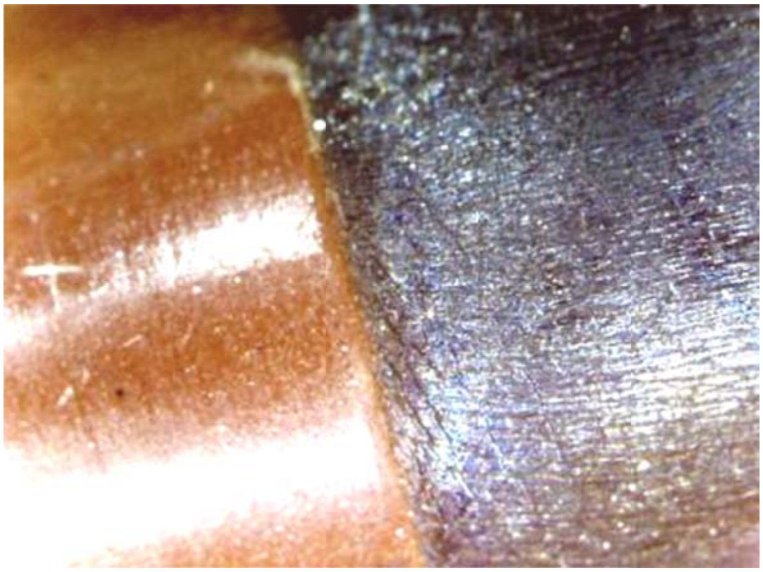

Figure 4. Border between a rubber specimen surface shielded by a fastener (left) and an openly exposed surface (right).

Based on the kinetics of exposed specimen residual strain accumulation, the remaining time that rubber materials retain functionality was determined, confirming the feasibility of establishing an overall guaranteed operating life of rubber seals (when shielded on the FGB) of at least 30 years.

3.2 Adhesive Specimens

Specimens of adhesive bonded joints were in the form of fiberglass and aluminum alloy plates bonded with epoxy adhesives. Sixteen specimens using three types of adhesives and the two types of plates in various combinations were attached to Komplast Panel 10. Adhesive specimens were placed perpendicular to the bottom of the panel so that one edge surface faced space and was exposed to all spaceflight factors: solar ultraviolet radiation, atomic oxygen, radiation, temperature differences, and micrometeoroid flows. Some specimens after exposure in space underwent additional (post-exposure) irradiation with a beam of electrons at a dose equivalent to a total duration of 30 years in LEO similar to the orbit of the ISS.

The investigations conducted on adhesive specimens demonstrated that all three types of epoxy adhesives retain functionality in FGB structures for 30 years. This conclusion is based on the results of studying fracture resistance parameters, the surface and volume properties of the adhesive layers in the adhesive specimens after 12 years of exposure in space, and their additional irradiation with electrons at a dose equivalent to 30 years of exposure in space. In this context, the failure of all the adhesives studied was "adhesional" (Figure); i.e., at the interface with the substrate material, while the polymer base of all the adhesive layers (hardened epoxy polymer) was resistant to the effect of spaceflight factors, and in adhesive bonded joints on the FGB this polymer base is protected against direct spaceflight factors by the bonded elements.

Figure 5. Example of "adhesional" failure of an exposed adhesive bonded joint specimen during laboratory testing.

3.3 Cable and Cable Network Material Specimens

Specimens of cables and onboard cable network materials were exposed on Komplast Panel 2. Twelve cable and material specimens were exposed. Figure shows a photograph of these specimens after their removal from the Komplast panel. The studies included an inspection of specimens, measurement of mass loss, and an assessment of the results of wire bending.

As had been expected, the materials exhibiting the greatest stability to long-term (12 years) exposure to spaceflight factors were wire insulation made of fluoroplastic 4 and 4D (polytetrafluorethylene of various molecular weight) and wire sheaths made of fiberglass. These materials have been widely used in rocket and space hardware for over a half century and maintain their leading position to this day. These specimens exhibited the least loss of mass and experienced the least significant damage as a result of exposure and during wire bending tests.

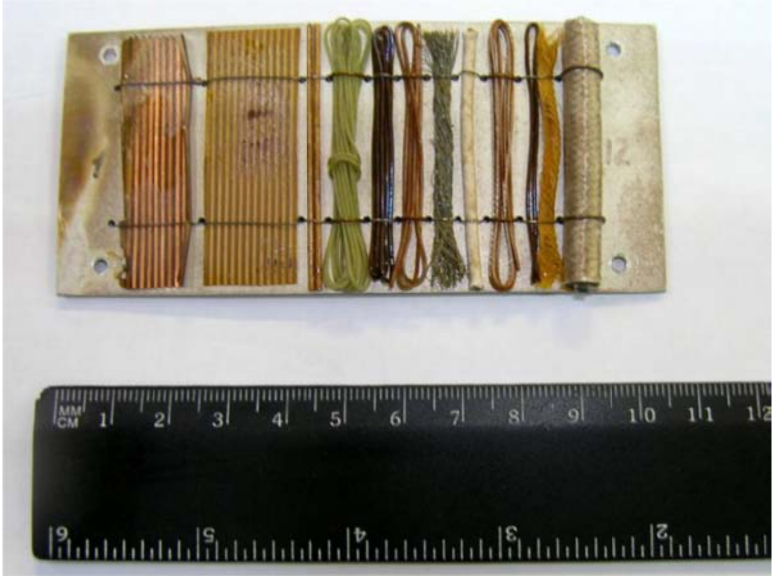

Figure 6. Cable article specimens after removal from the Komplast panel.

The qualitative and quantitative characteristics obtained during the study of the response of cable and onboard cable network material specimens to spaceflight factors over 12 years of exposure allow the exposed cables and materials to be considered stable to such exposure.

3.4 Carbon Composite Specimens

These specimens were exposed on Komplast Panel 10 on the exterior surface of the FGB (Figure 2b) and consisted of thin-layer plates of grade КМУ-4лс carbon composite epoxy, as well as plates of КМУ-4лс carbon composite and Амг6 aluminum bonded using [ВК-9] epoxy adhesive.

Based on the study conducted of bonded specimens (КМУ-4лс carbon composite/[ВК-9] adhesive/Амг6 aluminum) and of thin-layer carbon composite specimens after 12 years of exposure, experimental data were obtained regarding the stability of the carbon composite macro- and microstructure, as well as changes in strength in response to pulling and bending.

It was determined that the macro- and microstructure of thin-layer КМУ-4лс composite material and its bonded joints differed little between exposed and control (laboratory) specimens.

The pulling strength of exposed КМУ-4лс carbon composite and Амг6 aluminum bonded joints (using [ВК-9] adhesive) does not change, for all intents and purposes, and the pulling strength of the original bonded joint is retained.

Strength measurements in response to three-point bending permit the conclusion that no critical changes that might result in a change in strength properties occurred in the studied materials over 12 years of exposure.

A study was also done of the mass lost by carbon composite specimens after 12 years of exposure. The losses identified in shielded and unshielded carbon composite specimens in this experiment coincided with the theoretical models employed. It was demonstrated that over 30 years of exposure, the mass loss in КМУ-4лс carbon composite does not exceed 2%, which proves the stability of this material's properties as part of bonded joints over the stated period.

In connection with КМУ-4лс carbon composite, it was determined that shielding of its surface completely prevents microstructure changes. After 12 years of exposure, specimens exhibited no significant microstructure changes.

The assessments of the impact of spaceflight factors on structure, on the composition and properties of КМУ-4лс carbon composite, and on КМУ-4лс-based joints bonded using [ВК-9] adhesive allowed the prediction that the stability of these indicators will be retained over a 30-year period of exposure aboard the FGB.

4. CONCLUSIONS

In practical terms, the in-situ Komplast experiment enabled an understanding of the processes occurring in materials under SEE, and made it possible to confirm the feasibility of establishing an overall expected operating life of FGB materials of at least 30 years.

5. REFERENCES

1. Model of Space, (Модель Космоса – In Russian only),Volume II, Editors – Novikov, L.S., Mileev, V.N., Soloviev, G.G., and Chernik, V.N., Section 4, University Press - Moscow (2007).