



Accelerated Exposure Testing of Sundog Solar Technologies

Cooperative Research and Development Final Report

CRADA Number: CRD-17-688

NREL Technical Contact: Robert Tirawat

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5500-76128
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Cooperative Research and Development Final Report

Report Date: 02/14/20

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Sundog Solar Technology

CRADA Number: CRD-17-688

CRADA Title: Accelerated Exposure Testing of Sundog Solar Technologies

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	\$50,000.00
TOTALS	\$50,000.00

Abstract of CRADA Work:

Sundog Solar Technology (SST), is interested in investigating the durability of protective coating materials for solar reflectors through accelerated exposure testing (AET) using the Ultra Accelerated Weathering System (UAWS). SST will provide materials to NREL for characterization and exposure.

Summary of Research Results:

The National Renewable Energy Laboratory (NREL) characterized the optical performance and durability of solar mirror materials provided by Sundog Solar Technology. Optical performance was evaluated as a function of accelerated aging through hemispherical and specular reflectance measurements. Accelerated aging of the material was implemented using the UAWS at NREL. The UAWS is a specialized system that allows high concentrations (100x) of ultra-violet (UV) irradiance from natural sunlight while maintaining controlled sample temperatures through the attenuation of visible and infrared (IR) wavelengths and a temperature-controlled sample backplate. Two tasks comprise the CRADA as described below:

Task 1 – Initial characterization results.

Task 2 – Final characterization results following UAWS exposure. Results will be presented in a pdf document and cover final and interim performance results. A description of equipment and methods used will also be included in the report.

The following explains results and methods for Task 1 (baseline) Initial characterization related to Task 2 final characterization in text and figures showing outcomes.

Reflectance Characterization

Hemispherical reflectance was characterized using a Perkin Elmer Lambda 1050 spectrophotometer with a 150-mm integrating sphere attachment. Reflectance spectra were taken from 250 nm to 2500 nm in 5 nm increments. Hemispherical reflectance is taken against a similar reflectance standard that is National Research Council traceable. The solar weighted hemispherical reflectance (SWHR) was calculated for each reflectance spectrum using the weighted integral:

$$\rho_{2\pi} = \frac{\int I(\lambda)\rho(\lambda)}{\int I(\lambda)}$$

where $I(\lambda)$ is the ASTM G173 air-mass 1.5 direct normal solar irradiance spectrum, $\rho(\lambda)$ is the measured spectrum, and the limits of integration are over the measurement wavelength range.¹

Specular reflectance was characterized using two Devices & Services 15R-USB reflectometers. This instrument measures specular reflectance at 660 nm into a selected acceptance angle. The instruments can make measurements at 7-mrad, 15-mrad, 25-mrad, and 46-mrad whole acceptance angles. For the purposes of this effort, we primarily made specular reflectance measurements at 25 mrad.



Figure 1. Ultra-accelerated weathering system

¹ ASTM G173-03(2012), Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface, ASTM International, West Conshohocken, PA, 2012, www.astm.org

Accelerated Aging

Specimens were aged with the UAWS (Figure 1). The UAWS uses 29 specialized mirror facets in a dish configuration to concentrate natural sunlight onto the sample plane. The facets utilize a 96-layer coating comprising several quarter-wave interference reflectance packages to selectively reflect UV irradiance (300 nm to 500 nm) with high fidelity while attenuating visible and IR wavelengths for temperature control.² Sample temperature is maintained through a temperature-controlled backplate. The 6"×6" backplate is a vacuum chuck attached to glycol chilling/heating recirculators. The backplate is split in half vertically to allow for exposure of two different temperature zones simultaneously. Temperatures on both halves of the backplate are monitored at the glycol outlet and with a dummy sample of 1"×1"×0.125" polished aluminum with an embedded thermocouple. The temperatures of the recirculators are set to maintain temperatures, as measured by the dummy samples, of 30°C and 60°C at peak insolation.

The UAWS accelerates aging through the increase of UV-radiant exposure per unit time. The equivalent exposure in years is dependent on the use-location of the material and may be found by dividing the UV-radiant exposure from the UAWS by the historical average yearly UV-radiant exposure of the use-location. Extremely sunny locations have high yearly UV exposures. Phoenix, AZ, has a yearly average UV exposure of 334 MJm⁻².³ As a comparison, the average yearly UV exposure in south Florida and Stockholm, Sweden, is approximately 300 MJm⁻² and 161 MJm⁻², respectively.^{2,4}

Material Performance

Throughout the CRADA, Sundog has submitted 11 materials for characterization and aging. Materials were characterized upon receipt (Task 1) and at periodic intervals during aging (approximately every 1,000 MJ m⁻² of additional exposure). Duration of aging activities for each material submitted for study was at Sundog's discretion and direction. A written report (Task 2) was provided to Sundog describing the performance results of the Al-Lite reflective mirror film (summarized herein and attached in Supplemental Document A below).

Al-Lite Results

Following over 2732 MJm⁻² UV exposure, the Al-Lite reflective mirror film specimens exhibited only a 1.6% and a 1.2% drop in solar weighted hemispherical reflectance (SWHR) for the 30°C and 60°C exposure, respectively (Figure 2). The hemispherical reflectance at each measurement interval is reported in Table 1 while the spectral reflectance is presented in Figure 3. As discussed above, a UV dose of 2732 MJm⁻² would require many years of exposure to natural sunlight, with the number of years dependent on the use-location. In Denver, Colorado, it would require approximately 8 years to reach this dose, whereas in Stockholm, Sweden, the same dose would require about 17 years of natural exposure. In addition to the UAWS exposure, Al-Lite material was exposed to 65°C and 65% relative humidity for 92 hours. The Al-Lite specimens had no observable change in appearance nor any change in reflectance.

² Hardcastle, H.K., G.J. Jorgensen, and C.E. Bingham. "Ultra-Accelerated Weathering System I: Design and Functional Considerations." *Journal of Coatings Technology* 7.NREL/JA-550-49455 (2010).

³ "Arizona Benchmark Testing Site." ATLAS Material Testing Solutions, www.atlas-mts.com/products/testingservices/natural-weathering/natural-weathering-testing-sites/north-american-sites/arizona-benchmark-testing-site.

⁴ "Extracting STRÅNG data." Swedish Meteorological and Hydrological Institute, <http://strang.smhi.se/extraction/index.php>.

A small amount of surface scratching was observed on the Al-Lite reflective mirror film specimens following UAWS weathering. UAWS Specimens may become abraded by windblown dust, contact with the covers that are placed against the specimens between periods of exposure, or from residual particulates present during cleaning. An example of this may be seen in Figure 4 where darkfield images of unaged and aged Al-Lite is displayed. To further examine the possible impact of specimen abrasion, transmittance measurements were taken for unaged and aged Al-Lite. Unmounted Al-Lite material was used for the unaged measurement. The aged measurement was performed on one of the UAWS 60°C specimens after 2732 MJm⁻² UV exposure. The aged material was peeled from the aluminum substrate for characterization. While the unaged material had a solar-weighted hemispherical transmittance of 0.5%, the aged material had a transmittance of 2.6% with an increase in transmittance over the entire measurement spectrum. Surface scratching of Al-Lite may explain, at least in part, the small loss in reflectance (less than 2%) that has been measured following UAWS weathering.

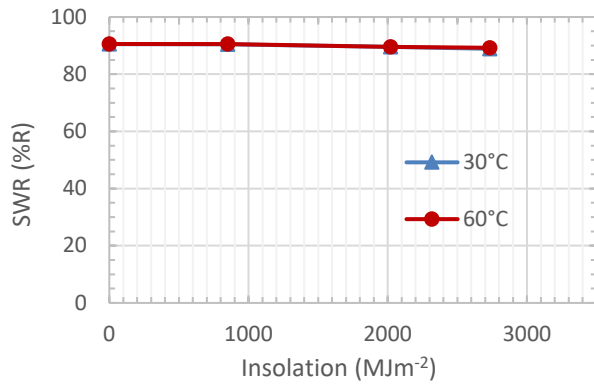


Figure 2. Solar weighted hemispherical reflectance of Al-Lite material vs. exposure

Table 1. Solar weighted hemispherical reflectance of Al-Lite reflective mirror film.

Insolation (MJ m ⁻²)	SWHR	
	30°C	60°C
0	90.5 ± 0.2	
849	90.4 ± 0.3	90.5 ± 0.1
2020	89.5 ± 0.4	89.5 ± 0.1
2732	88.9 ± 0.3	89.2 ± 0.2

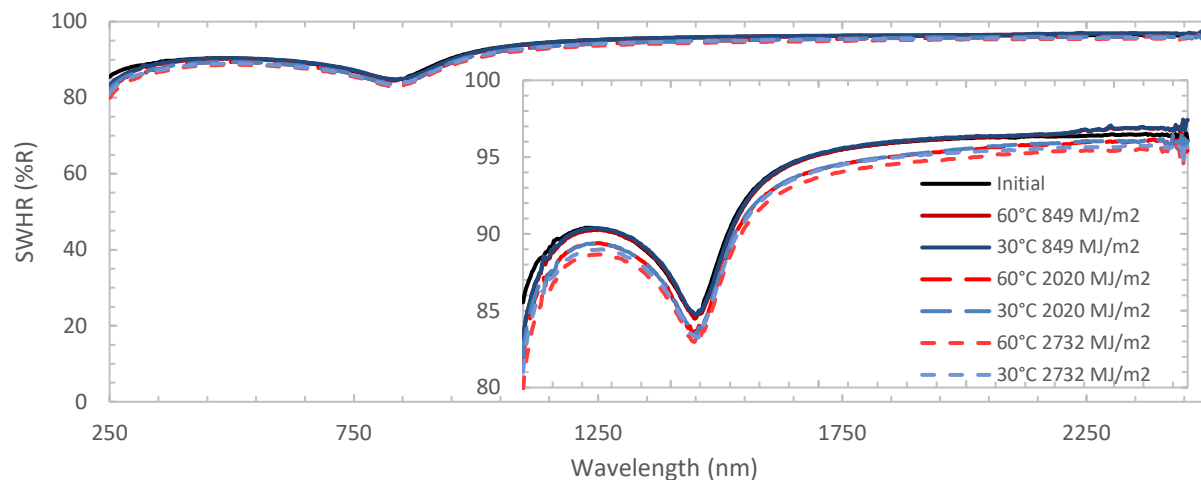


Figure 3. Spectral reflectance of Al-Lite material. Inset shows a reduced SWHR scale with the same wavelength range.

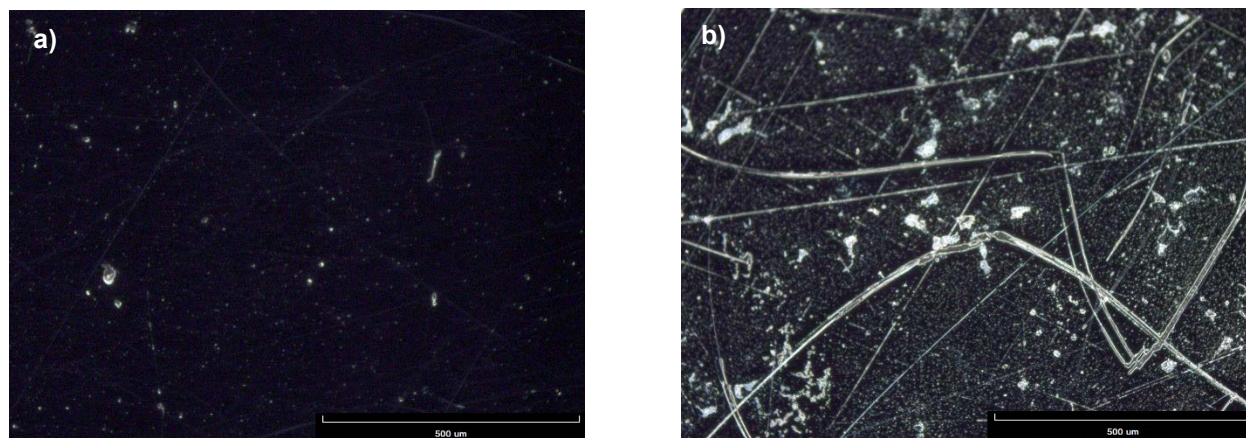


Figure 4. Darkfield images of (a) unaged material and (b) following 2732 MJm⁻² exposure. Scale bars are 500 μm.

Subject Inventions Listing:

None

ROI #:

None

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Randy Gee | randycgee@comcast.net

DOE Program Office:

Office of Energy Efficiency and Renewable Energy, Solar Energy Technologies Office (SETO)

Supplemental Documentation A

Ultra-Accelerated Aging of Al-Lite Reflector Material July 13, 2018 – January 31, 2019

Robert Tirawat¹ and Randy Gee²

¹ National Renewable Energy Laboratory

² Sundog Solar Technology

1 Introduction

The National Renewable Energy Laboratory (NREL) characterized the optical performance and durability of Al-Lite reflective mirror film provided by Sundog Solar Technology. Optical performance was evaluated as a function of accelerated aging through hemispherical and specular reflectance measurements. Accelerated aging of the material was implemented using the Ultra-Accelerated Weathering System (UAWS) at NREL. The UAWS is a specialized system that allows high concentrations (100x) of ultra-violet (UV) irradiance from natural sunlight while maintaining controlled sample temperatures through the attenuation of visible and infrared (IR) wavelengths and a temperature-controlled sample backplate. In addition to the extensive UV exposure using the UAWS, Al-Lite reflective mirror film specimens were also tested with a continuous damp heat environment for 92 hours.

2 Results

Following over 2732 MJm⁻² UV exposure, the Al-Lite reflective mirror film specimens exhibited only a 1.6% and a 1.2% drop in solar weighted hemispherical reflectance (SWHR) for the 30°C and 60°C exposure, respectively (Figure 1). The hemispherical reflectance at each measurement interval is reported in Table 1 while the spectral reflectance is presented in Figure 2. As discussed in section 3.3, a UV dose of 2732 MJm⁻² would require many years of exposure to natural sunlight, with the number of years dependent on the use-location. In Denver, Colorado, it would require approximately 8 years to reach this dose, whereas in Stockholm, Sweden, the same dose would require about 17 years of natural exposure. In addition to the UAWS exposure, Al-Lite material was exposed to 65°C and 65% relative humidity for 92 hours. The Al-Lite specimens has no observable change in appearance nor any change in reflectance.

A small amount of surface scratching was observed on the Al-Lite reflective mirror film specimens following UAWS weathering. UAWS Specimens may become abraded by windblown dust, contact with the covers that are placed against the specimens between periods of exposure, or from residual particulates present during cleaning. An example of this may be seen in Figure 3 where darkfield images of unaged and aged Al-Lite is displayed. To further examine the possible impact of specimen abrasion, transmittance measurements were taken for unaged and aged Al-Lite. Unmounted Al-Lite material was used for the unaged measurement. The aged measurement was performed on one of the UAWS 60°C specimens after 2732 MJm⁻² UV exposure. The aged material was peeled from the aluminum substrate for characterization. While the unaged material had a solar-weighted hemispherical transmittance of 0.5%, the aged material had a transmittance of 2.6% with an increase in transmittance over the entire measurement spectrum. Surface scratching of Al-Lite may explain, at least in part, the small loss in reflectance (less than 2%) that has been measured following UAWS weathering.

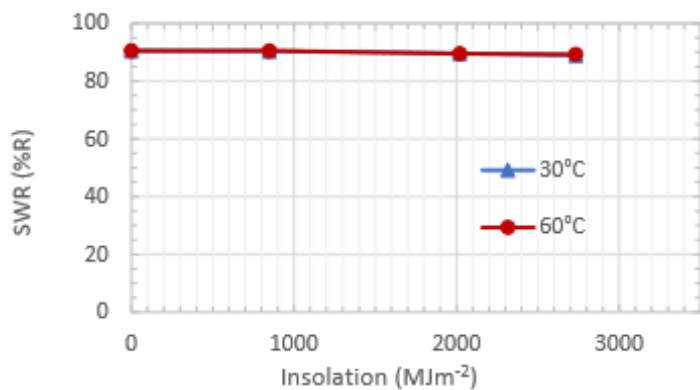


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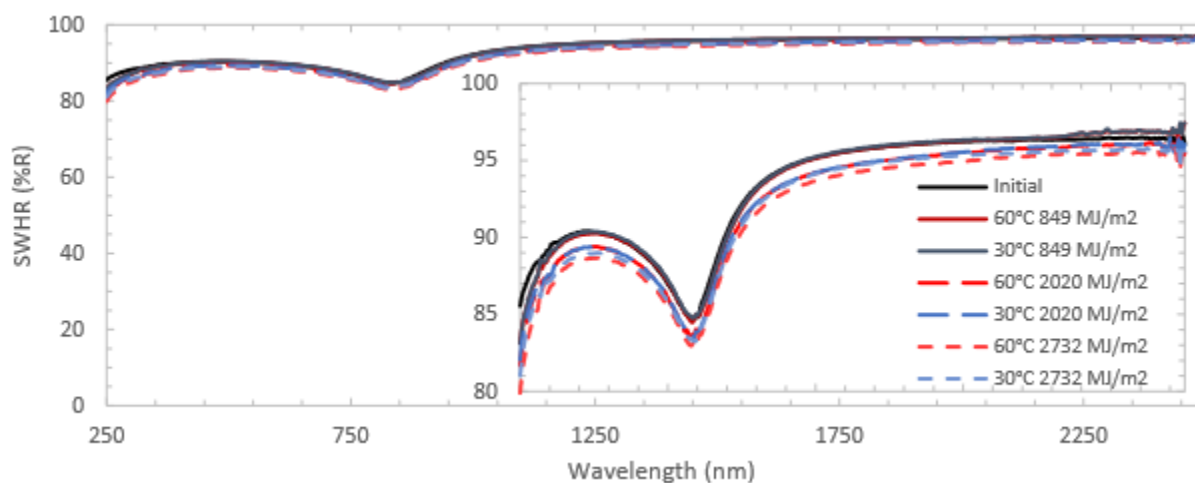


Figure 2. Spectral reflectance of Al-Lite material. Inset shows a reduced SWHR scale with the same wavelength range.

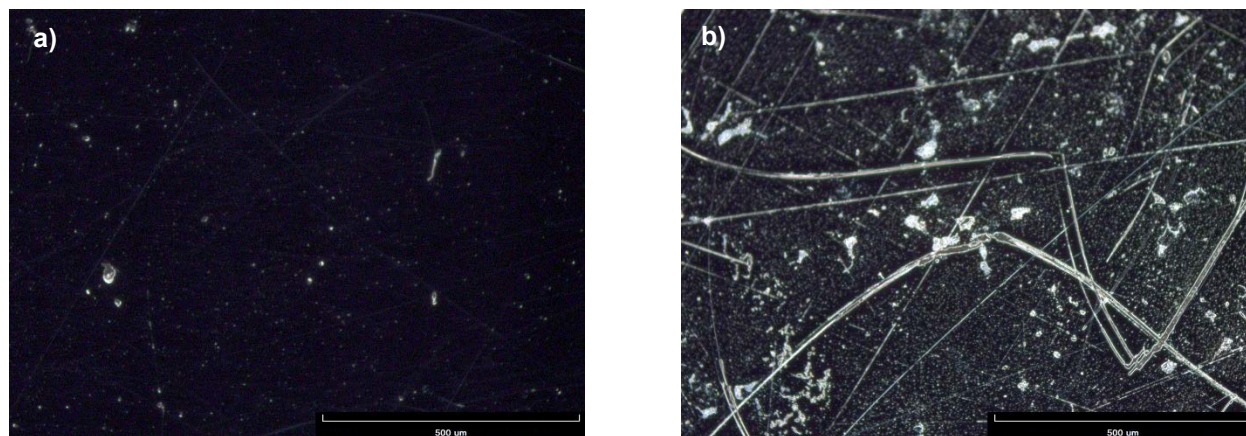


Figure 3. Darkfield images of (a) unaged material and (b) following 2732 MJm⁻² exposure. Scale bars are 500 μm.

3 Methods

Sundog Solar Technology provided the Al-Lite reflective mirror film to NREL. Sample preparation, characterization, and aging was performed at NREL as described below.

3.1 Material Preparation

The Al-Lite material was supplied in sheets with a liner and a pressure-sensitive adhesive. The reflective film was cut to size and mounted to 1"×1"×0.06" aluminum substrates using a laminator. Prior to measurements, samples were cleaned with Liquinox anionic detergent (1:100 deionized water dilution) and deionized water and blown dry with compressed nitrogen.

3.2 Hemispherical Reflectance

Hemispherical reflectance was characterized using a Perkin Elmer Lambda 1050 spectrophotometer with a 150-mm integrating sphere attachment. Reflectance spectra were taken from 250 nm to 2500 nm in 5 nm increments. Hemispherical reflectance is taken against a similar reflectance standard that is National Research Council traceable. The solar weighted hemispherical reflectance (SWHR) was calculated for each reflectance spectrum using the weighted integral:

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where $I(\lambda)$ is the ASTM G173 air-mass 1.5 direct normal solar irradiance spectrum, $\rho(\lambda)$ is the measured spectrum, and the limits of integration are over the measurement wavelength range.¹

3.3 Accelerated Aging

Specimens were aged with the Ultra-Accelerated Weathering System (UAWS, Figure 4). The UAWS uses 29 specialized mirror facets in a dish configuration to concentrate natural sunlight onto the sample plane. The facets utilize a 96-layer coating comprising several quarter-wave interference reflectance packages to selectively reflect UV irradiance (300 nm to 500 nm) with high fidelity while attenuating visible and IR wavelengths for temperature control.² Sample temperature is maintained through a temperature-controlled backplate. The 6"×6" backplate is a vacuum chuck attached to glycol chilling/heating recirculators. The backplate is split in half vertically to allow for exposure of two different temperature zones simultaneously. Temperatures on both halves of the backplate are monitored at the glycol outlet and with a dummy sample of 1"×1"×0.125" polished aluminum with an embedded thermocouple. The temperatures of the recirculators are set to maintain temperatures, as measured by the dummy samples, of 30°C and 60°C at peak insolation.



Figure 4. Ultra-accelerated weathering system

The UAWS accelerates aging through the increase of UV-radiant exposure per unit time. The equivalent exposure in years is dependent on the use-location of the material and may be found by dividing the UV-radiant exposure from the UAWS by the historical average yearly UV-radiant exposure of the use-location. Extremely sunny locations have high yearly UV exposures. Phoenix, AZ, has a yearly average UV exposure³ of 334 MJm⁻². As a comparison, the average yearly UV exposure in south Florida and Stockholm, Sweden, is approximately 300 MJm⁻² and 161 MJm⁻², respectively.^{2,4}

References

- 1 ASTM G173-03(2012), Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface, ASTM International, West Conshohocken, PA, 2012, www.astm.org
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- 4 “Extracting STRÅNG data.” Swedish Meteorological and Hydrological Institute, <http://strang.smhi.se/extraction/index.php>.