

Anodized Aluminum as Used for Exterior Spacecraft Dielectrics

G.B. Hillard, S.G. Bailey, and D.C. Ferguson
NASA Lewis Research Center
Cleveland, OH 44135

Introduction

Because of a number of key properties, anodized aluminum continues to be one of the more common spacecraft surfaces in use today. It is perhaps most commonly used because its optical properties, especially absorptivity (α) and emissivity (ϵ), can be tailored to produce a surface having excellent thermal control properties. Furthermore, since it is an oxide and is almost impervious to atomic oxygen, it is ideal for use in Low Earth Orbit (LEO) where AO attack is a major design issue.

In addition to these traditional uses of the material, the recent introduction of high-voltage space power systems has caused designers to take note of the excellent insulating properties of this material. As a result, a great deal of laboratory work as well as limited space testing has been performed. We will report here on a sample of material from the Solar Array Module Plasma Interaction Experiment (SAMPIE). We believe our findings to apply generally to this material as we assess its value as a high voltage insulator in space.

Background

Anodized aluminum became a high-priority issue in the late 1980s when Space Station Freedom (SSF) designers specified vast amounts of the material (more than 2000 m²). Virtually all exposed surfaces, including the main truss structure as well as all hab modules, were to be made from this material. The power system for SSF was originally designed to use 20Khz alternating current (ac). One of the benefits of high-frequency ac is that it may have no significant plasma interactions.

When the power system was changed to a 160-volt direct current (dc) system in late 1989,

it was realized immediately that serious interactions between high voltage surfaces and the ambient plasma were probable. The issues were studied over the next two years by the Space Station Freedom Electrical Grounding Tiger team (hereafter called the "Tiger Team") involving several dozen experts from the government, industry and academia. Among their conclusions were that the space station main truss would "float" as much as 140 volts negative with respect to space.

The ideal solution to such a problem would be a complete redesign of the solar arrays to eliminate current collection. The technology necessary for such an effort was in its infancy at the time and such a course would have meant significant program delays. The solution turned to instead was to add a plasma contactor to SSF, a brute force approach which will maintain the electrical potential at all points to within 40V of the plasma. All of these considerations continued as SSF was redesigned and became the International Space Station (ISS). With the addition of the Plasma Contactor, the problem is under control.

During this effort there were many questions about the behavior of materials and systems if a suitable plasma contactor could not be designed, failed or was not ready in early stages of ISS operation. It was also clear that similar considerations would arise in future programs, as high voltage power systems become more common. The suitability of anodized aluminum as a high voltage insulator continued, therefore, to be of interest.

Among the implications for high voltage on SSF external surfaces was that the anodized aluminum was unlikely to stand off such potentials. Dielectric breakdown and arcing to space has the potential to destroy the coating in time as well as to produce significant

electromagnetic interference. Exactly how the coating would behave became an area of research and the subject of extensive numerous ground testing.

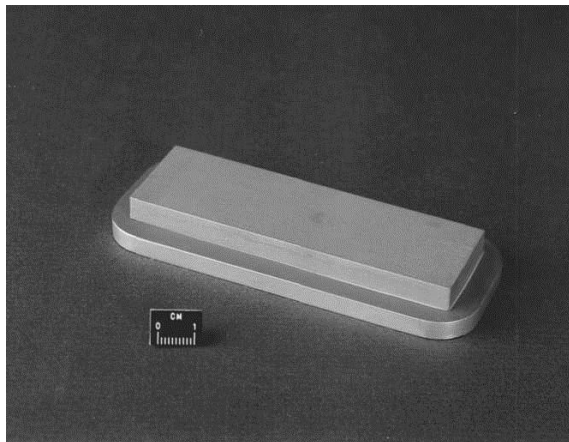
Ground Tests

Testing of anodized aluminum concentrated on material made to SSF, and later ISS, specifications. For all tests samples the alloy was type 2219 (Federal Specification QQ-A-250/30). Nominal 0.5 mil anodization was done by sulfuric acid to specifications STP 0554-0101 and Mil-A-8625. Details of these experiments are part of the Tiger Team records.

Of interest to us here is the fact that the ground test program was beset from the beginning by an inability to reliably reproduce experimental results. In one case, for example, two identical samples (from the same batch) were tested and found to break down at -300V and -700V. In another case, the original sample arced at -120V while a new one made to spec broke down at -250V. A number of samples arced with less than -100 volts and, in the worst case, samples arced at as little as -55V. When these tests were concluded, it was clear that ISS was safe with the plasma contactor on board and no surfaces exceeding 40V. The suitability of the material for high voltage surfaces was, however, still unclear.

SAMPIE

SAMPIE was flown on STS-62 in March 1994. The experiment has been documented extensively elsewhere including the behavior of the anodized aluminum sample.¹ The sample,

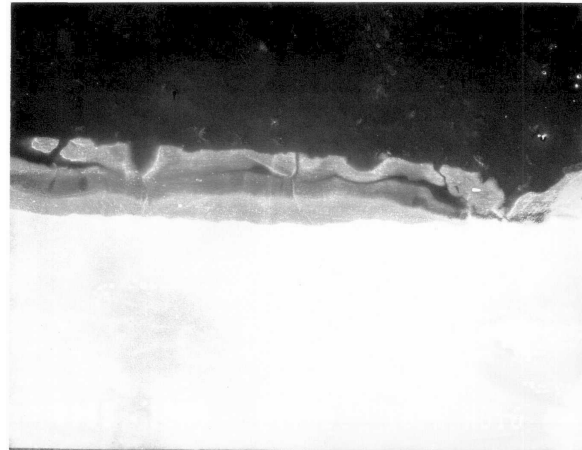


which withstood voltages to -220V, was unremarkable in its flight behavior and gave only one more (unreproducible) data point. It is shown here on its mounting plate prior to flight.

Post-flight Analysis

After the flight, a review of all results to date failed to shed light on the widely variable arcing threshold. It was decided to sacrifice the sample to allow SEM analysis of its surfaces. The original interest was in details of the various arc pits and of ejected material around them as several theories of arc initiation differed in their predictions. Much more interesting was a close look at the coating in cross section.

Scale: 1 cm = 10 μ m (\approx .39 mil)



In this picture, the lower white portion is solid metal while the dark black upper part is open air. The gray layer is the coating and, as can be seen, is highly non-uniform. Nominally 0.5 mil thick, there are numerous gaps and voids, places where the actual thickness is less than one tenth of nominal thickness. While we show only this one picture, it is not exceptional but typical.

Clearly this high degree of non-uniformity is the reason for the material's erratic behavior under test. This material was never designed to be an electrical insulator and nothing in its production specs covers coating uniformity.

Conclusion

We conclude that anodized aluminum, while a superb thermal control surface, is not well suited in the role of electrical insulator. Limited in-house efforts at NASA Lewis have shown that it may be possible to significantly improve uniformity.² These efforts may eventually point the way to a coating process that would meet a uniformity specification for the material and allows its widespread use on high voltage spacecraft.

Because of various constraints and priorities, no further research efforts are underway at this time.

References

¹ G.B. Hillard and D.C. Ferguson, *Measured Rate of Arcing From an Anodized Sample on the SAMPIE Flight Experiment*, 33rd Aerospace Sciences Meeting & exhibit, AIAA 95-0487

² David B. Snyder, NASA Lewis Research Center, private communication.