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Simulation of UV Radiation Degradation of Polymers on MISSE-6 in the Low Earth Orbit Environment

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Degradation of Space Polymers: A Case Study

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Abstract

Materials International Space Station Experiment 6 (MISSE-6) was an experiment designed to examine the consequences of the space environment on various materials used in space-component design. USU's contribution was comprised of approximately 180 samples that were suspended from the side of the International Space Station (ISS) for 18 months and returned to allow for pre- and post-flight comparisons. The sample with the most evident changes was a thin film of polyethylene terephthalate (PET) Mylar^{TM} coated with Vapor Deposited Aluminum (VDA). The post-flight analysis showed evidence of atomic oxygen erosion of the VDA layer, UV-induced discoloration of the polymer, and a crater created by a micrometeoroid impact. This project includes an analysis of the UV-induced discoloration and the creation of laboratory tests to simulate this discoloration. The UV tests place Mylar^{TM} samples under vacuum and then expose them to varying intensities of UV radiation. Using an array of deuterium lamps and an elliptical reflector allows for a condensed time span and a quantification of the discoloration of the polymer through comparison of the UV/Vis/NIR reflection spectra. The results from the UV simulation are used to determine the approximate time period of the UV exposure for the VDA coated Mylar^{TM} sample and in turn the erosion rate of the VDA layer. This project also includes an analysis of the impact crater and ramifications of the micrometeoroid impact.

Introduction

Materials International Space Station Experiment 6 (MISSE-6) was a NASA funded project that began in 2007 to test varying effects on materials whilst exposed to the space environment. This collaborative effort brought various universities, aerospace companies, and government organizations together to expose samples to the space environment in order to characterize the degradation of materials used in space component design (2). Samples of various materials used in space-component design were flown on MISSE-6 and spent 18 months suspended from the Columbus Space Laboratory, off the side of the International Space Station (ISS) see Figure 1.

Figure 1 MISSE-6 on ISS.

The Utah State University's State of Utah Space Environment & Contamination Study (SUSpECS) project was a unique student led experiment that allowed for pre- and post-flight analysis of the approximately 180 material samples, which were returned in pristine condition after exposure to the space environment (1). While this project centered on the SUSpECS portion of MISSE-6, the MISSE experiments are ongoing with MISSE-8 currently on the ISS (3). Investigation of the returned MISSE-6 samples, particularly a Vapor Deposited Aluminum (VDA) coated Mylar^{TM} sample, showed signs of sever degradation due to UV radiation, as shown in Figure 4 (7).

Motivation

Material degradation of materials like those flown on SUSpECS in the space environment is a highly relevant study today. The most common application is the construction of spacecrafts and satellites. MISSE-6 is of significance because it alone comprises ~10% of all the samples that have ever flown in space and been returned to earth in pristine condition for scientific analysis. The understanding gained from this analysis will allow for proper material choice to allow for space components with lengthened durability and less frequent repairs.

James Webb Space Telescope, NASA's current flagship project, hoping to replace the Hubble, will be sent into space far beyond repairable range, see Figure 2 (4). The two large blue panels featured on the JWST are each about the size of a tennis court and are made of metal coated polymers, much like my sample of interest. This sensitive optical equipment will be launched further into the vastly unknown space environment than any permanent equipment thus far with an operational lifetime measured in decades. It therefore requires careful consideration in choice of materials for maximum time before erosion renders it useless.

MISSE samples are also found in other space component designs such as astronaut's space suits (8). NASA's typical space suit is comprised of seven layers of which three are Mylar^{TM}. Understanding how these materials degrade is essential not only to equipment func-tioning but to astronaut's lives as well.

The specific motivation for this research project stems from the MISSE-6 experi-ment, particularly the afore mentioned VDA coated Mylar^{TM} sample. Preliminary analysis of this sample shows evidence of atomic oxygen erosion of the aluminum layer, exposing the white Mylar^{TM} underneath, see Figure 4. This simulation focuses on recreating the UV radiation portion of the sample's exposure for in depth understanding of how UV radiation erodes materials.

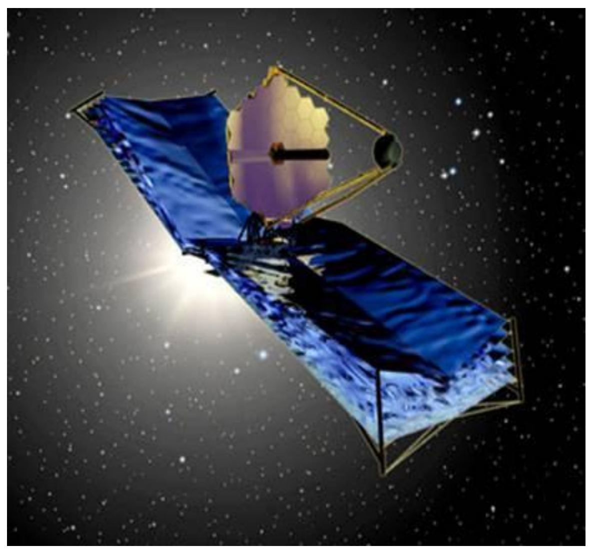


Figure 2, (above) James Webb Space Telescope (JWST) NASA's current flagship project.

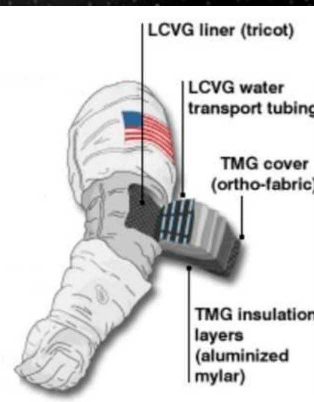


Figure 3, (right) Typical layers of a NASA spacesuit.

Past Work

The SUSpECS investigation started in 2007 when materials were gathered and began undergoing pre-flight testing that would allow for comparison upon their return (5). USU's SUSpECS trays were assembled by previous undergrads and the Get Away Special program at USU (6). USU's three trays were integrated into the larger array with samples from other universities and organizations, see figure 4. In 2008 the USU SUSpECS samples were launched with other MISSE-6 samples, suspended from ISS on the Columbus Space Laboratory for 18 months (9). In 2009 USU undergrads went and retrieved our samples from NASA Langley Space Flight Center; they were in pristine conditions to bring back to USU. At this point, the post-flight analysis began (10).

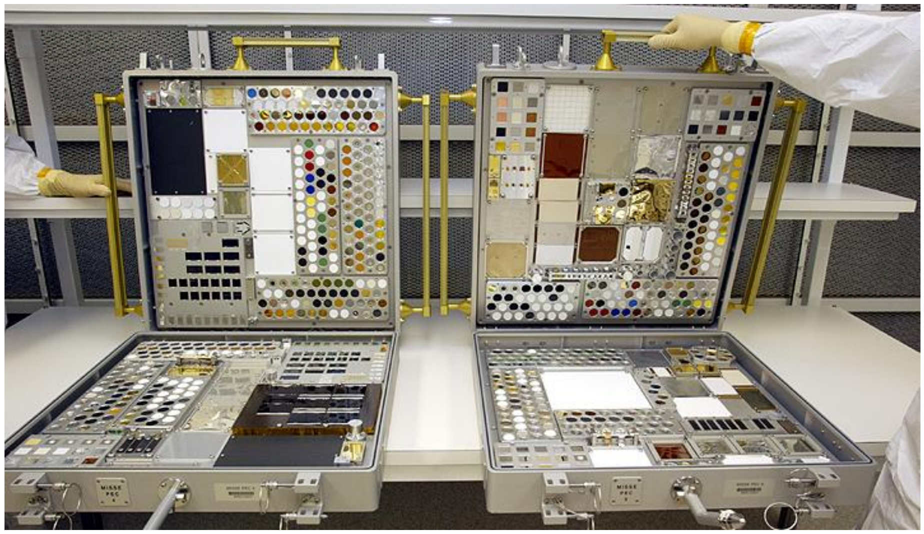


Figure 4 MISSE-6 samples, pre-flight, with USU's SUSpECS integrated.

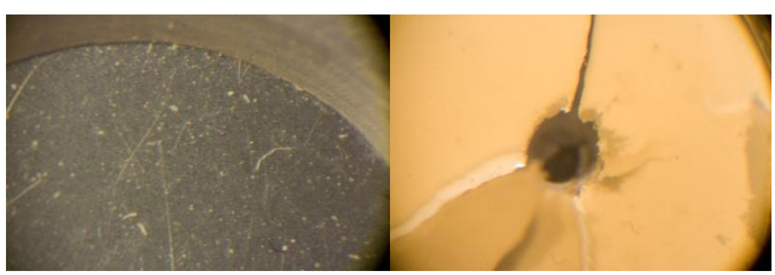
Degradation of VDA coated Mylar^{TM}

From 2009 until the present the samples have undergone post-flight analysis. The comparisons to the pre-flight analysis have allowed for a clearer understanding of the effects of the space environment. The effects vary from sample to sample depending on the properties of the sample.

Of the numerous samples in USU's contribution to MISSE-6, a sample, Vapor Deposited Aluminum coated Mylar^{TM}, is of particular interest due to its degradation, see Figure 5. Among various other methods, this sample has undergone three easily recognizable forms of degradation: atomic oxygen erosion, UV degradation, and a micrometeoroid impact. This case study will describe these multiple forms of degradation and the analysis of each stage of degradation.

Atomic Oxygen Erosion

Atomic oxygen erosion is a two part process. First, the prevalent O_2 molecules are split into single, atomic, oxygen atoms through UV photoionization, see Figure 6. These atomic oxygen atoms interact strongly with the materials and chemically erode the material, see Figure 7. This



Before After

Figure 5 VDA coated Mylar^{TM} pre- and post- ISS flight.

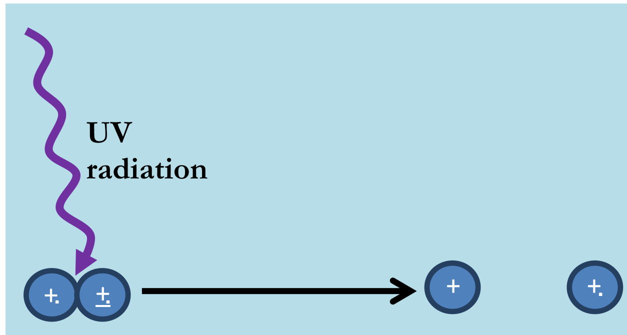


Figure 6, (left) Creation of atomic oxygen by UV radiation breaking the bonds holding the 2 oxygen atoms together in a stable unit.

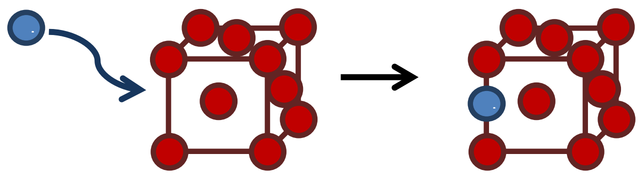


Figure 7, (below) Atomic oxygen interacting with the crystalline structure of polymers to disrupt and degrade them.

process is very similar to the rusting of iron here on Earth, though due to the lack of a protective O-zone layer and in turn the presence of atomic oxygen this process happens much more vapidly and to a wider variety of materials than observed on earth. The VDA coated Mylar™ underwent atomic oxygen erosion that ate away at the aluminum layer exposing the white Mylar™ underneath.

UV Degradation

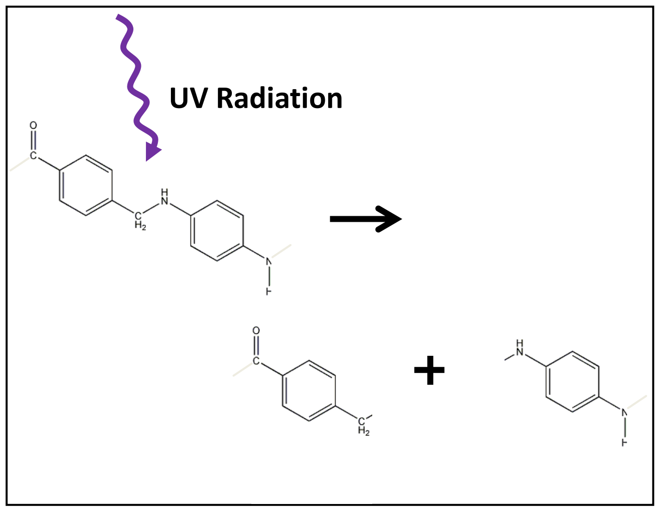


Figure 8 UV Radiation breaking the bonds of the polymer and yellowing the material.

Once the atomic oxygen erosion removed the VDA coating exposing the white Mylar™ underneath, it became much more susceptible to UV degradation. Much like the creation of atomic oxygen, where the UV radiation broke the bonds of the O_2 molecules, UV radiation breaks the bonds within the polymer causing the polymer to yellow, see figure 8. Again, without the O-zone to protect from UV radiation this process happens much more quickly in space. While yellowing may not seem significant, it changes the properties of the material and thus can vastly change how it responds and affects spacecraft functioning (11).

In order to gain a more in depth understanding of the undergone UV degradation and the timescales over which this occurs a ground simulation was created to replicate the UV degradation undergone by the Mylar™ while on the ISS. An ellipsoidal reflector was designed to maximize the exposure of the samples by directing the light to a focal point where the samples can be placed, see figure 9. The specific configuration of the lighting combined with the designed ellipsoidal reflector allow this deuterium lamp to simulate the UV solar radiation undergone in a condensed time frame.

In order to estimate a rate at which the UV degrades the material, three samples were placed various distances from the focal point to so that they would be exposed to various intensities of

UV light. To most accurately represent the space environment the Mylar™ samples were placed under vacuum for the duration of their exposure.

For the closest sample the reflector provides an enhancement factor of about 8. Combined with the intensity acceleration factor of the lamp, only ~3.3% of the time the sample was in space, or approximately 18 days is required to get the equivalent UV exposure seen by the MISSE samples. Due to the harmful effects of UV light this entire configuration was placed within a light-tight solar UV light containment box for the simulation.

Micrometeoroid Impact

As is notably visible in figure 13, the Mylar™ sample was struck by space debris while suspended from the ISS. In order to analyze the impact two assumptions were made; first that the impacting object was roughly spherical and second that it was comprised of astroidal debris rather than cometary. Through calculations of the velocity of ISS and in turn the kinetic energy of the micrometeoroid calculations of the mass of micrometeoroid were made, see table (14). It was found to be an approximate 182 Million to 1 chance that this particular sample was struck.

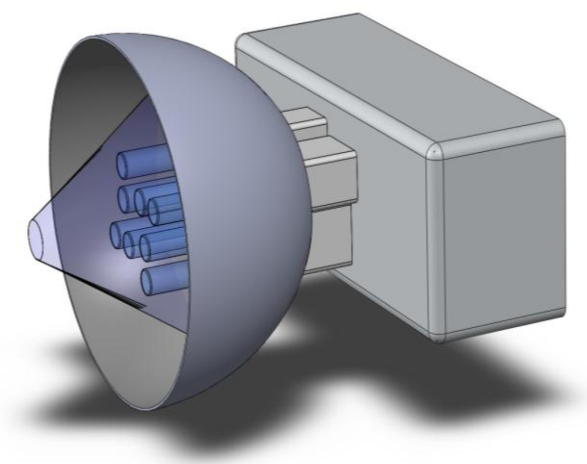


Figure 9, (top left) The bluish portion of the solid model represents the light cone and focal point of the reflector.

Figure 10, (top right) The light array is an image of the deuterium lamp configuration that allows for uniform light

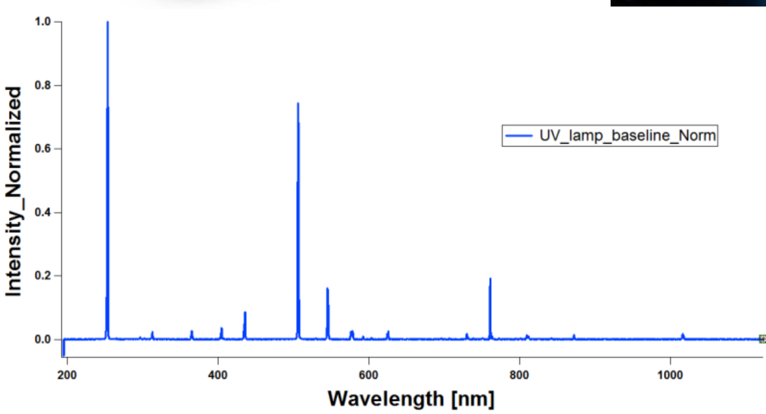


Figure 11, (bottom left) Wavelength spectra of the UV/deuterium lamp configuration, pictured above. Note the intense peak at 250 nm, right in the range of UV spectrum of UV in vacuum.

Figure 12, (bottom right) Mini vacuum chambers were assembled to house the samples during the UV

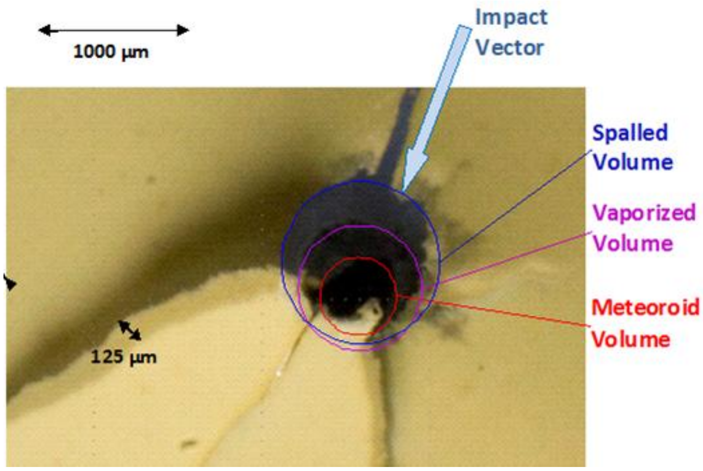
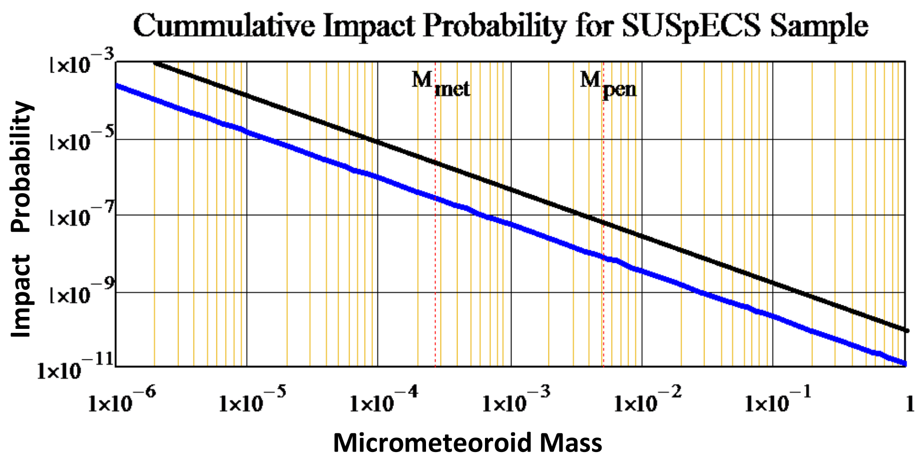


Table I. Sample and impact specifications deduced from the impact crater analysis.

Diameter of Exposed Mylar:	**9mm**
Diameter of Vaporized Region:	**1.0 mm**
Diameter of Spall volume:	**1.5 mm**
Diameter of Micrometeoroid:	**529 µm**
Thickness of Mylar Sample:	**125 µm**
Volume of Micrometeoroid:	**7.7×10^{-5} cm^3**
Density of Micrometeoroid:	**3.5 gm/cm^3**
Mass of Micrometeoroid:	**2.7×10^{-4} gm**

Figure 13, (above) Detailed analysis of the impact crater of the micrometeoroid impact in SUSpECS' Mylar™

Figure 14, (right) Impact probability of a micrometeoroid striking a SUSpECS sample and penetrating through a SUSpECS sample.



Future Work

Work on analysis of the effects of space environment exposure on the 168 samples has only begun. Measurements of optical and electron microscopy, reflectivity, FTIR, emissivity, mass loss, electron-, ion- and photon-induced electron emission, photoyield, AES, photoemission, and variable angle UV/VIS/NIR reflectivity will continue. Work will also progress in collaboration with the AEDC space simulation facility to understand the origins of these effects and quantify their impacts (15).

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