Space Environmental Effects on Coated Tether Materials

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The University of Alabama in Huntsville's Propulsion Research Center has teamed with NASA's Marshall Space Flight Center (MSFC) to research the effects of atomic oxygen (AO) bombardment on coated tether materials. Tethers Unlimited Inc. has provided several candidate tether materials with various coatings for AO exposure in MSFC's Atomic Oxygen Beam Facility. Additional samples were exposed to ultraviolet (UV) radiation at MSFC. AO erodes most organic materials, and ultraviolet radiation embrittles polymers. This test series was performed to determine the effect of AO and UV on the mechanical integrity of tether materials that were treated with AO-protective coatings, such as polyhedral oligomeric silsesquioxane (POSS) or metallization. Both TUI's Multi-Application Survivable Tether (MAST) Experiment and Marshall Space Flight Center's Momentum Exchange Electrodynamic Reboost (MXER) programs will benefit from this research by helping to determine tether materials and coatings that give the longest life with the lowest mass penalty.

I. Introduction

A space tether is best described as a physical connection between two orbiting bodies that allows for the transfer of momentum and/or energy. To date, approximately sixteen tether missions have flown, beginning with the Gemini XI mission in 1966,[1] which used tethers for artificial gravity experiments to the Tether Physics and Survivability (TiPS) mission launched in 1996,[2] to study the long term dynamics and survivability of a 4 km non-conductive tether in low Earth orbit.

Currently, there are two space tether missions being considered, researched and evaluated. The first of these missions is the Multi-Application Survivable Tether (MAST) Experiment,[3] proposed by Tethers Unlimited Inc., (TUI). The MAST mission consists of three one-kilogram satellites along a one kilometer Hoytether™. The main goal of this mission is to gather data on the long-term survivability of a Hoytether™ in low Earth orbit. The second tether mission being considered is the Momentum eXchange and Electrodynamic Reboost (MXER) Mission by NASA's Marshall Space Flight Center. The MXER tether system itself can be likened to a 100-120 km bolo in a highly elliptical Earth orbit. The MXER mission employs a slingshot-like momentum exchange to launch payloads into higher orbits and then regains the momentum by passing a current through the conductive portion of its tether. Both of these missions are designed to remain in low Earth orbit for an extended period of time, subjecting them to various hazards, including atomic oxygen and ultraviolet radiation.

Atomic oxygen is formed by the dissociation of oxygen molecules by vacuum UV radiation into free oxygen atoms. AO is the dominant species in low Earth orbit (LEO) from 200 to 700 km altitude and has a significant effect on most organic materials. This is due to the fact that polymeric materials contain many C-H and C-C bonds which

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require only 4.29 eV and 3.59 eV[5] respectively to break. The spacecraft's orbital velocity of approximately 7.8 km/s translates to being bombarded by AO with an energy level of approximately 5 eV[6]. Mass loss of polymers and composite materials due to AO erosion is well-documented[7-9]. Protective coatings are needed to maintain the mechanical integrity of tether materials, particularly if the mission is in low Earth orbit and is long duration.

There are several criteria that an AO resistant coating must meet in order to be used in orbit. These criteria include low weight penalty, high flexibility, abrasion resistance, UV radiation tolerance, and durability in thermal cycling. There are numerous possibilities for tether coating material, however, past experiments[7, 10-12] with polymeric material and new developments in coating technology have greatly assisted in narrowing the choices for the best tether material and coating combination.

II. Tether Materials and Coatings

A number of candidate fibers and coatings were selected for AO exposure. Spectra 2000 from the Honeywell Corporation, composed of ultra-high molecular weight polyethylene (UHMWPE), was coated with Photosil for this test. Samples of Spectra 2000 coated with Photosil were in the form of 130 denier strand and 4 x 130 denier braid 18.14 kg (40 lb.) test Spiderwire.

The second sample set was Zylon coated with Photosil. Zylon is composed of poly(p-phenylene-2,6-benzobisoxazole)(PBO) and is trademarked by the Toyobo Co. Ltd. Samples of Zylon coated with Photosil were in the form of 1000 denier strand and 3 x 1000 denier braid. Tensile data for the Spectra and Zylon strand samples coated with Photosil were previously reported in reference 13.

Photosil is a coating developed and trademarked by Integrity Testing Laboratories, Inc. which incorporates silicon-containing functional groups into the top micron of an organic material. This coating is applied in a three-step process such that a graded transition region is formed from the surface, allowing the material to survive the cracking caused by thermal cycling and handling of the material. It has been shown to reduce reactivity to AO with polyurethane- and epoxy-based thermal control coatings[14]. Originally the Photosil process was designed to mask flat materials such as thermal blankets and has just recently been applied to rougher, curved objects such as braids and strands of tether materials[15].

The third sample set was 250 denier strand Zylon metallized with nickel. The nickel coating was deposited in a 1μm thick layer onto each Zylon fiber through a multi-step process developed by Tethers Unlimited. Whereas nickel does have the ability to withstand AO attack, there are some concerns that thermal cycling may cause the nickel coating to crack because of the difference in the coefficient of thermal expansion between nickel and Zylon. Also, because nickel is a ferromagnetic material, there is concern that the interaction between the earth's magnetic field and the nickel material could produce an effect that is not yet well understood.

The fourth sample set was Zylon coated with 6% Triton Oxygen Resistant – Low Modulus (TOR-LM) polymer. TOR-LM was developed by Triton Systems, Inc. and is based on the polyarylene ether benzimidazoles class of polymers. TOR polymer films have been previously exposed in the AOBF[16] and have flown on the Passive Optical Sample Assembly (POSA) – I experiment on the space station *Mir*[17]. A variant of TOR called TOR-BP was tested as a tether coating for the ProSEDS mission[18]. These samples included 3 x 2943 braid and a Hoytether with coated and uncoated Zylon tows.

The fifth sample set was PBO fiber coated with 10% mono-OH polyhedral oligomeric silsesquioxane (POSS). POSS is a complex copolymer that contains Si-O bonds. During an initial mass loss period, the surface-exposed organic groups are lost and silicon and AO react to form SiO_2. Previous tests of POSS on Kapton film[19] indicated the coating's viability as an AO-resistant coating. The samples consisted of 20 fibers twisted together at 2 turns/cm.

The sixth sample set was Magellan Systems International M5 fiber, made of the polymer poly{2,6-diimidazo[4,5-b:4',5'-e]pyridinylene-1,4(2,5-dihydroxy)phenylene} (PIPD). PIPD was originally developed by Akzo Nobel Central Research in the Netherlands[20]. The M5 samples, similar to the PBO/POSS samples, were 20 fibers twisted together at 2 turns/cm.

To prepare the samples for testing, each was knotted twice before cutting to prevent loss of any of the strands. Samples ranged from fifteen to twenty centimeters in length, depending on how much material was available. To ensure that none of the materials were hydroscopic, each was placed into a vacuum chamber and brought to 50 millitorr and then immediately removed and weighed with readings being taken every minute for five minutes. Regression analysis to time zero was then used to eliminate any water weight gain. The samples were also photographed before exposure to simulated space environment.

Figure 1. Atomic Oxygen Beam Facility at the Marshall Space Flight Center.

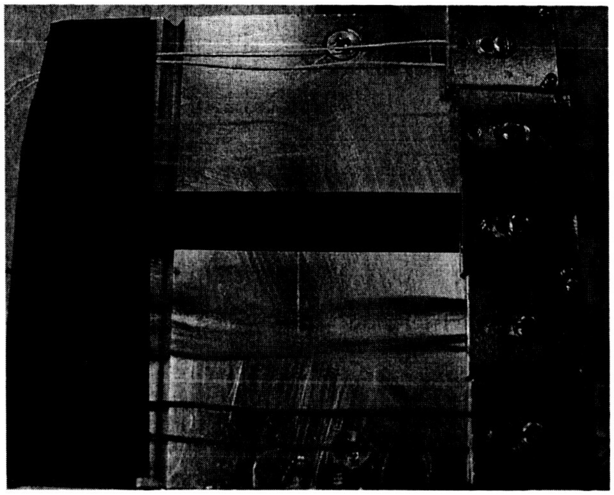

Figure 2. Test Fixture.
(Shown top to bottom) Spectra braid with Photosil, Spectra strand with Photosil, Kapton calibration strip, Zylon strand with Photosil, and Zylon braid with Photosil.

III. Space Environment Simulation

AO and UV radiation tests were performed at MSFC. The Atomic Oxygen Beam Facility (AOBF) (fig. 1) generates a neutral beam of AO at 5 eV, closely approximating low Earth orbit AO. Samples exposed to AO are also exposed to vacuum UV radiation of 130 nm wavelength in the AOBF. An AO flux of approximately 5×10^{15} atoms/cm^2/s is produced by the AOBF in a pulsed fashion. A calibration run of all Kapton samples was performed prior to exposing any tether samples. There is variation of the AO beam across the sample holder, which precisely measured before each test and change in configuration, using this method. A Kapton witness sample is always placed in the center of the test fixture, and the ratio of AO flux of the witness sample to each sample slot is measured. Kapton was used as a witness material because its AO reactivity is a well known value and is highly reproducible in the AOBF.

Tether samples were loaded onto the AO test fixture (fig. 2) and placed into the AOBF with a Kapton witness sample for varying lengths of time up to a maximum exposure of approximately 3×10^{21} atoms/cm^2. After each exposure, the materials were photographed, removed from the testing fixture and weighed. The Kapton witness sample was first vacuum dehydrated because of its hydroscopic nature and then weighed over a period of five minutes. From the AOBF beam current and time of exposure, corroborated with Kapton mass loss, a value for the fluence in the AOBF can be found.

Tether samples were also exposed in one of MSFC's Ultraviolet Radiation Test Chambers (fig. 3) for a minimum of 500 equivalent sun-hours (ESH) of UV radiation ranging in wavelength from 250 to 400 nm in a vacuum of 10^{-6} torr or better. A water filter is used to minimize infrared heating of the samples. More details of the AO and UV facilities may be found in reference 21.

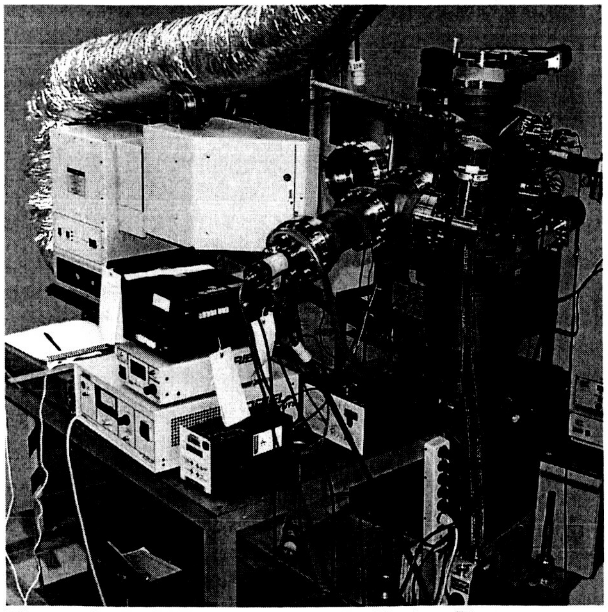

Figure 3. MSFC Ultraviolet Radiation Test Chamber.

After simulated space exposure, the samples were taken to the Mechanical Properties Test Lab where an Instron mechanical test machine was used to determine tensile strength. To prepare for the testing, the ends of each sample were doped with Phillystran Socketfast® Blue or Adhesive Systems cyanoacrylate to allow the Instron to better grab and pull the tether sample.

IV. Results

A. Spectra-Photosil

It should be noted that only a small amount of coated tether material was available for testing. While preparing the samples for tensile testing, multiple samples of uncoated Spectra and Zylon were tested in the Instron mechanical test machine to ensure that the alignment and preparation of the Photosil samples would be correct. In doing this, data was gathered on the maximum tensile load for each uncoated sample. When the control samples for each group were pulled, a discrepancy was found between the maximum tensile strength of the coated and uncoated fibers. One explanation for the decrease in tensile strength could be the additional handling of the samples, particularly the fine Spectra strand of only 130 denier. As testing progressed, evidence pointed towards UV effects, as the braids had better sample integrity but still showed a significant drop in maximum tensile load. Table 1 contains the mass loss and maximum tensile load data for the Spectra-Photosil braid samples.

Table 1. Test Results for Spectra-Photosil Braid

Sample	AO Fluence atoms/cm^2	% Mass Loss	Maximum Tensile Load N (lbf)
Control – Uncoated	0	0	134.66 (30.27)
Control – Photosil	0	0	90.37 (20.32)
UV	0	0	69.21 (15.56)
AO-A	2.80E+20	1.41%	54.93 (12.35)
AO-B	6.06E+20	3.48%	62.70 (14.09)
AO-C	1.07E+21	3.69%	50.90 (11.44)
AO-D	9.70E+20	4.19%	52.32 (11.76)
AO-E	2.92E+21	13.84%	0.34 (0.08)

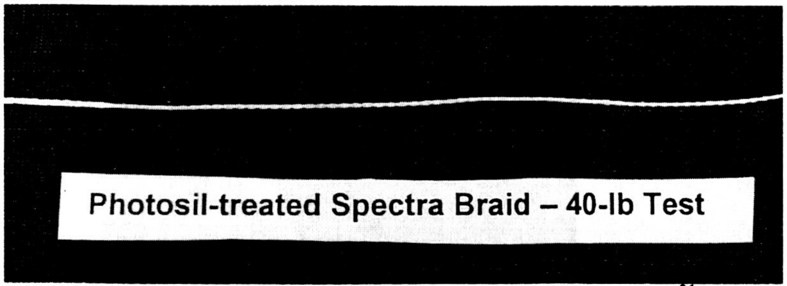

Figure 4. Spectra-Photosil Braid after exposure to 1.07 x 10^{21} atoms/cm^2 AO fluence.

Because the exact density of the Spectra-Photosil is not known, the AO reactivity can only be approximated. It is possible, however to estimate the AO reactivity by using the following equation:

$$R_e = \frac{\Delta m}{\rho * F * A} \qquad (1)$$

where ρ, in this case, is the density of uncoated Spectra. By performing these calculations and comparing the reactivity data to that for uncoated Spectra it was found that the Photosil was able to lower the AO reactivity by a factor of 5. The AO reactivity for uncoated Spectra[7] is 4.8x10^{-24} cm^3/atom whereas the reactivity for braided Spectra coated with the Photosil was found to be 0.93x10^{-24} cm^3/atom and the AO reactivity for Spectra-Photosil strand was calculated to be 1.2x10^{-24} cm^3/atom. While the Photosil offered some AO protection, the decrease in tensile strength from the coating process is problematic. A decrease of at least an order of magnitude in the AO reactivity is desired for a long duration tether mission such as MXER.

B. Zylon-Photosil

Based on mass loss and appearance, it was concluded that the Zylon strands had received an uneven coating of Photosil. A sample of stranded Zylon-Photosil receiving 9.83×10^{20} atoms/cm^2 of AO eroded completely through, while a sample receiving the same AO exposure remained intact. This latter sample was further exposed to a total of 2.04×10^{21} atoms/cm^2 and still had a few strands holding it together. AO reactivity calculations for the Zylon strand samples ranged from 3.0 to 9.3×10^{-24} atoms/cm^2. The Zylon-Photosil braids (fig. 5) fared better and demonstrated more consistent AO reactivity. AO reactivity for the Zylon-Photosil braids was calculated to be 1.7×10^{-24} cm^3/atom. The samples also looked slightly bleached by the AO exposure.

Zylon is apparently more sensitive to UV effects than Spectra. Mass loss and maximum tensile load data for the Zylon-Photosil braid samples can be found in Table 2. During tensile testing, all samples failed in the gage section. In the case of the Zylon-Photosil braid, we had assumed that the uncoated tether material would suffice for control samples and exposed all of the material to AO or UV rather than omit a Zylon-Photosil braid from a step in the test procedure. Given the 29% drop in strength for the UV-exposed braid, we can assume that an unexposed coated braid sample would have exhibited significantly less tensile strength than uncoated braid.

Table 2. Test Results for Zylon-Photosil Braid

Sample	AO Fluence atoms/cm^2	% Mass Loss	Maximum Tensile Load N (lbf)
Control – Uncoated	0	0	385.9 (86.75)
UV	0	0	274.3 (61.66)
AO-A	3.17E+20	0.82%	312.9 (70.35)
AO-B	5.58E+20	1.55%	262.5 (59.02)
AO-C	1.00E+21	2.28%	229.4 (51.57)
AO-D	1.16×10^{21}	2.58%	249.92 (56.18)
AO-E	3.04×10^{21}	7.11%	156.30 (35.14)

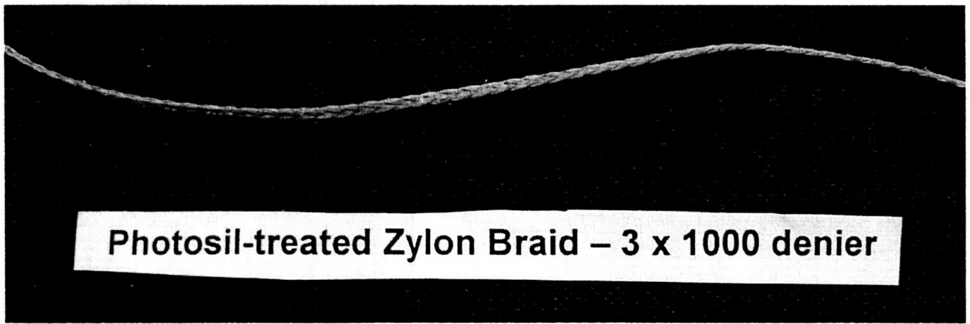

Figure 5. Zylon- Photosil braid after exposure to 1.00×10^{21} atoms/cm^2 AO fluence.

C. Zylon-Nickel

Zylon strands with nickel coating (fig. 6) had only small changes in mass after exposure in the AOBF, with two samples gaining weight. This weight gain may be due to slight inaccuracies in weighing, or possibly formation of nickel oxide. For the samples that lost weight, the AO reactivity was calculated to be 0.88×10^{-24} cm^3/atom.

The other point that needs to be addressed is the strength "gain" between samples AO-D and AO-E. Several theories can explain this gain as no more than an anomaly. The first possible cause is that this sample simply received better coating than the other ones. This cause is unlikely because the samples were all cut from the same spool and therefore came from the same treatment batch. The second, and more likely cause, is that the samples were damaged slightly during handling. While the greatest care was taken while handling the samples, there exists the definite possibility that individual strands were inadvertently broken or lost from the sample, even though the ends were tied to prevent just that. We recommend braided samples for future AO testing rather than strand samples.

Table 3. Test Results for Zylon®-Nickel

Sample	AO Fluence (atoms/cm^2)	% Mass Loss	Maximum Tensile Load N (lbf)
Control	0	0	42.47 (9.55)
UV	0	0	16.04 (3.61)
AO - A	6.120x10^{20}	6.39%	6.38 (1.43)
AO - B	7.319x10^{20}	1.29%	14.26 (3.21)
AO - C	1.275x10^{21}	1.62%	9.08 (2.04)
AO - D	1.186x10^{21}	-9.51%	6.39 (1.44)
AO - E	2.461x10^{21}	-2.96%	19.18 (4.31)

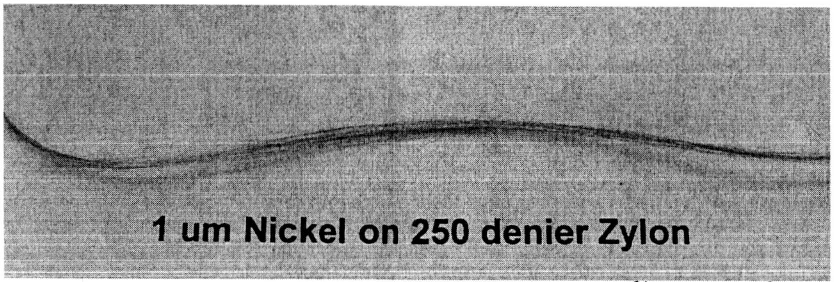

Figure 6. Zylon-Nickel strand after exposure to 1.27x10^{21} atoms/cm^2 of AO.

D. Zylon-6% TOR-LM

Constructed of 3 x 2,943 denier braid, the TOR-LM coated material naturally had a higher initial tensile strength. However, as table 4 illustrates, after only 518 hrs of UV exposure, the TOR-LM coated material had lost almost sixty percent of its initial strength. The other samples also lost a large portion of their initial strength after exposure to the AO and VUV. The AO-C sample decreased in strength from 1151 N to 554 N after being exposed to 1.1x10^{21} atoms/cm^2 of atomic oxygen and 768 ESH of concurrent vacuum UV radiation. The extreme reaction to the UV radiation suggests that the TOR-LM coating was not able to sufficiently protect the material from UV. This is especially true since earlier results from the Photosil-coated Zylon showed that Zylon reacted strongly to UV radiation. Furthermore, the AO-D sample received 1344 ESH of VUV radiation, which could account for its nearly eighty percent drop in tensile strength. It is difficult to say whether the AO also contributed to the strength loss. Figure 7 is of a typical TOR-LM coated Zylon braid, while figure 8 is that of a Hoytether which was braided with both TOR-LM coated and uncoated 2,943 denier Zylon material. The TOR-LM coated strands are marked by the three white arrows and can also be defined from the rest of the materials by their coherency and light tan color. The bleached yellow coloring and material fraying identify the uncoated, AO-eroded materials.

Table 4. Test Results for TOR-LM Coated Zylon

Sample	Session	AO Fluence (atoms/cm^2)	% Mass Loss	Maximum Tensile Load N (lbf)
AO-A (Control)		Unexposed	0	1511.05 (339.70)
UV		0	0	584.71 (131.45)
AO - B	1	7.487x10^{20}	1.28%	477.49 (107.34)
AO - C	1	5.80x10^{20}	1.31%	
	2	1.10x10^{21}	0.77%	554.23 (124.60)
AO - D	1	5.80x10^{20}	1.23%	
	2	1.10x10^{21}	1.45%	
	3	1.68x10^{21}	3.04%	326.58 (73.42)

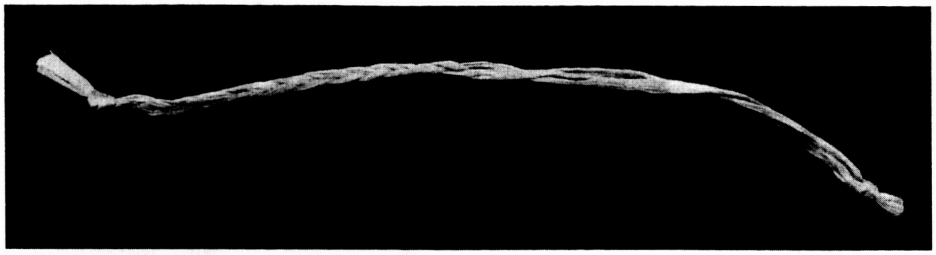

Figure 7. TOR-LM Coated Zylon®, AO-D, After Exposure to 1.10×10^{21} atoms/cm^2 of AO

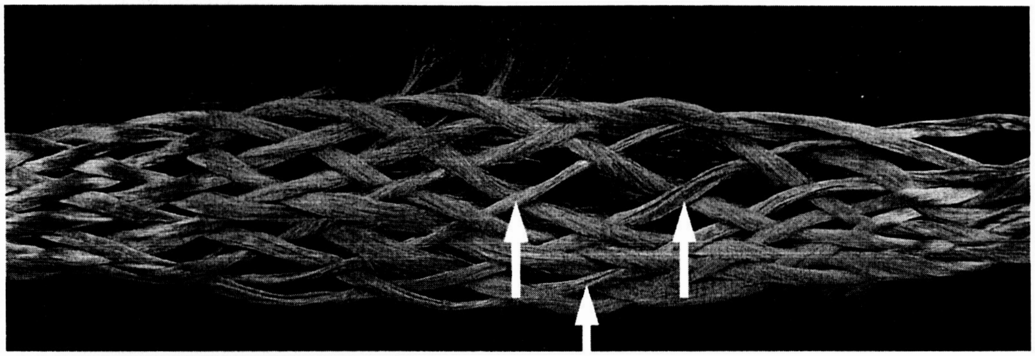

Figure 8. Hoytether, AO-C, after exposure to 1.07×10^{21} atoms/cm^2 of AO. Arrows indicate TOR-LM coated tows, remainder were uncoated.

E. PBO/POSS

The test regime for the Zylon®-POSS samples differed from the earlier tests because of the small amount of available material. Only two samples were supplied for testing, so tensile testing was not performed. The materials were tested by exposing them to several rounds at an AO fluence of 4.37×10^{20} atoms/cm^2. After each round, the samples were removed from the chamber and weighed, allowing the AO reactivity to be calculated. The fluence and mass changes were recorded in Table 5.

After the first round of exposure, significant mass loss was recorded in both samples. Based upon previous research[19], it was known that there would be an initial mass loss while the coating absorbed AO and began to build its protective layer but a mass loss of 9.44% was a matter of concern. As visual inspection of the sample in Figure 9 showed no noticeable fraying or color change, the materials were placed back in the chamber for another round of AO exposure.

After the second round of exposure, both samples had received a total of 8.26×10^{20} atoms/cm^2 atomic oxygen. They were taken out of the chamber and weighed with much more auspicious results. After this round of AO bombardment, AO-C lost only 0.85% of its mass while the AO-D sample lost only 0.29% of its mass. These results reaffirm the earlier assumptions of initial mass loss during the formation of the protective SiO_2 layer. At this point, it was decided to remove AO-C from the test cycle. AO-D was placed back in the AOBF for another round of AO bombardment.

By the third round of AO exposure, the AO-D sample had received a total of 1.438×10^{21} atoms/cm^2 of atomic oxygen. Upon weighing the material it was found that there had been a mass decrease of 5.56%. The reactivities for the AO-C and –D samples were calculated at 5.69×10^{-24} cm^3/atom and 12.28×10^{-24} cm^3/atom respectively. While this is a very high reactivity, the material held together extremely well over the entire test regime. In comparison, the AO-C Zylon®-Photosil™ strand sample had an AO reactivity of 9.35×10^{-24} cm^3/atom and it failed during handling after receiving 9.83×10^{20} atoms/cm^2 of AO.

Table 5. Test Results for Zylon®-POSS

Sample	Session	AO Fluence (atoms/cm^2)	% Mass Loss
AO-C	1	4.37×10^{20}	2.22%
	2	3.89×10^{20}	0.85%
AO-D	1	4.37×10^{20}	9.44%
	2	3.89×10^{20}	0.29%
	3	1.438×10^{21}	5.56%

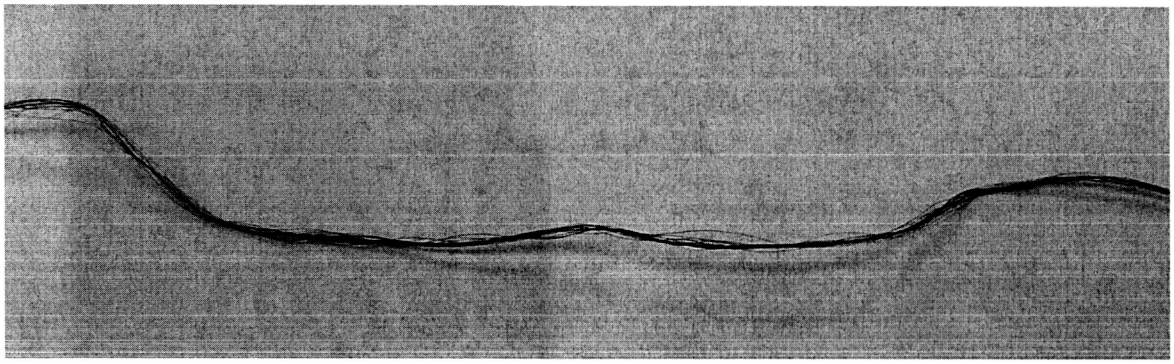

Figure 9. Zylon®-POSS, AO-C, After Exposure to 8.26×10^{20} atoms/cm^2 of AO

F. M5

Along with the TOR-LM and POSS samples, M5 was examined for its AO resistance and feasibility as a space tether. One thing that was immediately noticed about this material was its stiffness and brittleness. M5 is flexible and was bent into a circle of approximately six centimeters and looped into an overhand knot in order to fit it on the Mettler balance. This action was repeated several times over the course of the testing with no damage to the material. There is a point, however, at which the material ceases to bend and will crease and break. This unfortunately was the case when it was placed in the AOBF. Excess tether material is placed so that only a fixed length is exposed the AO beam. During the repeated testing and weighing cycles, the M5 materials were bent and began cracking and splitting (fig. 10). It should be noted however, that none of the cracking occurred along the AO exposed portion of the material. Further visual inspection of the exposed section revealed no tell tale marks that it had been exposed except for a very slight darkening.

Very little is known about this material's ability to resist atomic oxygen and judging from its chemical structure, the numerous carbon and hydrogen bonds should make it very susceptible to AO erosion. The AO reactivity was calculated to be 4.71×10^{-24} cm^3/atom for AO-C$_1$, 1.83×10^{-24} cm^3/atom for AO-C$_2$, 18.24×10^{-24} cm^3/atom for AO-D$_1$, and 32.93×10^{-24} cm^3/atom for AO-D$_3$. No fraying or cracking was evident in the exposed areas of the AO-C or AO-D samples

Table 6. M5 Test Results

Sample	Session	Total AO Fluence atoms/cm^2	% Mass Change
AO-C	1	4.74×10^{20}	2.23%
	2	8.96×10^{20}	0.79%
AO-D	1	4.74×10^{20}	6.72%
	2	8.96×10^{20}	-3.35%
	3	1.628×10^{21}	6.60%

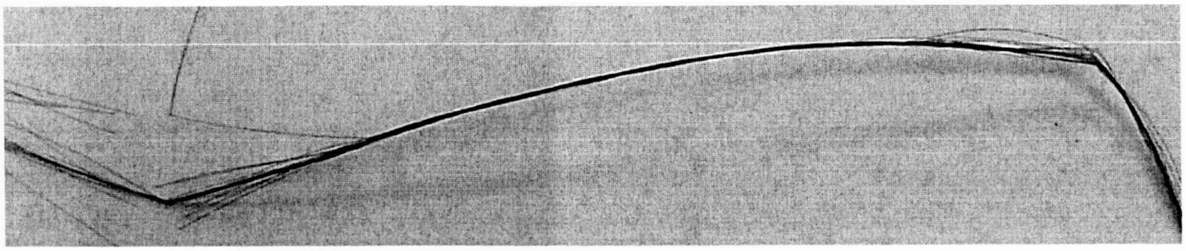

Figure 10. Cracking and Splitting of M5, AO-D After Handling and Exposure to 1.628×10^{21} atoms/cm^2 of AO

V. Conclusions

Each sample set carried with it its own obstacles that affected the outcome of the testing in one manner or the other. The Photosil and TOR-LM coatings did not provide the amount of protection that they had in previous experiments[18, 10, 26]. According to the reactivity calculations, nickel coated Zylon was able to resist AO's erosive effects but due to it being a loose set of strands, tensile test results were scattered. Finally, from a visual perspective, M5 and POSS were able to survive the testing regime without any apparent fraying or other damage.

Both the Spectra and Zylon tether materials coated with Photosil lost tensile strength even without exposure to AO and UV. This may be due to increased handling of the fibers during coating, especially in the case of the strand samples. However, the first step in the Photosil process[14] is to expose the samples to a combination of UV radiation and oxygen, making the surface more susceptible to the Photosil coating. It is more likely therefore, that Spectra and Zylon are sensitive to the UV radiation used, especially given the decrease in strength for the samples exposed to only 563 equivalent sun-hours of UV radiation. A long-term space mission means thousands of hours of UV radiation, so further coating work is needed to improve the performance of Spectra and Zylon. Photosil was more effective in reducing AO reactivity on a coherent, tightly woven tether sample rather than the loose fibers of the strand samples, however, an improvement in AO reactivity on the order of 3×10^{-25} cm^3/atom or less is required for a long-term mission.

The nickel coating appeared to improve the Zylon strand samples' resistance to AO erosion. The AO-D and –E nickel coated samples actually experienced mass gain by the end of their test regime suggesting that a nickel oxide had formed and was protecting the Zylon from any further damage. The AO reactivity for the samples that did lose weight averaged to 0.88×10^{-24} cm^3/atom. The tensile test results were inconclusive, mainly because of the handling problems of the strands.

The average reactivity for the TOR-LM coated samples was calculated to be 2.21×10^{-24} cm^3/atom, which is on par with that of uncoated Zylon. Based on this evidence alone, the conclusion can be drawn that the TOR-LM coating did not sufficiently protect the Zylon® from AO erosion. There is other evidence that points to TOR-LM not being able to protect Zylon from UV radiation. UV radiation causes Zylon to rapidly lose its tensile strength. When the data for the tensile tests are examined, it becomes clear that the TOR-LM is not doing an adequate job of providing UV protection. An unexposed sample of TOR-LM coated Zylon® had a maximum tensile load of 1511.05 N. The UV sample, which received only 518 hrs of UV radiation, had a maximum tensile strength of merely 584.71 N, a decrease of 61.3%. The AO exposed samples did not fare any better as they were exposed to 576, 768 and 1344 ESH of VUV radiation for the AO-B, -C, and –D samples respectively. After AO-D's final exposure, its mass loss amounted to a mere 5.7%, yet it was able to retain only 21.6% of its initial tensile strength.

When the POSS and M5 samples were examined, it was decided that tensile testing these materials would prove fruitless with only two samples of twenty strands each for testing. In addition, the M5 exhibited cracking outside the AO-exposed area and would certainly have failed outside the gage length. The reactivity calculations performed on the materials do lead to some conclusions. The first is that M5, with its chemical structure consisting of mainly C-C bonds and high reactivity, needs to be coated with some AO resistant material to survive the LEO environment. The POSS coated material had a surprisingly high AO reactivity, which either leads to the conclusion that it was not coated fully or the protective SiO2 layer was unable to fully protect the material. However, with only twenty strands of material, it is difficult to draw any further conclusions.

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