JOURNAL OF SPACECRAFT AND ROCKETS
Vol. 29, No. 1, January–February 1992

Engineering Notes

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Vacuum Ultraviolet Radiation/ Atomic Oxygen Synergism in Fluorinated Ethylene Propylene Teflon Erosion

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Introduction

THE concerted synergistic interaction between high-velocity oxygen atoms and vacuum ultraviolet (VUV) radiation has been found to contribute significantly to materials degradation in low-Earth-orbiting spacecraft. In particular, organic polymers used as electrical insulation materials and as thermal control blankets show the most significant degradation due to these environmental effects.

The existence of this synergistic effect has been proven under laboratory conditions [1,2] and inferred from the degradation observed in samples of silverized FEP (fluorinated ethylene propylene) Teflon (®E.I. Du Pont de Nemours Inc.) thermal blanketing materials recovered from the Solar Maximum Mission satellite and,[3,4] more recently, from the Long Duration Exposure Facility (LDEF) satellite. To date, the detailed chemical origin of this synergistic effect has not yet been fully elucidated.

We report here preliminary results of a micrographic investigation of FEP thermal blanket samples recovered from the LDEF satellite. From this investigation and from laboratory experiments, we are able to propose a possible mechanism for the synergistic effect by identifying the role VUV radiation plays in enhancing the atomic oxygen reactivity of FEP.

Experimental

Samples of silverized FEP (Teflon) thermal blankets recovered from two specific areas of the LDEF satellite were analyzed. A sample was taken from row 2 on the trailing edge (P0004) of the spacecraft, which received predominantly VUV exposure (9346 equivalent solar hours) with very little atomic oxygen fluence (4.7×10^9 atoms/cm^2), and a sample was taken from row 8 (a position ~ 40 deg off ram), which received both VUV (9346 equivalent solar hours) and significant atomic oxygen fluence (6.4×10^{21} atoms/cm^2).[5] Both of these samples received approximately the same equivalent solar hours of exposure, which, for the Lyman-α line (121 nm), amounts to approximately 10^{19} h υ/cm^2 total radiant flux.

Samples of commercial FEP [Du Pont; 2.5-cm disk, 50.8 μm (2 mil) thick] were exposed with a deuterium lamp (Cathedon VO-1; 15 W at a distance of 7.6 cm under an argon atmosphere. The surface morphology of samples was investigated after 92 days of exposure, which approximately duplicated the LDEF exposure of 10^{19} h υ/cm^2 of Lyman-α exposure (for the deuterium source the wavelength is actually 124 nm). Micrographic analysis of all of the samples was performed on a Cambridge Model S-360 scanning electron microscope. Infrared spectra were acquired on an Analect 6160 FTIR.

Results and Discussion

Thermal blankets for use in spacecraft applications are a laminate of 127 μm (5 mil) FEP with a reflective silver coating (~0.1–0.2 μm) that is vapor deposited on one surface. The silver coating is followed by an Inconel coating (~0.1–0.2 μm) that, for the LDEF blankets, was coated with a final layer of black paint (Chemglaze Z306: ® Lord Corp.). The FEP acts as a thermal (infrared) emitter as well as a transparent window to protect the reflective properties of the silver and, as a consequence of this, receives direct exposure to the space environment.

The surface morphology of unexposed control samples of FEP is relatively smooth and untextured under scanning electron microscopy (SEM), which is in sharp contrast to the samples recovered from LDEF. The sample recovered from the leading edge of LDEF, which received atomic oxygen and VUV exposure, proved to be highly eroded with dramatic roughening and sharp, angled peaks that point in the direction of the atomic oxygen flow.[6]

The material recovered from the trailing edge of LDEF, which received primarily VUV exposure with relatively little atomic oxygen impingement, shows a unique surface morphology that differs dramatically from both the control sample and from the leading-edge sample. In particular, the surface of this material is characterized by a hard brittle surface

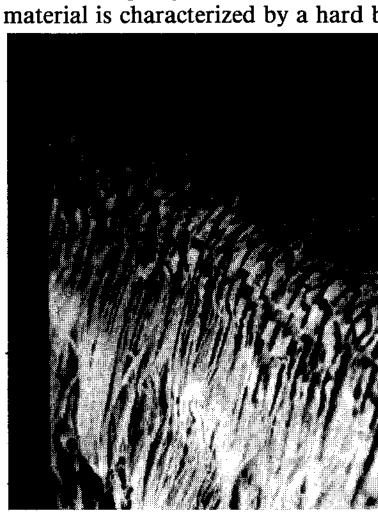

Fig. 1 Sheared edge of FEP thermal blanket recovered from the trailing edge of LDEF (×500 mag).

Received March 23, 1991; revision received July 16, 1991; accepted for publication July 16, 1991.

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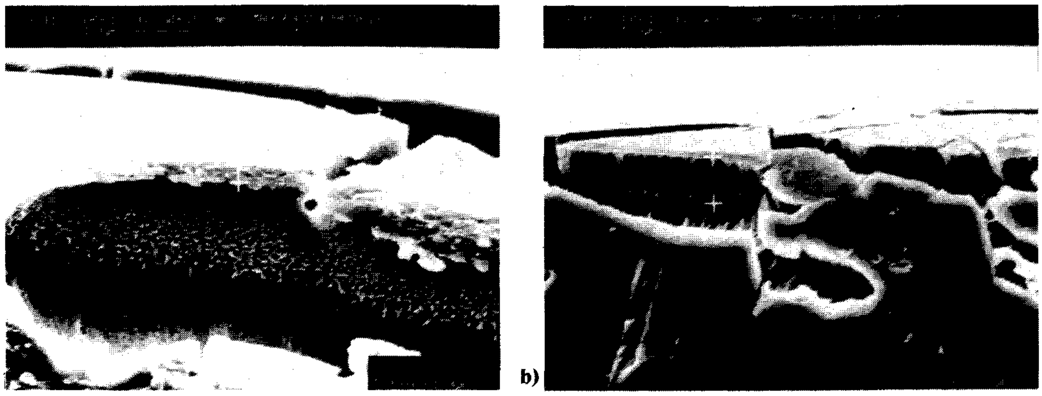

a) b)

Fig. 2 Magnified view (×4000 mag) of FEP samples exposed to VUV radiation: a) on the trailing edge of LDEF; b) in the laboratory.

layer that is not present in either of the other samples. This embrittled layer is only readily visible at the sheared edge of the sample where the stress of shearing has broken the layer into the cracked mosaic pattern seen in Fig. 1. This embrittled layer has no counterpart in the reference FEP sample, suggesting that it results from exposure to the space environment and, given the trailing edge origin of the sample, to VUV radiation in particular. The embrittled layer is also absent from the atomic oxygen exposed sample, suggesting that it either never forms or is continuously removed by the combined atomic oxygen/VUV environment!

FEP films exposed to a VUV light source (deuterium lamp) under laboratory conditions also develop an embrittled layer that is qualitatively similar to that seen on the trailing-edge LDEF sample. This is consistent with the interpretation that the embrittled layer is formed by the action of VUV radiation acting alone. A high-magnification image (Fig. 2) shows this surface layer clearly and permits the thickness of the layer to be measured [1.1 μm for the LDEF sample (Fig. 2a) and 2.8 μm (Fig. 2b) for the laboratory prepared sample]. This hard surface layer has been observed in other fluorinated polymers (polytetrafluoroethylene) and results from the photochemically induced cleavage and cross-linking of the polymer chains at the surface.[7,8] This chain cleavage process results in the erosion of the surface by the ejection of small molecules with the concomitant production of organic radicals [$-CF_2(\bullet)$ and $-CF_2CF(\bullet)CF_{2-}$].[9] Subsequent rearrangement of these radicals results in the formation of unsaturation (perfluorinated carbon-carbon double bonds) that can be identified by their characteristic infrared bands at 1375 and 1379 cm^{-1} for the laboratory exposed and LDEF samples, respectively, and cross-linking of the polymer chains, which yields the observed embrittlement. Both the radical species produced in the primary photoprocess and the unsaturated groups that result from rearrangement of the radicals are much more susceptible to oxidation than the parent saturated fluorocarbon. We propose that the observed synergism arises from the preparation of an oxidatively reactive surface by VUV radiation that is etched away by the impinging oxygen atoms. In the real space environment, where both effects are occurring simultaneously, the embrittled layer may never really form because the atomic oxygen flux will react with the radicals and double bonds as quickly as they appear.

A detailed analysis of this embrittled layer and its reactivity with atomic oxygen is currently being pursued in order to validate this proposed mechanism. Results of this study will be published subsequently.

Conclusions

We have observed the formation of a potentially reactive embrittled surface layer on the FEP recovered from the trailing edge of LDEF that forms due to exposure to VUV radiation. The absence of this layer in the oxygen atom exposed LDEF sample suggests that it never forms or is eroded away by the action of atomic oxygen and, therefore, may be responsible for the synergism between these effects. Implicit in this result is that polymers that are stable to VUV radiation may have greater atomic oxygen stability as well.

Acknowledgments

The work described in this publication was performed at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with NASA. Funding for the LDEF sample analysis was supported by the Key Technologies Directorate of the Strategic Defense Initiative Organization (SDIO) through the Air Force Materials Laboratory of the Wright Research and Development Center. The vacuum ultraviolet studies were performed at JPL as part of its Center for Space Microelectronics Technology, which is supported by the Innovative Science and Technologies Directorate of SDIO. Atomic oxygen studies were funded by the Materials and Structure Division, Office of Aeronautics and Exploration Technologies of NASA Headquarters. LDEF samples were provide by the LDEF Project Office.

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