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Modified Truncated Cone Target Hyperthermal Atomic Oxygen Test Results

J.A. Vaughn, R.R. Kamenetzky, and M.M. Finckenor
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AO	atomic oxygen
AOBF	Atomic Oxygen Beam Facility
BRDF	bidirectional reflectance distribution function
CR	contrast ratio
ESH	equivalent Sun hours
HeNe	helium-neon
MSFC	Marshall Space Flight Center
MTCT	modified truncated cone target
UV	ultraviolet
VUV	vacuum ultraviolet

TECHNICAL MEMORANDUM

MODIFIED TRUNCATED CONE TARGET HYPERTHERMAL ATOMIC OXYGEN TEST RESULTS

1. INTRODUCTION

The modified truncated cone target (MTCT) is a docking target planned for use on the *International Space Station*. The current design consists of aluminum treated with a black dye anodize, then crosshairs are laser etched for a silvery color, as shown in figure 1. In this study, three samples of the material were exposed to laboratory simulation of orbital atomic oxygen (AO) and vacuum ultraviolet (VUV) radiation to determine if significant degradation might occur. Performance was defined by the optical properties, specifically the contrast ratio (CR) between the black and white/silver areas of the target.

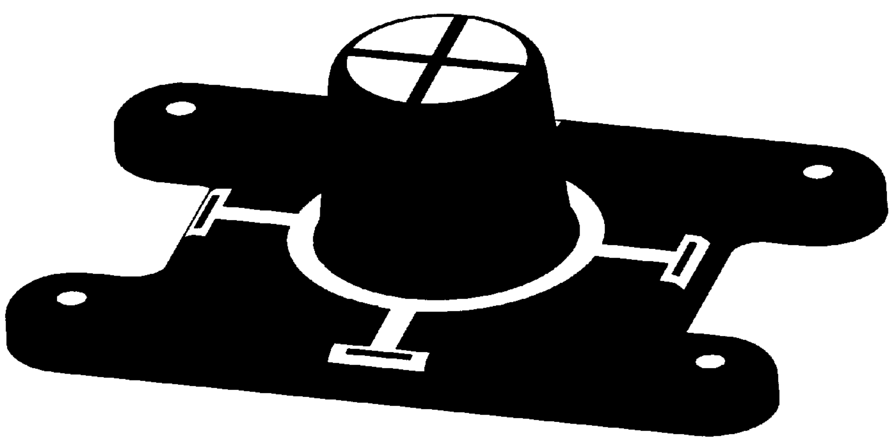

Figure 1. Modified truncated cone target.

AO is produced by the interaction of molecular oxygen and ultraviolet (UV) radiation. At a typical orbital velocity of 8 km/sec (18,000 mi/hr), AO impacts the surface of a spacecraft with an energy of ≈5–7 eV, causing erosion and oxidation damage to exposed materials. In this study, simulated orbital AO was produced in the Marshall Space Flight Center's (MSFC's) Atomic Oxygen Beam Facility (AOBF).[1] VUV radiation, primarily at the 130-nm wavelength, was produced along with the AO.

The samples were characterized prior to any AO or VUV exposure. Periodically, the AO exposure was halted, the samples were removed from the AOBF, and the optical properties measured. By taking measurements in increments, we may extrapolate to the 15-yr exposure in the ram direction in low-Earth orbit.

2. TEST SETUP

A previous study of black-dye anodized aluminum at MSFC[2] indicated no significant change in appearance or optical properties when exposed to 5-eV AO for a fluence of 6.8×10^{20} atoms/cm^2 and ≈8,000 equivalent Sun hours (ESH) VUV. For a sample protected from AO but exposed to the VUV, solar absorptance decreased 2.4 percent, while infrared emittance was unchanged. LeVesque et al.[3] reported visible bleaching of their black anodic coating on 7075–T73 clad, but not on 7075–T6 or 7075–T7351 clad.

The AOBF, shown in figure 2, generates plasma by a 2.45-GHz, 2-kW r-f field that is confined by a 4-kG magnetic field to increase the flux. Any ions are neutralized by collision with a metal plate. The AOBF is tunable from 3 to 20 eV energy and can produce an AO flux of approximately 10^{16} atoms/cm^2/sec with a 5-percent duty cycle. For this study, the AOBF was tuned to produce a 5-eV AO beam, and the planned exposure was a cumulative fluence of 7.5×10^{21} atoms/cm^2. The samples received between 7.6×10^{21} and 1.4×10^{22} atoms/cm^2, depending on their location in the test chamber.

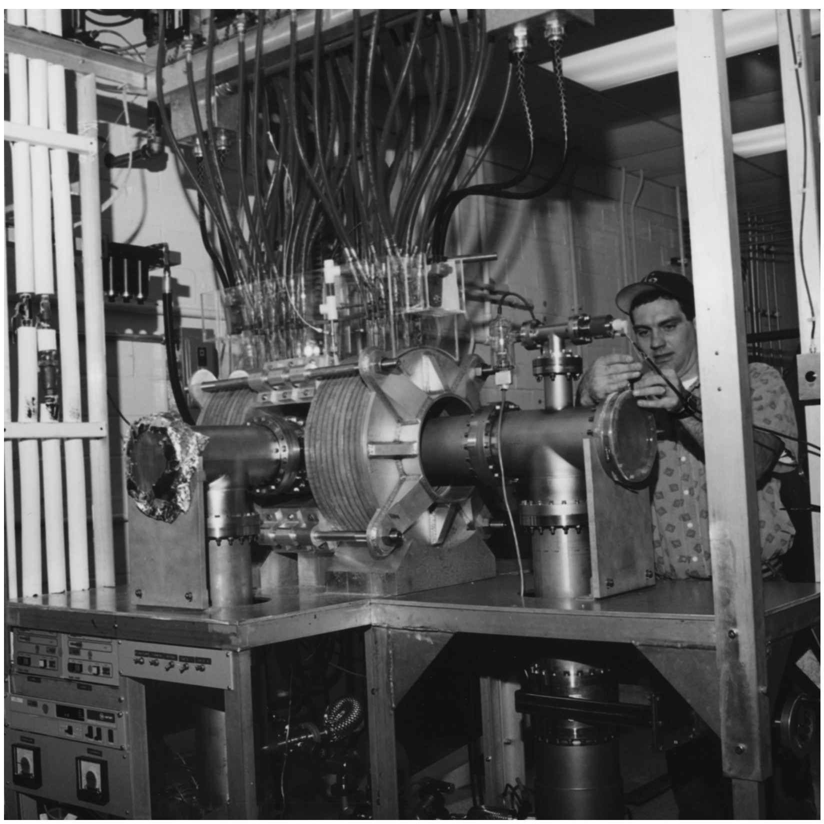

Figure 2. MSFC's Atomic Oxygen Beam Facility.

Electromagnetic radiation is produced during the dissociation and ionization process of AO plasma production. The primary radiation line is 130 nm, the AO resonant peak in the VUV region. An exposure of 3,000–4,000 ESH of VUV was requested. All three samples received 9,037 ESH VUV during the AO exposure.

Three samples were provided by Oceaneering Space Systems, Houston, Texas for this study. The aluminum alloy used was AL 6061–T6. The black-dyed anodize was performed by AaCron, Minneapolis, Minnesota, and then laser etched so that two-quarters of each sample were silvery white. This larger etched area made it easier to measure solar absorptance and infrared emittance. Samples 971MI060–1a and 971MI060–1b were clear alodined according to MIL–C–5541, type 1A; sample 971MI060–7b was not. These samples were placed in a test fixture along with Kapton® witness samples. Mass and thickness loss of the Kapton® samples were used to calculate the AO fluence, which was in general agreement with periodic AOBF beam current measurements during the exposure.

At $\approx 1\text{–}1.5 \times 10^{21}$-atoms/cm^2 intervals, the exposure was interrupted, and the samples were removed for optical property measurements.

3. TEST RESULTS

Bidirectional reflectance distribution function (BRDF) measurements were made on the samples using the TMA QwikScan™ scatterometer. BRDF is defined as the ratio of the luminance of the sample to its illuminance. Illumination is provided by a helium-neon (HeNe) laser (λ=632.8 nm), and reflected light is measured with one specular reflectance detector and eight diffuse reflectance detectors. The BRDF measurements were made with the sample at a 5-deg angle to the incident light, and the specular reflectance detector placed at 10 deg. The remaining eight detectors were placed at 2.5-, 10-, 20-, 30-, 45-, 55-, 65-, and 80-deg angles to the specular detector (see fig. 3).

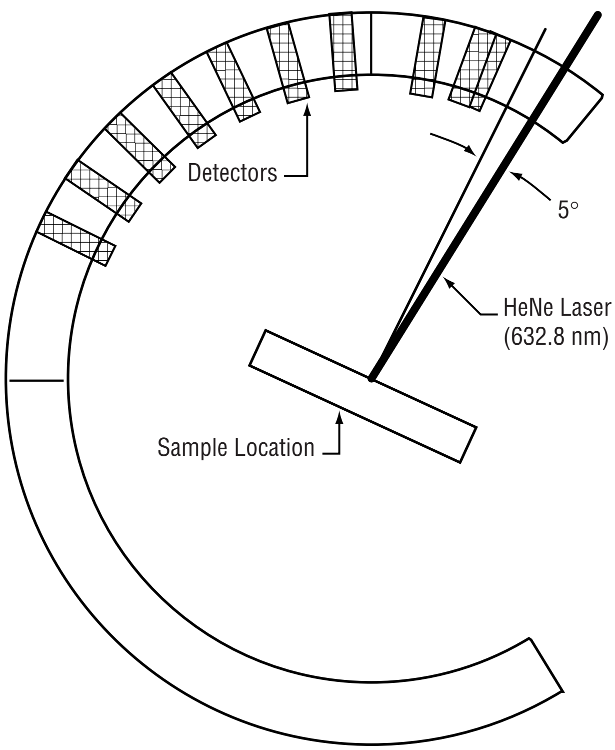

Figure 3. Setup to measure bidirectional reflectance distribution function.

The TMA QwikScan™ has the capability of a raster scan. The raster scans were performed with the sample at a 45-deg angle to the incident light, using only one detector normal to the sample (fig. 4). Each sample was raster scanned with a spot size of 2 mm and a step size of 1 mm. The QwikScan™ program then averaged all of the BRDF readings for a specific area. CR was calculated using the following formula:

$$CR = \frac{\text{Average BRDF (Silver area)} - \text{Average BRDF (Black area)}}{\text{Average BRDF (Black area)}} \quad . \qquad (1)$$

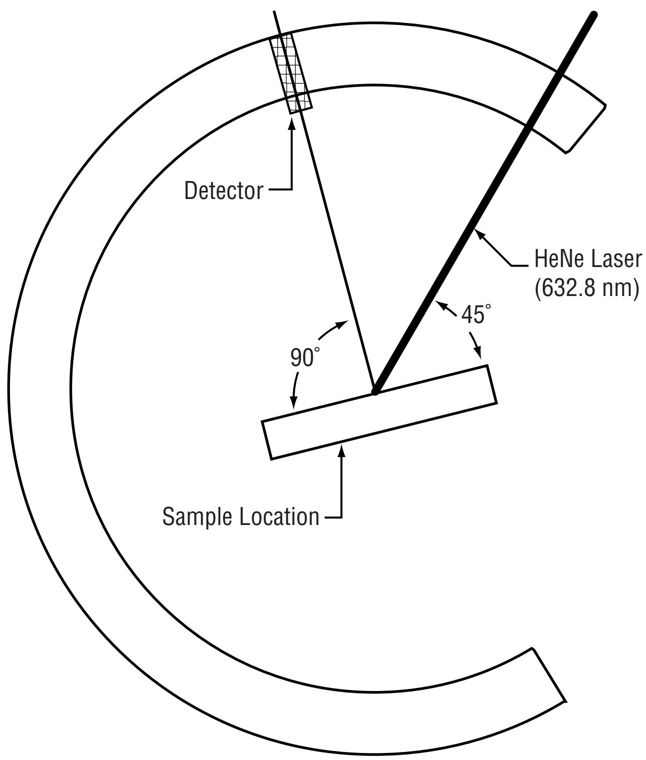

Figure 4. Setup to measure contrast ratio.

Tables 1 through 3 contain the BRDF data and CR for each interval of the AOBF exposure. The maximum BRDF numbers are from the 2.5-deg angle detector. It was noted that the CR of the alodined samples decreased after 4.6×10^{21} atoms/cm^2; the CR of the nonalodined sample did not appear to change significantly.

Solar absorptance and infrared emittance measurements were performed at the same intervals as BRDF measurements. Solar absorptance was measured using an AZ Technology laboratory portable spectroreflectometer, which measures total hemispherical reflectance from 250 to 2,500 nm. Solar absorptance increased for the white/silver areas of all three samples; visual inspection showed these areas to be slightly grayer. The increase in solar absorptance was 8–9 percent for the alodined samples and 5 percent for the nonalodined sample. The black areas did not appear to change. Infrared emittance was measured using an AZ Technology TEMP 2000 portable infrared reflectometer. No significant changes in infrared emittance were noted for any of the samples.

Table 1. AOBF exposure of sample 971MI060–1a.

Date	Total AO Fluence (atoms/cm^2)	Total VUV Exposure (W/cm^2)	ESH	CR	Max BRDF Black	Max BRDF White
5/6/97	0	0	0	8.0	0.0277	0.271
5/21/97	2.0×10^{21}	1.1×10^{-2}	1,615	9.0	0.0254	0.284
5/30/97	3.4×10^{21}	2.0×10^{-2}	2,916	8.6	0.0275	0.309
6/6/97	4.7×10^{21}	2.8×10^{-2}	4,063	8.3	0.0271	0.296
6/20/97	6.2×10^{21}	3.9×10^{-2}	5,509	6.5	0.0313	0.255
7/9/97	8.3×10^{21}	5.0×10^{-2}	7,146	6.6	0.0314	0.277
7/21/97	1.0×10^{22}	6.3×10^{-2}	9,037	6.3	0.0337	0.258

Table 2. AOBF exposure of sample 971MI060–1b.

Date	Total AO Fluence (atoms/cm^2)	Total VUV Exposure (W/cm^2)	ESH	CR	Max BRDF Black	Max BRDF White
5/6/97	0	0	0	8.8	0.0284	0.242
5/21/97	1.5×10^{21}	1.1×10^{-2}	1,600	9.8	0.0261	0.271
5/30/97	2.5×10^{21}	2.0×10^{-2}	2,916	9.4	0.0270	0.290
6/6/97	3.5×10^{21}	2.8×10^{-2}	4,063	9.3	0.0258	0.266
6/20/97	4.6×10^{21}	3.9×10^{-2}	5,509	7.8	0.0285	0.230
7/9/97	6.1×10^{21}	5.0×10^{-2}	7,146	8.0	0.0269	0.235
7/21/97	7.6×10^{21}	6.3×10^{-2}	9,037	7.8	0.0275	0.229

Table 3. AOBF exposure of sample 971MI060–7b.

Date	Total AO Fluence (atoms/cm^2)	Total VUV Exposure (W/cm^2)	ESH	CR	Max BRDF Black	Max BRDF White
5/6/97	0	0	0	8.4	0.0277	0.315
5/21/97	2.7×10^{21}	1.1×10^{-2}	1,600	9.4	0.0255	0.350
5/30/97	4.5×10^{21}	2.0×10^{-2}	2,916	9.2	0.0276	0.361
6/6/97	6.3×10^{21}	2.8×10^{-2}	4,063	9.7	0.0282	0.354
6/20/97	8.4×10^{21}	3.9×10^{-2}	5,509	9.3	0.0317	0.336
7/9/97	1.1×10^{22}	5.0×10^{-2}	7,146	9.4	0.0282	0.342
7/21/97	1.4×10^{22}	6.3×10^{-2}	9,037	9.2	0.0254	0.318

4. CONCLUSIONS

It is desirable to keep the CR of the MTCT at ≥8 for optimum performance of the automated docking system. The CR of sample 971MI060–1a decreased to 6.3, sample 971MI060–1b decreased to 7.8, and the nonalodined sample 971MI060–7b kept a good CR of 9.2. Processing parameters need to be considered before a final material selection.

Degradation of optical properties appeared to level off after an initial period of exposure of 4.6×10^{21} atoms/cm^2. This is in agreement with previous studies of dyed anodized aluminum exposed to AO and VUV.

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The modifed truncated cone target is a docking target planned for use on the *International Space Station*. The current design consists of aluminum treated with a black dye anodize, then crosshairs are laser etched for a silvery color. Samples of the treated aluminum were exposed to laboratory simulation of atomic oxygen and ultraviolet radiation to determine if significant degradation might occur. Durability was evaluated based on the contrast ratio between the black and silvery white areas of the target. Degradation of optical properties appeared to level off after an initial period of exposure to atomic oxygen. The sample that was not alodined according to MIL–C–5541, type 1A, performed better than alodined samples.

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