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Radiation Durability of Candidate Polymer Films for the Next Generation Space Telescope Sunshield

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Abstract

The Next Generation Space Telescope (NGST), anticipated to be launched in 2009 for a 10-year mission, will make observations in the infrared portion of the spectrum to examine the origins and evolution of our universe. Because it must operate at cold temperatures in order to make these sensitive measurements, it will use a large, lightweight, deployable sunshield, comprised of several polymer film layers, to block heat and stray light. This paper describes laboratory radiation durability testing of candidate NGST sunshield polymer film materials. Samples of fluorinated polyimides CP1 and CP2; and a polyarylene ether benzimidazole, TOR-LM™, were exposed to 40 keV electron and 40 keV proton radiation followed by exposure to vacuum ultraviolet (VUV) radiation in the 115-200 nm wavelength range. Samples of these materials were also exposed to VUV without prior electron and proton exposure. Samples of polyimides Kapton® HN, Kapton® E, and Upilex-S were exposed to electrons and protons, only, due to limited available exposure area in the VUV facility. Exposed samples were evaluated for changes in solar absorptance and thermal emittance and mechanical properties of ultimate tensile strength and elongation at failure. Data obtained are compared with previously published data for radiation durability testing of these polymer film materials.

Introduction

The Next Generation Space Telescope (NGST) mission, a collaborative effort between NASA, the European Space Agency (ESA) and the Canadian Space Agency (CSA), is currently being designed. The planned launch is scheduled for 2009 with a mission

life of 10 years. The NGST will provide scientific observations that build and expand on those made by the Hubble Space Telescope (HST). Scientific goals of the NGST include measuring the geometry of the Universe and the distribution of dark matter, discovering and understanding the formation of the first stars and galaxies, the evolution of galaxies and the production of elements by stars, and the process of star and planet formation.[1] In order to achieve these goals, the NGST instruments will provide imaging and spectroscopy in the far visible to the mid infrared portion of the electromagnetic spectrum requiring the telescope to operate at very low temperatures with a target temperature of less than 50 K.[2] The intended orbit for the NGST spacecraft is a halo orbit about the second Sun-Earth Lagrangian point (L2), which is located 1.5×10^6 km from the Earth in the direction away from the sun.[1,3] This orbit will provide a cooler environment than Earth orbits, despite being a fully sunlit orbit. The NGST spacecraft will use a sunshield to block heat and stray light from the telescope. This sunshield will consist of several layers of lightweight thin polymer films in order to assure the sunshield's back-surface, or telescope-facing surface, temperature is no more than approximately 90 K, although the sun-facing surface will see a temperature of approximately 395 K.[3] Concepts for the NGST sunshield design call for 4 to 8 polymer film layers (12.5 to 25.4 μm thick) supported by deployable struts with a deployed size of approximately 30 m by 15 m.[2] The polymer film layers of the sunshield must maintain their structural integrity and must be seamable, foldable, resistant to tearing and creep, low outgassing, and resistant to environmental radiation and temperature effects. All sunshield polymer film surfaces will have a vapor deposited aluminum (VDA) coating except for the sun-facing surface. A coating for the sun-facing surface to improve thermal performance is yet to be determined. A program has been established by NASA Goddard Space Flight Center (GSFC), the agency responsible for the development of the NGST, to use ground testing to evaluate the space environmental effects on NGST candidate sunshield materials. Various environmental effects being evaluated as part of this program include electron and proton radiation, vacuum ultraviolet (VUV) radiation, and micrometeoroid impacts. Polymer films being considered for the NGST sunshield as part of this program have included polyimides Kapton® HN, Kapton® E, and Upilex-S; fluorinated polyimides LaRC™-CP1 and LaRC™-CP2; and TOR-LM™, a polyarylene ether benzimidazole (PAEBI). As part of the GSFC-led program, this paper reports results of electron and proton exposure of Kapton® HN, Kapton® E, and Upilex-S, and results of VUV exposure and electron and proton exposure followed by VUV irradiation for the CP1, CP2 and TOR-LM™. The roles of electron and proton radiation compared to that of VUV radiation are examined. Results of these tests are compared to other reported results of radiation durability testing for these candidate materials.

Experimental Procedures

Materials

Polymer films tested as part of this effort included: CP1 and CP2, fluorinated polyimides, which are trademarks of NASA Langley Research Center (LaRC) and are produced by SRS Technologies; TOR-LM™, a polyarylene ether benzimidazole (PAEBI), also a trademark of LaRC, produced by Triton Systems Inc.; Kapton® E and Kapton® HN, polyimides, trademarks of Dupont; and Upilex-S, a polyimide, trademark of UBE Industries, LTD. All materials were backside aluminized with approximately 100 nm of vapor deposited aluminum. All materials were tested with the polymer surface facing the direction of exposure. Test samples were 1.27 cm (0.5 in) wide and approximately 25.4 cm (10 in) long.

Tensile Testing

Tensile tests were conducted at NASA GSFC using an Instron model 4442 instrument with a 444.8 N (100 lb.) capacity load cell. Samples were tested in accordance with ASTM Standard D882-97. The 25.4 cm (10 in.) long specimens were installed in the rubberized flat platen grips so that the gage length, or distance between the grips at the test start, was 20.32 cm (8 in). Test speed was 1.27 cm/min (0.5 in/min) for all samples. Radiation-exposed CP1, CP2 and TOR-LM™ samples were tested at room temperature following several weeks of air storage along with controls. Electron/proton radiation-exposed Kapton® HN, Kapton® E and Upilex-S samples were tested at room temperature following approximately 10 months of air storage along with controls. Ultimate tensile strength and elongation at failure were determined for each sample.

Optical Properties Measurements

Thermo-optical properties of solar absorptance, α, and thermal emittance, ε, were obtained in accordance with standard practices.[4,5,6] Measurements of solar absorptance and thermal emittance were obtained before and after electron and proton exposure at NASA Marshall Space Flight Center (MSFC). For these measurements, an AZ Technology Laboratory Portable Spectral Reflectometer (LPSR) was used to measure spectral reflectance in the 250 to 2800 nm wavelength

range from which solar absorptance was calculated. Room temperature thermal emittance measurements were obtained with the AZ Technology Thermal Emittance Monitoring Package (TEMP) Model 2000A. MSFC also used an AZ Technology Laboratory Portable Infrared Reflectometer (LPIR), which obtains reflectance spectra over the 2-20 μm wavelength range and then calculates thermal emittance. Samples were stored in air following electron/proton exposure and prior to making these measurements within 1 hour of completion of exposure.

Before and after VUV exposure, NASA Glenn Research Center (GRC) used an AZ Technology LPSR to obtain spectral reflectance in the 250-2500 nm wavelength range from which solar absorptance was calculated. GRC used a Gier-Dunkle DB-100 to obtain room temperature thermal emittance and a Surface Optics Corp. SOC-400t to obtain infrared spectral reflectance in the 2.5 μm to 25 μm wavelength range from which thermal emittance was calculated. Following VUV exposure, but prior to optical measurements, samples were removed from the VUV exposure facility, photographed, and, within about 4 hours, placed in a vacuum desiccator. Optical measurements were obtained in air following 7 days of vacuum storage.

Samples and unexposed controls were measured at GSFC approximately 30 days after completion of exposure. Samples were stored in air prior to making these measurements. GSFC used an AZ Technology LPSR to measure spectral reflectance in the 250 to 2500 nm wavelength range from which solar absorptance was calculated. Thermal emittance was obtained using a Gier-Dunkle DB-100. Measurements were made in air.

Because the 1.27 cm (0.5 in) sample width was the same as the diameter of the measurement aperture for all instruments used, backing samples of the same material of a size larger than the aperture size were used behind the samples being measured in order to assure no room light was leaking through the measurement port during measurements.

Electron and Proton Radiation Exposure

Electron and proton radiation exposure was conducted at NASA MSFC. All samples were exposed to 40 keV electrons for a total fluence of 1.6×10^{16} electrons/cm^2 and to 40 keV protons for a total fluence of 2.0×10^{15} protons/cm^2. Electrons from a Kimball Physics Model EFG-9 flood gun were incident on the samples continuously during the test, and protons from a Model 2SH Pelletron were incident on the samples for approximately 3 hours per day during the test duration. Exposure area on each sample was approximately 10.16 cm (4 in), or +/- 5.08 cm from the center of the 25.4 cm sample length. Total test duration was approximately 30 days. The total electron/proton fluence provided was representative of approximately 10 years in the NGST mission environment. The first test included one sample each of Kapton® E, Kapton® HN, and Upilex-S. Due to a misunderstanding, these samples were exposed to half of the total fluence (8×10^{15} electrons/cm^2, and 1.0×10^{15} protons/cm^2) and then removed from the chamber. When the error was discovered, the samples, which had been stored in air for approximately 41 days, were returned to the electron/proton exposure facility and exposed to the remaining fluence. Pre- and post-exposure optical properties measurements were made before and after each of the two exposure runs. The second test included one sample each of CP1, CP2, and TOR-LM™. For this test run, the entire fluence was achieved in an uninterrupted 30-day test. The electron and proton exposed CP1, CP2, and TOR-LM™ samples were then sent to NASA GRC for VUV exposure.

Vacuum Ultraviolet Exposure

Two samples each of CP1, CP2, and TOR-LM™ were exposed to more than 5000 equivalent sun hours of VUV at NASA GRC in a 100-day test duration. One each of these materials had been previously exposed to electron and proton radiation as described in the previous section.

The GRC vacuum ultraviolet exposure facility used for this test consisted of a cryopumped high vacuum chamber with four individual exposure compartments separated by copper water-cooled walls. For this test, two exposure compartments were used. Each was equipped with a 30-watt VUV deuterium lamp with a magnesium fluoride window. These lamps provide wavelengths between 115 and 400 nm, although only the 115-200 nm wavelength range is accelerated in comparison to the sun's intensity at air mass zero solar (outside the Earth's atmosphere). The height of the 7.62 cm x 7.62 cm (3 in x 3 in) sample stage was moveable in order to adjust VUV intensity incident on the samples. A cesium iodide phototube was coupled with each sample stage and was moved in and out of the VUV beam for intensity measurements. VUV intensity was maintained between approximately 3 and 5 times the sun's intensity in the 115-200 nm wavelength range. Each exposure compartment contained two thermocouples for temperature measurement. Complete details regarding the features and test methodologies for this facility are given elsewhere.[8,9] In order to fit onto the 7.62 cm x 7.62 cm (3 in x 3 in) sample plates for the VUV facility,

aluminum foil holders were constructed that allowed the non-exposable sample lengths to be rolled around to the backside of the holder, thus keeping unexposed length out of the VUV exposure area. The VUV beam illuminated an area of approximately 5.08 cm (2 in) diameter. For these tests, sample temperature during exposure was approximately room temperature.

During the course of testing, the vacuum chamber was brought to atmosphere 3 times. The first interruption occurred following the first day of exposure when a sudden increase in vacuum system pressure was observed. The test was immediately terminated in order to correct the problem, which was a vacuum leak at the o-ring on the VUV lamp coupling caused by lack of adequate cooling of the VUV lamps. The o-rings for the VUV lamp couplings were replaced, provisions were made for fan-cooling of the VUV lamps, and the chamber was brought back to high vacuum condition to resume VUV exposure. The second interruption occurred approximately 9 days into the test when the cryopump compressor failed. The VUV lamps failed to turn off, and, therefore, continued to run until the problem was discovered. It was estimated that the VUV lamps were operating in air for 1 to 4 days. Because air does not transmit the VUV wavelengths, samples did not receive exposure to VUV during this time; however, these lamps produce ozone when operated in air, so samples were exposed to ozone for 1 to 4 days as a result of this failure. Additional interlocks were added to the facility to prevent this from occurring in the future. The third vacuum interruption occurred approximately 50 days into the test. At this time, the chamber was backfilled with nitrogen to bring it to atmosphere in order to minimize air bleaching, or reversal, of VUV degradation. A mechanical vibration problem with one of the positioners was investigated during this interruption, and, within a few hours, the chamber was returned to high vacuum condition and the test resumed. At the conclusion of 100 days of exposure, the chamber was backfilled with nitrogen to bring it to atmospheric condition.

The 5000 ESH VUV exposure was representative of approximately 208 days (0.57 years) in the NGST mission environment. This is significantly less than the 10-year fluence provided by the electrons and protons, because VUV cannot be accelerated above approximately 3-5 times the sun's intensity due to the uncertainty in how increased intensity affects degradation mechanisms. Electron and proton irradiation can be conducted using a significantly greater acceleration factor while still maintaining the same degradation mechanisms.[7] Kapton® E, Kapton® HN and Upilex-S were not exposed to VUV in this test due to time constraints and limited exposure area in the facility. CP1, CP2 and TOR-LM™ were prioritized as more important to test based on the fact that they are newer materials with limited or no flight experience.

Results

Optical Properties

Tables 1 and 2 show solar absorptance and thermal emittance, respectively, for irradiated samples and controls along with exposure conditions for each sample. Columns are arranged chronologically to show the order of measurements and exposures.

Before examining the data to determine effects of the exposures on optical properties, it is important to estimate the error in the solar absorptance and thermal emittance measurements made among the various instruments used. Because control samples were measured along with exposed samples at each phase of testing for CP1, CP2 and TOR-LM™, these materials were used to estimate standard deviation in the optical properties measurements. Four solar absorptance measurements were made on unexposed samples: 1 with the MSFC LPSR, 1 with the GSFC LPSR, and 2 different unexposed samples with the GRC LPSR. Based on these measurements, the maximum standard deviation in solar absorptance is $\pm$ 0.009. Five thermal emittance measurements were made on unexposed samples: 1 each with the MSFC LPIR and the MSFC TEMP, 1 each with the GRC DB-100 and SOC, and 1 with the GSFC DB-100. Based on these measurements, the maximum standard deviation in thermal emittance is $\pm$ 0.034.

Changes in the individual properties of solar absorptance and thermal emittance are shown in Figure 1a and Figure 1b, respectively. As shown in Figure 1a, electron/proton radiation exposure caused significant solar absorptance increases for all materials. Kapton® HN showed the least change, and Kapton® E showed the greatest change. VUV caused significantly less change in solar absorptance than electron/proton radiation for the three materials exposed to VUV. CP1 showed the least α increase, and TOR-LM showed the greatest α increase. The final measurements of solar absorptance for materials exposed to electron/proton radiation and VUV radiation indicate less overall change than that due to electron/proton exposure alone. This is presumed to be an artifact due to air bleaching of electron/proton-induced degradation between the time of exposure and the time of subsequent measurements. Such bleaching, or reversal of degradation, is evident in Table 1 for the Kapton® E,

Table 1: Solar Absorptance, α, of Electron/Proton (e-/p+) and VUV Irradiated Samples and Controls

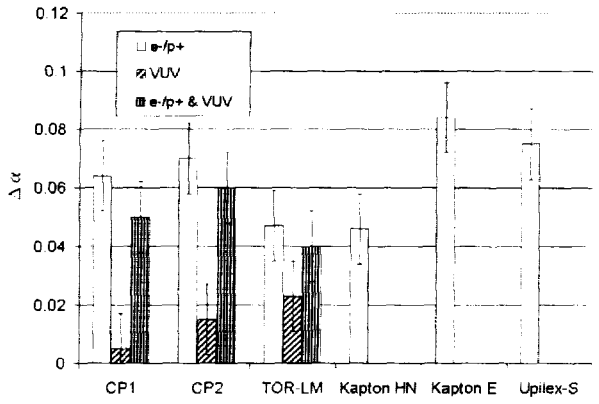
Material	Label	Pre-test α LPSR MSFC	Total e-/p+ Exposure Fluence (#/cm^2)	Post e-/p+ α LPSR MSFC	Pre-VUV α LPSR GRC	VUV ESH	Post-VUV α LPSR GRC	Post-test α LPSR GSFC
CP1	M-1	0.223	$1.6 \times 10^{16}/2 \times 10^{15}$	0.287	0.277	5214	0.279	0.29
	G-1	--	0	--	0.238	5214	0.240	0.26
	Control	--	0	--	--	0	0.235	0.24
CP2	M-1	0.223	$1.6 \times 10^{16}/2 \times 10^{15}$	0.293	0.284	5214	0.307	0.30
	G-1	--	0	--	0.241	5214	0.253	0.25
	Control	--	0	--	--	0	0.238	0.24
TOR-LM	M-1	0.249	$1.6 \times 10^{16}/2 \times 10^{15}$	0.296	0.288	5330	0.299	0.31
	G-1	--	0	--	0.261	5330	0.282	0.28
	Control	--	0	--	--	0	0.259	0.27
Kapton HN	M-1*	0.337	$8.0 \times 10^{15}/1 \times 10^{15}$	0.359	--	0	--	--
	M-1*	0.333	$1.6 \times 10^{16}/2 \times 10^{15}$	0.383	--	0	--	--
Kapton E	M-1*	0.313	$8.0 \times 10^{15}/1 \times 10^{15}$	0.402	--	0	--	--
	M-1*	0.329	$1.6 \times 10^{16}/2 \times 10^{15}$	0.397	--	0	--	--
Upilex-S	M-1*	0.452	$8.0 \times 10^{15}/1 \times 10^{15}$	0.536	--	0	--	--
	M-1*	0.456	$1.6 \times 10^{16}/2 \times 10^{15}$	0.527	--	0	--	--

*For Kapton HN, Kapton E, and Upilex-S materials, electron and proton exposure was split into 2 separate exposure tests with optical properties measured before and after each test.

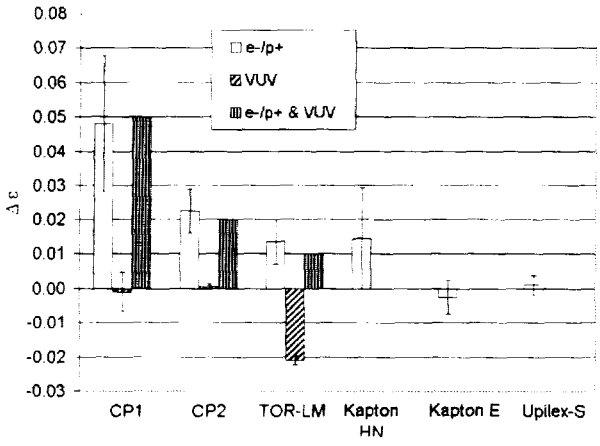
Table 2: Thermal Emittance, ε, of Electron/Proton and VUV Irradiated Samples and Controls

Material	Label	Pre-test ε LPIR MSFC	Pre-test ε TEMP MSFC	e-/p+ Exposure Fluence (#/cm^2)	Post e-/p+ ε LPIR MSFC	Post e-/p+ ε TEMP MSFC	VUV ESH	Post-VUV ε DB-100 GRC	Post-VUV ε SOC GRC	Post-test ε DB-100 GSFC
CP1	M-1	0.593	0.619	$1.6 \times 10^{16}/2 \times 10^{15}$	0.655	0.653	5214	0.610	0.627	0.61
	G-1	--	--	0	--	--	5214	0.569	0.584	0.58
	Control	--	--	0	--	--	0	0.566	0.589	0.56
CP2	M-1	0.616	0.688	$1.6 \times 10^{16}/2 \times 10^{15}$	0.643	0.706	5214	0.666	0.695	0.67
	G-1	--	--	0	--	--	5214	0.640	0.664	0.64
	Control	--	--	0	--	--	0	0.639	0.664	0.65
TOR-LM	M-1	0.721	0.673	$1.6 \times 10^{16}/2 \times 10^{15}$	0.739	0.682	5330	0.670	0.728	0.69
	G-1	--	--	0	--	--	5330	0.631	0.684	0.65
	Control	--	--	0	--	--	0	0.653	0.704	0.68
Kapton HN	M-1*	0.661	0.671	$8.0 \times 10^{15}/1 \times 10^{15}$	0.660	0.673	0	--	--	--
	M-1*	--	0.672	$1.6 \times 10^{16}/2 \times 10^{15}$	0.665	0.696	0	--	--	--
Kapton E	M-1*	0.678	0.684	$8.0 \times 10^{15}/1 \times 10^{15}$	0.652	0.677	0	--	--	--
	M-1*	--	0.692	$1.6 \times 10^{16}/2 \times 10^{15}$	0.672	0.685	0	--	--	--
Upilex-S	M-1*	0.662	0.667	$8.0 \times 10^{15}/1 \times 10^{15}$	0.655	0.663	0	--	--	--
	M-1*		0.676	$1.6 \times 10^{16}/2 \times 10^{15}$	0.665	0.666	0			

* For Kapton HN, Kapton E, and Upilex-S materials, electron and proton exposure was split into 2 separate exposure tests with optical properties measured before and after each test.



(a)



(b)

Figure 1: Optical properties changes for radiation exposed polymer films: (a) changes in solar absorptance, $\Delta\alpha$, and (b) changes in thermal emittance, $\Delta\varepsilon$.

Kapton® HN, and Upilex-S samples that were exposed to electron/proton radiation in 2 separate exposure increments with 41 days air storage in between. The pre-exposure α values for the second exposure increment are lower than the post-exposure α for the first increment, indicating a partial recovery of solar absorptance degradation during the air-storage time.

Figure 1b shows change in emittance due to radiation exposure. Error bars shown are for the average of measurements made with 2 different instruments for the measurements before and after electron/proton exposure and before and after VUV exposure. An emittance increase actually improves thermal performance as it facilitates an increased rate of heat rejection. Increased surface roughness is one possible mechanism for increasing emittance, although these samples were not analyzed for surface roughness. Kapton® E and Upilex-S showed the least change in ε due to electron/proton exposure. VUV exposure caused negligible emittance changes for CP1 and CP2, probably within measurement error. TOR-LM™ showed a significant reduction in emittance due to VUV exposure. Reduction in thickness due to erosion is one possible mechanism for emittance reduction, although material thickness changes were not analyzed for these samples.

A measure of performance of a thermal control material is its ratio of solar absorptance to thermal emittance (α/ε), where α is the absorbed solar radiation, the primary external heat input to the spacecraft, and ε is the measure of how efficiently a surface can reject heat. For thermal control applications such as the NGST sunshield, the lower the α/ε value, the cooler the spacecraft can operate. Figure 2 shows α/ε ratios for each material type for pristine samples, and samples exposed to electron/proton radiation and VUV radiation individually and sequentially. Note that Kapton® HN, Kapton® E, and Upilex-S were exposed only to electron/proton radiation in these tests. Error bars indicate the maximum standard deviation for α/ε.

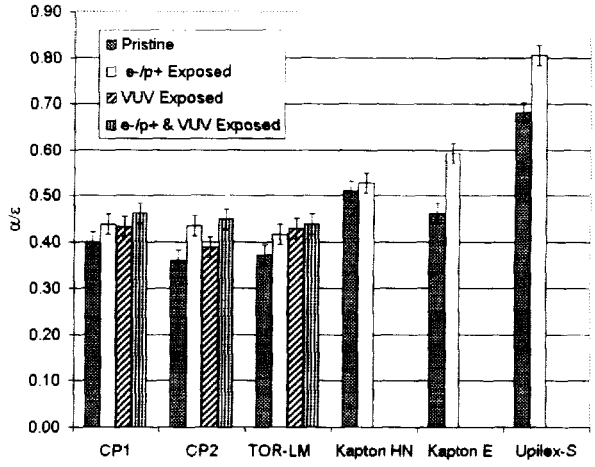


Figure 2: Solar absorptance/thermal emittance ratios for radiation exposure of polymer film samples.

As shown in Figure 2, Kapton® E and Upilex-S show the largest increases in α/ε due to electron/proton radiation exposure. Kapton® HN shows only a slight increase, which is within measurement error. CP1, CP2 and TOR-LM™ showed α/ε increases only slightly greater than the measurement error for exposure to electrons/protons, VUV, and electrons/protons followed by VUV. The effect of VUV on α/ε was similar to or slightly less than the effect of electron/proton radiation exposure for CP1, CP2 and TOR-LM™, despite varied changes in the individual properties of α and ε as shown in Figures 1a and 1b, respectively.

Tensile Testing

Table 3 shows results of tensile testing of exposed samples and controls indicating exposure conditions for each sample and ultimate tensile strength (UTS) and elongation at failure (%). Figures 3a and 3b show UTS and elongation, respectively, for the exposed samples and controls. As shown in Table 3 and Figures 3a and 3b, CP1, CP2, and TOR-LM™ have significantly lower strength and elongation in their pristine condition than the polyimides Kapton® HN, Kapton® E, and Upilex-S.

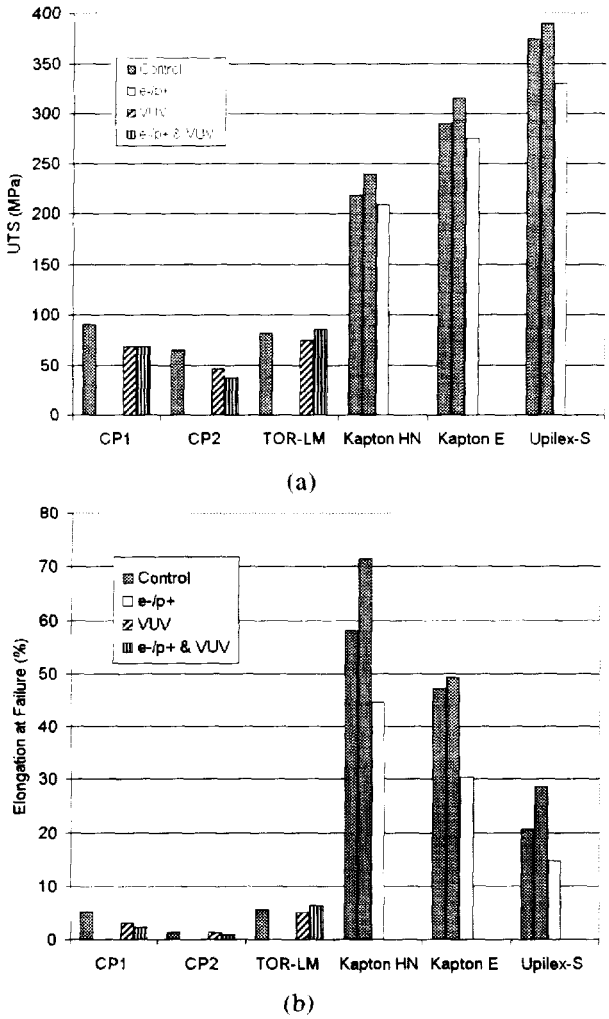


Figure 3: Ultimate tensile strength (a) and elongation at failure (b) for radiation-exposed polymer films and unexposed controls.

All materials except TOR-LM™ showed a significant reduction in strength and in elongation due to radiation exposure as shown in Figures 3a and 3b. Kapton® HN, Kapton® E, and Upilex-S still possess very high strength and elongation, even after radiation-induced degradation. It should be noted that these three materials were stored in air for several months longer than CP1, CP2 and TOR-LM™ prior to tensile testing, and the effects of air on these radiation-damaged materials is not known.

For CP1 and CP2, VUV exposure caused reductions in mechanical properties similar to electron/proton exposure. Considering that this degradation is for only 5% of the anticipated solar exposure on the NGST sunshield, further degradation in mechanical properties would be likely with continued VUV exposure.

Discussion: Comparison to Other Results

The results of NASA's testing described here are in good qualitative agreement with data obtained by Boeing Company.[10] Boeing characterized the same films (with the exception of TOR-LM™) exposed to a 5-year equivalent fluence of electrons and protons along with 1000 ESH of UV in the 200-400 nm wavelength range.[10] In comparison, the NASA testing provided a 10-year electron/proton fluence followed by VUV exposure in the 115-200 nm wavelength range. Like the NASA results, Boeing reported α increases for all materials, increases in emittance for CP1 and CP2, and decreases in strength and elongation for all materials.[10] TOR-LM™, exposed in the NASA tests but not the Boeing tests, indicated some degradation, but comparatively greater durability than the other materials tested. Boeing tested other versions of the TOR™ material, TOR-RC™ and TOR-LMBP™. TOR-RC™ showed significant solar absorptance increase, a decrease in strength, and no change in elongation.[10] The TOR-LMBP™ disintegrated during the irradiation.[10]

Summary

Samples of CP1 and CP2, fluorinated polyimides, and TOR-LM™, a polyarylene ether benzimidazole, were exposed to 40 keV electron and 40 keV proton radiation followed by exposure to approximately 5000 equivalent sun hours of vacuum ultraviolet (VUV) radiation in the 115-200 nm wavelength range. Electron/proton exposure simulated 10 years in the NGST environment, whereas VUV exposure represented 0.57 years in the NGST environment. Samples of these materials were also exposed to 5000 equivalent sun hours VUV without prior electron and proton exposure, and samples of polyimides Kapton® HN, Kapton® E, and Upilex-S were exposed to electrons and protons, only. Exposed samples were evaluated for changes in thermo-optical properties of solar absorptance and thermal emittance and mechanical properties of ultimate tensile strength and elongation at failure. Results indicated significant increases in the α/ε ratio

for all materials except Kapton® HN. Degradation in mechanical properties was observed for all materials except TOR-LM™. For CP1 and CP2 materials, exposure to only VUV caused less change in solar absorptance and thermal emittance than electron/proton exposure, but similar mechanical properties degradation. Considering that the VUV exposure was representative of only 0.57 years on NGST whereas electron/proton exposure represented 10 years on NGST, further degradation with continued VUV exposure would be likely.

TABLE 3: Results of Tensile Testing of Radiation-Exposed Polymer Films and Unexposed Controls

Material	Label	e-/p+ Exposure Fluence (#/cm^2)	VUV Exposure (ESH)	Ultimate Tensile Strength (Mpa)	Elongation at Failure (%)
CP1	M-1	$1.6x10^{16}/2x10^{15}$	5214	68.41	2.34
	G-1	0	5214	68.14	3.06
	Control	0	0	90.21	5.23
CP2	M-1	$1.6x10^{16}/2x10^{15}$	5214	37.66	1.04
	G-1	0	5214	46.21	1.3
	Control	0	0	65.31	1.24
TOR-LM	M-1	$1.6x10^{16}/2x10^{15}$	5330	85.38	6.33
	G-1	0	5330	74.07	5.13
	Control	0	0	82.34	5.47
Kapton HN	M-1	$1.6x10^{16}/2x10^{15}$	0	208.83	44.49
	Control-1	0	0	218.21	58.19
	Control-2	0	0	239.03	71.48
Kapton E	M-1	$1.6x10^{16}/2x10^{15}$	0	274.90	30.36
	Control-1	0	0	290.07	47.19
	Control-2	0	0	315.72	49.37
Upilex-S	M-1	$1.6x10^{16}/2x10^{15}$	0	329.52	14.69
	Control-1	0	0	374.76	20.69
	Control-2	0	0	389.66	28.65

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13. ABSTRACT ***(Maximum 200 words)***

The Next Generation Space Telescope (NGST), anticipated to be launched in 2009 for a 10-year mission, will make observations in the infrared portion of the spectrum to examine the origins and evolution of our universe. Because it must operate at cold temperatures in order to make these sensitive measurements, it will use a large, lightweight, deployable sunshield, comprised of several polymer film layers, to block heat and stray light. This paper describes laboratory radiation durability testing of candidate NGST sunshield polymer film materials. Samples of fluorinated polyimides CP1 and CP2; and a polyarylene ether benzimidazole, TOR-LM™, were exposed to 40 keV electron and 40 keV proton radiation followed by exposure to vacuum ultraviolet (VUV) radiation in the 115 to 200 nm wavelength range. Samples of these materials were also exposed to VUV without prior electron and proton exposure. Samples of polyimides Kapton® HN, Kapton® E, and Upilex-S were exposed to electrons and protons only, due to limited available exposure area in the VUV facility. Exposed samples were evaluated for changes in solar absorptance and thermal emittance and mechanical properties of ultimate tensile strength and elongation at failure. Data obtained are compared with previously published data for radiation durability testing of these polymer film materials.

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