Spectroscopic Behavior of Composite, Black Thermal Paint, Solar Cell, and Multi-layered Insulation Materials in a GEO Simulated Environment

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Introduction

The population of objects orbiting Earth is dominated by orbital debris. The following study presents reflectance spectroscopic measurements and bidirectional reflectance distribution function (BRDF) evaluations taken on common spacecraft materials (Table 1), some of which are likely candidates in the orbital debris population. Their optical properties were assessed in their pristine conditions, as well as after exposure in a space environmental chamber used to simulate space weathering. The materials studied will prove that they have excellent properties in resisting the effects of damage that are common in both low Earth orbit and geosynchronous Earth orbit (GEO) based on the research discussed in this work.

Table 1. List of materials and their slot positions on the sample carousel for Campaigns #1 and #2.

CAMPAIGN #1		CAMPAIGN #2	
Slot #	**Material Sample**	**Slot #**	**Material Sample**
1	GPS Solar Cell (bare/no interconnects) • Silicon based, high absorption	1	C-C Composite • Multi-directional layup; isotropic • High fracture toughness, low CTE, high strength-to-weight ratio
3	CMG Cover Glass • Cerium doped (UV/proton/electron radiation protection) • Thin, transparent, brittle	3	Black Paint RM-550 • Thermally conductive, maintains optical properties • Inorganic
5	CMO Cover Glass • Cerium doped (UV/proton/electron radiation protection) • Thin, transparent, brittle	4	Black Paint AZ-1000-ECB • Thermally conductive, maintains optical properties • Inorganic
7	CMX Cover Glass • Cerium doped (UV/proton/electron radiation protection) • Thin, transparent, brittle	5	Black Paint MLS-85-SB-C • Thermally conductive, maintains optical properties • Organic • Electrically conductive version of MLS-85-SB
9	Cu Tape • Copper orange hue, flexible, thin, shiny	6	Black Paint MLS-85-SB • Thermally conductive, maintains optical properties
11	Kapton (aluminized) • Thermoset polyimide • Withstands high/low temps • MLI component	8	Kapton (aluminized) • Thermoset polyimide • Withstands high/low temps • MLI component

Methods

1. Samples in vacuum ~16 hours prior to radiation exposure
2. Measured pre-weathered HR using in-vacuum fiber coupled integrating sphere
3. Calibrated each measurement with Spectralon & Acktar Black standards
4. Samples exposed to 100 keV electron radiation to simulate GEO electron flux
5. Weathered HR continued over 3-4 days
6. Samples were allowed to sit overnight in vacuum with no electron radiation exposure
7. Calculated HR% using Eq. 1. as a function of wavelength and electron radiation exposure

Set-up

- JUMBO Environmental Chamber at Spacecraft Charging and Instrumentation Calibration Laboratory (Kirtland AFB)
- Chamber in vacuum and electron radiation emission = 100 keV
- Kimball Physics electron gun

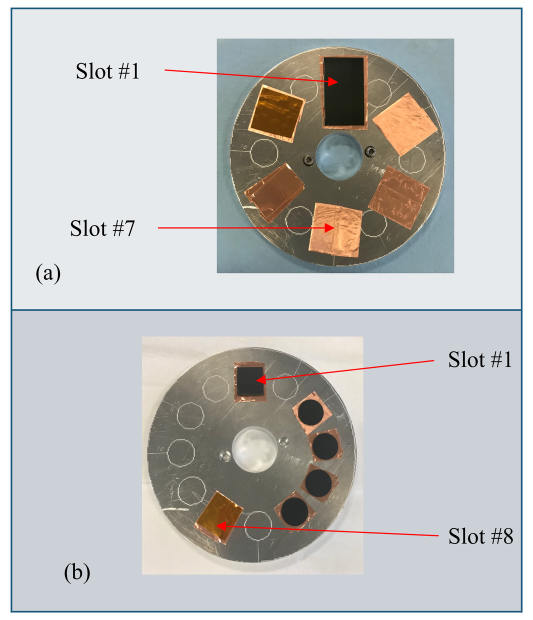

Figure 1. Image of the sample carousel with materials mounted for (a) Campaign #1 and (b) Campaign #2.

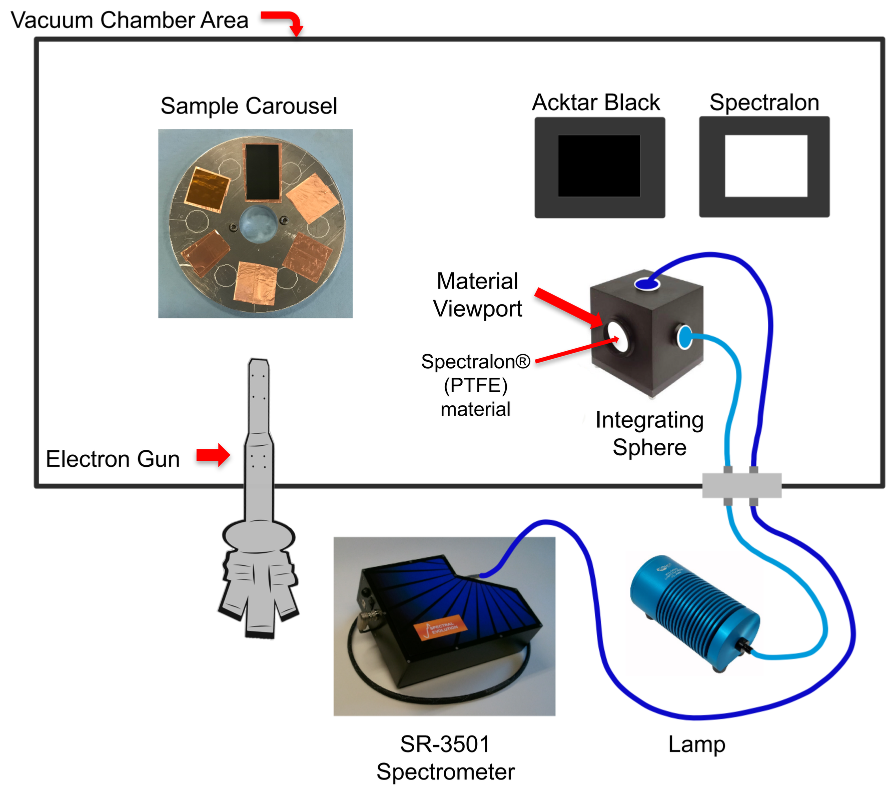

Fig. 2. Schematic representation of instrumentation set-up involving the environmental chamber.

$$HR\,\% = \frac{\dfrac{N_{sample} - N_{Acktar}}{N_{Spectralon} - N_{Acktar}}}{R_{Spectralon}} * 100$$

Eq. 1. Absolute hemispherical reflectance calculation where N represents raw digital numbers provided by the spectrometer and $R_{Spectralon}$ refers to the calibrated reflection values that the Spectralon material possesses at a given wavelength.

Results

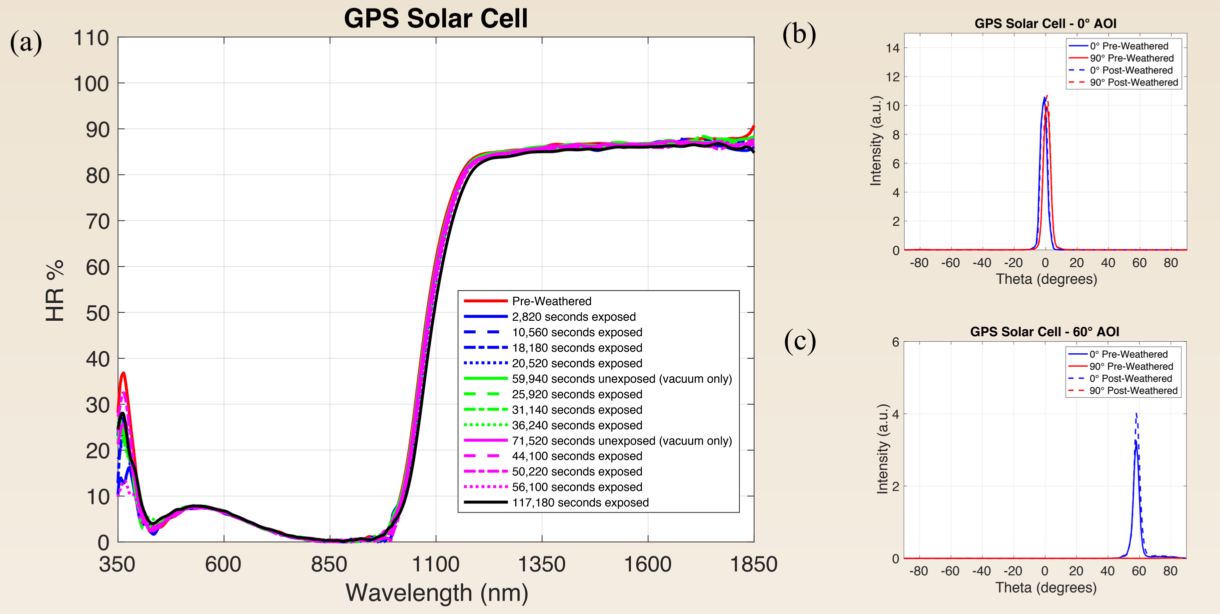

Fig. 3. The (a) reflectance spectrum and BRDF results at (b) 0° and (c) 60° angles of incidence for pre- and post-weathered GPS Solar Cell measured during Campaign #1.

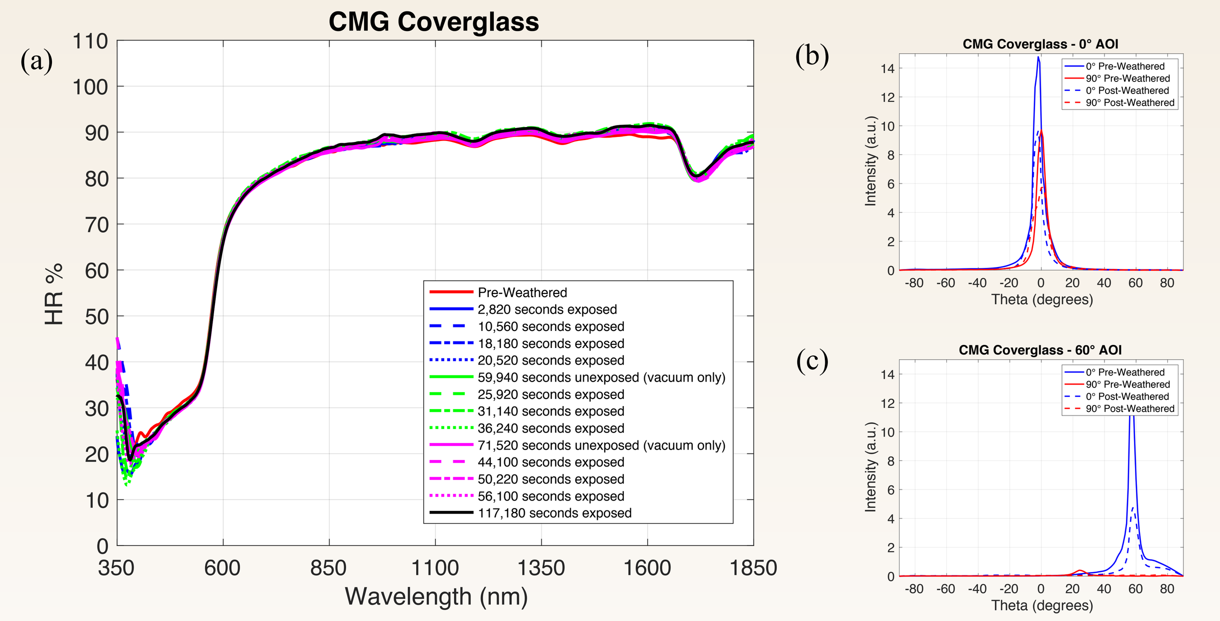

Fig. 4. The (a) reflectance spectrum and BRDF results at (b) 0° and (c) 60° angles of incidence for pre- and post-weathered CMG cover glass measured during Campaign #1.

Time (s)	Total Flux ($electrons/cm^2$)	Time (s)	Total Flux ($electrons/cm^2$)
CAMPAIGN #1		**CAMPAIGN #2**	
2,820	6.066E+11	3,600	7.640E+12
10,560	1.815E+13	6,480	1.368E+13
18,180	1.972E+13	9,420	1.955E+13
20,520	2.013E+13	14,040	2.820E+13
25,920	2.094E+13	19,980	3.784E+13
31,140	2.183E+13	24,240	4.529E+13
36,240	2.268E+13	32,520	6.080E+13
44,100	2.379E+13	38,340	7.097E+13
50,220	2.486E+13	45,060	8.271E+13
56,100	2.611E+13	104,700	1.721E+14
117,180	3.793E+13		

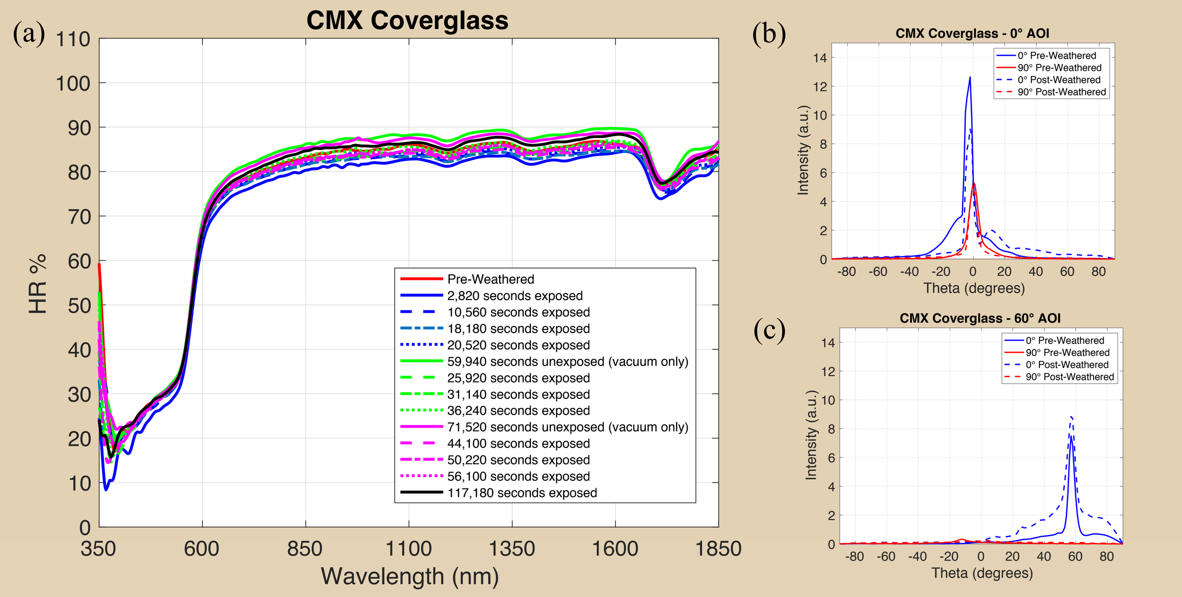

Figure 5. The (a) reflectance spectrum and BRDF results at (b) 0° and (c) 60° angles of incidence for pre- and post-weathered CMX cover glass measured during Campaign #1.

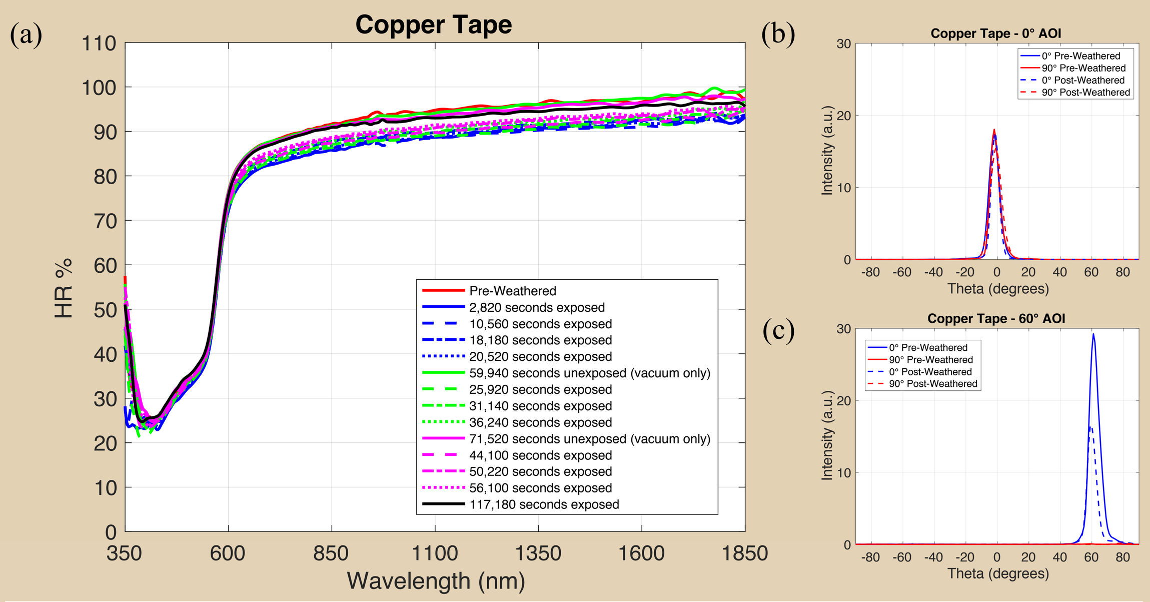

Figure 6. The (a) reflectance spectrum and BRDF results at (b) 0° and (c) 60° angles of incidence for pre- and post-weathered Cu tape measured during Campaign #1.

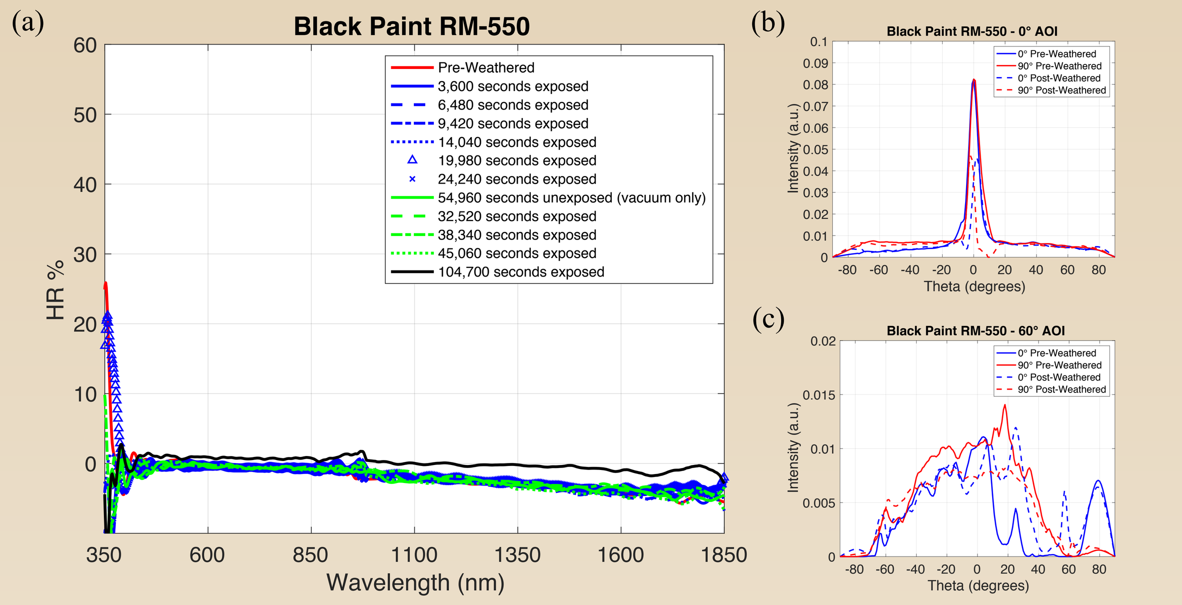

Figure 7. The (a) reflectance spectrum and BRDF results at (b) 0° and (c) 60° angles of incidence for pre- and post-weathered black paint RM-550 measured during Campaign #2.

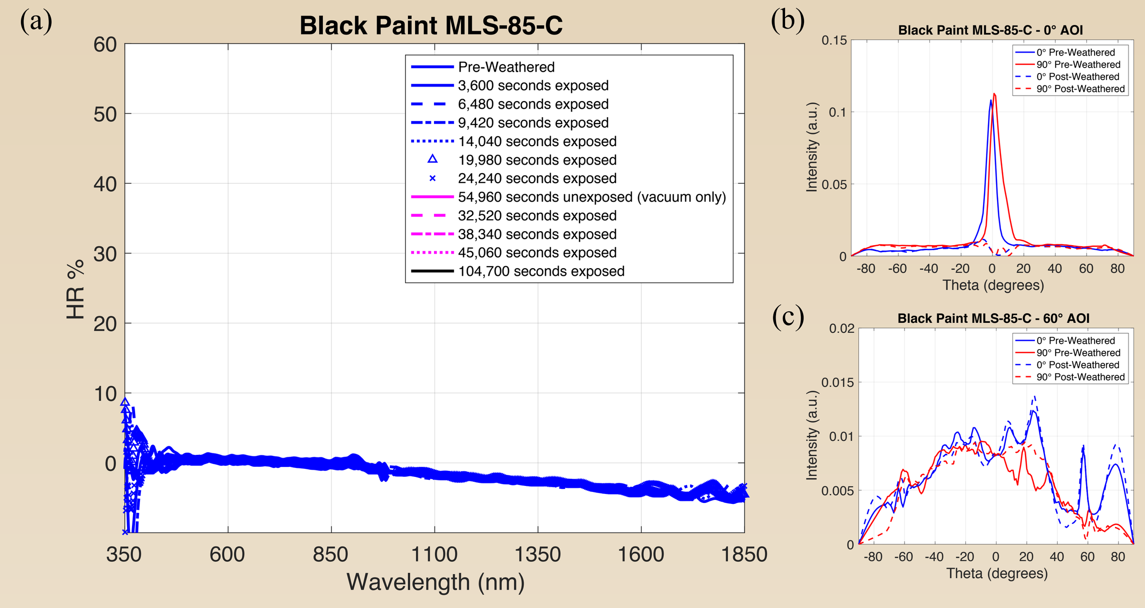

Figure 8. The (a) reflectance spectrum and BRDF results at (b) 0° and (c) 60° angles of incidence for pre- and post-weathered black paint MLS-85-C measured during Campaign #2.

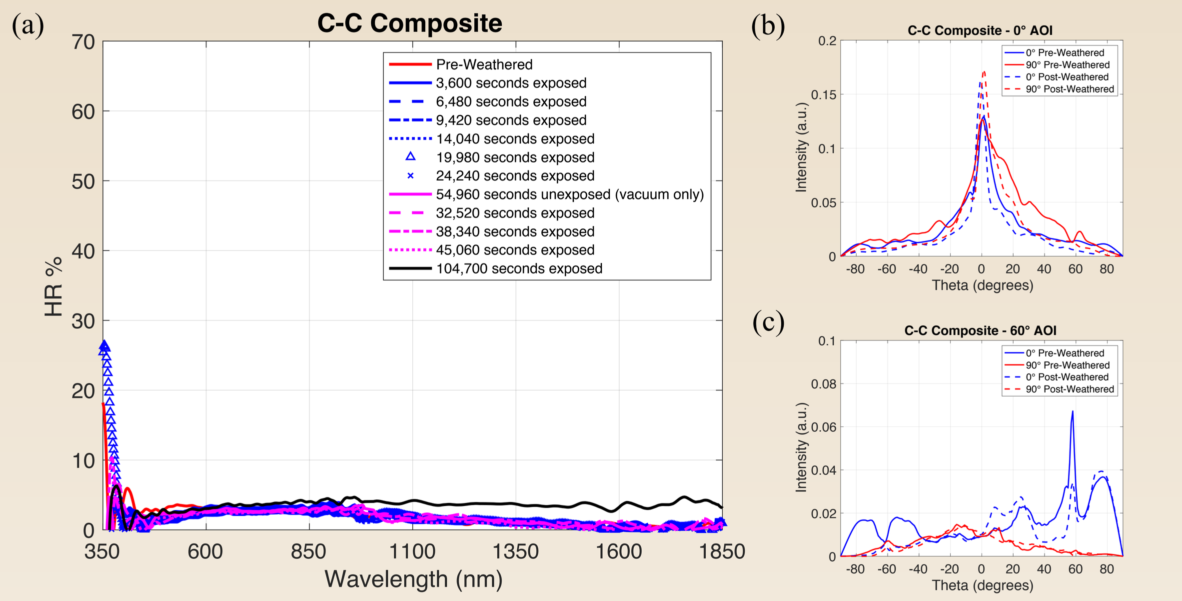

Figure 9. The (a) reflectance spectrum and BRDF results at (b) 0° and (c) 60° angles of incidence for pre- and post-weathered c-c composite measured during Campaign #2.

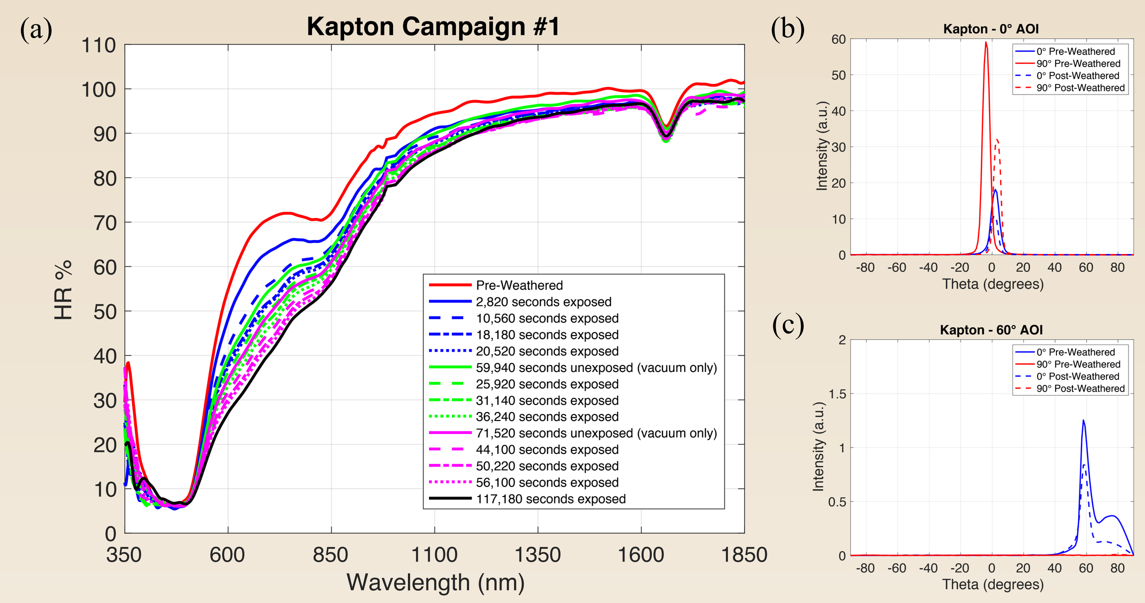

Figure 10. The (a) reflectance spectrum and BRDF results at (b) 0° and (c) 60° angles of incidence for pre- and post-weathered Kapton measured during Campaign #1.

Conclusion & Future Work

Kapton behaved as expected during both measurement campaigns, showing evident amounts of recovery at foreseeable times of measurement. The Cu tape also showed similar behavior to that of the Kapton regarding optical recovery. The CMG, CMO, and CMX cover glasses produced spectrum results comparable to what was seen for the Cu tape, suggesting that these glasses provided high transparency and would thus contribute information regarding the material that sits beneath them. The GPS solar cell and MLS-85-C displayed great optical stability throughout space weather simulations, as did the c-c composite and RM-550, AZ-1000-ECB, and MLS-85 black paints. All four black paints and the c-c composite exhibited a great deal of absorption throughout the visible and near infrared regions of the spectrum as anticipated. The author is currently investigating a goniometer setup for spectral measurements with accurate incident and reflective directions relative to surface to achieve a deeper understanding of material optical properties. This will allow the BRDF of material surfaces to be measured at multiple angles, which will enhance and augment collected data particularly with determination of object position in orbit.