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Comparison of Observed Beta Cloth Interactions With Simulated and Actual Space Environment

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September 1999

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LIST OF ACRONYMS

AOBF	Atomic Oxygen Beam Facility
AODTS	Atomic Oxygen Drift Tube System
CVCM	collected volatile condensable material
ESCA	electron spectroscopy for chemical analysis
ESH	equivalent Sun-hour
EVA	extravehicular activity
FEP	fluorinated ethylene propylene
ISS	*International Space Station*
LDEF	Long Duration Exposure Facility
LEO	low-Earth orbit
LPSR	laboratory portable spectroreflectometer
MLI	multilayer insulation
MSFC	Marshall Space Flight Center
NUV	near ultraviolet
OPM	optical properties monitor
PFA	perfluoralkoxy
POSA	Passive Optical Sample Assembly
PTFE	polytetrafluoroethylene
PVA	polyvinyl alcohol
UV	ultraviolet
VUV	vacuum ultraviolet

TECHNICAL MEMORANDUM

COMPARISON OF OBSERVED BETA CLOTH INTERACTIONS WITH SIMULATED AND ACTUAL SPACE ENVIRONMENT

1. INTRODUCTION

The Environmental Effects Group has several facilities for the study of space environmental effects on materials. The Atomic Oxygen Beam Facility (AOBF) and the Atomic Oxygen Drift Tube System (AODTS) have been used to determine the effect of AO on a number of materials. Solar simulation facilities are also available for ultraviolet (UV) radiation exposure of materials. Full details of the capabilities of the Environmental Effects Group (formerly known as the Physical Science and Environmental Effects Branch) may be found in reference 1. This report discusses individual exposures to AO and UV as well as synergistic exposure in the laboratory.

Actual exposure to the space environment is preferable but not always possible when studying candidate spacecraft materials. Comparison of flight results to ground simulations gives confidence to the simulation method and the durability of the material for longer exposures. Beta cloth has been flown on several flight experiments involving materials. Results from the Long Duration Exposure Facility (LDEF) and the Passive Optical Sample Assembly (POSA) experiments flown on *Mir* give confidence in beta cloth's durability when used as a multilayer insulation (MLI) blanket outer cover in the low-Earth orbit (LEO) environment. Unexpected darkening of the beta cloth in the Optical Properties Monitor (OPM) experiment during its stay on *Mir* demonstrates the need for product familiarity and quality assurance, particularly when manufacturing processes are changed without alerting the customer.

2. LABORATORY INVESTIGATIONS

Qualifying beta cloth for use on the *International Space Station* (*ISS*) required testing in AO and UV environments and ensuring the stability of the optical properties and mechanical integrity. Koontz, Jacobs, and Le[2] performed a number of tests on beta cloth in 1992, including exposure to UV radiation. The key factor in darkening due to UV exposure appeared to be the use of a polysiloxane, which was added for flexibility. Aluminized beta cloth with 2 percent, 0.22 percent, and no silicone was exposed to 800 equivalent Sun-hours (ESH's) of xenon lamp UV radiation with a cutoff at 180 nm. Solar absorptance values for this research are given in table 1.

Table 1. UV effects on solar absorptance of aluminized beta cloth.[2]

ESH	2% Silicone	0.22% Silicone	Silicone-Free
0	0.29	0.31	0.32
200	0.30	0.32	0.32
400	0.32	0.32	0.32
800	0.34	0.32	0.33

At that same time, Marshall Space Flight Center (MSFC) was comparing the performance of unaluminized and aluminized beta cloth in near UV (NUV) radiation (250 to 400 nm). These materials contained some polysiloxane, probably <1 percent. Optical properties were measured using an AZ Technology laboratory portable spectroreflectometer (LPSR) to measure solar absorptance and a Gier-Dunkle DB100 infrared reflectometer to measure infrared emittance. For unaluminized beta cloth, solar absorptance measurements were made with a blackbody backing the samples. One aluminized beta cloth was returned to the UV chamber for further exposure. See table 2 for unaluminized and aluminized comparison.

Table 2. NUV effects on beta cloth.

Beta Cloth Material Description	Total NUV Dose (ESH)	Solar Absorptance		
		Pretest	Posttest	$\Delta\alpha_S$
Unaluminized	393	0.348	0.380	0.032
Aluminized No. 2	286	0.307	0.359	0.052
	662	–	0.366	0.059
Aluminized No. 3	396	0.307	0.355	0.048

Laboratory investigations of beta cloth at MSFC[3] showed that beta cloth may noticeably darken when exposed to UV radiation alone, and the amount of darkening varies by UV source and beta cloth batch. Degradation is also dependent on lack of oxygen, as beta cloth samples did not darken when exposed to UV radiation in air but did darken when the same test was repeated in vacuum. Beta cloth darkened by exposure to UV was bleached by subsequent exposure to AO.

Based on available data at that time, we recommended ordering beta cloth without the silicone and performing lot testing for *ISS* beta cloth prior to MLI blanket assembly with a minimum of 500 ESH of UV radiation.

Investigations in support of *ISS* activities continued at MSFC. Aluminized beta cloth without any added silicone was then obtained from the vendor and exposed to UV radiation. The samples were prepared prior to UV exposure by vacuum baking for 72 hr at 80 to 90 °C. Although the samples were exposed in the same chamber for the same number of clock hours, the ESH dose varies because of variations in the UV lamp and its light-focusing optics.

It is noteworthy that the beginning solar absorptance of these samples is higher than the previous batch of aluminized beta cloth but is consistent with later batches of beta cloth. Koontz et al. note that the beta cloth was sandblasted on one side prior to aluminization. The manufacturer has changed the preparation technique prior to aluminization since those tests were performed. The current preparation process uses a film that is heat-bonded to the beta cloth, making it easier to apply the aluminization. The aluminized beta cloth samples in table 3 most likely has this heat-bonded film, but confirmation of this by the manufacturer could not be readily established.

Table 3. NUV effects on silicone-free beta cloth.

Beta Cloth Sample No.	Total NUV Dose (ESH)	Solar Absorptance		
		Pretest	Posttest	$\Delta\alpha_S$
1	437	0.377	0.424	0.047
2	336	0.374	0.405	0.031
3	370	0.372	0.402	0.030
4	437	0.383	0.431	0.048
5	437	0.375	0.411	0.036
6	403	0.374	0.407	0.033

3. FLIGHT RESULTS

The first flight experiment included in this study was the LDEF. One experiment, the Transverse Flat-Plate Heat Pipe Experiment,[4] used plain beta cloth as part of its MLI blankets. This experiment was 22° off the ram direction, receiving 8.43×10^{21} atoms/cm^2 of AO and 8,680 ESH of solar UV radiation. Though the beta cloth lost Teflon™ due to AO erosion, the fiberglass weave was tight enough to prevent any AO damage to underlying layers. No apparent darkening occurred, and optical properties remained stable.

Aluminized beta cloth was flown on three long-duration flight experiments, the POSA–I, POSA–II, and the OPM, which are phase I risk mitigation experiments for the *ISS* and were attached to the *Mir*/Shuttle docking module (fig. 1) of the *Mir Space Station* by extravehicular activity (EVA). *Mir* is in a 390-km orbit at 51.6° inclination. POSA–I consisted of a specially designed "suitcase" carrier with two identical sets of samples, oriented so that one set faced the *Mir* core and the other set faced space. POSA–II was identical to POSA–I in the suitcase design but carried a completely different set of samples and was oriented 45° off the ram direction.

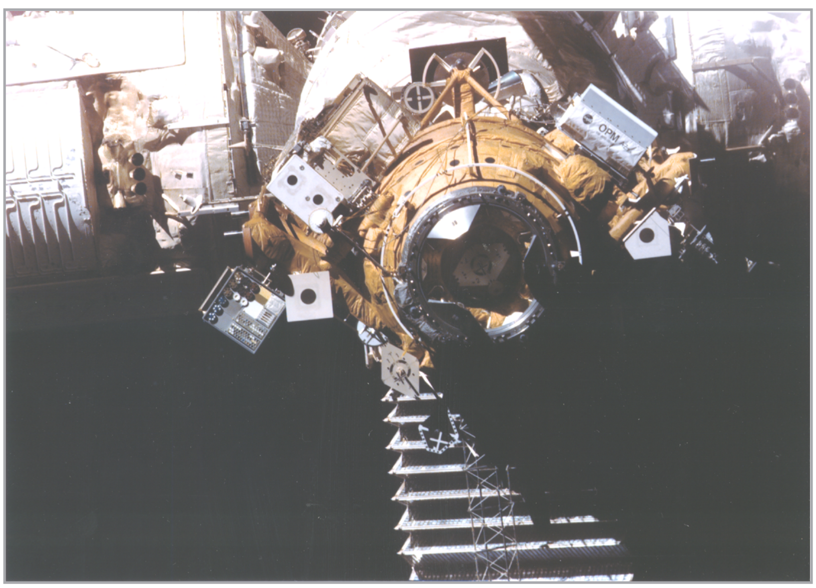

Figure 1. *Mir* docking module with POSA–I, POSA–II, and OPM experiments.

POSA–I and POSA–II were exposed to the *Mir*-induced and natural space environment for 18 mo. Both experiments flew 6 in. × 6 in. MLI blankets identical to the *ISS* configuration. MLI blankets on POSA–I used two different threads—one of Nomex and the other of beta glass and Teflon™. MLI blankets on POSA–II used a beta glass and nylon thread, which had a collected volatile condensable material (CVCM) of 0.12 percent, a borderline failure of the strict thermal vacuum stability requirement. Yellowing of the beta cloth was noted around this thread.

The POSA–I MLI blanket facing the *Mir* core received approximately 7×10^{19} atoms/cm^2 of AO and 413 ESH of solar UV. The beta cloth on this blanket had a 3.4-percent increase in solar absorptance and no significant change in infrared emittance. The POSA–I MLI blanket facing space was contaminated on-orbit with silicone photodeposition[5] and saw an increase of 8.9 percent in solar absorptance. The percent change data for these samples has been corrected for instrumentation drift with preflight control sample measurements by the following formula:

$$\%\ \text{Change} = \frac{\left(\dfrac{\text{Control}_{\text{Preflight}}}{\text{Control}_{\text{Postflight}}} * \text{Sample}_{\text{Postflight}}\right) - \text{Sample}_{\text{Preflight}}}{\text{Sample}_{\text{Preflight}}} * 100 \ . \qquad (1)$$

The POSA–II MLI blanket in the nominal ram direction received 2.1×10^{20} atoms/cm^2 of AO[6] and 576 ESH of solar UV. This blanket was also contaminated with some silicone though not of the same magnitude as POSA–I. Visible splash areas on POSA–II surfaces facing the Space Shuttle indicate contamination by a fluid dump. Despite the level of manmade contamination, solar absorptance increased only 3.3 to 6.1 percent for this blanket, depending on proximity to the beta glass and nylon thread and the amount of contamination. The POSA–II MLI blanket in the nominal wake direction also increased in solar absorptance by 6.1 to 8.6 percent. The exposure for the wake samples was 8.2×10^{19} atoms/cm^2 of AO and ≈500 ESH of solar UV. No significant change in infrared emittance was noted for any of the samples (see table 4).

Table 4. Results from POSA–I and POSA–II flight experiments.

MLI Blankets With Aluminized Beta Cloth Cover		Ave. Solar Absorptance	Ave. Infrared Emittance
POSA–I	Control	0.355	0.87
	Mir-facing	0.363	0.87
	Space-facing	0.381	0.87
POSA–II	Control	0.362	0.86
	Ram-facing*	0.388	0.86
	Wake-facing	0.379	0.86

*Contaminated by Shuttle fluid dump

The OPM was exposed on *Mir* for 9 mo. The top of the OPM exposed a carousel of material samples to the environment, and the sides of the OPM were covered with MLI blankets. The nonaluminized beta cloth outer cover for these blankets had been treated by application of Chemfilm DF–1100 on one side so that markings could be applied (fig. 2). This Chemfilm DF–1100 is the same material used to prep beta cloth for aluminization. The beta cloth vendor, Chemfab Corporation, was not aware that AZ Technology, the manufacturer of OPM, was using beta cloth in this manner; the DF–1100 film should not be exposed to the space environment. When OPM was returned to Earth, the darkening of the beta cloth was apparent (fig. 3). The consistency of the darkening around the experiment indicated that the increase in solar absorptance was due to UV interactions rather than contamination deposition, which was the cause on POSA–I and POSA–II. This led to the investigation of precisely what is occurring to darken the beta cloth and how this may impact the *ISS*.

Solar absorptance for MLI blankets on OPM increased from ≈0.25 to an average of 0.33, with a worst case of 0.49. The environmental exposure[7] for this worst case, the left side of OPM, was 7.5×10^{20} atoms/cm^2 of AO and 2903 ESH of direct solar exposure. The average solar absorptance of the right side was 0.37; this side received about the same AO fluence but only 379 ESH.

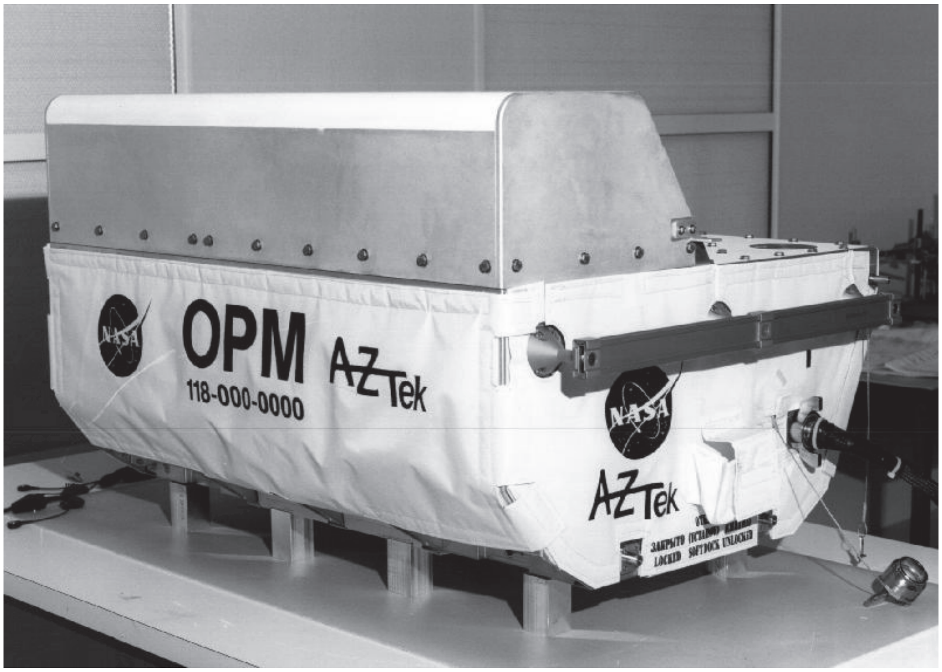

Figure 2. Preflight condition of the OPM.

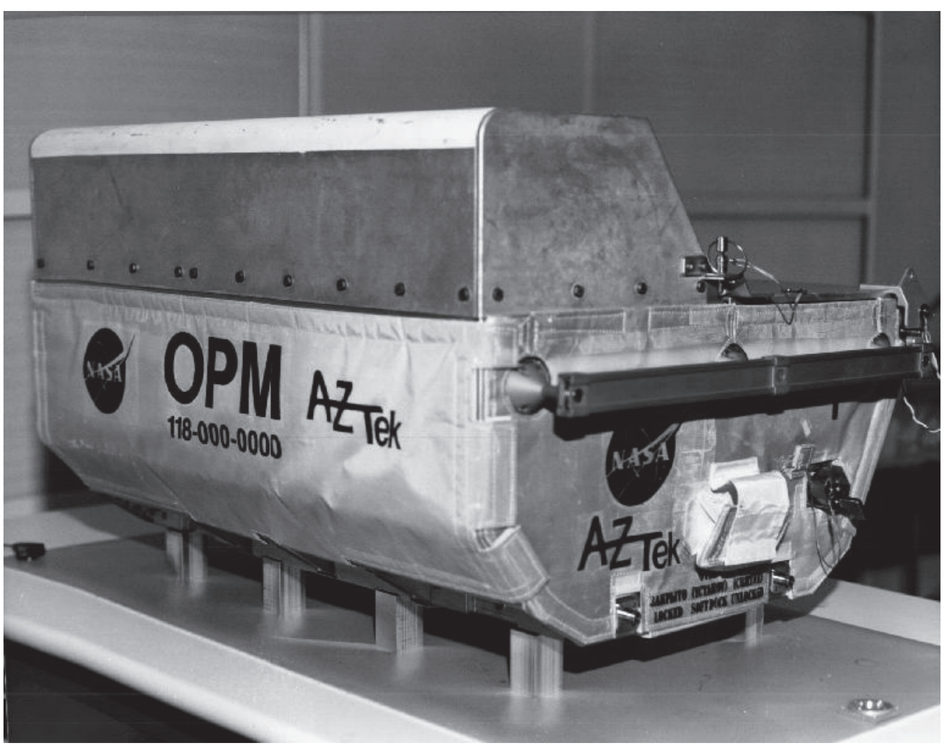

Figure 3. OPM postflight.

4. COMPONENTS STUDY

The manufacturing process of beta cloth by Chemfab Corporation is as follows. B-glass from Owens Corning is woven into a tight mat, which has a polyvinyl alcohol (PVA) sizing agent and a surfactant added. The surfactant is to improve adhesion of the Teflon™. Both the sizing and the surfactant are volatile and are theoretically removed during a heat treatment later in the manufacturing process. Teflon™ is then applied so that the final product is 17 to 22 percent Teflon™ by weight. The customer has the option of 1 to 2 percent phenylsilicone being added to the Teflon™ to improve flexibility, though this is specifically omitted for *ISS* material. For aluminized beta cloth, one side is prepared by the application of Chemfilm DF–1100 before aluminization. Chemfilm DF–1100 contains polytetrafluoroethylene (PTFE), perfluoralkoxy (PFA), and colloidal silica, and is heated to bond to the cloth. Dunmore Corporation then adds the aluminum layer and sells the final product to the *ISS* contractor.

A variety of beta cloth samples and component materials have been exposed in the MSFC laboratory to a minimum of 500 ESH enhanced UV radiation. It is important to note that these beta cloth samples were vacuum baked for a minimum of 24 hr at 100 °C prior to exposure. The cleanliness of the UV exposure chamber was monitored during every test with an optical witness sample. Contamination on the optical witness samples was negligible, ruling out darkening due to UV interaction with contamination.

Optical properties of the beta cloth samples were measured before and after exposure. Infrared emittance did not change significantly for any of the materials exposed to UV, so only solar absorptance measurements are given. Samples tested were:

- Chemglas 500F without silicone, without DF–1100, and without aluminization, from the manufacturer

- Chemglas 500F without silicone and with DF–1100, from the manufacturer

- Chemglas 500F with DF–1100, without silicone, and without aluminization, from the same lot as OPM MLI blankets

- Chemglas 500F without silicone, with DF–1100, and with aluminization, from the same lot as the *ISS* MLI blankets.

Also included in this study was a variant of Chemglas 500F, noted as beta cloth “plus.” The glass fibers in the woven mat are of slightly larger diameter than those used in traditional beta cloth. Chemfab Corporation will be transitioning to supplying only the beta “plus” material as inventories of traditional weave beta cloth are depleted.

The components tested include:

- Loom state fiberglass cloth with the PVA sizing
- Loom state fiberglass cloth with the sizing burned off
- PTFE film
- Fluorinated ethylene propylene (FEP) film
- PFA film
- Chemfilm DF–1100.

Optical property measurements are noted in table 5. MSFC solar absorptance measurements are made with a blackbody backing the samples, resulting in a higher α than reported on the OPM MLI blankets, since the beta cloth had an aluminized Kapton layer directly behind it, reflecting light. However, the increase in solar absorptance due to UV exposure is comparable.

Table 5. Enhanced UV effects on beta cloth.

Beta Cloth Chemglas 500F Material Description	DF–1100	Aluminum	UV Dose ESH	Solar Absorptance		$\Delta\alpha/\alpha$ (%)
				Pretest	Posttest	
Loom state cloth with PVA sizing	—	—	844	0.314	0.381	21.5
Loom state cloth, PVA removed	—	—	844	0.310	0.323	4.1
Chemfab	—	—	579	0.367	0.431	17.4
Chemfab	—	—	844	0.369	0.447	21.3
Chemfab—DF–1100 side exposed	√	—	844	0.356	0.608	71.0
OPM lot—DF–1100 side exposed	√	—	579	0.371	0.525	41.5
OPM lot—DF–1100 side unexposed	√	—	579	0.377	0.431	14.3
ISS lot—aluminized side unexposed	√	√	579	0.354	0.429	21.2
ISS lot—aluminized side exposed	√	√	579	0.314	0.319	1.6
Beta cloth "plus"	—	—	844	0.391	0.454	16.3

The loom state cloth with PVA sizing darkened, but the loom state cloth with the sizing removed did not, therefore the PVA must be adequately removed. Darkening of the beta cloth from the same lot as OPM was more significant when the DF–1100 was directly exposed (fig. 4). The DF–1100 component film darkened considerably. At 400 nm, the transmission of DF–1100 drops from 86.2 to 41.9 percent (fig. 5).

All samples with DF–1100 showed some degradation, except for the *ISS* lot sample with the aluminization exposed. However, samples without DF–1100, PVA, or silicone darkened due to UV exposure. A component of the proprietary mix of Teflon™ must be responsible for the degradation, since polymeric films of PTFA and FEP did not darken with UV exposure.

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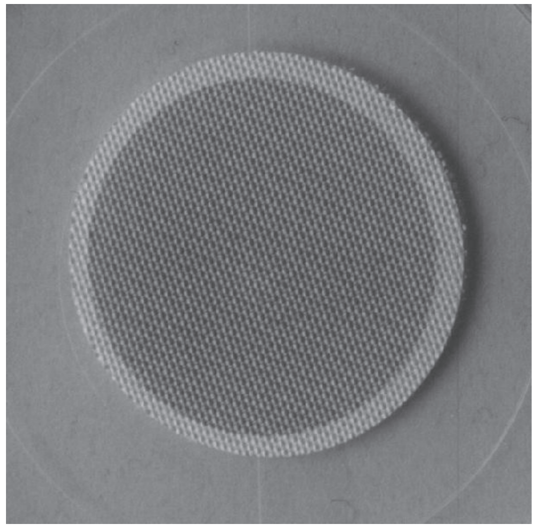

Figure 4. DF–1100/beta cloth from OPM lot darkened by 579 ESH UV.

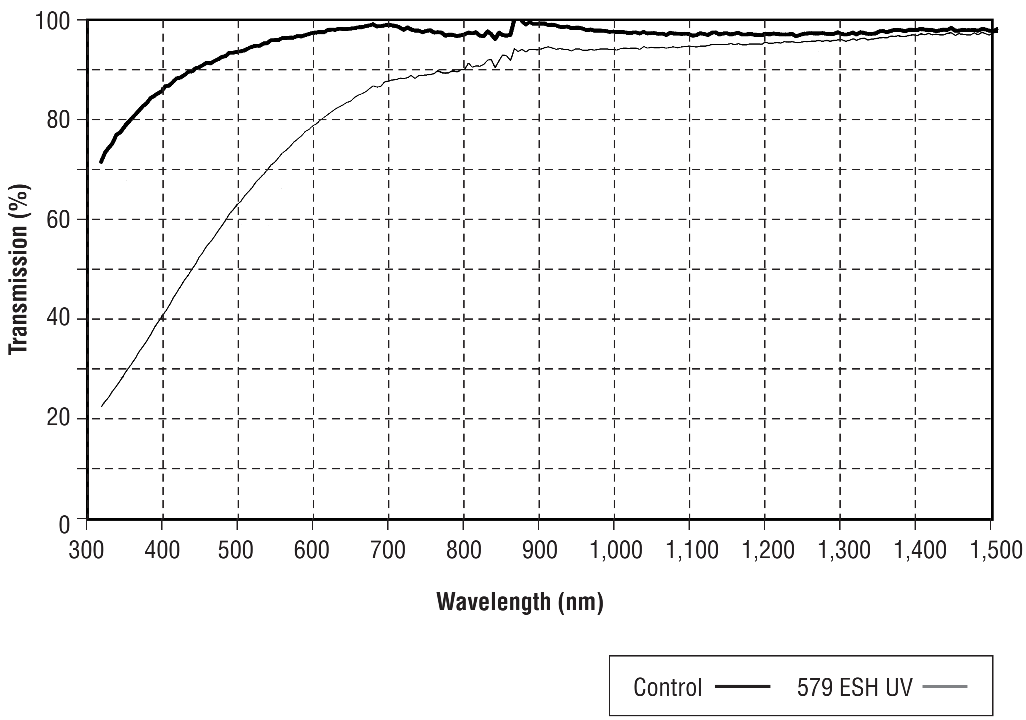

Figure 5. DF–1100 film transmission.

5. SYNERGISTIC EXPOSURES

AO penetration tests of the beta cloth “plus” material were conducted to ensure that the larger diameter fiber weave performed similarly to the previously manufactured material. This included AO exposure equivalent to 0.2 yr on orbit in the ram direction. AO exposure in the MSFC AOBF includes synergistic exposure to vacuum UV (VUV) radiation due to atomic dissociation and ionization (table 6). Samples tested were:

- Chemglas 500F without silicone, without DF–1100, and without aluminization, from the manufacturer
- Chemglas 500F, aluminized, from the same lot as *ISS* MLI blankets
- Unaluminized beta cloth “plus” with a preparatory vacuum bakeout.
- Unaluminized beta cloth “plus” without a preparatory vacuum bakeout.

The unbaked beta cloth “plus” samples were exposed in a separate test to prevent any cross-contamination.

For these tests, Kapton polyimide film samples were placed behind the beta cloth samples. Mass loss measurements of the Kapton after AO exposure indicate that the beta cloth “plus” provided AO penetration protection similar to traditional beta cloth with the smaller fiber diameter (table 7).

All of the beta cloth samples were slightly bleached due to the AO exposure. Mass loss of the beta cloth is consistent with AO erosion of the Teflon™. Infrared emittance was 0.86 for all samples before and after exposure.

Table 6. Synergistic AO and VUV effects on beta cloth.

Beta Cloth Material Description	AO Fluence $\times 10^{21}$ Atoms/cm^2	VUV Dose (ESH)	Mass Loss (mg)	Solar Absorptance	
				Pretest	Posttest
Chemglas 500F, no aluminum	0.99	1,950	4.76	0.359	0.348
	1.30	1,950	5.20	0.354	0.348
ISS lot, unaluminized side	1.24	1,950	5.47	0.355	0.342
	1.33	1,950	4.96	0.351	0.341
Beta cloth “plus,” baked	0.89	1,950	3.20	0.371	0.365
	1.21	1,950	3.74	0.369	0.362
	1.46	1,950	3.41	0.369	0.363
Beta cloth “plus,” unbaked	1.34	1,250	3.26	0.370	0.362
	1.62	1,250	3.84	0.376	0.361

Table 7. AO penetration through beta cloth.

Beta Cloth Material Description	AO Fluence $\times 10^{21}$ Atoms/cm^2	Kapton Mass Loss (mg)	Equivalent Open Area (%)
Chemglas 500F, no aluminum	0.99	0.49	2.99
	1.30	0.62	2.89
ISS lot, unaluminized side	1.24	0.36	1.76
	1.33	0.55	2.50
Beta cloth "plus," baked	0.89	0.37	2.52
	1.21	0.44	2.20
	1.46	0.51	2.11

6. CONTAMINATION CONCERNS

Gold mirrors were used as optical witness samples during the AO exposure of the unbaked beta cloth “plus.” Ellipsometry indicates deposition of ≈125 Å of contamination. Electron spectroscopy for chemical analysis (ESCA) of this contamination indicates an ester or organic acid.

Visible fogging of the gold mirror optical witness samples led to testing of the beta cloth “plus” and the traditional beta cloth for thermal vacuum stability and optics compatibility. Both forms of beta cloth passed ASTM–E–595, with the average total mass loss and CVCM both equal to 0.013 percent. However, the beta cloth “plus” again fogged the optical witness sample, failing MSFC–SPEC–1443. Investigations in this area are continuing.

7. CONCLUSIONS

In the absence of oxygen, solar UV radiation can degrade the thermal performance of beta cloth. While the sizing agent does darken in UV, this study shows that the PVA is adequately removed by heat treatment during manufacturing. There appears to be a component of the proprietary mix of Teflon™ resin that darkens when exposed to UV. In addition, DF–1100 also contributes to the darkening of aluminized beta cloth. The presence of molecular contamination, particularly silicone, also affects the solar absorptance of beta cloth. In the absence of contamination and when AO is present, beta cloth does not darken and may be slightly bleached.

Existing flight data on beta cloth indicates that the synergistic presence of AO and UV in LEO does not significantly degrade beta cloth. Significant degradation was observed with laboratory UV exposures. At the present time, we have no flight data on beta cloth exposed to only UV radiation. The increase in solar absorptance due to UV degradation for space exposure where AO is not present must be considered in thermal design. Beta cloth may not be the optimum material for wake surfaces or for spacecraft orbiting above 1,000 km when optical properties must be maintained. Beta cloth bonded with Chemfilm DF–1100 should be flown with the DF–1100 side down. The spacecraft designer should also be aware that AO may enhance photodeposition of molecular contamination, which can lead to an increase in solar absorptance.

There is a concern over quality assurance when manufacturing changes are implemented without requalifying the material for space. In this case, sandblasting prior to aluminization was replaced by application of the DF–1100 film. Outgassing of beta cloth has been noted by deposition on optical witness samples during vacuum bakeout. Contamination-sensitive surfaces should not be placed in line-of-sight to beta cloth that has not been vacuum-baked. Vacuum bakeout of beta cloth prior to blanket assembly is preferred over bakeout of the entire MLI blanket.

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13. ABSTRACT *(Maximum 200 words)*

A common component of multilayer insulation blankets is beta cloth, a woven fiberglass cloth impregnated with Teflon™. It is planned for extensive use on the *International Space Station*. The Environmental Effects Group of the Marshall Space Flight Center Materials, Processing, and Manufacturing Department has investigated the impact of atomic oxygen (AO) and ultraviolet (UV) radiation on the optical properties of plain and aluminized beta cloth, both in the laboratory and as part of long-duration flight experiments. These investigations indicate that beta cloth is susceptible to darkening in the presence of UV radiation, dependent on the additives used. AO interactions resulted in bleaching of the beta cloth.

14. SUBJECT TERMS

space environment, ultraviolet radiation, atomic oxygen

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