Characterization of Metallized Polymer Films for Long-Distance Heliostat Applications

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Abstract

Commercially available Solar Mirror Film (SMF) 1100 from 3M was evaluated for application in concentrating solar power tower applications. The reflectance and soiling rate was compared to silvered glass mirrors during outdoor exposure for over a year. In addition, the reflected beam quality and peak flux resulting from solar reflections from SMF1100 and silvered glass facets at distances up to ~1700 m were conducted. Results showed that the impacts of soiling and outdoor exposure on the reflectance of the SMF1100 did not differ significantly from that of silvered glass over a year of testing. The peak flux resulting from the SMF1100 facet was statistically similar to the peak flux resulting from the silvered glass facet, and the size and shape of the flux distributions were also similar.

1. Introduction

Metallized polymer films are being evaluated as an alternative to silvered glass mirrors for concentrating solar power applications [1]. Potential advantages include lower weight, easier application, larger continuous reflective area, and competitive costs. Previous studies found that while the clean specular reflectivity of 3M SMF1100, a silvered acrylic solar mirror film, was 2% lower than that of low-iron silvered glass, the size and shape of the projected beams from heliostats employing SMF1100 and silvered glass were similar at a distance of 200 m [1]. However, large power tower plants, such as the 110 MW_e Crescent Dunes Solar Energy Project being constructed near Tonopah, Nevada, rely on large fields of heliostats, where the furthest heliostat can be nearly 1,600 m (~1 mile) away from the tower. This paper presents the results of tests that evaluate the reflected flux distribution from facets consisting of SMF1100 and silvered glass at these longer distances. Reflectivity measurements of exposed silvered-glass and SMF1100 coupons were also recorded over a period greater than a year to evaluate the quality and durability of the polymer films.

2. Approach

2.1. Reflectance Measurements

Figure 1 shows the reflectance measurements of mirror coupons that were exposed outdoors for nearly a year using a Surface Optics 410 Solar reflectometer. The total and specular reflectivity of the SMF1100 and several silvered-glass coupons was measured on a sawhorse in both face-up and side-facing positions. The 410 Solar measures the reflectivity in seven spectral bands from 335 – 2500 nm at a 20 degree incidence angle. The beam spot size is 6.35 mm in diameter with a 6° (105 mrad) cone angle for specular measurements. The solar weighted reflectivity is also calculated from these data using an air mass index of 1.5. Additional measurements of the specular reflectivity were also taken using the Device & Services (D&S) 15R reflectometer at smaller acceptance angles [1], but the long-term measurements reported in this paper were collected using the Surface Optics 410 Solar.

Figure 1. Left: mirror samples affixed to sawhorse. Right: measuring reflectivity of samples.

2.2. Beam Characterization

Figure 2 shows the testing that was performed on individual mirror facets placed at distances up to ~1700 m away from a long-range heliostat target (LRHT) at the National Solar Thermal Test Facility (NSTTF) in Albuquerque, New Mexico. Both low-iron silvered-glass (silver coating was applied between two 3-mm panes of glass) and 3M SMF1100 solar mirror film were tested. The SMF1100 mirror film was applied to a 0.508 mm painted aluminum substrate with an acrylic adhesive on the back side. The SMF1100 panel was then laminated to an existing glass-mirror facet.

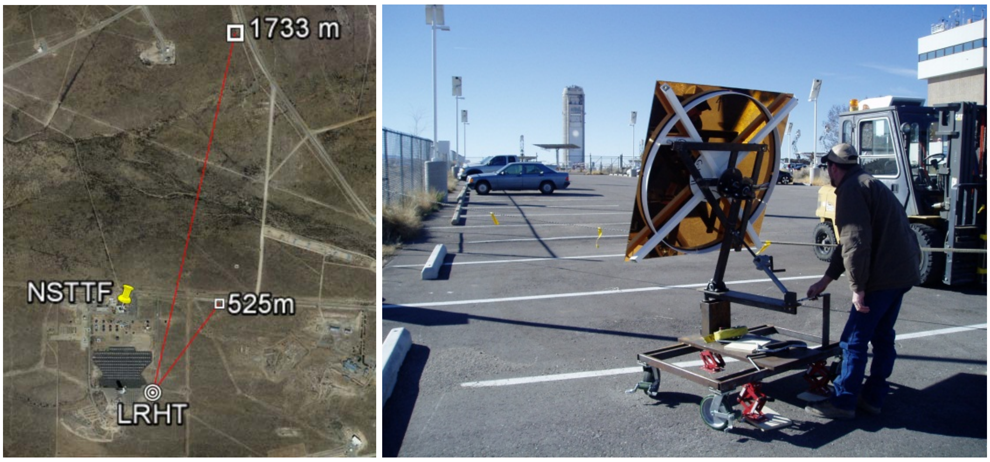

Figure 2. Left: Map showing the locations of the single-facet beam tests at 525 m and 1733 m away from the long-range heliostat target (LRHT). Right: Rig used to hold and track the facets.

The long-range heliostat target (LRHT) consists of a vertical array of collimated Li-COR pyranometers attached to a portable 15 m tower [2]. Figure 3 shows the LRHT and a view of the solar reflection from a single facet ~1700 m away from the target. Each sensor on the LRHT was aimed at the reflected sunlight from the facet before each test. During the test, the beam was swept with a known rate across the LRHT. The resulting irradiance values from each sensor along the vertical tower were then stitched together to create a flux map of the beam. Background irradiance was subtracted from the flux maps of the beam irradiance distribution.

Figure 3. Left: Long-range heliostat target (LRHT) [2]. Right: View from the (LRHT) looking at the solar reflection from a single facet ~1700 m away.

3. Results and Discussion

3.1. Reflectance Measurements

Figure 4 shows the normalized specular reflectivity values of different silvered-glass coupons and the SMF1100 coupon as a function of days exposed for both face up and side facing orientations obtained using the Surface Optics Corporation 410 Solar reflectometer. Current results show that the SMF1100 (black dots) has not shown any accelerated degradation relative to the silvered-glass coupons. Significant fluctuations in reflectivity result from dust and particulate soiling, rain, and/or snow, and no coupon type was identifiable as having superior or inferior properties. Side-facing samples maintained significantly higher reflectivity, with no coupon type dropping below a normalized specular reflectivity value of 0.85, whereas all face-up samples reached normalized values as low as 0.70 over the course of the exposure period (Figure 4). Continued evaluation of each sample may reveal reflectivity trends, averaged over random soiling and cleaning (rain/snow) events during exposure.

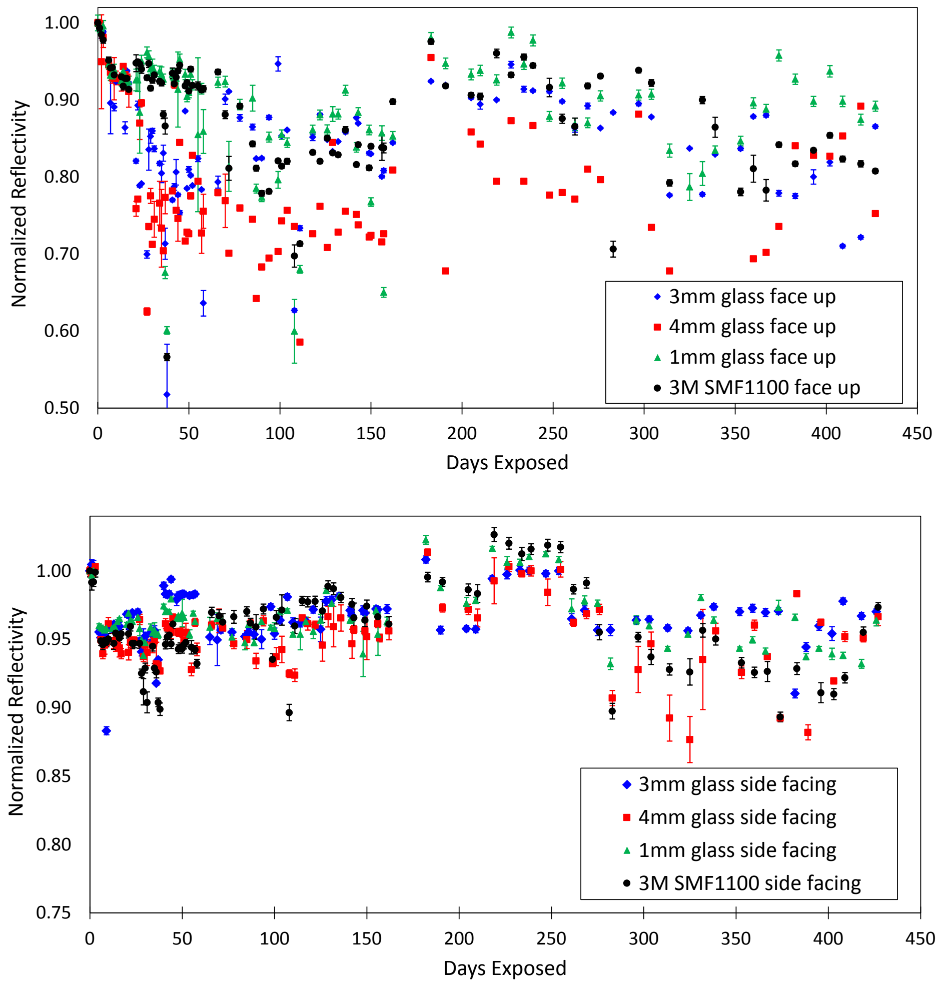

Figure 4. Normalized specular reflectivity from face-up and side-facing silvered glass and SMF1100 coupons as a function of outdoor exposure time, measured using Surface Optics Corporation 410 Solar reflectometer.

3.2. Beam Characterization

The results of the beam characterization tests at ~500 m and ~1700 m distances are reported in this section. The peak flux and general size and shape of the beam resulting from the silvered glass and SMF1100 facets are compared.

3.3. ~500 m Test

Figure 5 shows the measured irradiance distribution resulting from single-facet beam tests at ~500 m away from the target. The flux maps from both the silvered glass (left image) and the SMF1100 (right image) show similar irradiance distributions with the peak flux ~80 W/m^2. The height and width of the beams are approximately ~6 m and 8 – 10 m, respectively. The horizontal sweep rate of the beams was controlled manually, so large uncertainties in the width of the beam exist.

Figure 6 and Figure 7 show ray-tracing simulations using the commercial code ASAP of the silvered glass and SMF1100 facets for the ~500 m test. Horizontal and vertical focal lengths and slope errors were obtained using SOFAST [3]. Results show that the simulated peak fluxes for both the silvered glass and SMF1100 beams were ~70 W/m^2. The size of the simulated beams was ~6 m in the vertical direction and 7 – 8 m in the horizontal direction.

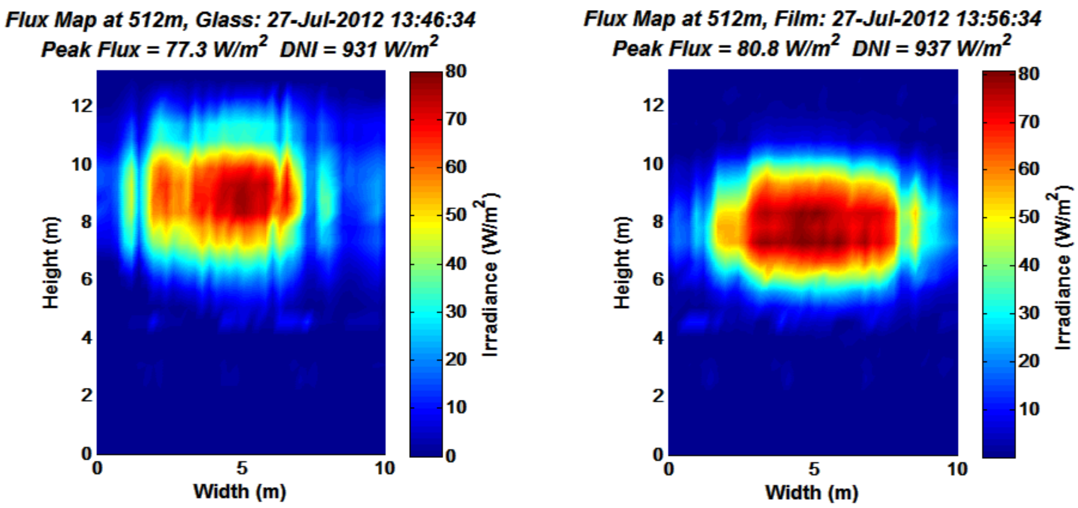

Figure 5. Measured irradiance distribution at ~500 m from the silvered glass facet (left) and the SMF1100 facet (right). The peak flux in both cases is ~80 W/m^2.

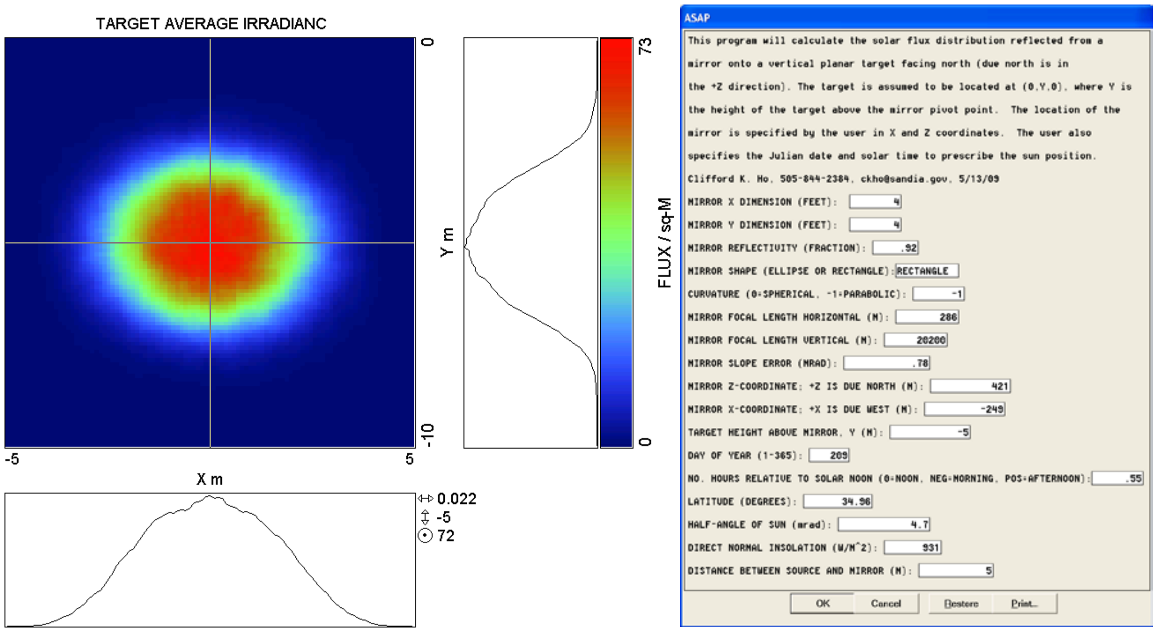

Figure 6. Ray tracing simulation for glass at ~500 m: focal lengths and slope error measured by SOFAST, 0.55 hours after solar noon on 7/27/12, DNI = 931 W/m^2, measured reflectance = 0.92. The peak flux is ~73 W/m^2.

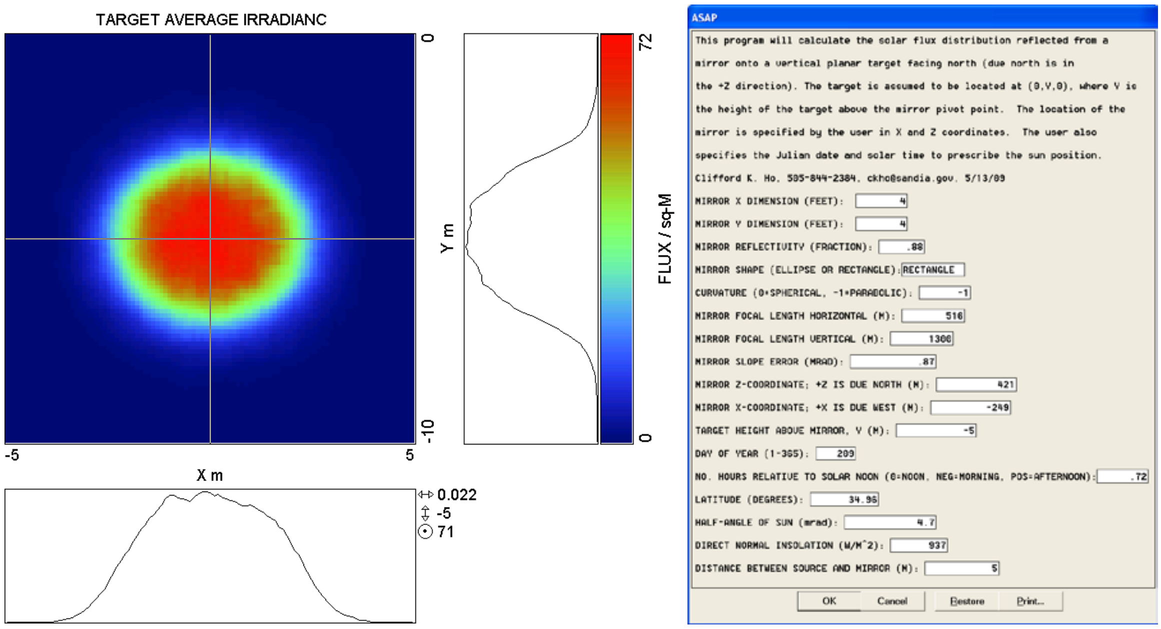

Figure 7. Ray tracing simulation for SMF1100 at ~500 m: focal lengths and slope error measured by SOFAST, 0.72 hours after solar noon on 7/27/12, DNI = 937 W/m^2, measured reflectance = 0.88. The peak flux is ~72 W/m^2.

3.4. ~1,700 m Test

Figure 8 shows the measured irradiance distribution resulting from single-facet beam tests at ~1700 m away from the target. The flux maps from the silvered glass (left image) and the SMF1100 (right image) show irradiance distributions with peak flux values ranging from ~7 and 8 W/m^2. The height of the beam is difficult to ascertain since the height of the target was only 15 m. However, the height of the beams appear to be ~20 m and the width of the beams are approximately ~30 - 40 m, respectively.

Figure 9 and Figure 10 show ray-tracing simulations of the silvered glass and SMF1100 facets for the ~1700 m test. Horizontal and vertical focal lengths and slope errors were obtained using SOFAST [3]. Results show that the simulated peak fluxes for both the silvered glass and SMF1100 beams were ~6 W/m^2. The size of the simulated beams was ~6 m in the vertical direction and ~20 - 30 m in the horizontal direction.

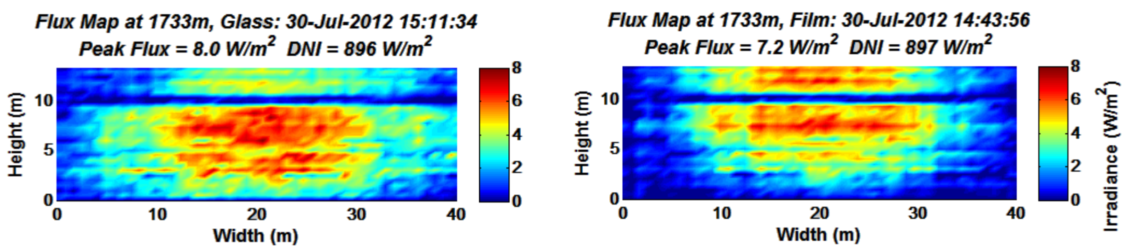

Figure 8. Measured irradiance distribution at ~1700 m from the silvered glass facet (left) and the SMF1100 facet (right). The peak flux in both cases is ~7-8 W/m^2.

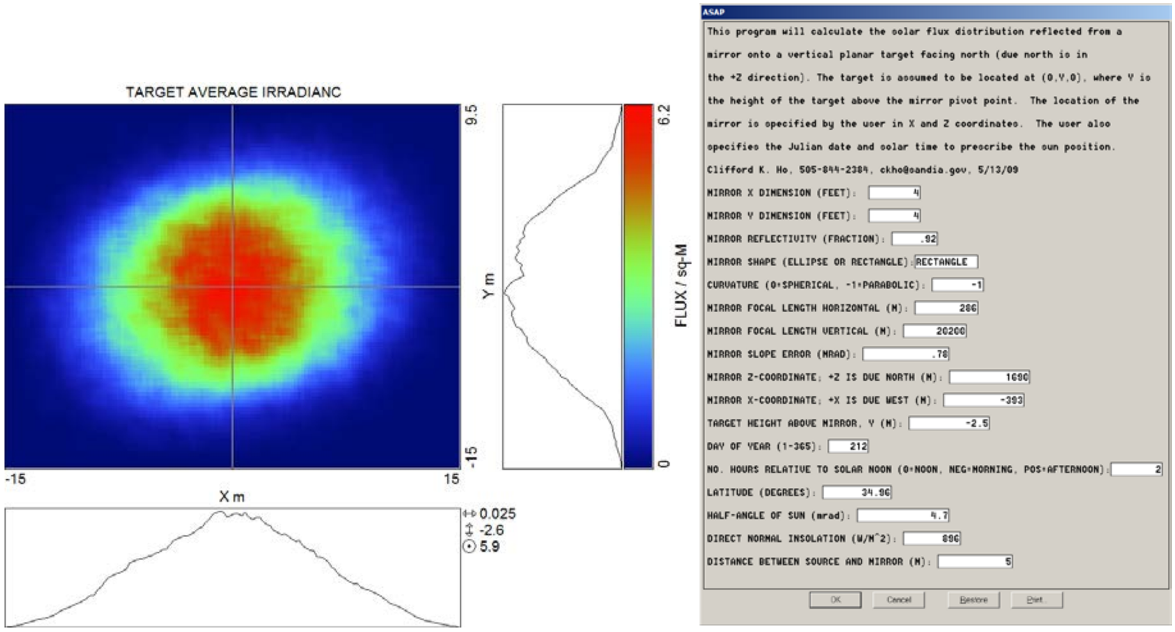

Figure 9. Ray tracing simulation for silvered glass at ~1700 m: focal lengths and slope error measured by SOFAST, 2 hours after solar noon on 7/30/12, DNI = 896 W/m^2, measured reflectance = 0.92. The peak flux is ~6.2 W/m^2.

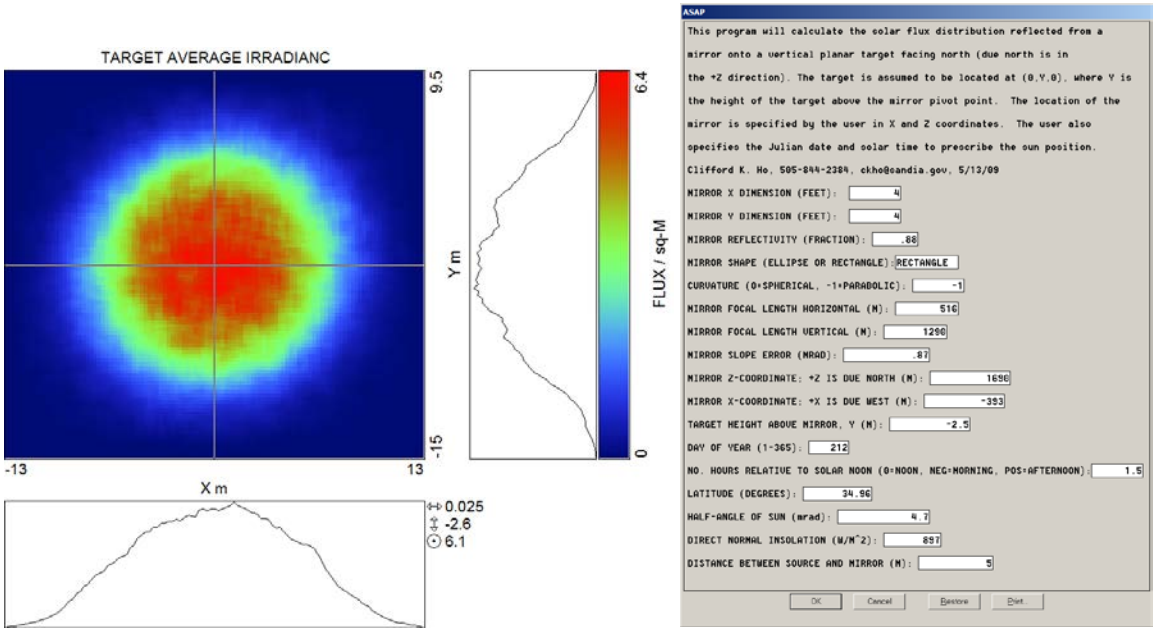

Figure 10. Ray tracing simulation for SMF1100 at ~1700 m: focal lengths and slope error measured by SOFAST, 1.5 hours after solar noon on 7/30/12, DNI = 897 W/m^2, measured reflectance = 0.88. The peak flux is ~6.4 W/m^2.

3.5. Comparison of Tests

Figure 11 shows the peak flux values from each test normalized by the measured DNI during each test. The error bars represent the range of measured values. A paired t-test showed that the mean peak flux values from the silvered glass and SMF1100 values were statistically the same for each distance.

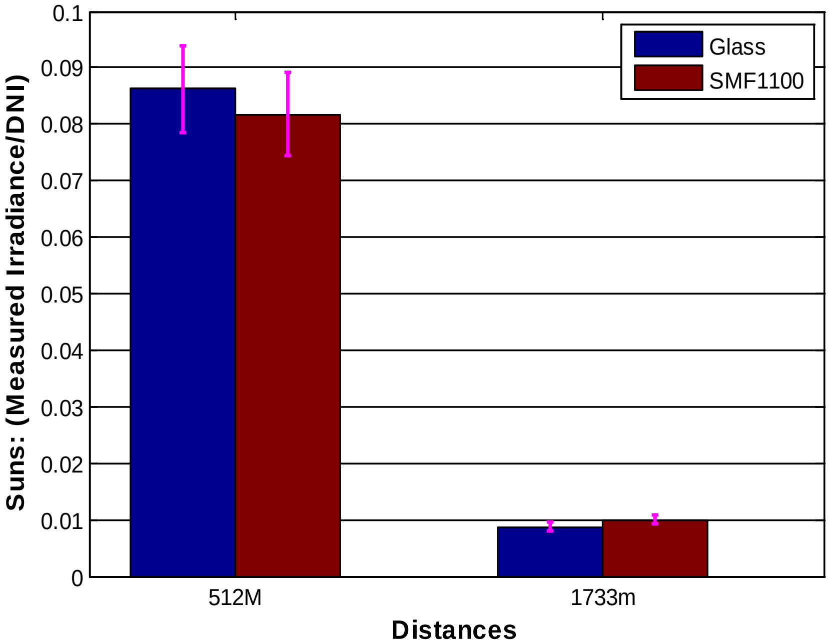

Figure 11. Peak flux normalized by DNI for silvered glass and SMF1100 facets at 512 m and 1733 m.

4. Conclusions

A commercial metallized polymer film (3M SMF1100) was evaluated for use in concentrating solar power applications. Reflectance measurements showed that there was no discernible difference in soiling rates between silvered glass and SMF1100 samples when exposed to outdoor conditions for over a year. Beam tests were conducted at distances up to 1700, and results showed that the peak flux values resulting from solar reflections from silvered-glass and SMF1100 facets were statistically similar. The size and shape of the beams were also similar. Uncertainties existed in the horizontal dimension of the beam due to manual control of the horizontal beam sweep rate.

5. Acknowledgments

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6. References

[1] Ho, C.K., C.M. Ghanbari, M.B. O'Neill, and J. Yuan, 2011, *On-Sun Testing of a Heliostat Using Facets with Metallized Polymer Films*, in *Proceedings of SolarPACES 2011*, Granada, Spain, September 20 - 23, 2011.

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[3] Andraka, C.E., S. Sadlon, B. Myer, K. Trapeznikov, and C. Liebner, 2009, *Rapid Reflective Facet Characterization Using Fringe Reflection Techniques*, in *Proceedings of ASME 2009 International Conference on Energy Sustainability* ES2009-90163, San Francisco, CA, July 19-23, 2009.