National Aeronautics and Space Administration

Sulfuric acid-resistant conductive thermal control white paint for Venus aerobot payload modules

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Objectives:

The goal of this project was to develop thermal control coatings with low solar absorptance, high emissivity, ESD-compliance, and, exceptional tolerance/survival in H_2SO_4 aerosol/mist at 60-100°C for ~100 days in Venus atmosphere. Some well-known white TCC paints are: Z93C55 (ZnO pigment dispersed in K_2SiO_3 inorganic binder), TiO_2-based Acrylic paint and Y_2O_3 in KBr (inorganic binder). However, despite excellent thermal properties (low solar absorptivity and high emissivity), their H_2SO_4 resistance is unknown. $BaSO_4$-based acrylic paint and films with significant radiative cooling due to its extraordinary thermal properties ($\alpha < 0.05$; $\varepsilon > 0.97$), have recently been reported, though not for aerospace application. In this case too, sulfuric acid tolerance is unknown. Since $BaSO_4$ is one of the most stable sulfates; intuitively, it was perceived that the sulfate paint composition could provide adequate resistance towards sulfuric acid. Therefore, if the sulfuric acid mitigation potential of these paints could be demonstrated, they could potentially provide a superior alternative to Teflon and substantially improve the thermal design challenge for a Venus aerobot payload module. Z-93C55 and $BaSO_4$ were selected and evaluated for tolerance in 96.2% sulfuric acid between 25°-80°C for 168h.

Background:

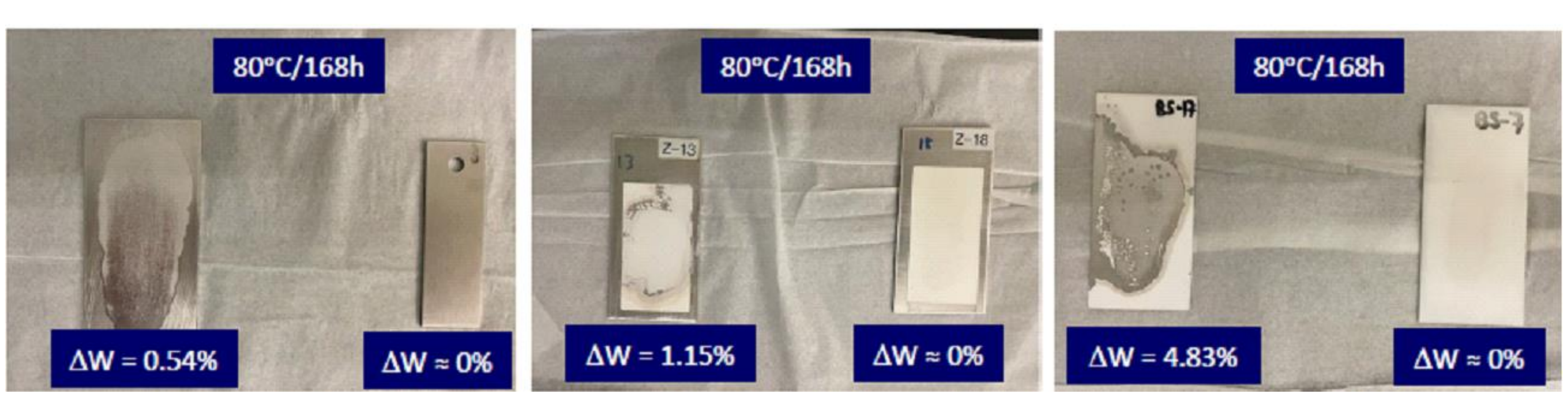
JPL's Venus aerobot (robotic balloon) mission would consist of a variable altitude balloon that would explore the cloud layer between 52 and 62 km over a mission lasting weeks or months. A key technical challenge for such an aerobot mission is to protect the payload module from the sulfuric acid aerosols in the clouds while simultaneously providing a surface that limits solar heating through a low absorptivity coating. The Venus Flagship Mission study, and prior JPL Venus balloon proposals (such as VALOR, 2010), had specified a Teflon coating on a metallic structure. While Teflon provides adequate sulfuric acid protection, its thermal control performance is marginal. This leads to a higher than desired temperature of the payload in sunlight. This temperature increase threatens the ability to reach altitudes as low as 52 km with adequate design margin, motivating a search for an alternative. Recently work on the remarkable daytime subambient radiative cooling properties (solar absorptivity, $\alpha < 0.05$; emissivity, $\varepsilon > 0.97$) of $BaSO_4$ paint provides a possible solution to this problem for Venus. ZnO-based white paint (Z-93C55) also has excellent thermal properties. If the sulfuric acid mitigation potential of these paints could be demonstrated, they could potentially provide a superior alternative to Teflon for a Venus aerobot payload module.

Approach and Results:

Each paint was prepared by mixing the respective solid pigment with aqueous suspension of K_2SiO_3 (inorganic binder). Twenty-five Al 6061 coupons (4" x2" x 0.061") were painted with each paint, after the coupons were throughly surface prepared and cleaned. Coupons with Z-93C55 were made at JPL paint shop. Coupons with $BaSO_4$ (aka APTEK 95506) paint were prepared by APTEK. The painted coupons were cured at room temperature between 5 days (for $BaSO_4$) to 14 days (for Z-93C55). Dry film thickness was measured. They were evaluated for optical absorptance, emissivity, surface resistivity, adhesion, cyclic thermal shock and post-thermal shock adhesion performance. Microscopic examination of the dried paints was also conducted to reveal their surface morphology. Acid tolerance tests on coupons from both batches were carried out in 96.2% sulfuric acid at room temperature for 24h, at 80°C for 24h and at 80°C for 168h. ~1.14 mil thick Parylene C coating was applied to few randomly selected coupons, which were also subjected to acid tests. Absorptance and emissivity were remeasured on all the acid-treated samples as well; X-cut adhesion tests were also performed. Pristine and Parylene-coated $BaSO_4$ and Z93-C55 coupons were weight accurately before and after exposure to 96.2% sulfuric acid for 24h to 168h at RT and 80°C. Once the acid exposure was complete, they were taken out of the oven and washed, dried, weighed, examined visually and tested for absorptivity, emissivity and adhesion properties.

L to R: Al coupons coated with (a) $BaSO_4$ paint and (b) Zn93-C55 paint. Optical micrographs (500x) of $BaSO_4$ (top) and Z93-C55 films (bottom). Parylene C-coated BaSO4 and Z93-C55 coupons.

Bare Paint Coupon	α	ε
Z-1/3.33 mil	0.123	0.835
Z-7/3.57 mil	0.117	0.835
Z-13/2.99 mil	0.130	0.835
Z Average	**0.123**	**0.835**
BS-3/3.06 mil	0.098	0.974
BS-6/3.44 mil	0.087	0.974
BS-11/4.01 mil	0.081	0.973
BS-14/4.20 mil	0.073	0.973
BS-18/4.74 mil	0.072	0.973
BS Average	**0.082**	**0.973**



Post-Acid Test Absorptivity (α) and Emissivity (ε)

ID	α	ε
Z-7	0.186	0.822
Z-13	0.172	0.790
Z-18-P	0.138	0.817
BS-6-P	0.135	0.821
BS-7-P	0.15	0.82

L to R: Absorptivity and emissivity of paints before acid test. Results of acid tests at 80°C for 168h on Al, Z93-C55 and $BaSO_4$-painted coupons. Post-acid test values of absorptivity and emissivity.

Significance/Benefits to JPL and NASA: Exploring the prospects of more resilient alternative ceramics as white paint materials for application in Venus' sulfuric acid-bearing environment in its upper clouds is relevant to JPL and NASA for future Venus Missions. NASA's New Frontier programs could benefit from it.

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