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MISSE Thermal Control Materials with Comparison to Previous Flight Experiments

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Abstract

Many different passive thermal control materials were flown as part of the Materials on International Space Station Experiment, including inorganic coatings, anodized aluminum, and multi-layer insulation materials. These and other material samples were exposed to the low Earth orbital environment of atomic oxygen, ultraviolet radiation, thermal cycling, and hard vacuum, though atomic oxygen exposure was limited for some samples. Materials flown on MISSE-1 and MISSE-2 were exposed to the space environment for nearly four years. Materials flown on MISSE-3, MISSE-4, and MISSE-5 were exposed to the space environment for one year.

Solar absorptance, infrared emittance, and mass measurements indicate the durability of these materials to withstand the space environment. Effects of short duration versus long duration exposure on ISS are explored, as well as comparable data from previous flight experiments, such as the Passive Optical Sample Assembly (POSA), Optical Properties Monitor (OPM), and Long Duration Exposure Facility (LDEF).

Introduction

Passive thermal control of spacecraft relies entirely on the ability of the spacecraft materials to absorb and radiate heat. The most common thermal control materials have a ratio of solar absorptance to thermal emittance (α/ϵ) of 1 or lower. Solar radiation combined with molecular contamination may raise the solar absorptance of a coating, also raising the temperature of the spacecraft. Atomic oxygen (AO) may counter these effects, especially where coatings with organic binders are concerned. However, atomic oxygen also attacks organic binders, leaving pigment particles behind.

The Materials on International Space Station Experiments (MISSE) are a series of "suitcases", externally attached to the International Space Station, that have exposed over 2,000 material samples to the space environment.

Dozens of different thermal control coatings were flown. This paper focuses on three types of thermal control coatings:

- Zinc oxide in potassium silicate binder, known as Z-93 (Alion Science and Technology, formerly IITRI) or AZ-93 (AZ Technology)[*]
- White polyurethane coatings made by Deft, used on the Solid Rocket Boosters, planned for use on Ares First Stage
- White polyurethane coating A-276 (Lord Chemical), modified with leafing aluminum

Environment

MISSE-1 and MISSE-2 were attached to the Quest airlock for 4 years (fig. 1). MISSE-3 and MISSE-4 were attached at the same locations but for only 1 year. All four suitcases were oriented so that one side nominally faced the velocity vector, or ram direction. One side was intended to be in the wake direction and be shielded from AO. However, ISS went through many changes in orientation, so that both sides received AO, though the ram-facing side received an order of magnitude or more of AO than the wake-facing side. At times, ISS's structure shielded part of the experiment, so that samples closer to the airlock received about 25% less AO and ultraviolet radiation (UV) than the samples farthest from the airlock.

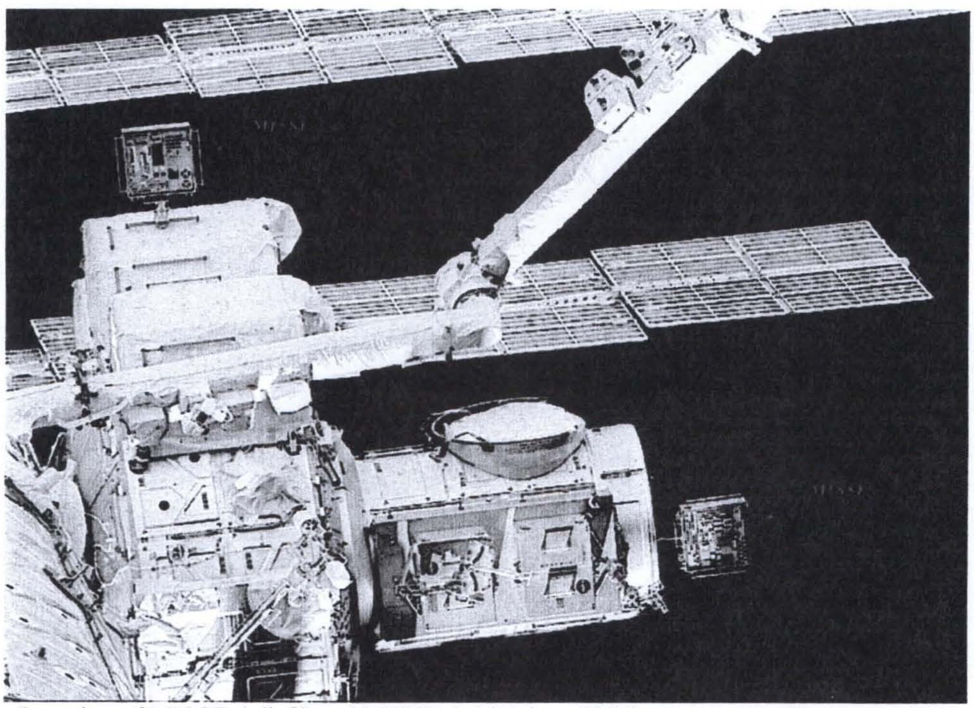

Figure 1. Location of MISSE-1 (left) and MISSE-2 (right) on ISS from August 2001 to July 2005 MISSE-3 and MISSE-4 were placed in the same locations from August 2006 to August 2007.

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[*] NASA gives no recommendation, endorsement, or preference, either expressed or implied, concerning vendors of the materials discussed in this paper.

The AO fluences to the experiments were determined by modeling and confirmed, if possible, by measurements of thin film mass loss and thickness loss. UV exposure in equivalent sun hours (ESH) was also determined by modeling. Radiation dose to MISSE-1 and MISSE-2 was measured by thermoluminescent detectors to be about 1 x 10^5 rads. Any material effects due to radiation would have been swamped by the AO and UV effects.

MISSE-1 and MISSE-2 went through approximately 22,800 thermal cycles mostly between +40 and -30 degrees Celsius, with some cycles with more extreme temperatures. MISSE-3 and MISSE-4 underwent approximately 5,700 similar thermal cycles.

MISSE-5 (fig. 2) was attached to the P6 Truss segment from August 2005 to September 2006. One side consisted of a solar cell experiment. The other side was a thermal blanket with over 200 material samples attached. Rather than being oriented in a ram/wake configuration, MISSE-5 was oriented by zenith and nadir, with the materials specimens on the nadir face.

Figure 2. Nadir face of MISSE-5 on ISS

Post-Flight Analysis

After disassembly, the samples were photographed, weighed, and their optical properties measured.

A. Zinc Oxide/Potassium Silicate

This inorganic white coating was selected for use on the ISS radiators based on its performance on LDEF. Z-93 with the original PS7 potassium silicate binder was flown on both the S0069 Thermal Control Surfaces Experiment and the A0034 Atomic Oxygen Stimulated Outgassing Experiment, as well as other experiments on LDEF. The Atomic Oxygen Stimulated Outgassing Experiment consisted of two passively exposed trays, one on the ram face, rotated eight degrees from the velocity vector, and one tray on the trailing edge. Some paint samples were completely exposed to space, while some samples were covered with either an ultraviolet-grade transmitting quartz window or an aluminum cover to block both AO and UV. All of these samples showed very little change in solar absorptance and no change in infrared emittance after 5.8 years in space. The S0069 sample had solar absorptances of 0.14 and 0.15 for pre-flight and post-flight, respectively. The A0034 samples had solar absorptance of 0.16 for the controls, and 0.16 and 0.17 for ram-facing and wake-facing samples, respectively.

Production of PS7 binder ceased in the early 1990's and was replaced with Kasil 2130. Alion Z-93 with the newer binder is referred to as Z-93P. Both Alion Z-93 and Z-93P were flown on POSA-I and MISSE. Z-93P was flown on OPM. AZ Technology flew AZ-93 with Kasil 2130 and 2135 binders on POSA-I, and with the Kasil 2130 binder only on MISSE. All three binders have shown good durability in the space environment.

When contamination is minimal (300Å or less), as in the case of LDEF, OPM, and the Mir-facing side of POSA-I, Z-93, Z-93P, and AZ93 maintain solar absorptance close to that of beginning-of-life. When heavier levels of contamination are present, these inorganic white coatings become yellowed or tan, with corresponding higher solar absorptance (fig. 3). For example, Z-93P on the space-facing side of POSA-I received approximately 5,000Å of silicone contamination but only 571 ESH of UV, and its solar absorptance increased from 0.16 to 0.23. Ground tests of pre-contaminated zinc oxide/potassium silicate indicated much higher solar absorptances with increased UV exposure.

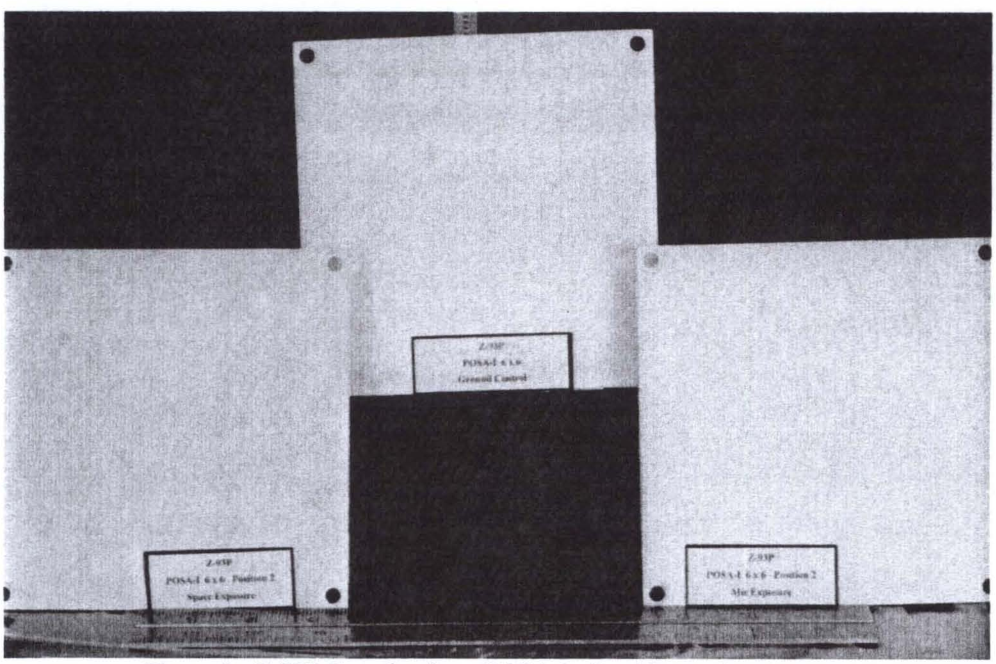

Figure 3. Z-93P Samples from POSA-I after 18 months exposure
Left, space-facing with ~5,000Å silicone contamination, center, control sample, right, Mir-facing with ~250 Å silicone contamination.

All of the Alion coatings on MISSE were on aluminum substrates. AZ Technology flew their MISSE coatings on aluminum, composite, beta cloth, and Kapton® substrates. In Table 2, the substrate is aluminum unless otherwise noted.

MISSE-5 had over 200 materials samples attached to the nadir side as part of the insulation blanket. Because of the configuration, samples had to be thin and flexible. AZ93 was sprayed on beta cloth and Kapton® substrates in a nominally 2-mil thick layer, much thinner than would normally be applied to aluminum (5 mils). The result is a higher beginning-of-life solar absorptance for these samples.

Table 1. Alion Zinc Oxide/Potassium Silicate Coatings

Material	Experiment	AO (atoms/cm^2)	UV (ESH)	Solar Absorptance	
				Pre-flight	Post-flight
Z-93	MISSE-2	1.4×10^{20}	5,130	0.14	0.14
Z-93	MISSE-2	7.2×10^{21}	5,660	0.14	0.14
Z-93	MISSE-3	1.2×10^{21}	~1,200	0.14	0.14
Z-93	MISSE-4	2.0×10^{20}	~1,200	0.14	0.15
Z-93P	MISSE-2	1.4×10^{20}	5,130	0.14	0.14
Z-93P	MISSE-2	7.2×10^{21}	5,660	0.14	0.13
Z-93P	MISSE-3	1.2×10^{21}	~1,200	0.14	0.14
Z-93P	MISSE-4	2.0×10^{20}	~1,200	0.14	0.14

Table 2. AZ Technology Zinc Oxide/Potassium Silicate Coatings

Material	Experiment	AO (atoms/cm^2)	UV (ESH)	Solar Absorptance	
				Pre-flight	Post-flight
AZ93	MISSE-2	7.2×10^{21}	5,209	0.14	0.15
AZ93	MISSE-2	7.2×10^{21}	5,209	0.15	0.15
AZ93	MISSE-2	7.2×10^{21}	5,209	0.15	0.15
AZ93	MISSE-3	1.6×10^{20}	~1,200	0.15	0.16
AZ93	MISSE-3	1.6×10^{20}	~1,200	0.15	0.16
AZ93	MISSE-4	1.8×10^{21}	~1,200	0.15	0.15
AZ93	MISSE-4	1.8×10^{21}	~1,200	0.15	0.15
AZ93 on composite	MISSE-1	9.5×10^{21}	5,857	0.15	0.16
AZ93 on composite	MISSE-1	9.5×10^{21}	5,857	0.15	0.16
AZ93 on composite	MISSE-4	1.8×10^{21}	~1,200	0.15	0.15
AZ93 on composite	MISSE-4	1.8×10^{21}	~1,200	0.15	0.16
AZ93 on beta cloth	MISSE-5	1.8×10^{20}	525	0.17	0.20
AZ93 on Kapton	MISSE-5	1.8×10^{20}	525	0.21	0.22

Figure 4 is of the AZ93 on beta cloth from MISSE-5. The beta cloth around the AZ93 has darkened, and enough UV may have been transmitted through the AZ93 to also darken the substrate beta cloth.

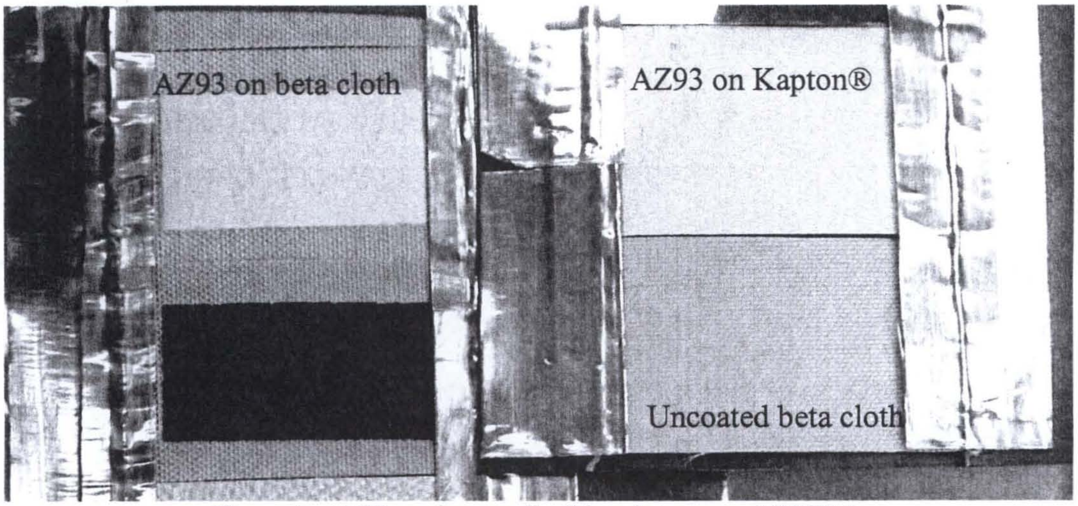

Figure 4. AZ93 coatings on flexible substrates on MISSE-5.
Beta cloth has darkened with exposure to UV, AZ93 is nominally white.

B. Deft Polyurethane

This glossy white coating has been used on the Solid Rocket Boosters (SRB) and is a candidate for the Ares First Stage. The baseline coating 03-W-127A, which meets MIL-PRF-85285, and two derivatives, the Deft Extended Life Topcoat (ELT) and Deft Zero Volatile Organic Compound (VOC) were flown on MISSE. On MISSE-1 and MISSE-2, the polyurethane binder was heavily eroded by four years of AO. Samples flown on MISSE-3 and MISSE-4 were diffuse in appearance due to AO attack but did not have the pigment particle release like the longer-exposed samples.

Solar absorptance measurements of spacecraft materials are normally only given for air mass zero per ASTM-E490. Solar absorptances adjusted for air mass 1.5, as given in ASTM G159, can be useful for the thermal modeling of launch conditions.

Table 3. Deft Polyurethane Coatings

Material	Exposure	AO (atoms/cm^2)	UV (ESH)	Solar Absorptance		Infrared Emittance
				AM 0	AM 1.5	
03-W-127A	Control	-	-	0.25	0.20	0.89
03-W-127A	MISSE-4	1.8×10^{21}	~1,200	0.23	0.17	0.91
03-W-127A	MISSE-4	1.8×10^{21}	~1,200	0.24	0.19	0.91
03-W-127A	MISSE-1	9.5×10^{21}	5,669	0.23	0.18	0.91
ELT	Control	-	-	0.26	0.21	0.88
ELT	MISSE-4	1.8×10^{21}	~1,200	0.24	0.19	0.91
ELT	MISSE-4	1.8×10^{21}	~1,200	0.25	0.19	0.91
ELT	MISSE-2	1.4×10^{20}	5,957	0.29	0.23	0.90
Zero VOC	MISSE-4	1.8×10^{21}	~1,200	0.30	0.25	0.91
Zero VOC	MISSE-4	1.8×10^{21}	~1,200	0.31	0.26	0.91
Zero VOC	MISSE-1	9.5×10^{21}	5,683	0.31	0.27	0.91

C. A-276 Polyurethane with Leafing Aluminum

A-276 was flown in numerous places on LDEF, with the majority of samples painted on the tray clamps, placed at regular intervals on the longerons and intercostals. Its erosion by AO and darkening by UV on LDEF is well-documented (ref. 5), as was the lack of significant contamination. Beginning-of-life solar absorptance properties for A-276 are 0.23 ± 0.03, as required by MSFC-PROC-547. Ram-facing A-276 maintained solar absorptance around 0.30, though a sample exposed on experiment S0069 had a slightly higher absorptance of 0.33. This sample was exposed only during the first 16 months of the LDEF mission, with less AO to erode away the UV-darkened binder. Wake-facing A-276 samples had much higher solar absorptance, measuring as high as 0.57.

Even with its reaction to the space environment, A-276 is a useful coating for short-term missions, such as the flight support equipment for the Space Station Remote Manipulator System. It is cheaper and less difficult to apply than inorganic coatings.

For MISSE, leafing aluminum was added to the A-276 coating for static dissipation. Here, 1% leafing aluminum refers to 1% by volume in the coating mix.

Table 4. A-276 with Leafing Aluminum

Material	Exposure	AO (atoms/cm^2)	UV (ESH)	Solar Absorptance	Infrared Emittance
1%	Control	-	-	0.35	0.84
1%	MISSE-4	1.8×10^{21}	~1,200	0.30	0.84
1%	MISSE-4	1.8×10^{21}	~1,200	0.29	0.86
1%	MISSE-1	9.5×10^{21}	5,700	0.30	0.87
5%	Control	-	-	0.40	0.79
5%	MISSE-4	1.8×10^{21}	~1,200	0.31	0.78
5%	MISSE-1	9.5×10^{21}	5,600	0.31	0.78
10%	Control	-	-	0.42	0.76
10%	MISSE-1	9.5×10^{21}	5,600	0.32	0.74
10%	MISSE-2	1.7×10^{20}	5,900	0.33	0.72
15%	Control	-	-	0.42	0.76
15%	MISSE-4	1.8×10^{21}	~1,200	0.30	0.69
15%	MISSE-2	1.7×10^{20}	5,900	0.38	0.71

Discussion and Conclusions

The consistency of optical properties for zinc oxide/potassium silicate thermal control coating indicates durability for years in low Earth orbit, provided that materials selection, venting design and other contamination control methods are followed to limit outgassing and other molecular deposition on the white coating. Data from MISSE agrees with previous flight experiments where contamination was 300A or less. Samples of AZ93 on aluminum and on Kapton® have been included on both the ram and wake sides of the MISSE-6 experiment. At time of publication, MISSE-6 was attached to the Columbus module on ISS.

White polyurethane coatings were attacked by AO, as expected; however, the Deft 03-W-127A and ELT materials maintained their solar absorptance. A control sample for the Deft Zero VOC was not available at time of publication. Recent solar absorptance (air mass zero) measurements of Deft coatings for SRB and the Ares first stage ranged from 0.24 for older paints to 0.33 for newer samples.

The amount of leafing aluminum in A-276 can be balanced between the need for static dissipation and thermal control. Solar absorptance varied between 0.35 and 0.42 for the 1% and 15% leafing aluminum by volume, respectively. The space environment appeared to have bleached the coatings. The average infrared emittance decreased for the leafing aluminum materials, except for the 1% samples, which had a slight increase.

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