National Laboratory of the Rockies (NLR)

CSP Facilities for Thermal, Optical, and Performance Testing of Materials and Systems (CSP TOP Facilities)
15013 Denver West Parkway | Golden, CO 80401
www.nrel.gov | www.nrel.gov/csp

Test Report
Solar Mirror Reflectance

Requester: Randy Gee
Company: Sundog Solar Technology
Address: 13991 West 54th Avenue, Arvada, CO 80002
Product Description: solar reflectors
Issue Date: January 28th, 2026
Request #: AOMO202601
Report ID: AOMTR2K2601

Test Report by: Stephanie Meyen *Reviewed by:* Paul Ndione

I. Mirror Sample Description

Mirror sources are outlined in Table 1

Table 1. Samples information as received by the manufacturer.

Manufacturer	Sample ID	Number Received	Number Sampled	Sample Size (inch)	Mirror material and type
Sundog Solar Technology	AOML03212024-1	2	1	~3x3	EverBright Aluminum film, with an adhesive backing
Sundog Solar Technology	AOML03212024-2	2	1	~3x3	EverBright Aluminum film, with an adhesive backing
Evaluative description of samples: The samples are Everbright Aluminum film, with an adhesive backing. The samples were laminated onto aluminum sheet using a pressure laminator.					
Goal or type of characterization: Evaluate solar weighted hemispherical reflectance and specularity of prototype mirror samples compared to an aluminum control sample (1st-ALU-24120, 1st surface mirror).					

II. Measurement Parameter and Method Description

Three different instruments are being used to measure relevant reflectance parameters in agreement with the SolarPACES Reflectance Measurement Guideline. Reflectance is defined as a function of wavelength λ, incidence angle θ_i and acceptance aperture angle φ. All values reported here for acceptance angle φ refer to the angle related to the aperture radius (as opposed to the full cone angle related to aperture diameter).

- SWR hemispherical (total): Solar weighted hemispherical reflectance $\rho_{s,h}([\lambda_a,\lambda_b],\theta_i,h)$ is measured with a spectrophotometer Lambda1050+ and the SOC Solar 410 across the spectrum of λ = 250-2500 nm and incidence angle θ_i = 8 deg (L1050) and θ_i = 20 deg (SOC). The solar weighting is performed using the solar spectrum from ASTM G 173-03 for AM 1.5.

- Specular reflectance $\rho_{\lambda,\varphi}(\lambda,\theta_i,\varphi)$ is measured with the D&S reflectometer at λ = 660 nm and distinct acceptance angles φ ranging from 3.5 mrad to 23 mrad (7 mrad to 46 mrad full cone angle). For highly specular mirrors the specular reflectance and hemispherical reflectance values at the same wavelength should agree within ±0.5 percentage points.
- Specularity: As the specular performance of mirrors is critical to performance on site and the mirror's ability to focus light to the receiver, specularity is a key component to understanding how a mirror will perform in a solar concentrating system. Here, specularity is reported as RMS σ_s as explained in appendix B.3. This fit function was developed for glass mirrors. It might give less accurate results for other mirror materials, where a double gauss or a polynomial fit might be more appropriate.

Note: During this analysis, the SOC measurements were not performed, as this information was not deemed necessary due to the availability of L1050+ data.

The standard characterization of a mirror sample consists of the measurements at NLR shown in Table 2:

Table 2. Standard initial characterization measurements

Instrument	Measurements	Method
Reflectometer D&S 15R	5 readings at 4 apertures (25, 12.5, 7.5 and 3.5 milliradians)	5 randomly selected locations. Use each aperture at each location.
Spectrophotometer L1050	3 readings at approximate center of sample	Sample is rotated approximately 90 degrees between each reading, with the incident beam aimed approximately at the same location (0°, 90°, and 180° rotating them clockwise).

III. Measurement Results

Measurement Data for individual samples are given in Table 3. The reflectivity and specularity of Sample #1 and Sample #2 are shown in Figure 1, Figure ***2***, Figure ***3***, and Figure ***4*** respectively. Their corresponding pictures are shown in Figure 5.

Table 3. Averaged measurement results

Sample ID	Solar-weighted hemispherical reflectance	Specularity RMS Beam Spread
Sample1	87.54±0.11 %	1.01±0.0 mrad
Sample2	87.49±0.12 %	1.05±0.0 mrad

Sample1 = AOML03212024-1

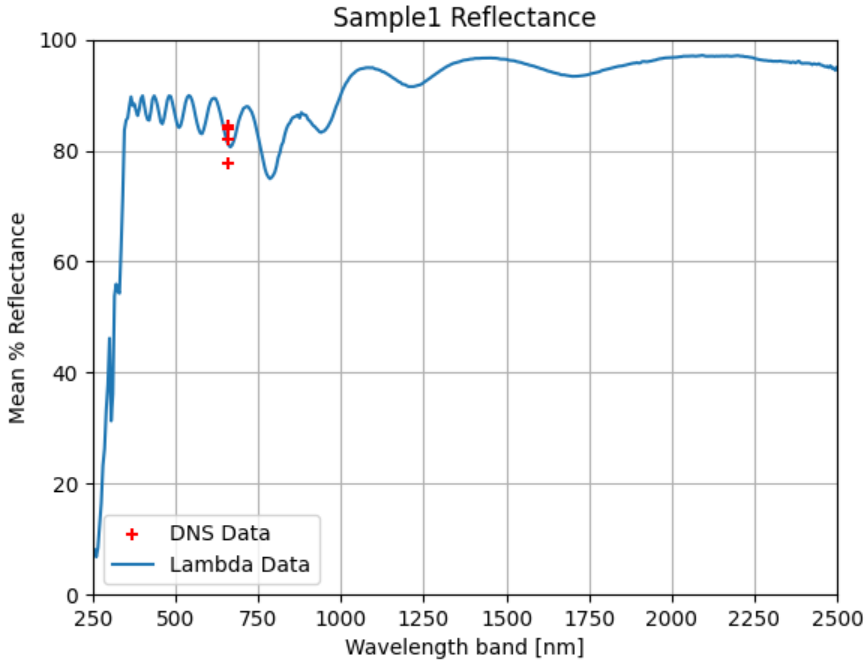

Figure 1. Reflectivity data from Sample 1

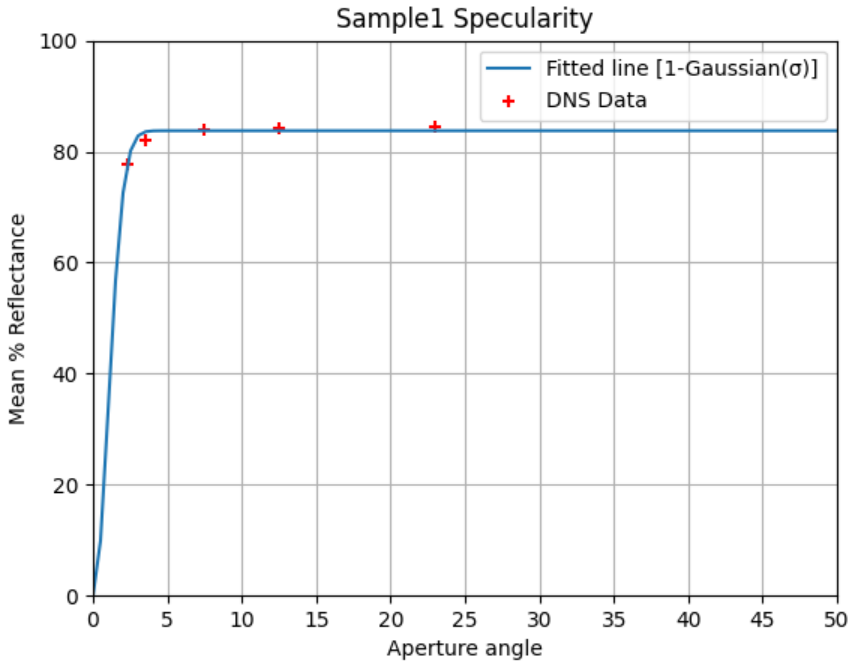

Figure 2. Specularity data from Sample 1.

Sample2 = AOML03212024-2

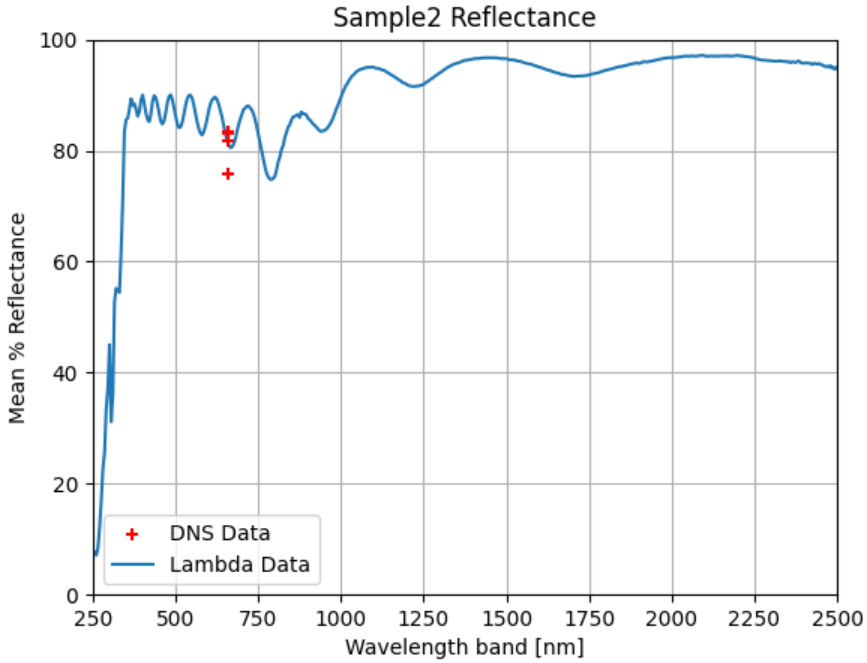

Figure 3. Reflectivity data from Sample 2.

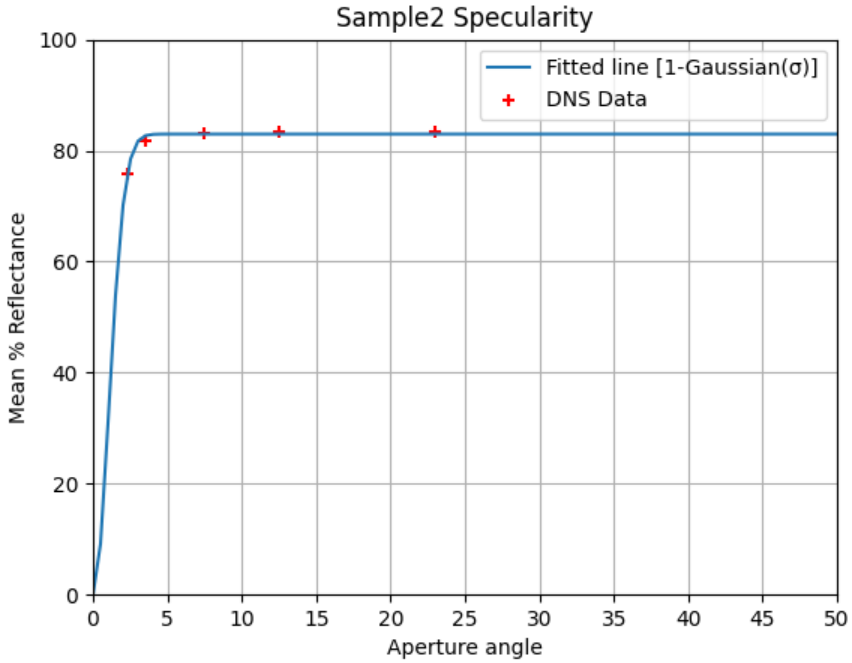

Figure 4. Specularity data from Sample 2.

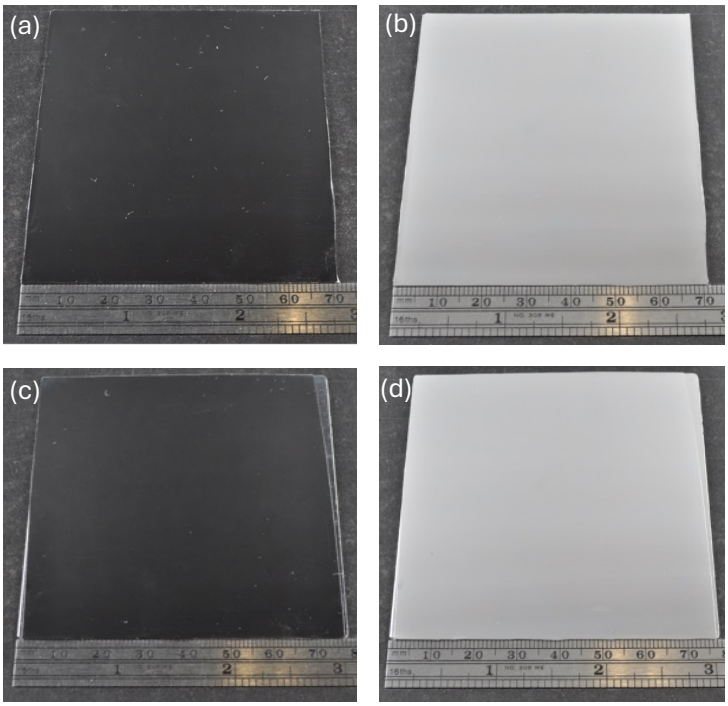

Figure 5. Pictures of Samples 1 and 2 (a) Dark background for Sample 1. (b) White background for Sample 1. (c) Dark background for Sample 2. (d) White background for Sample 2.

IV. Discussion

This section is meant to facilitate interpretation of results. All resulting values need to be considered to obtain a full understanding of the mirror performance.

The reflectance spectra of these samples show the typical dip in reflectance between 500 and 1000 nm wavelengths for aluminized reflectors. This leads to a lower solar weighted value than silvered mirrors.

Specularity has been calculated as the RMS beam spread (using a Gaussian fit) to the four D&S measurements at the four different acceptance angles. However, this fit function was developed for glass mirrors. For these samples, a double gaussian or a polynomial fit might be more appropriate, which was not available at the time of this report. However, Figures 1 and 3 show the specular reflectance measurements (at 7.5 mrad and 660 nm) are in close agreement to the hemispherical reflectance (at 660 nm), which confirms good specularity. Measurement uncertainty for D&S measurements is higher due to the steep slope in the reflectance spectrum in that wavelength window. The acceptance angle of φ = 7.5 mrad (full aperture angle = 15 mrad) has been determined to be significant for central receiver CSP application and any reflectance outside of this angle can be considered lost to the energy chain.

Appendix A: Instruments

The instruments used include a PerkinElmer Lambda 1050+ Spectrophotometer (L1050), a Device and Services 15R USB Portable Specular Reflectometer (D&S). General characteristics of each measurement are provided in Table A **1** and are fully detailed in the proceeding sections.

Table A 1. Summary of the instruments and settings used for measurements.

Instrument	Measurement Type	Wavelength Ranges	Incidence Angle	Measured Spot Size	Acceptance Aperture
L1050	Hemispherical	250-2500 nm, 5 nm increments	8°	0.50 cm^2	hemispherical
D&S	Specular	660nm peak irradiance	15°	$5.07x10^{-4}$ cm^2	3.5, 7.5, 12.5 and, 23 mrad

Reflectance is a measurement of the light reflected with respect to several factors given by Equation 1.

$$\rho = \rho(\lambda, \theta, \varphi) \qquad \text{Equation 1}$$

Where ρ is reflectance, λ is wavelength of light (typically in nm), θ is incidence angle of the light to the reflective surface, and φ is the aperture angle of the detector area or detector aperture. hemispherical reflectance is measured with an integrating sphere which is represented by $\varphi = 2\pi$, while specular reflectance refers to smaller acceptance angles that should lie between 3.5 – 23 mrad.

Appendix B: Measurement and Analysis Procedure

B.1 Sample preparation

1. Received samples are logged and assigned an identifier
2. Protective coatings and wrappings are removed from mirror surface if required
3. Samples received weathered, soiled, or damaged may be measured prior to cleaning to collect soiling data
4. Samples are cleaned
    a. Samples are rinsed with deionized water
    b. Samples are sprayed with Bilco cleaning solution
    c. Samples are lightly scrubbed with cotton swabbing material
    d. Samples are rinsed thoroughly with deionized water
    e. Samples are blown dry using compressed nitrogen
5. If required, samples are cut and rewashed

B.2 Instrument setup and calibration

B.2.1 *Surface Optics Portable Reflectometer*

1. The instrument is powered on and warms up for 30 minutes
2. User follows the calibration procedure prompted by the instrument:
    a. Collect a reading on a diffuse coupon
    b. Collect a reading on a calibration mirror coupon – this coupon should closely resemble the samples to be tested (i.e. secondary surface or primary surface, glass thickness, etc.)
    c. Collect a reading of ambient light conditions
3. User collects a measurement of the calibration coupon post-calibration to verify reflectance values are within 0.2% of the value prescribed on the coupon

B.2.2 *Devices and Services Specular Reflectometer*

1. The instrument is powered on and warmed up for 30 minutes
2. The device is set to the 25 mrad aperture
3. Ensure the calibration coupon is properly seated over the aperture
4. Adjust the gain on the device until the reading reads the value prescribed by the instrument for the supplied calibration coupon.

B.2.3 *PerkinsElmer Lamda-1050+ Spectrophotometer*

1. The instrument is powered on and warmed up for 30 minutes
2. User inserts the control and reference materials into the appropriate locations on the L1050 (note that reference materials should be as much representative as possible of the samples being tested)
3. The program collects data on the reference material
4. The program collects data on ambient conditions inside the machine
5. The user should inspect the output for anomalies and inconsistencies across the spectrum
6. Prior to measuring samples, the user inputs a witness module into the machine
7. The L1050 runs through the spectrum of wavelengths and outputs reflectance data
8. The user should compare this witness reading to the original witness reading using the same materials for anomalies and inconsistencies. If the witness reading raises concerns, the calibration should be repeated
9. The witness reading should be periodically repeated if testing large numbers of samples

B.3 Specularity calculation

Specularity is a surface property and describes how well the total amount of reflected light is directed into the specular direction according to Snell's law of reflection. A perfectly specular surface is perfectly smooth and reflects all light in a single specular direction and has no scattered portion. Most materials however display some amount of microstructure that leads to scattering of a portion of the reflected light and/or a widening of the specular beam cone. The exact measurement of specular reflectance is challenging and is best performed by approaching the ideal case with a series of measurements at detector acceptance apertures that gradually close in on the specular position of the beam. Then a Gaussian fit is applied to calculate the beam spread of the reflected light, expressed as σ_s, the RMS specularity value.

D&S specular reflectometers measure monochromatic specular reflectance at four apertures: 7mrad, 15mrad, 25mrad, and 46mrad, at a fixed incident angle of 15°. As the specular performance of mirrors is critical to performance on site and the mirror's ability to focus light to the receiver, specular reflectance is a key component to understanding how a mirror will perform in a solar concentrating system.

The RMS σ_s value of each individual sample can be found by formulating the specular reflectance as a Gaussian function of the aperture ϕ using
Equation *2* [1] below:

$$\rho_{spec}(\phi) = \rho_{spec,tot}\left(1 - e^{-\left(\frac{\phi}{\sqrt{2}\sigma_s}\right)^2}\right) \qquad \text{Equation 2}$$

If the measurement at maximum acceptance angle is assumed to be $\rho_{spec,tot}$, and ϕ is the array of maximum acceptance angles (3.5 mrad, 7.5 mrad, 12.5 mrad, and 23 mrad for each aperture used herein, or half of the aperture's total width) with respect to the specular direction, we can find the RMS σ_s by minimizing the residuals from
Equation *2*. The residuals are defined by Equation 3 below, representing $\rho_{spec}(\phi)$.

$$residual = \left|\left|\rho_{gauss} - \rho_{meas}\right|\right| \qquad \text{Equation 3}$$