Characterization of the Reflectivity of Various Black Materials II

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ABSTRACT

We report on an expanded catalog of total and specular reflectance measurements of various common (and uncommon) materials used in the construction and/or baffling of optical systems. Total reflectance is measured over a broad wavelength range (250 nm $< \lambda <$ 2500 nm) that is applicable to ultraviolet, visible, and near-infrared instrumentation. Characterization of each sample's specular reflection was measured using a helium-neon laser in two degree steps from near normal to grazing angles of incidence. The total and specular reflection measurements were then used to derive the specular fraction of each material.

Keywords: Optical instrumentation, infrared instrumentation, scattered light minimization

1. INTRODUCTION

Maximizing the sensitivity of any optical or infrared astronomical instrument requires careful consideration of stray and scattered light within. Minimization of these unwanted reflections and scattering can be accomplished via baffles, material surface finishes, and coatings. In the first paper of this series[1] a broad range of black materials and coatings were tested. We now report on an expanded set of samples and improved testing methods for determining the specular reflectance. The total reflectivity measurements are relevant to optical and near-infrared instrumentation (250 nm $< \lambda <$ 2500 nm). The specular fraction was characterized at 633 nm. Updates to the project website (http://instrumentation.tamu.edu/reflectance.html) including downloadable data files and interactive plots are in progress.

2. MATERIALS TESTED

The samples can be broadly separated into two categories, those that would be appropriate for long term use in a completed instrument (aluminum, steel, and invar with a range of surface finishes and coatings) and less durable materials (tape, permanent marker, cloth) that would be better suited to use in a laboratory environment where a trade in durability and performance in favor of cost-efficiency and availability may be acceptable.

Samples were prepared out of both metal and non-metal materials. Sample sizes were limited to two inch square or round, and no more than 0.75 inch thick in order to accommodate the space constraints of the spectrophotometer. A list of newly tested samples is provided in Table 1.

3. TOTAL REFLECTANCE MEASUREMENTS

Texas A&M University maintains a Materials Characterization Facility (MCF) that includes a wide range of instrumentation for investigating material properties. We used the Hitachi High-Tech U-4100 UV-Visible-NIR Spectrophotometer and obtained reflectance profiles for the samples. The U-4100 dual beam spectrophotometer uses two different lamps to cover a wide range of wavelengths. A deuterium lamp covers the far UV ($<$ 345 nm),

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Table 1. New samples and samples with updated testing data.

Code	**Sample**
ABH	Bead-Blasted 6061 Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
AMH	Machined 6061 Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
APH	Polished 6061 Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
ARH	Raw 6061 Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
CBB	Bead-Blasted Cast Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
CBH	Bead-Blasted Cast Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
CMB	Machined Cast Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black
CMH	Machined Cast Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
CPH	Polished Cast Aluminum, Anodized (MIL-A-8625, Type III, Class 1, Non-dyed)
CRB	Raw Cast Aluminum, Anodized (MIL-A-8625, Type II, Class 2, Black)
SMN	Machined Stainless Steel, Electroless Nickel Coat (MIL-C-26074)
SPN	Polished Stainless Steel, Electroless Nickel Coat (MIL-C-26074)
F07	Hatchbox Black 3D Printed ABS 1.75mm (diameter) filament printed at 225C
P06	Black RTV on glass plate
P09	Aeroglaze Z306 Flat Black
P19	Duranar XL Stellar Black 9778 with BN5C103B Clear Coat (*ppgideascapes.com*)
P21	Culture Hustle Black 2.0 Acrylic paint (*culturehustle.com*)
T01-1	Black Heat Shrink Tubing
T01-2	Black Heat Shrink Tubing - Shrunk

and a tungsten lamp is used for UV, visible, and near-IR measurements. The U-4100 is capable of measuring both reflectance and transmittance of solid and liquid samples. With this system we measured precise reflectance values at each wavelength (in 1 nm steps) for the wavelength range 250 nm $< \lambda <$ 2500 nm. Figure 1 shows the instrumental setup of the Hitachi High-Tech U-4100 UV-Visible-NIR Spectrophotometer. The reference and test sample are placed in the 6 o'clock and 3 o'clock positions of the integrating sphere, respectively. The data acquisition procedure involves obtaining a baseline measurement at each wavelength of the reference $BaSO_4$ wafers ($\sim$ 100% reflectance) in both the reference and sample slots of the dual beam spectrophotometer. We then measure a second reference sample having 5% reflectivity (Labsphere SRS-05), and measure the reflectivity of the test sample. We compare the 5% reflectance reference sample to the values provided by the manufacturer and use this ratio to construct the absolute reflectivity of the test sample as a function of wavelength. During each day of testing the SRS-05 standard is measured to ensure measurements from different test days are tied to a common reference.

Several new materials have been tested since our 2014 publication on this subject, and their respective total reflectivities are shown in Figures 2 and 3.

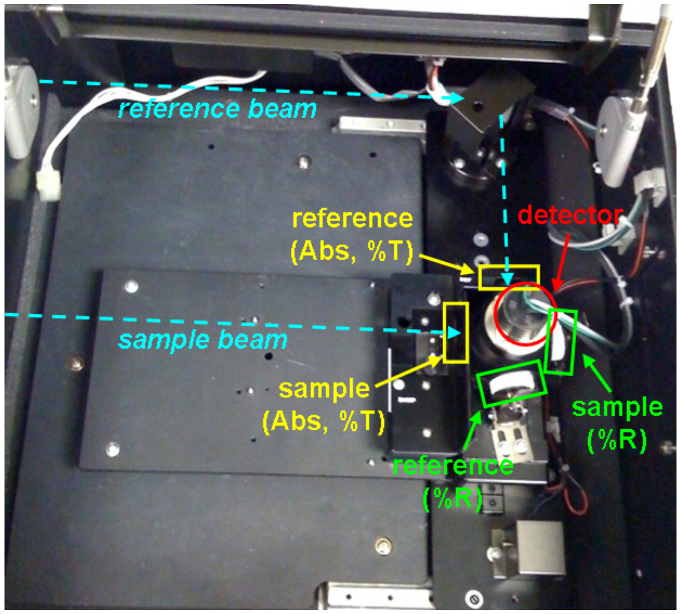

Figure 1. Internal view of the U-4100 UV-Visible-NIR Spectrophotometer. Test samples are placed at the 3 o'clock position.

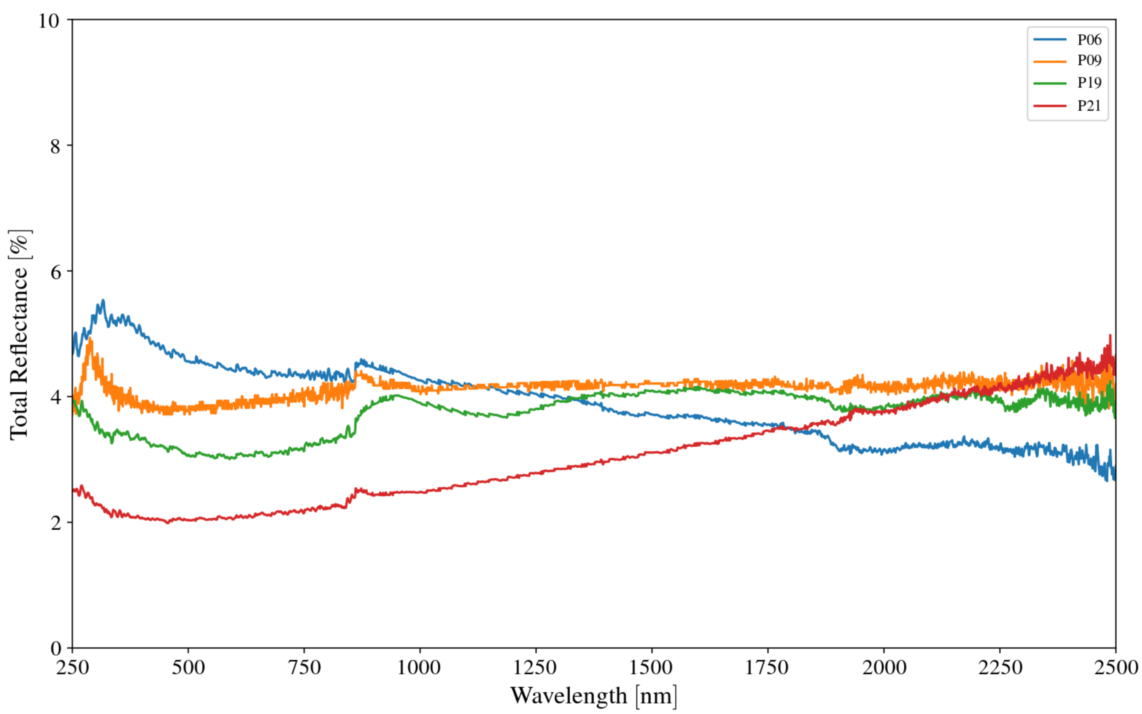

Figure 2. Total reflectance of several new coating samples, Black RTV (P06), Aeroglaze Z306 (P09), Duranar XL Stellar Black (P19), and Culture Hustle Black 2.0 (P21).

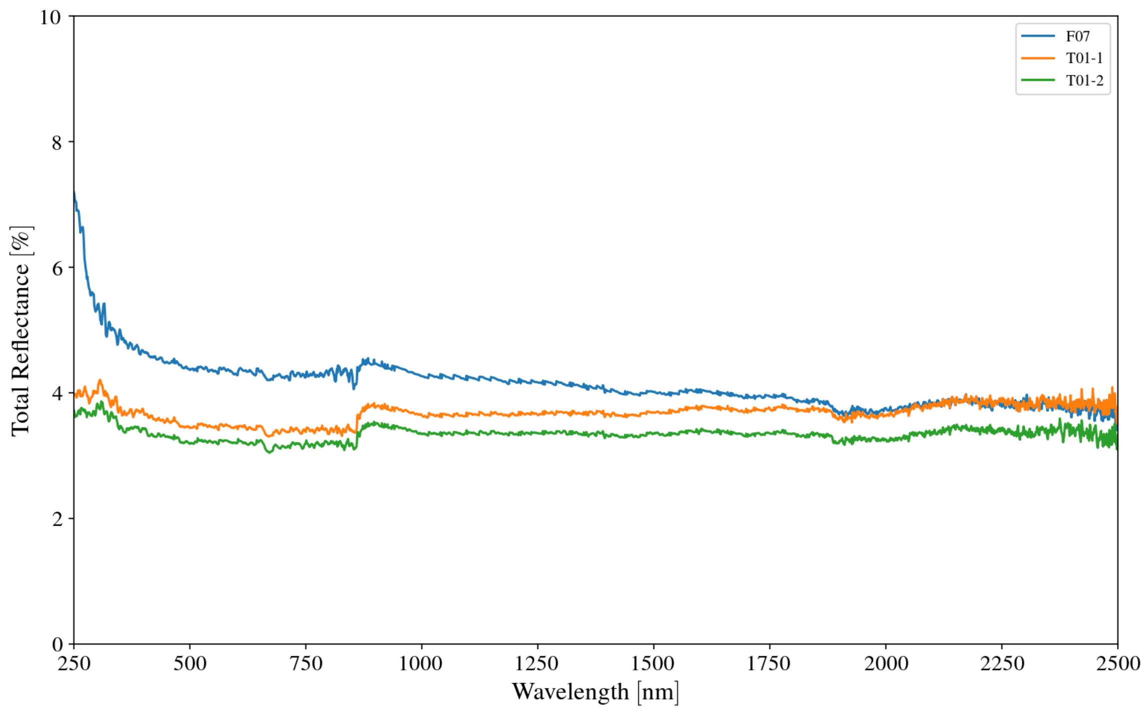

Figure 3. Total reflectance of black 3D printer filament (F07) printed into a 2" square sheet and heat shrink tubing both shrunk (T01-2) and un-shrunk (T01-1).

4. SPECULAR REFLECTANCE

The first paper in this series[1] included preliminary results measuring the specular fraction of the total reflectance. The 2014 values were reported as the average specular reflectance measured at 10°, 22°, and 44° divided by the total reflectance measured at the MCF. We now report on updated measurements using MADLaSR[2] (Multi-Angle Detection of Lambertian and Specular Reflectivity). MADLaSR consists of a HeNe laser and Gentec photodiode mounted on movable arms that allow for testing the reflected power of the laser off of a sample at variable angles. With MADLaSR, we measure the specular reflectance every 2°, so the new specular fraction uses the average of all measurements between 10° and 44°. As seen in Figures 5 and 6 this portion of the reflectance curve is relatively flat. The U-4100 spectrophotometer measures the total reflectance of the sample with the sample surface inclined 10° to the test beam so we cannot characterize any changes in total reflectance or the specular fraction at more extreme angles. The error in the specular fraction is dominated by the measurement of our STAN-SSL (Ocean Optics) low specular reflectivity standard and is set by the stated accuracy of the Gentec photodiode at the measured power level. This standard is made from Schott ND9 glass and has a reflectivity of $\sim 4\%$ when measured at 6°. Due to mechanical interference, MADLaSR can only measure down to 10°. The flatness of measured specular reflectivity curves below 45° gives us confidence that this difference in measurement angles has a minimal impact on measurement accuracy. We compared the original specular fraction measurements reported in 2014[1] for the samples listed in Table 2 and found they were consistent with our new measurements with a small positive systematic offset. The offset for the more highly specular samples (SMN and SPN) had a larger positive systematic offset, but were still consistent with previous measurements. We attribute this difference to the completely different experimental setup, where distances between source, sample, and detector are shorter in the new setup, as well as changes in baffling. The shorter distances between source, sample, and detector mean that MADLaSR can see a larger fraction of the specular lobe surrounding the specular spike seen on an imperfectly specular surface and could account for this difference. As these measurements are most useful for a relative comparison between materials, we do not view this as an issue that needs resolved.

Table 2. The average specular fraction from 10°-44°.

Code	Specular Fraction [%]
ABH	0.17 ± 0.02
AMH	0.11 ± 0.02
APH	0.59 ± 0.02
ARH	0.07 ± 0.02
CBB	0.07 ± 0.02
CBH	0.23 ± 0.02
CMB	0.15 ± 0.02
CMH	0.14 ± 0.02
CPH	0.56 ± 0.02
CRB	0.57 ± 0.02
SMN	5.46 ± 0.02
SPN	76.3 ± 0.02

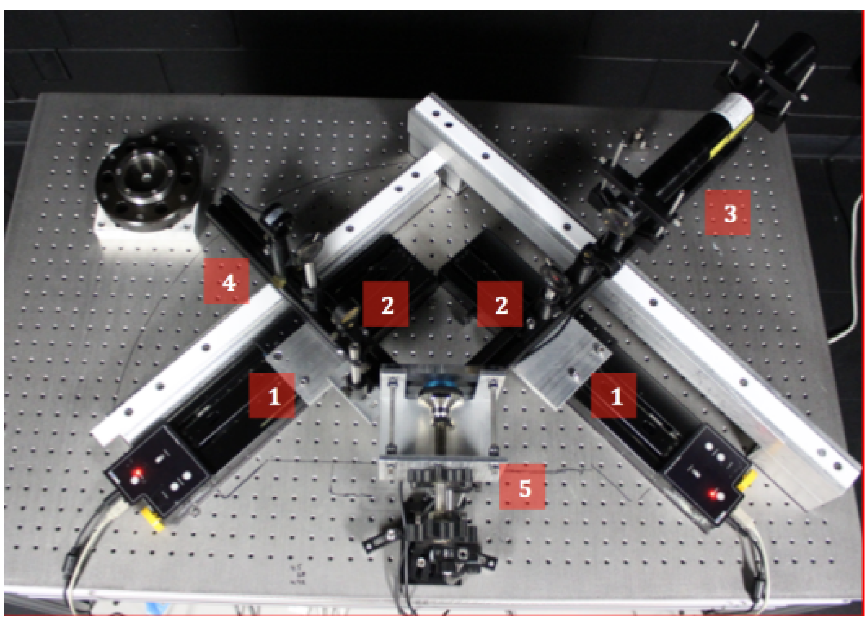

Figure 4. MADLaSR top view configured for specular reflectance testing. Two linear motorized stages (1), rotating arms (2), HeNe light source (3), Photodiode (4), and sample holder (5).

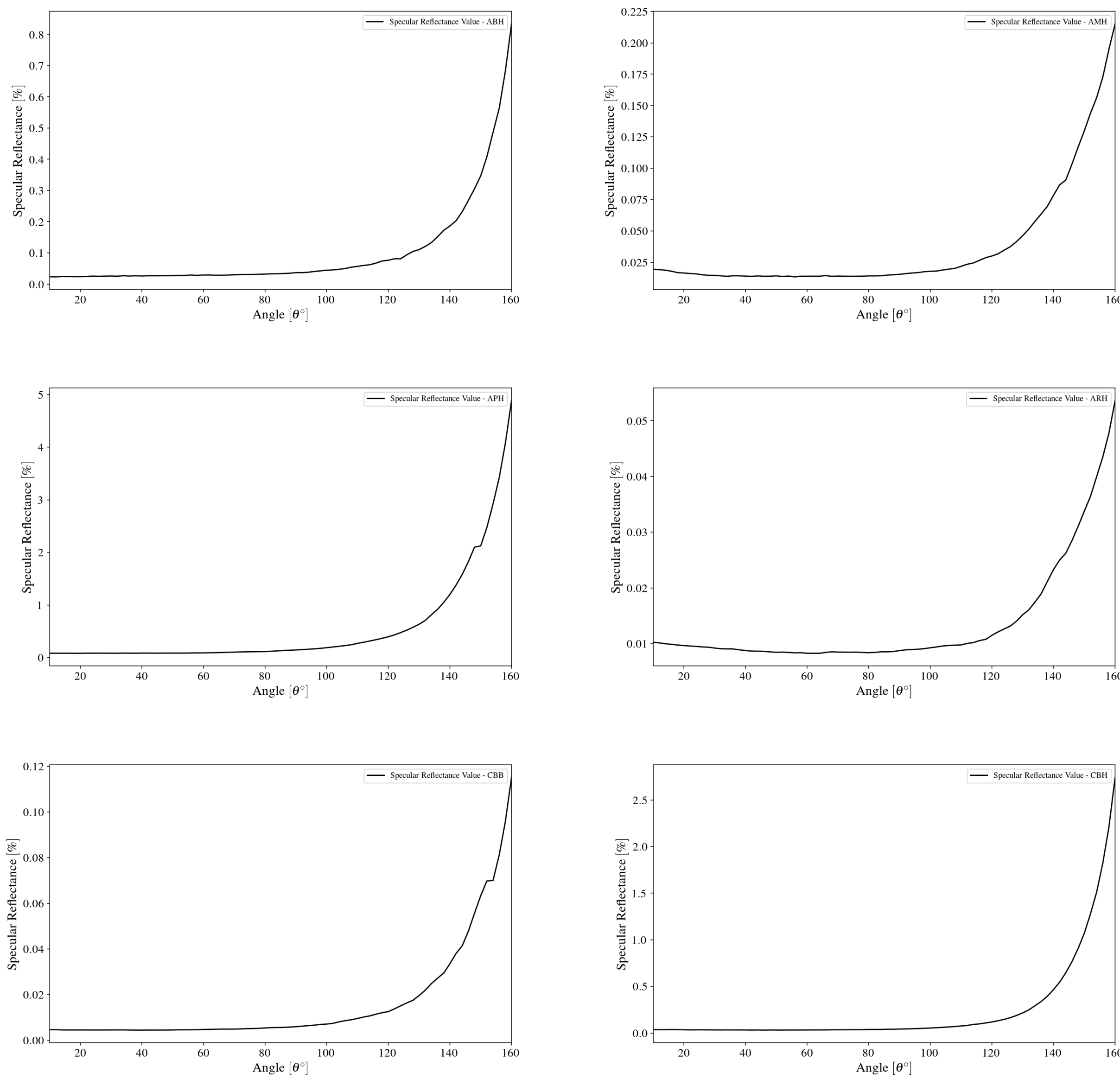

Figure 5. Specular reflectance of ABH, AMH, APH, ARH, CBB, and CBH.

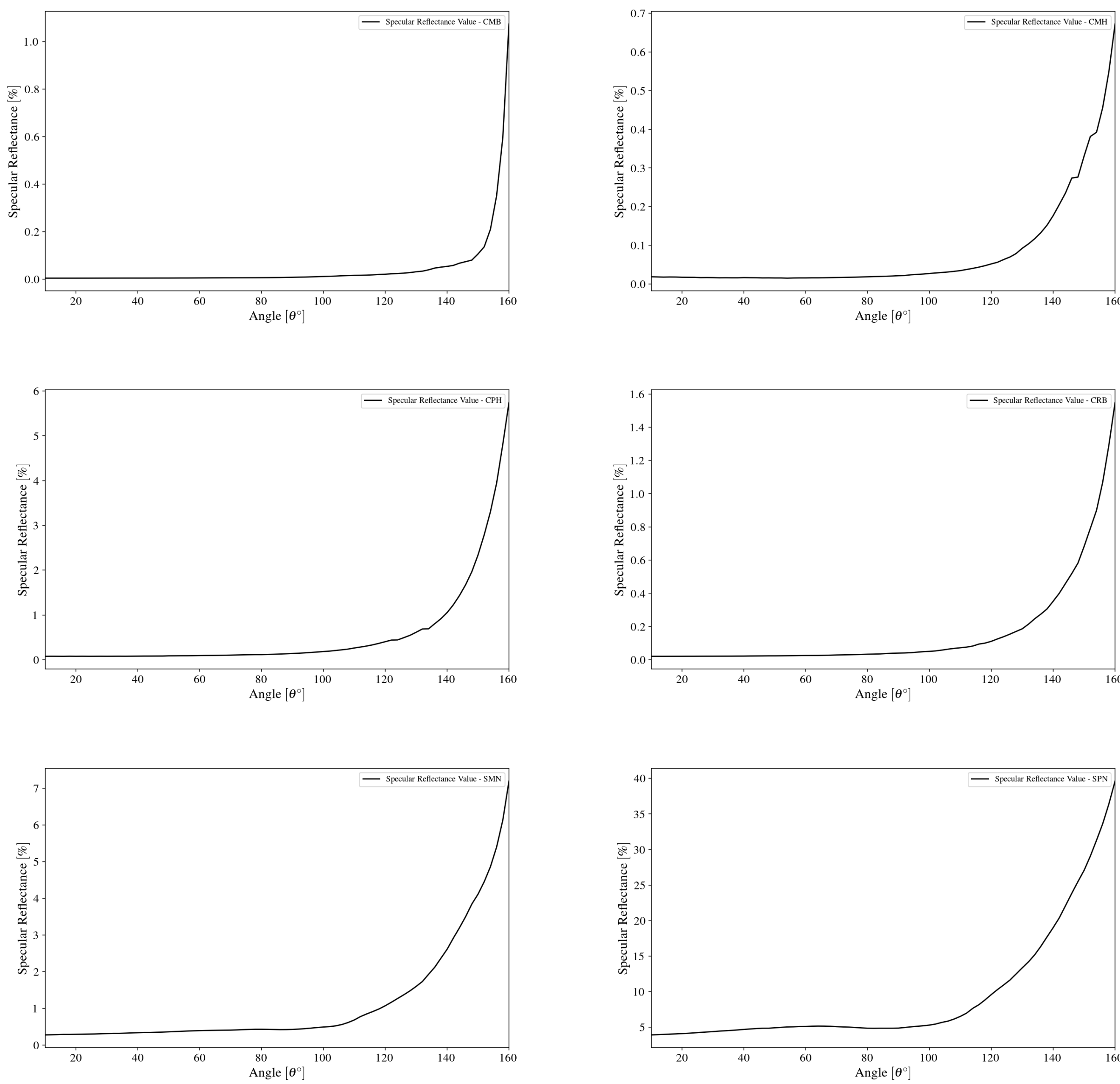

Figure 6. Specular reflectance of CNB, CMH, CPH, CRB, SMN, and SPN.

5. DISCUSSION

We continue to expand our sample library and improve our testing methods and capabilities. All of the new samples perform well across the full tested spectrum. The Culture Hustle Black 2.0 paint performs particularly well in the UV and optical, with less than 3% total reflectance, out-performing even materials like Aeroglaze Z306. However, the performance of the Culture Hustle paint comes at a cost of durability. We had trouble with the Culture Hustle paint cracking and flaking off of an aluminum substrate. Remaking the samples with careful surface preparation (light sanding and cleaning with Isopropyl Alcohol) helped improve adhesion and cracking was reduced somewhat by thinning the paint before applying multiple coats. It would still make an excellent coating for a temporary laboratory enclosure or baffle.

Our lab increasingly finds use for 3D printed parts in prototype systems. Despite a higher reflectivity of the Hatchbox Black 3D filament in the UV, the optical and near-infrared range tested has less than 5% total reflectivity and would be a suitable material for generating test baffles during instrument prototyping.

The expanded specular testing made possible by MADLaSR demonstrates that for all samples tested so far, specular reflectivity and the specular fraction of the total reflectivity has minor variations as a function of angle across all samples. Below $\sim 90^{\circ}$ consistent performance can be expected. At larger angles physical baffles in addition to surface treatments are a better approach, as surface coatings are not as effective at grazing angles. We plan to continue the expanded specular testing of the rest of our sample library.

Information about all of the samples including reflectivity plots and text files of the calibrated data are available at http://instrumentation.tamu.edu/reflectance.html. We are in the process of updating the plots to be interactive, allowing a user to zoom in on a particular region of interest and then save it as an image as well as better features for comparing materials. The same page includes information on how to suggest or submit a sample for testing. Due to resource availability no guarantee is made on sample testing turn around time and results will be made public on our website. We are also unable to return any samples that are submitted for testing.

6. CONCLUSIONS

We have presented additional total and specular reflectance measurements of various materials that have been — or may be— used to minimize stray and scattered light within optical and near-infrared astronomical instruments. Expanded capabilities for testing the specularity of materials and the specular fraction of the total reflectance have enhanced the utility of this project. Control of stray light within an instrument is an important concern and the material choice and surface treatment within the instrument requires careful consideration.

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[2] Gardner, L. E., Prochaska, T., Schmidt, L. M., Marshall, J. L., Sauseda, M., Torregosa, M., and DePoy, D. L., "Madlasr: multi-angle detector of lambertian and specular reflectivity," *Proc.SPIE* **10706** (2018).