



Optical Properties of Thermal Control Coatings After Weathering, Simulated Ascent Heating, and Simulated Space Radiation Exposure

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Abstract

Spacecraft radiators reject heat to their surroundings and coatings play an important role in this heat rejection. The coatings provide the combined optical properties of low solar absorptance and high infrared emittance. The coatings are applied to the radiator panel in a number of ways, including conventional spraying, plasma spraying, or as an appliqué. Not designed for a terrestrial weathering environment, the durability of spacecraft paints, coatings, and appliqués upon exposure to weathering and subsequent exposure to ascent heating, solar wind, and ultraviolet radiation was studied. In addition to traditional aluminum panels, new isocyanate ester composite panels were exposed for a total of 90 days at the Atmospheric Exposure Site of Kennedy Space Center's (KSC) Beach Corrosion Facility for the purpose of identifying their durability to weathering. Selected panel coupons were subsequently exposed to simulated ascent heating, solar wind, and vacuum ultraviolet (UV) radiation to identify the effect of a simulated space environment on as-weathered surfaces. Optical properties and adhesion testing were used to document the durability of the paints, coatings, and appliqués.

Introduction

Radiators are used on spacecraft to reject heat. They function through radiant heat transfer utilizing surfaces having tailored optical properties (ref. 1). Radiators are either mounted on the body of a vehicle or are designed as panels that deploy from the vehicle (ref. 2). Desired optical properties are achieved through the use of specialized coatings (ref. 3). Because of these specialized coatings, radiator surfaces are often protected during ground handling and launch to prevent any degradation in radiator heat rejection performance.

The current state-of-the-art is to protect the radiators and their specialized coatings prior to launch. For example, the Apollo radiators were installed on the Service Module in a controlled environment and were protected by an over-wrap. The radiators were covered for ground transportation, launch vehicle stacking, and rollout to the launch pad. The wrapping was removed at the launch pad and a mobile service structure provided access and protection to the radiators while on the pad. The mobile service structure was rolled back prior to countdown.

A "clean launch pad" architecture is proposed for the future. In a clean launch pad architecture, mobile service structures are eliminated. This would require all checkout and maintenance to be performed at the vehicle assembly building, with minimal support at the launch pad. Any maintenance would require rollback to the vehicle assembly building. Hence, for radiators on the exterior of a

spacecraft utilizing the clean launch pad architecture, the radiators would be exposed to weathering for some time.

The objective of this paper is to evaluate the effect of weathering on radiator coating optical properties and adhesion. Coupon optical properties were obtained before and after atmospheric exposure, and after subsequent ascent heating, solar wind, and ultraviolet radiation exposure. Adhesion properties were obtained after atmospheric exposure alone.

Materials and Methods

Test Panels

The coatings were applied to 10 cm by 15 cm aluminum and composite panels. The aluminum panels were manufactured using 6061-T6 aluminum. The composite panels were manufactured using unidirectional plies of K1100 pitch based carbon fibers and a RS9D isocyanate ester resin matrix. The 10 cm by 15 cm panels were large enough to allow for several 2.5 cm diameter coupons to be cut from the panels utilizing a hole saw. Coupons were cut from the panels after weathering for subsequent ascent heating, solar wind, and ultraviolet radiation exposure.

A total of 15 panels were prepared, eight aluminum panels and seven isocyanate ester composite panels. The paints, coatings, and appliqué utilized are listed in table 1. They were selected based on their availability. The list includes a variety of white paints, some with overcoats, and one silver Teflon appliqué.

TABLE 1.—CANDIDATE COATING LIST

AZ-93, by AZ Technology, Huntsville, Alabama
AZ-93 with Teflon Overcoat, by AZ Technology, Huntsville, Alabama
AZ-93 with Lotus Overcoat, by AZ Technology, Huntsville, Alabama and nGimat Co., Atlanta, Georgia
S13GP, by Alion Science and Technology, Chicago, Illinois
ZnO in Lithium Silicate, by Applied Material Systems Engineering, Inc., Schaumburg, Illinois
Lithium Silicate Encapsulated ZnO in Platinum Addition Cured Silicone, by Applied Material Systems Engineering, Inc., Schaumburg, Illinois
Lithium Silicate Encapsulated ZnO in Low Cost, Low Outgassing Primerless Poly-Siloxane, by Applied Material Systems Engineering Inc., Schaumburg, Illinois (applied to aluminum panel only)
Silver Teflon, by Goddard Space Flight Center, Greenbelt, Maryland

Optical Property Measurements

Panel and coupon solar absorptance (α_s) was evaluated utilizing an AZ Technology Laboratory Portable Spectroscopic Reflectometer (LPSR). Spectral reflectance was obtained in the wavelength range of 250 to 2500 nm, subtracted from unity, and weighted with respect to the air mass zero solar spectrum to yield solar absorptance (ref. 4). Solar absorptance, as calculated using this technique, is temperature independent. Panel infrared emittance (ϵ) was evaluated utilizing a Surface Optics Corporation SOC-400t portable infrared reflectometer (ref. 5). Spectral reflectance was obtained in the wavelength range of 2 to 25 μm , subtracted from unity, and weighted with respect to the blackbody spectrum at room temperature to yield infrared emittance. Although room temperature emittance values are utilized here for comparison, this method can also be used for identifying emittance at temperatures other than room temperature, providing the appropriate blackbody spectrum is used during the weighting step in the calculation. Infrared emittance, as calculated using this technique, is temperature dependent. Infrared emittance of selected coupons was evaluated utilizing a Gier-Dunkle DB-100 reflectometer (ref. 3). Infrared reflectance was obtained in the vicinity of 9.7 μm and for opaque samples the infrared reflectance provided by the DB-100 is subtracted from unity to yield emittance. The samples remained at room temperature, hence the emittance provided by the DB-100 is a room temperature emittance value.

Adhesion Testing

Adhesion testing was based on ASTM D 3359 test method A, the X-Cut Tape Test (ref. 6). In test method A, a 5 cm "X" is scribed onto the panel with a scalpel, a 2.54 cm wide pressure sensitive standard tape is applied on top of the "X" using a rubber eraser. The tape is then removed rapidly within 90 sec of

its application, pulling back at an angle as close to 180° as possible. A six point scale is provided in the standard to rate the adhesion. Table 2 summarizes the rating scale. The tape for the tape test was a 3M 250 paper backed masking tape, the same type of tape used in previous evaluation of Z-93P thermal control paint.

TABLE 2.—RATING SCALE FOR THE ADHESION TEST

Rating	Description
5A	No peeling or removal
4A	Trace peeling or removal along incisions
3A	Jagged removal along incisions up to 1.8 mm on either side
2A	Jagged removal along most of incisions up to 3.2 mm on either side
1A	Removal from the area under the tape
0A	Removal beyond the area under the tape

Weathering

The coated panels were placed at the Atmospheric Exposure Site for two durations, 30 and 60 days, for a cumulative exposure of 90 days. Figure 1 is a photograph of the coupons on site. The Atmospheric Exposure Site at Kennedy Space Center’s (KSC) Beach Corrosion Facility is cited as the most corrosive atmospheric test site in the United States, and the panels were exposed at the Beach Corrosion Facility for 30 days between August 23, and September 25, 2006, and for 60 days between January 9, and March 16, 2007. Typical for that time of year, the panels accumulated dew in the mornings, direct illumination during the day, and occasional rainfall. Because they were placed outside during the hurricane season, it was decided that they would be removed in the event of any tropical storms. One week after the test started, they had to be removed for Hurricane Ernesto.

For the 30 day exposure, the weather was typical of late summer at KSC. The daily temperatures are shown in figure 2, and ranged from approximately 32 to 21 °C. The amount of rain was also typical, with 14.7 cm of rain for the 30 day period. The daily rainfall is shown in figure 3. The average wind speed was 11 km/hr. The 2 minute average gust wind speed during thunderstorms was as high as 32 km/hr.

The 60 day exposure occurred between January 9 and March 16, 2007, and included several days of light rain, fog, and haze. The panels were removed from February 20 to February 27. Over the 60 day period, the average temperature ranged from approximately 10 to 32 °C. The daily temperatures are shown in figure 4. The total amount of rain for the 60 day period was 10.9 cm. The daily rainfall is shown in figure 5. The average wind speed was 14 km/hr. The highest wind speed occurred on March 2, with the highest gust speed of 69 km/hr.



Figure 1.—Atmospheric exposure site at KSC.

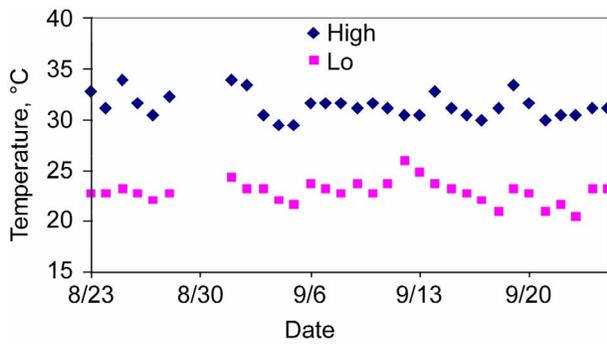


Figure 2.—Daily highs and lows; 30 day period.

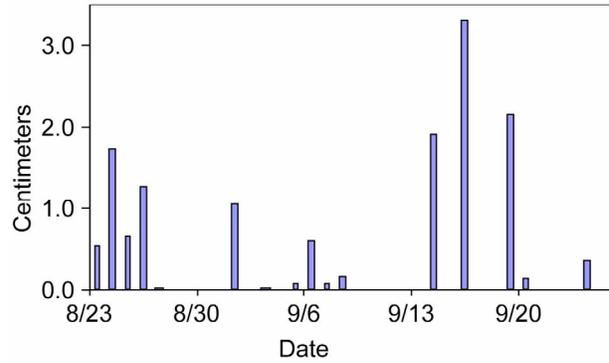


Figure 3.—Rain fall amount; 30 day period.

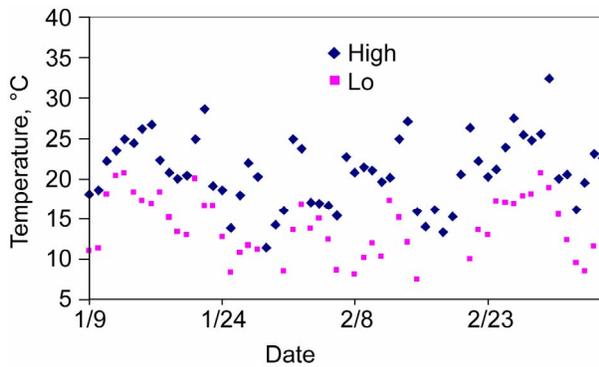


Figure 4.—Daily highs and lows; 60 day period.

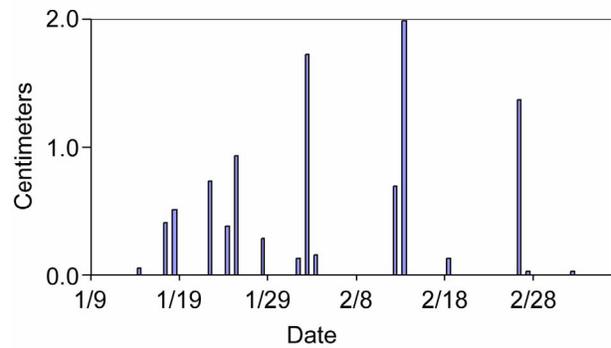


Figure 5.—Rain fall amount; 60 day period.

Solar Wind and UV Exposure

Solar wind and UV exposure was conducted at the Goddard Space Flight Center's (GSFC) Solar Wind Facility. This facility simulates the low energy protons and electrons of the solar wind and provides simultaneous illumination in the UV. The facility consists of a main vacuum chamber with three ports where one port houses the proton source, one the electron source, and one a beam from a solar simulator, all converging on a single exposure plane. The electron beam is generated by a Kimbal Physics EFG9 electron flood gun and can be varied from an electron energy of 500 eV to 50 KeV with current densities up to 20 nA/cm² at the exposure plane. The proton source is generated by a Kimbal Physics IMG31. The proton beam is created by bleeding a small quantity of hydrogen into an ionization chamber and ionizing the gas by microwave. Electrostatic accelerators and lenses extract and shape the beam creating a beam that is approximately 0.75 cm in diameter at the exposure plane. The proton source also has deflection plates and a raster generator, allowing the beam to be scanned over the entire exposure plane with a maximum current density of approximately 1 nA/cm²-s. A Spectrolab X25 solar simulator outside the vacuum chamber provides the solar beam. This solar simulator is capable of beam intensities from 0.5 to 2.2 equivalent suns with a beam uniformity of 5% over the exposure plane. A UV grade quartz window allows the full spectrum of the solar simulator to enter the chamber with little loss in intensity. Coupons 2.5 cm in diameter cut from the 10 cm by 15 cm panels were exposed to a solar beam of

1.2 to 1.9 suns for approximately 450 to 470 equivalent UV sun hours, while simultaneously being exposed to an average of 1.2×10^{10} p⁺/cm² s of solar wind protons at an energy of 3 KeV and an average of 1.4×10^{11} e⁻/cm² s electrons at an energy of 10 KeV. Hence, the e⁻/p⁺ fluence for the solar wind test was essentially equivalent to approximately one year in a geostationary Earth orbit.

Ascent Heating

Ascent heating varies based on numerous mission parameters and spacecraft geometry. For Apollo, ascent heating was both modeled and measured (ref. 7). A one-dimensional model was utilized, incorporating bare and cork-clad honeycomb panels 2.54 cm thick. Modeling of the bare panel predicted a maximum temperature of 150 °C at an elapse time of 160 sec while modeling of the cork-clad honeycomb panel predicted a maximum temperature of 110 °C at an elapse time of 170 sec. Flight data revealed that the modeling was conservative, with measured data slightly less than prediction. One spike was observed and was attributed to the firing of retrorockets at the first stage separation. The target ascent temperature for the tests reported here was 100 °C.

Ascent heating simulation was conducted at the GSFC utilizing a Delta Design Model 9039 Thermal Chamber. The chamber was preheated to 177 °C. Once the chamber reached 177 °C, the chamber was opened and the test coupons were placed in the chamber. The purpose for overheating the chamber was for maintaining the temperature as high as possible for the loading of the coupons, so when the chamber was closed again the temperature would reach 100 °C quickly exposing the test coupons to aeroheating-like conditions. The 2.5 cm diameter coupons were placed on a Teflon block. Two of the aluminum coupons were instrumented with thermocouples to monitor temperature. Coupon temperatures were monitored via LabView and temperatures were plotted in 15 sec increments. Coupons were heated up to and stabilized at 100 °C for 30 min and then allowed to cool to ambient prior to removal. Pre- and post-heating optical properties were measured, α_s values were obtained utilizing an AZ Technology LPSR and ε values were obtained near room temperature utilizing a Gier Dunkle DB-100. Selected coupons were submitted for subsequent solar wind and UV testing to simulate sequential ascent heating, and solar wind and UV exposure.

Test Plan

Prior to the initial 30 day exposure, the test plan called for pre-test evaluation of the panel optical properties. After the 30 day exposure, the optical properties were evaluated again, adhesion testing was done, and sub coupons were cut utilizing a diamond hole saw for ascent heating and solar wind and UV exposure. Care was taken to use only deionized water during the cutting process. The 10 cm by 15 cm panels were returned to the Beach Corrosion Facility for an additional 60 days of weathering followed by another set of optical properties evaluation, adhesion testing, and sub coupon cutting.

Results and Discussion

Results are presented as a function of paint product. In general, the optical properties of most samples remained nearly constant upon weathering, with the obvious exception of silver Teflon. The paint on some panels was visibly eroded, and the paint on one panel was gone. The adhesion of the samples varied considerably. Failure in adhesion may be attributed to weathering, the paint/coating application process, or both. The solar absorptance of samples having a silicate binder darkened some upon subsequent solar wind and UV exposure, while samples having a silicone binder darkened more than the silicate binder samples upon subsequent solar wind and UV exposure. The infrared emittance of samples was little changed upon subsequent solar wind and UV exposure.

AZ-93 and AZ-93 with Teflon Overcoat

The two products evaluated from AZ Technology were AZ-93 and AZ-93 with Teflon overcoat. The Z-93 family of paints consists of a zinc oxide pigment in a potassium silicate binder. For the isocyanate ester composite, an epoxy interface layer was used between the composite and the paint. For the aluminum, no epoxy interface layer was needed. The AZ-93 results are summarized in tables 3(a), (b), and (c).

TABLE 3.—(a) AZ-93, AZ-93 WEATHERED 30 DAYS, AND AZ-93 WEATHERED 90 DAYS

	Aluminum			Isocyanate ester		
	0	30 days	90 days	0	30 days	90 days
α_s	0.177	0.150	0.181	0.168	0.146	0.159
ϵ	0.914	0.903	0.900	0.917	0.908	0.904
Adhesion	-----	4A	4A	-----	4A	4A

TABLE 3.—(b) AZ-93 WEATHERED 30 DAYS AND SOLAR WIND EXPOSED

	Aluminum		Isocyanate ester	
	30 days	After solar wind	30 days	After solar wind
α_s	0.196	0.270	0.167	0.246
ϵ	0.89	0.89	0.91	0.91

TABLE 3.—(c) AZ-93 WEATHERED 30 DAYS, ASCENT HEATED, AND SOLAR WIND EXPOSED

	Aluminum			Isocyanate ester		
	30 days	After ascent	After solar wind	30 days	After ascent	After solar wind
α_s	0.204	0.192	0.295	0.172	0.170	0.268
ϵ	0.89	0.89	0.88	0.91	0.91	0.91

Although there was some change in α_s , there was little change in ϵ . Adhesion properties were robust even for the composites utilizing the epoxy interface, with values similar to previous adhesion values on carbon-carbon composites ref. 8). The AZ-93 results after subsequent solar wind and UV exposure are summarized in table 3(b).

The AZ-93 results after subsequent sequential ascent heating simulation and solar wind and UV exposure are summarized in table 3(c). These results are remarkably similar to those after solar wind exposure alone, indicating little impact from the ascent heating step.

The optical properties of the AZ-93 with Teflon overcoat are summarized in tables 4(a), (b), and (c).

The optical properties of the AZ-93 with Teflon overcoat after weathering and subsequent solar wind and UV exposure are summarized in table 4(b).

TABLE 4.—(a) AZ-93 WITH TEFLON, AZ-93 WITH TEFLON WEATHERED 30 DAYS, AND AZ-93 WITH TEFLON WEATHERED 90 DAYS

	Aluminum			Isocyanate ester		
	0	30 days	90 days	0	30 days	90 days
α_s	0.177	0.176	0.181	0.194	0.193	0.253
ϵ	0.918	0.912	0.903	0.911	0.907	0.901
Adhesion		4A	3A		4A	4A

TABLE 4.—(b) AZ-93 WITH TEFLON OVERCOAT WEATHERED 30 DAYS AND SOLAR WIND EXPOSED.

	Aluminum		Isocyanate Ester	
	30 days	After solar wind	30 days	After solar wind
α_s	0.188	0.377	0.248	0.431
ϵ	0.91	0.91	0.91	0.91

TABLE 4.—(c) AZ-93 WITH TEFLON OVERCOAT WEATHERED 30 DAYS, ASCENT HEATED, AND SOLAR WIND EXPOSED

	Aluminum			Isocyanate ester		
	30 days	After ascent	After solar wind	30 days	After ascent	After solar wind
α_s	0.194	0.189	0.397	0.244	0.230	0.410
ϵ	0.91	0.90	0.90	0.91	0.91	0.91

The concept behind the Teflon overcoat is that a layer of Teflon would serve to protect the surface during ground handling, and would be removed on orbit by atomic oxygen. The as-received optical

properties utilizing the Teflon overcoat are similar to the pristine AZ-93, suggesting that the Teflon overcoat is quite thin. The optical properties are also unchanged upon 30 days of weathering suggesting that the Teflon overcoat is performing as expected, even under the initial weathering conditions experienced. Some deterioration in optical properties is observed after 90 days of weathering. Adhesion properties were robust, similar to the pristine AZ-93. However, the presence of the Teflon overcoat during solar wind and UV exposure results in a greater increase in solar absorptance than would otherwise be expected. No atomic oxygen etching occurred here to remove the Teflon overcoat.

The AZ-93 with Teflon overcoat results after subsequent sequential ascent heating simulation and solar wind and UV exposure are summarized in table 4(c). With no atomic oxygen removal of the Teflon overcoat, the α_s values of the solar wind and UV exposed coupons were considerably larger than their AZ-93 counterparts. Interestingly, these results are again remarkably similar to those after solar wind exposure alone, indicating little impact from the ascent heating step.

AZ-93 With Lotus Coating Overcoat

Two additional coupons were coated with AZ-93 and subsequently subjected to a chemical vapor deposition process employed by nGimat, Co. to create a lotus coating on the AZ-93 surface. The lotus coating emulates the structure found on the surface of a lotus leaf that prohibits dust and water from accumulating (ref. 9). The lotus coating utilized here was originally developed as a lunar dust mitigation tool. Although proprietary, the process heated the aluminum coupon such that the aluminum coupon appeared warped after lotus coating application. The appearance of the isocyanate ester coupon was unaltered. The lotus coating results are summarized in tables 5(a), (b), and (c).

TABLE 5.—(a) AZ-93 WITH LOTUS COATING, AZ-93 WITH LOTUS COATING WEATHERED 30 DAYS, AND AZ-93 WITH LOTUS COATING WEATHERED 90 DAYS

	Aluminum			Isocyanate ester		
	0	30 days	90 days	0	30 days	90 days
α_s	0.151	0.147	0.181	0.167	0.157	0.243
ε	0.930	0.907	0.906	0.926	0.911	0.912
Adhesion	-----	0A	0A	-----	3A	0A

TABLE 5.—(b) AZ-93 WITH LOTUS COATING WEATHERED 30 DAYS AND SOLAR WIND EXPOSED

	Aluminum		Isocyanate ester	
	30 days	After solar wind	30 days	After solar wind
α_s	0.194	0.233	0.216	0.253
ε	0.90	0.90	0.91	0.91

TABLE 5.—(c) AZ-93 WITH LOTUS COATING WEATHERED 30 DAYS, ASCENT HEATED, AND SOLAR WIND EXPOSED

	Aluminum			Isocyanate ester		
	30 days	After ascent	After solar wind	30 days	After ascent	After solar wind
α_s	0.220	0.214	0.288	0.340	0.341	0.397
ε	0.90	0.90	0.90	0.90	0.90	0.90

The initial α_s on aluminum was slightly lower than pristine AZ-93, and exhibited little change upon weathering for 30 days. However, a significant change was observed upon weathering for 90 days. The initial ε values were slightly higher than their pristine AZ-93 counterparts, suggesting that the lotus coating was of sufficient thickness to add to the emittance of the pristine AZ-93. The ε values decreased some upon weathering for 30 days, then stayed constant upon weathering for 90 days.

The optical properties after weathering are remarkably similar to those of bare AZ-93 after weathering, perhaps suggesting that the lotus coating was washed off upon weathering exposure. The adhesion properties were poor, with a 0A value reported for the aluminum coupon attributed not to weathering but rather to the heating experienced by the sample during the lotus coating deposition

process. The adhesion to the isocyanate ester composite coupon was degraded too, compared to its pristine counterpart. The optical properties after solar wind and UV exposure were similar to the pristine AZ-93 on aluminum and slightly higher on isocyanate ester.

The AZ-93 with lotus coating results after ascent heating simulation and subsequent solar wind and UV exposure are summarized in table 5(c). The trend with sequential ascent heating and solar wind and UV exposure is similar to the trends observed above, i.e. the results are remarkably similar to those after solar wind exposure and UV exposure alone, indicating little impact from the ascent heating step.

It should be noted that cutting of the coupons for ascent heating, and solar wind and UV exposure, was a challenge. Even with utilizing a deionized water wash, by virtue of cutting with the diamond hole saw some aluminum and carbon particles were undoubtedly left behind in the pores of the painted finish. Hence, the α_s as measured on a panel after 30 days of weathering was somewhat different than that as measured on the coupons after 30 days of weathering, and going through the hole saw cutting process, prior to ascent heating or solar wind exposure. This is particularly evident in the isocyanate ester composite coupons shown in table 5(c).

S13GP

The product evaluated from Alion Science and Technology was a contemporary version of S13GP, identified as S13GP:6N/LO-1, which utilizes a zinc oxide pigment in a methyl silicone binder. No interface layer was used between composite and paint. The S13GP results are summarized in tables 6(a), (b), and (c).

TABLE 6.—(a) S13GP, S13GP WEATHERED 30 DAYS, AND S13GP WEATHERED 90 DAYS

	Aluminum			Isocyanate ester		
	0	30 days	90 days	0	30 days	90 days
α_s	0.233	0.233	0.256	0.282	0.269	0.294
ε	0.929	0.925	0.922	0.930	0.927	0.926
Adhesion	-----	5A	5A	-----	5A	5A

TABLE 6.—(b) S13GP WEATHERED 30 DAYS AND SOLAR WIND EXPOSED

	Aluminum		Isocyanate ester	
	30 days	After solar wind	30 days	After solar wind
α_s	0.312	0.464	0.311	0.444
ε	0.91	0.91	0.91	0.91

TABLE 6.—(c) S13GP WEATHERED 30 DAYS, ASCENT HEATED, AND SOLAR WIND EXPOSED

	Aluminum			Isocyanate ester		
	30 days	After ascent	After solar wind	30 days	After ascent	After solar wind
α_s	0.318	0.317	0.497	0.313	0.310	0.466
ε	0.91	0.92	0.91	0.92	0.92	0.92

The values for α_s and ε were essentially unchanged upon weathering and adhesion properties were found to be very robust. As can be seen, this silicone product differs from the previous silicate products in that the α_s has an initial value slightly higher than the silicates. In addition, darkening upon solar wind and UV exposure is more pronounced, whether ascent heated or not.

The values for α_s and ε were essentially unchanged upon weathering for 30 days, increasing upon weathering for 90 days. Adhesion properties were very robust. The S13GP:6N/LO-1 results after ascent heating simulation and subsequent solar wind and UV exposure are summarized in table 6(c). The α_s values changed substantially upon solar wind and UV exposure, independent of the presence of ascent heating.

Zinc Oxide in Lithium Silicate and Encapsulated Zinc Oxide in Silicone

The three products evaluated from Applied Material Systems Engineering, Inc. (AMSENG) were developmental: 1) a lithium silicate encapsulated zinc oxide pigment in a lithium silicate binder, 2) a lithium silicate encapsulated zinc oxide pigment in a heritage silicone binder typically used in solar cell adhesives, and 3) a lithium silicate encapsulated pigment in a low cost, low outgassing, primerless polysiloxane binder (applied to an aluminum panel only). The AMSENG results are summarized in tables 7(a) through 9(c).

TABLE 7.—(a) AMSENG COATING NO. 1, AMSENG COATING NO. 1 WEATHERED 30 DAYS, AND AMSENG COATING NO. 1 WEATHERED 90 DAYS

	Aluminum			Isocyanate ester		
	0	30 days	90 days	0	30 days	90 days
α_s	0.161	0.152	0.230	0.170	-----	-----
ϵ	0.917	0.912	0.915	0.922	-----	-----
Adhesion	-----	3A	3A	-----	-----	-----

TABLE 7.—(b) AMSENG COATING NO. 1 WEATHERED 30 DAYS AND SOLAR WIND EXPOSED

	Aluminum	
	30 days	After solar wind
α_s	0.180	0.236
ϵ	0.91	0.91

TABLE 7.—(c) AMSENG COATING NO. 1 WEATHERED 30 DAYS, ASCENT HEATED, AND SOLAR WIND EXPOSED

	Aluminum		
	30 days	After ascent	After solar wind
α_s	0.189	0.185	0.266
ϵ	0.91	0.92	0.91

Although intact on aluminum after 30 days of weathering, developmental coating no. 1 was completely washed off the isocyanate ester composite. Hence, no discs were cut from the isocyanate ester composite panel for subsequent ascent heating or solar wind and UV exposure. On aluminum, the optical properties were typical of heritage zinc oxide pigments. Adhesion to aluminum was fair. Optical properties after solar wind and UV exposure were comparable to AZ-93. The AMSENG Coating no. 1 results after ascent heating simulation and subsequent solar wind and UV exposure are summarized in table 7(c).

For developmental coating no. 2, the values of α_s and ϵ were comparable to heritage thermal control coatings composed of silicone. The adhesion to aluminum was very robust while the adhesion to the isocyanate ester composite was fair to poor. The solar wind and UV exposure results were comparable to heritage thermal control coatings composed of silicone as well. As with all other coatings, the ascent heating had essentially no impact on the optical properties. The AMSENG Coating no. 2 results after ascent heating simulation and subsequent solar wind and UV exposure are summarized in table 8(c).

TABLE 8.—(a) AMSENG COATING NO. 2, AMSENG COATING NO. 2 WEATHERED 30 DAYS, AND AMSENG COATING NO. 2 WEATHERED 90 DAYS

	Aluminum			Isocyanate ester		
	0	30 days	90 days	0	30 days	90 days
α_s	0.203	0.200	0.215	0.227	0.203	0.222
ϵ	0.900	0.897	0.898	0.900	0.901	0.896
Adhesion	-----	5A	5A	-----	3A	0A

TABLE 8.—(b) AMSENG COATING NO. 2 WEATHERED
30 DAYS AND SOLAR WIND EXPOSED

	Aluminum		Isocyanate ester	
	30 days	After solar wind	30 days	After solar wind
α_s	0.245	0.431	0.263	0.452
ϵ	0.89	0.89	0.90	0.90

TABLE 8.—(c) AMSENG COATING NO. 2 WEATHERED 30 DAYS,
ASCENT HEATED, AND SOLAR WIND EXPOSED

	Aluminum			Isocyanate ester		
	30 days	After ascent	After solar wind	30 days	After ascent	After solar wind
α_s	0.232	0.238	0.432	0.291	0.291	0.510
ϵ	0.89	0.89	0.89	0.90	0.90	0.89

The AMSENG developmental coating no. 3, only applied to aluminum, was found to have optical properties, adhesion to aluminum, and optical properties after solar wind and UV exposure similar to heritage silicone thermal control paints. The AMSENG Coating no. 3 results are summarized in tables 9(a) to (c).

TABLE 9.—(a) AMSENG COATING NO. 3, AMSENG COATING NO. 3 WEATHERED
30 DAYS, AND AMSENG COATING NO. 3 WEATHERED 90 DAYS

	Aluminum		
	0	30 days	90 days
α_s	0.171	0.172	0.176
ϵ	0.891	0.890	0.891
Adhesion	4A	3A	-----

TABLE 9.—(b) AMSENG COATING NO. 3 WEATHERED
30 DAYS AND SOLAR WIND EXPOSED

	Aluminum	
	30 days	After solar wind
α_s	0.194	0.379
ϵ	0.89	0.89

TABLE 9.—(c) AMSENG COATING NO. 3 WEATHERED 30 DAYS,
ASCENT HEATED, AND SOLAR WIND EXPOSED

	Aluminum		
	30 days	After ascent	After solar wind
α_s	0.195	0.195	0.400
ϵ	0.89	0.89	0.89

Silver Teflon

Silver Teflon was provided as an appliqué by GSFC, and the results are summarized in table 10.

TABLE 10.—SILVER TEFLON AND SILVER TEFLON WEATHERED 30 DAYS

	Aluminum		Isocyanate ester	
	0	30 days	0	30 days
α_s	0.087	0.726	0.089	0.771
ϵ	0.886	0.904	0.885	0.908

The α_s values were found to deteriorate substantially upon weathering, undoubtedly due to oxidation of the silver. Although α_s values were quite low initially, they increased substantially after weathering. The ϵ values changed too, but not to as great an extent. No adhesion testing was carried out on these samples, and no solar wind and UV exposure was carried out on these samples because the α_s increased so much.

Conclusion

Several commercial and developmental paints, coatings, and one appliqué, applied to panels of aluminum and isocyanate ester composite were subjected to weathering at a seaside facility at KSC for 30 days in the late summer of 2006 and for an additional 60 days in the early spring of 2007. The optical properties of the paints and coatings were evaluated before and after weathering. The adhesion properties of the paints and coatings were also evaluated after weathering. A wide range of performance was observed, from no change to complete loss of paint. Small disks were cut from selected coupons and were subjected to subsequent ascent heating, solar wind, and ultraviolet radiation exposure. The objective was to capture weathering, ascent heating, and solar wind and UV exposure, sequentially.

The silicate paints survived on weathering well, with minor deterioration in optical properties, with the AZ-93 product line surviving best under the aggregate of conditions. For the silicate paints, subsequent solar wind and UV exposure resulted in a more severe degradation than weathering alone. The silicone paints also survived on weathering surprisingly well, with little deterioration in optical properties. Heritage silicones maintained excellent adhesion after the weathering. However, the silicone-derived paints were degraded substantially upon solar wind and UV exposure. In all cases, the ascent heating had essentially no effect on the optical properties of the coupons. Adhesion varied from excellent to total loss of paint upon weathering.

The results of this preliminary study suggest that weathering may not be as big a problem as first thought. However, the selection of paint having the right mix of acceptable optical properties and adhesion will ultimately be driven by the requirements of a particular mission. This paradigm shift in paint weathering durability may prove useful in the future for so-called clean launch pad architectures.

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14. ABSTRACT Spacecraft radiators reject heat to their surroundings, and coatings play an important role in this heat rejection. The coatings provide the combined optical properties of low solar absorptance and high infrared emittance. The coatings are applied to the radiator panel in a number of ways, including conventional spraying, plasma spraying, or as an applique. Not designed for a terrestrial weathering environment, the durability of spacecraft paints, coatings, and appliques upon exposure to weathering and subsequent exposure to ascent heating, solar wind, and ultraviolet radiation was studied. In addition to traditional aluminum panels, new isocyanate ester composite panels were exposed for a total of 90 days at the Atmospheric Exposure Site of Kennedy Space Center's Beach Corrosion Facility for the purpose of identifying their durability to weathering. Selected panel coupons were subsequently exposed to simulated ascent heating, solar wind, and vacuum ultraviolet (UV) radiation to identify the effect of a simulated space environment on as-weathered surfaces. Optical properties and adhesion testing were used to document the durability of the paints, coatings, and appliques.					
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