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THE CONTINUING MATERIALS ANALYSIS OF THE THERMAL CONTROL SURFACES EXPERIMENT (S0069)

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SUMMARY

The long term effects of the natural and induced space environment on spacecraft surfaces are critically important to future spacecraft--including Space Station Freedom. The damaging constituents of this environment include thermal vacuum, solar ultraviolet radiation, atomic oxygen, particulate radiation, and the spacecraft induced environment. The behavior of materials and coatings in the space environment continues to be a limiting technology for spacecraft and experiments. The Thermal Control Surfaces Experiment (TCSE) was flown on the National Aeronautics and Space Administration (NASA) Long Duration Exposure Facility (LDEF) to study these environmental effects on surfaces--particularly on thermal control surfaces.

The TCSE was a comprehensive experiment that combined in-space measurements with extensive pre- and post-flight analyses of thermal control surfaces to determine the effects of exposure to the low Earth orbit space environment. The TCSE is the first space experiment to directly measure the total hemispherical reflectance of thermal control surfaces in the same way they are routinely measured in the laboratory.

This paper describes the trend analyses of selected coatings performed as part of the continuing post-flight analysis of the TCSE. A brief description of the TCSE and its mission on LDEF will be presented. There are several publications available that describe the TCSE, it's mission on LDEF, and initial results in greater detail. These are listed in the TCSE Bibliography at the end of this paper.

Experiment Description

The basic objective of the TCSE on the LDEF was to determine the effects of the near-Earth orbital environment and the LDEF induced environment on spacecraft thermal control surfaces. To accomplish this objective, the TCSE exposed selected material samples to the space environment and used in-flight and post-flight measurements of their thermo-optical properties to determine the effects of this exposure.

The TCSE was a completely self-contained experiment package, providing its own power, data system, reflectometer, and pre-programmed controller for automatically exposing, monitoring, and measuring the sample materials (See Figure 1). The primary TCSE in-space measurement was total hemispherical reflectance as a function of wavelength from 250 to 2500 nm using a scanning integrating sphere reflectometer. The measurements were repeated at preprogrammed intervals until battery power depletion.

The LDEF with the TCSE on board was placed in low earth orbit by the Shuttle Challenger on April 7, 1984. LDEF was retrieved by the Shuttle on January 12, 1990 after 5 years 10 months in space. The LDEF was gravity-gradient stabilized and mass loaded so that one end of LDEF always pointed at the earth and one side pointed into the velocity vector or RAM direction. The TCSE was located on the leading edge (row 9) of LDEF and at the earth end of this row (position A9). In this configuration, the TCSE faced the RAM direction. This LDEF/TCSE orientation and mission duration provided the following exposure environment for the TCSE:

Total space exposure	5 years 10 months
Atomic oxygen fluence[1] atoms/cm^2	8.0×10^{21} atoms/cm^2
Solar UV exposure[2]	1.0×10^4 ESH
Thermal cycles	3.3×10^4 cycles
Radiation (at surface)[3]	3.0×10^5 rads

The TCSE operated for the first 584 days of the LDEF mission before its batteries were depleted. Although the flight recorder malfunctioned, data were recovered for the last 421 days of this operational period. The recovered data included eleven sets of reflectometry data. The battery power was fully expended while the sample carousel was being rotated leaving the carousel in a partially open position. Figure 2 is a photograph taken during the LDEF retrieval operations showing the final position of the carousel. This carousel position permitted exposure of 35 of the samples for the complete LDEF

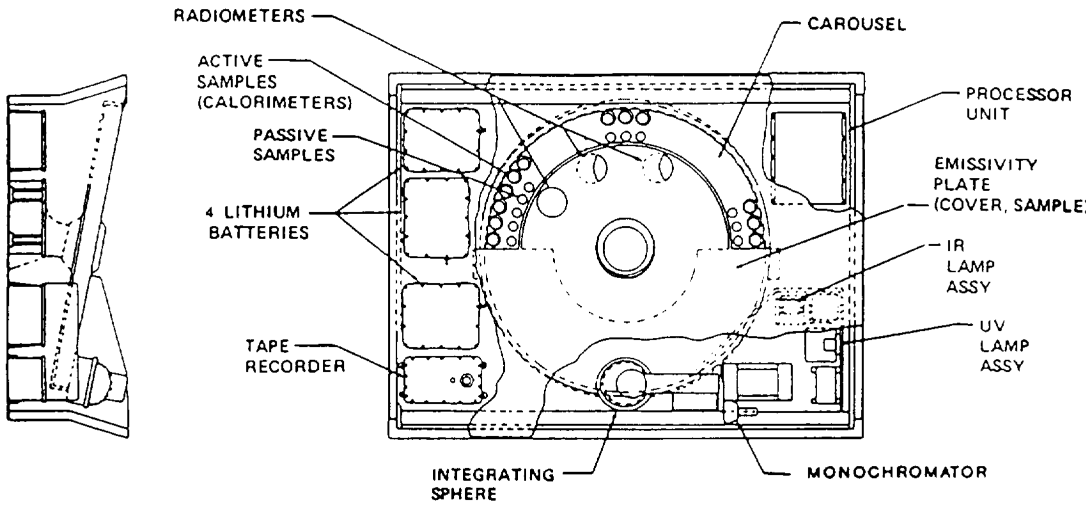


Figure 1. TCSE Assembly

mission (69.2 months), while 14 samples were exposed for only 19.5 months and protected from the space environment for the subsequent four years.

The test materials chosen for the TCSE mission comprised the thermal control surfaces of the greatest current interest (in 1983) to NASA, MSFC and the thermophysics community. The samples flown on the TCSE mission were:

- A276 Polyurethane White Paint
- A276/OI650 Clear Silicone Overcoat
- A276/RTV670 Clear Silicone Overcoat
- S13G/LO Inorganic White Paint
- Z93 Inorganic White Paint
- YB71 Inorganic White Paint
- YB71 over Z93
- Chromic Acid Anodize
- Silver/FEP Teflon (2 mil)
- Silver/FEP Teflon (5 mil)
- Silver/FEP Teflon (5 mil Diffuse)
- White Tedlar
- D111 Inorganic Black Paint
- Z302 Polyurethane Black Paint
- Z302/OI650 Clear Silicone Overcoat
- Z302/RTV670 Clear Silicone Overcoat

Note: Teflon and Tedlar are trademarks of Dupont.

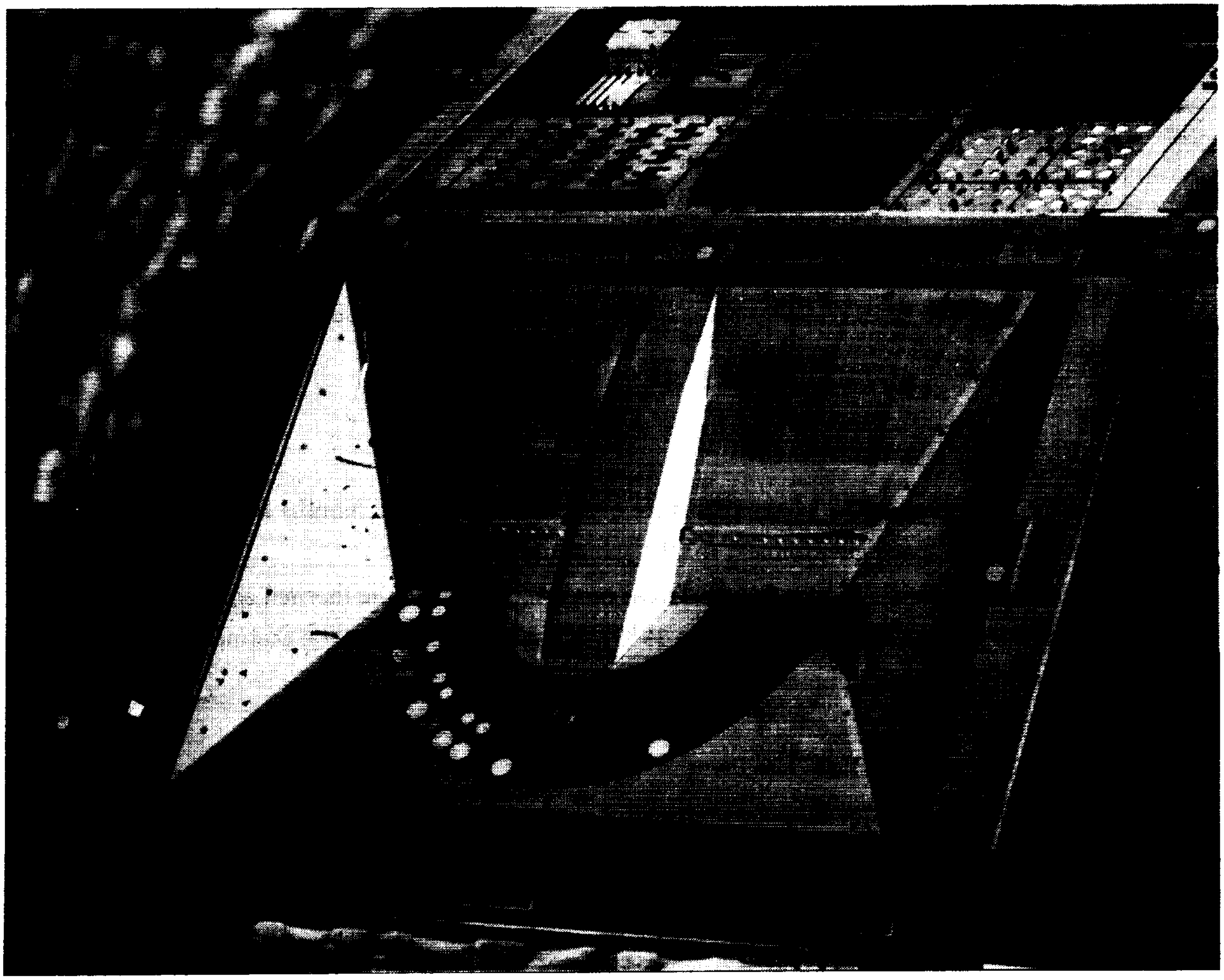


Figure 2. Photograph of LDEF Retrieval

Degradation Trend Analysis

The increasing duration of space missions requires significant extrapolation of flight and ground simulation data to provide predictions of end-of-life properties for thermal control surfaces. This is particularly true for NASA programs such as the 30 year lifetime Space Station Freedom, AXAF and the Hubble Space Telescope. The in-space optical measurements performed by the TCSE offer the unique opportunity to perform a trend analysis on the performance of materials in the space environment.

Trend analysis of flight data provides the potential to develop an empirical prediction model for some of the thermal control surfaces. For material research, trend analysis of the TCSE flight data can provide some insight into the damage mechanisms of space exposure.

The initial trend analysis for the TCSE samples has been limited to those materials that were not significantly eroded by the atomic oxygen (AO) environment. The performance of several materials on the LDEF mission was dominated by AO effects. This is particularly true for unprotected A276 and Tedlar where the AO eroded away the surface layers faster than they were degraded by Solar UV. This resulted in a fresh surface with unchanged or slightly improved optical properties. These coatings on the LDEF trailing edge suffered severe degradation of solar reflectance.

Preliminary analyses have been performed on the following five materials:

- Z93 White paint
- S13G/LO White Paint
- Chromic Acid Anodize
- A276 White Paint/RTV670 Clear Overcoat
- A276 White Paint/OI650 Clear Overcoat

These analyses were performed on the solar absorptance (α_S) values calculated from detailed spectral reflectance data taken in space and in ground pre-flight and post-flight measurements. Several standard regression analyses were tried including polynominal, exponential, logarithmic and power. In all cases the power regression analysis provided a better fit of the experimental data. The power regression line takes the form:

$$\alpha_S = \varepsilon^{(a + b \ln(t))}$$

Figures 3 through 7 show the results of the regression analysis on the five materials.

For Z93 there appear to be at least two mechanisms affecting the Z93 solar absorptance for the LDEF mission (see Figure 3). The first is an improvement (decrease) in α_S typical of silicate coatings in thermal vacuum. This improvement is normally associated with loss of water from the ceramic matrix. In ground simulation tests this process takes a much shorter time than the TCSE flight data suggests. This slower loss of water may be due to the cold temperature of the TCSE Z93 sample mounted on a thermally isolated calorimeter. The temperature of the Z93 sample ranged from approximately -55°C to + 6°C but remained well below 0°C most of the time.

The short term improvement is dominant for the first year of exposure after which a long term degradation becomes dominant. The log/log plot of the Z93 data and the regression analysis projects a 30 year end-of-life value of $\alpha_S = 0.185$. This predicted value is statistically a most likely value and not a worse case value.

An analysis of the S13G optical data also suggests more than one damage mechanism. The power regression analysis shown in Figure 4 of the S13G data (except for the pre-flight point) provides a good fit of the data. Degradation from competing mechanisms appears different during the first six months of exposure compared to the last twelve months. The regression model predicts a 30 year end-of-life value of 0.61 for S13G/LO.

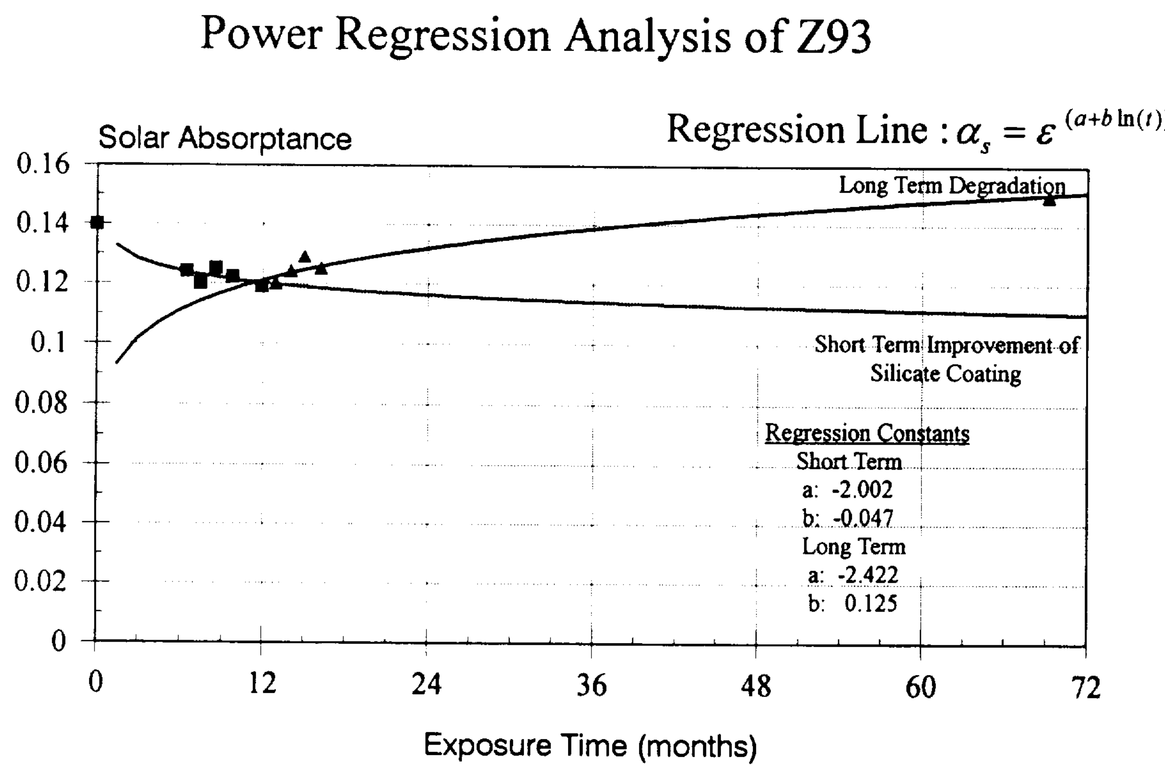
There were two thick chromic acid anodize samples on the TCSE active sample array. Solar absorptance values for the two samples tracked closely for the early part of the LDEF mission as shown by the TCSE in-space data shown in Figure 5. When the TCSE batteries were exhausted (at 19.5 months) the sample carousel stopped at a position where one of the samples was protected from further direct environmental exposure for the remaining duration of the LDEF mission. For the protected sample the post-flight α_S is plotted at the 19.5 month point. The anodize sample that was exposed for the entire mission had a mottled, washed out appearance suggesting a different damage mechanism occurring late in the mission. This is in contrast to the post-flight data that shows only a small degradation. In-flight data during the complete LDEF mission would have explained this ambiguity. This data is an excellent example of how misleading only pre- and post-flight data can be.

The regression analysis provides a good fit of the anodize sample data and predicts 30 year end-of-life α_S values of 0.82 and 0.76. As the predicted values approach $\alpha_S = 1.0$, the power regression model should fail, so these values may be somewhat high.

There were two samples of Chemglaze A276 polyurethane white paint with AO protective overcoats flown on TCSE. The protective overcoats were RTV670 and OI650. The regression analysis of the A276/RTV670 data shown in Figure 6 provides a good fit. However the power regression analysis of the A276/OI650 data provides a poor fit of the flight and post-flight measurements. This suggests a different degradation mechanism or combination of mechanisms for this coating; thus, it is not a surprising result considering the combining of completely different materials and the complexity of the environment.

These preliminary results from the trend analysis offer the potential of an empirical performance prediction model for some thermal control surfaces. Care must be exercised in use of empirical models in general and especially from this preliminary study. Log/log plots of experimental data can be misleading but are useful to examine the possibility of trends and the potential of an empirical model.

This analysis was performed on solar absorptance data. Solar absorptance is not a basic material property but an integrated value calculated using spectral reflectance data. This analysis will be extended to the detailed spectral reflectance data which should provide more insight into damage mechanisms for these materials.



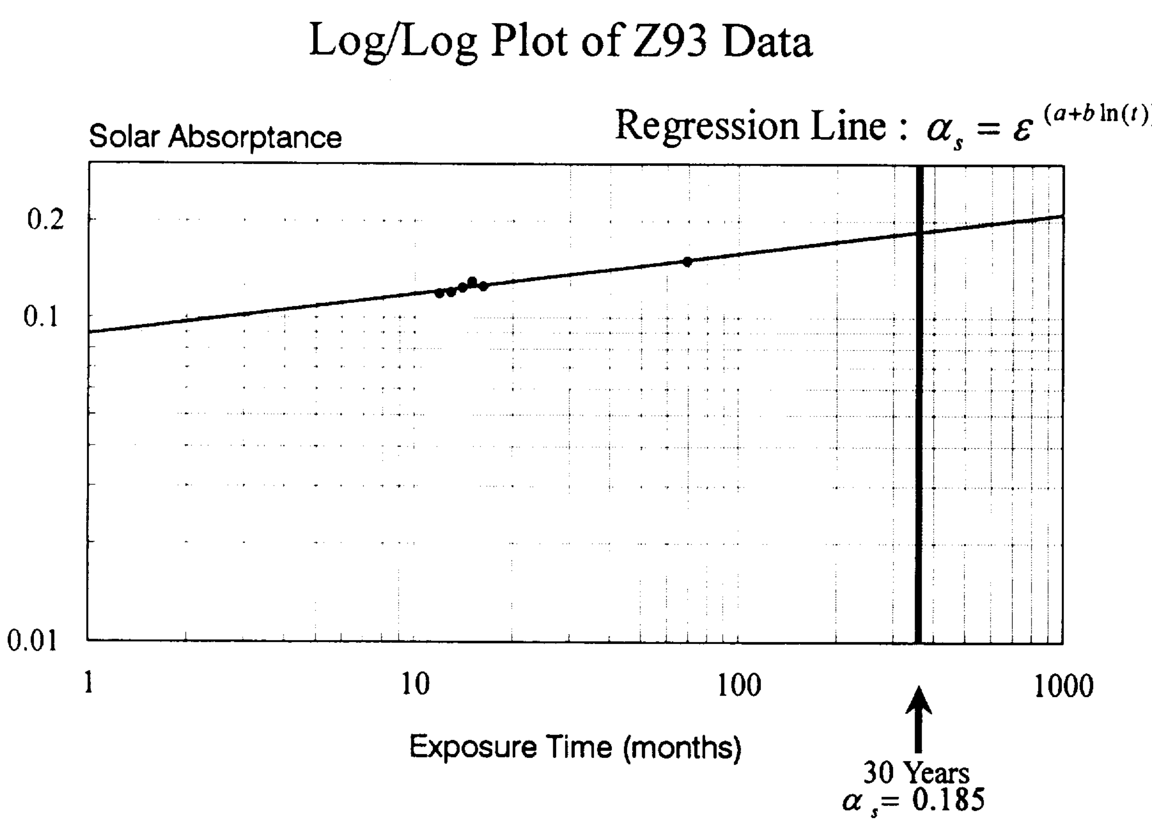
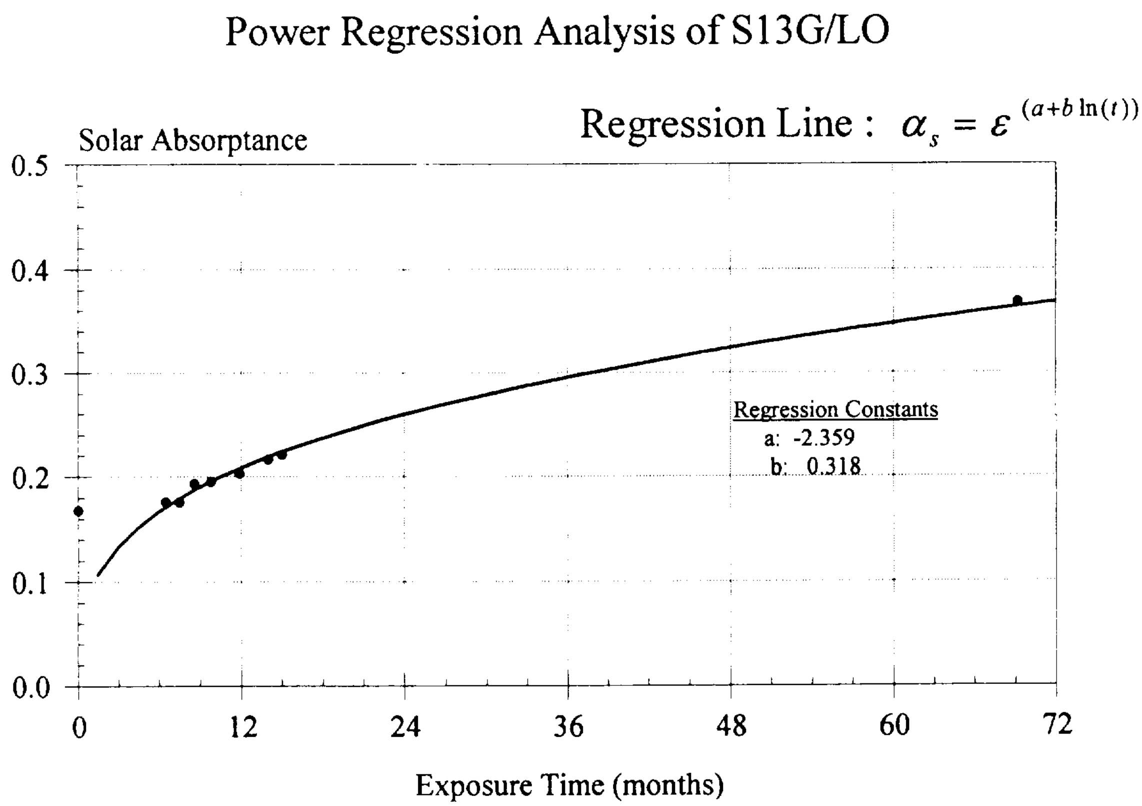


Figure 3. Degradation Rate Study of Z93



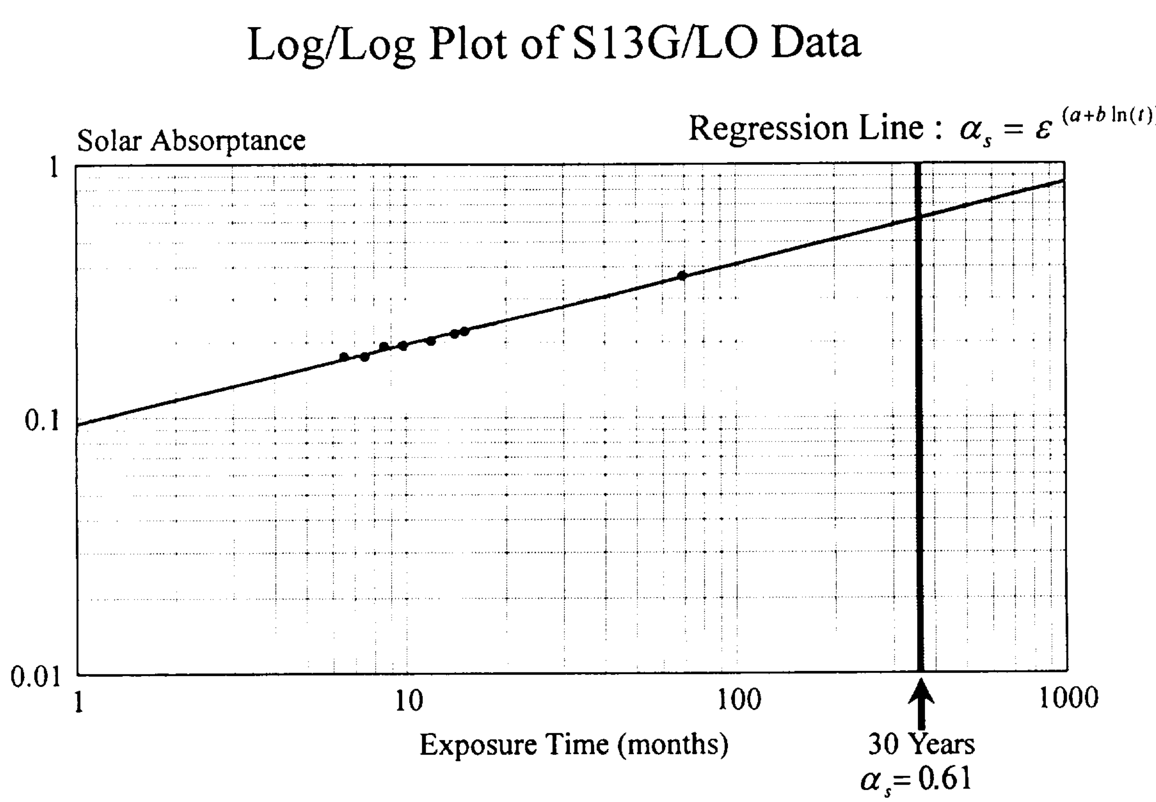


Figure 4. Degradation Rate Study of S13G/LO

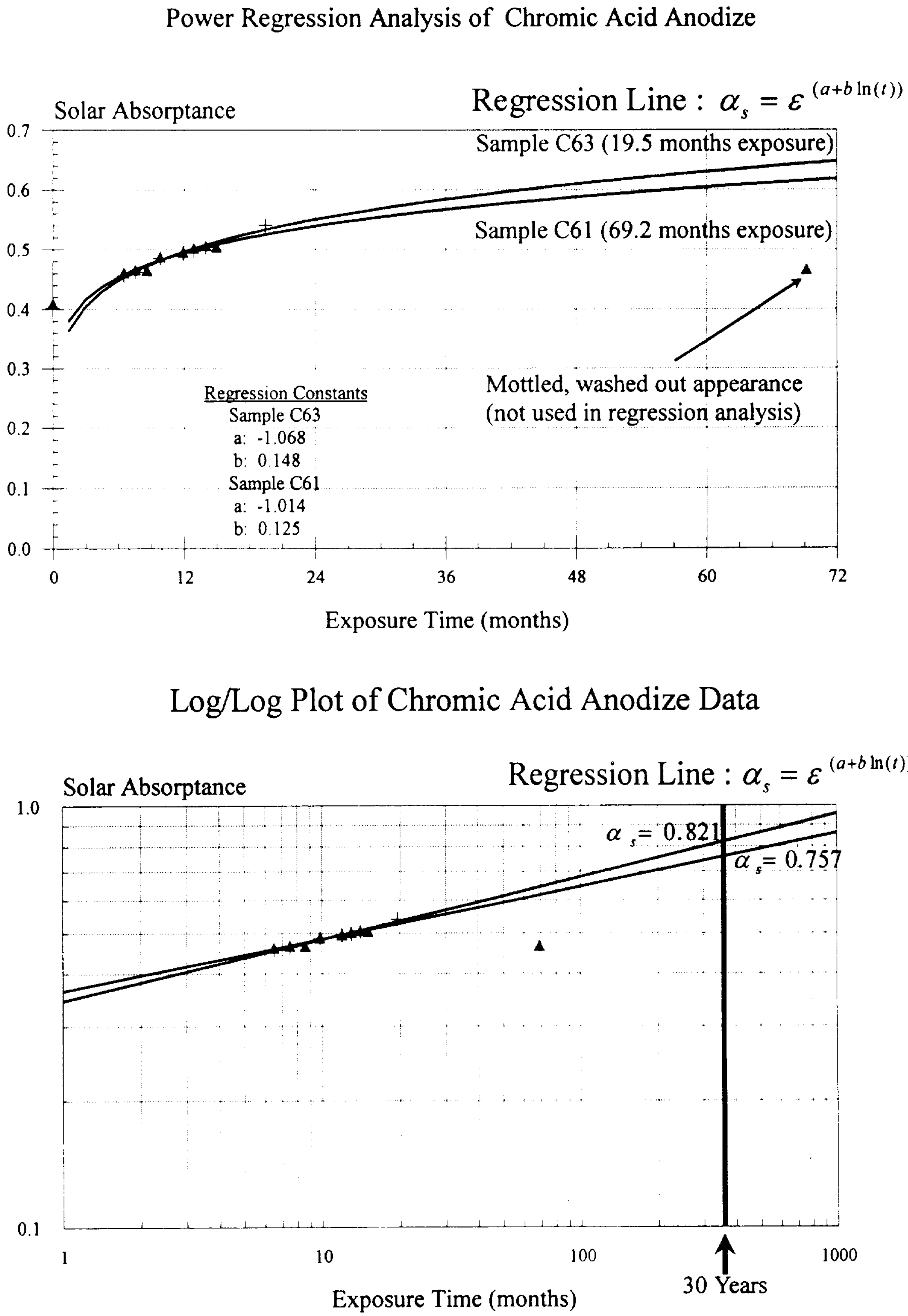


Figure 5. Degradation Rate Study of Chromic Acid Anodize

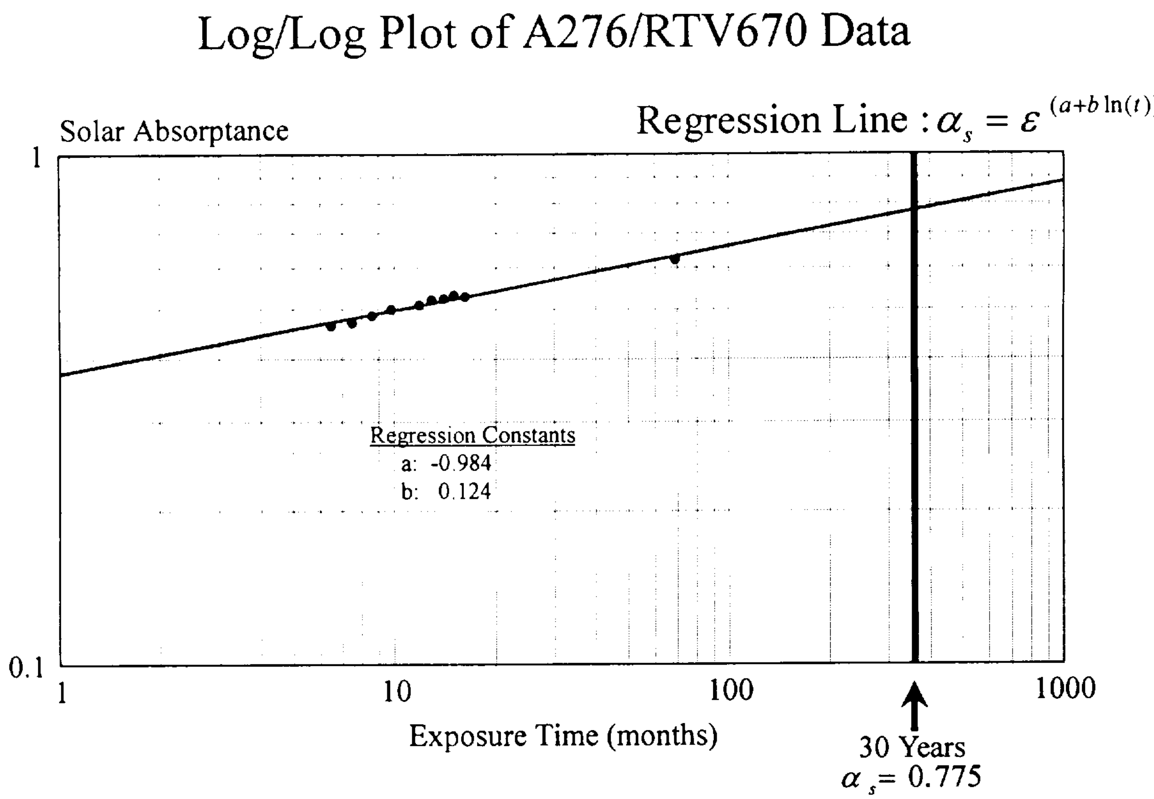


Figure 6. Degradation Rate Study of A276/RTV670 Data

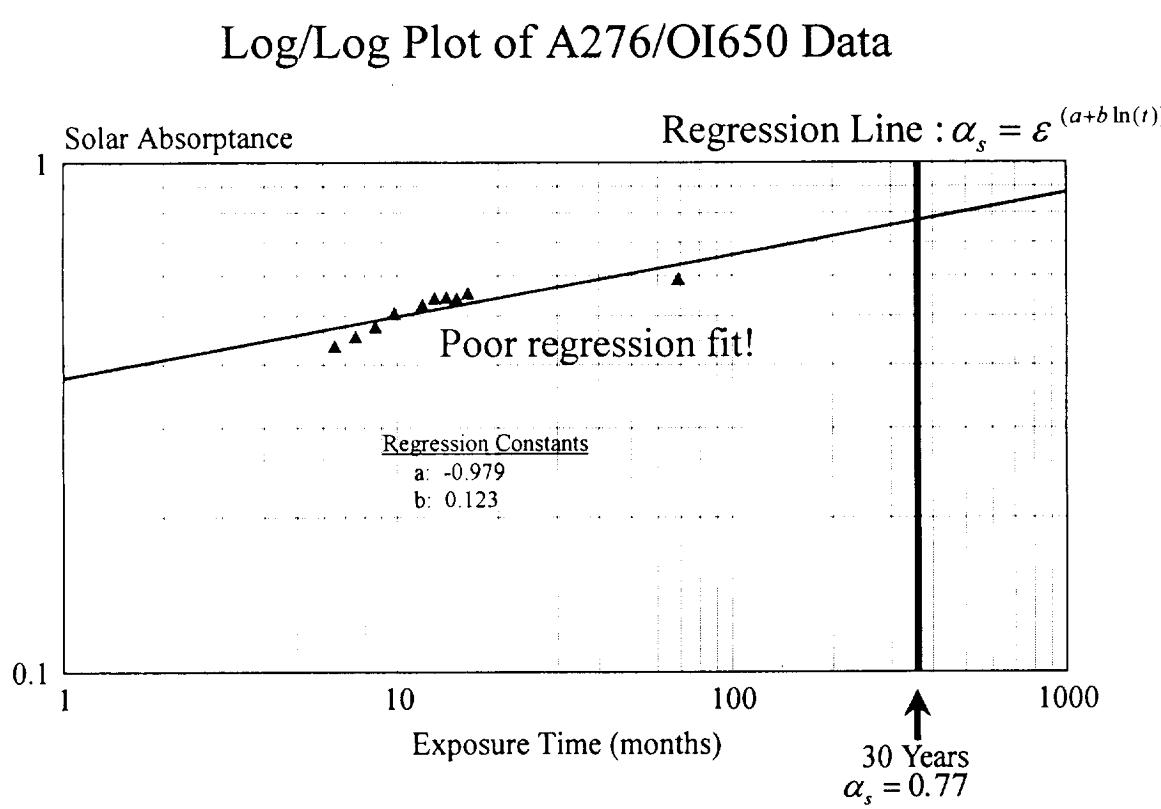


Figure 7. Degradation Rate Study of A276/OI650 Data

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