Analyzing Reflectance Data for Various Black Paints and Coatings

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ABSTRACT

The US Army NVESD has previously measured the reflectance of a number of different levels of black paints and coatings using various laboratory and field instruments including the SOC-100 hemispherical directional reflectometer (2.0 – 25 µm) and the Perkin Elmer Lambda 1050 (0.39 – 2.5 µm). The measurements include off-the-shelf paint to custom paints and coatings. In this talk, a number of black paints and coatings will be presented along with their reflectivity data, cost per weight analysis, and potential applications.

1.0 OVERVIEW

Black paints and coatings find an important role in hyperspectral imaging from the sensor side to the applications side. Black surfaces can enhance sensor performance and calibration performance. On the sensor side, black paints and coatings can be found in the optical coatings, mechanical and enclosure coating. Black paints and coating can be used inside the sensor to block or absorb stray light, preventing it from getting to the detector and affecting the imagery. Stray light can affect the signal-to-noise ratio (SNR) as well introduce unwanted photons at certain wavelengths. Black paints or coatings can also be applied to a baffle or area around the sensor in laboratory calibration with a known light source. This is to ensure that no stray light enter the measurement and calculations.

In application, black paints and coatings can be applied to calibration targets from the reflectance bands (VIS-SWIR) and also in the thermal bands (MWIR-LWIR). As calibration targets, a black paint or coating is mostly likely used as the dark reference or the darkest point in a calibration curve. In order for the paint or coating to be a good reference, it should have a low as possible reflectance value. Therefore, it is important to quantify the reflectance values of the paint or coating. In the thermal bands, black paints and coatings are used on blackbodies or thermal sources. Since emissivity is equal to 1 – reflectivity, the lower the reflectance, the better the emissivity for the blackbodies. Below is a figure depicting a calibration panel including a black panel for reflectance calibration and four blackbodies with a black coating.

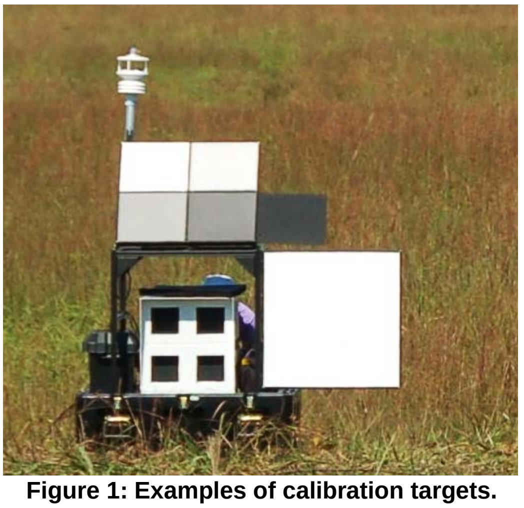

Figure 1: Examples of calibration targets.

When selecting a paint or coating, other considerations include surface treatment. Certain surfaces are radiation-resistant and can withstand environment exposures such as sun and rain with high heats and low temperatures. Robust and environmental resistance paints and coatings are generally preferred for applications such as calibrations in the field. Some of the matte paints and coatings that were measured were found to flake with touch and needs to be in a protective environment like a dewar. Other considerations include the paints' or coatings' outgassing property, which is when the coating or paint breaks off from the surface that it is applied on and its products may form with other properties—sometimes ruining or contaminating whatever application it is used on. If the application is sensitive, then the most matte paint that could be fragile and flake may not be the best option. Other things and trade-offs include: cost and pricing, paint and coating degradation over time, thermal cycling effects, and radiation effects. If a paint or coating meets are criteria but comes at a high price and/or long lead time then it might not be worth it or practical. If the paint or coating is incorporated in a system that goes through thermal cycling, then it should be able to within the effects of constant heating and cooling. Some paint or coating may crack or lose its properties after a period of time. Overall, there are many considerations when it comes to picking the right black paint or coating. This paper will highlight just the basic criteria such as reflectance spectra along with some known information.

Availability of paints and coatings should be taken into account as well. Paints are generally easier to find than coatings, most often cheaper and easier to apply either by a paintbrush or spray can. This availability makes them ideal for certain applications. Finally, some paints and coatings can be low in the reflectance region and higher in the emissive region and vice versa. Not all paints and coatings are made equally in cost and time comparison and not all are equal along the entire spectrum. We will show them through the reflectance measurements of various paints and coatings.

2.0 DATA SET

Various black paints and coatings were measured and analysed. The paints and coatings measured in this dataset are created through different means and out of different materials including the following processes: anodized process, etching process, electrodeposited surfaces, etc. Paints and coatings were collected over a period of time. Some were provided by Lawrence Livermore National Laboratory, who were collecting coatings for a specific application. Other samples come from applications found in the laboratory and from the commercial market.

The dataset include the following paints and coatings:

- Acktar Spectral Black
- Avian Black-S
- BLACK 3.0
- Black Pioneer Coating
- Current US Army Military Paint
- Electroless Nickel Boron Black
- Fountain Plating Black Nickel
- Krylon Ultra Black
- Optical Black Anodized Coating
- Permaflect
- Vince's super-secret coating

Information for each paint and coating will be provided in the Results section along with the reflectance data.

3.0 LABORATORY INSTRUMENTS

The laboratory instruments that were used to take the measurements include the PerkinElmer Lambda 1050+ UV/Vis/NIR Spectrophotometer, which covers 175 nm to 3300 nm, and the SOC-100, which covers 2.5 microns to 25 microns. Although all samples were measured by both instruments, it should be noted that the measurements were taken at various times with some samples being measured almost two-three years apart. The measurements could also be made using different methods, gains, and offsets. The overall curve of the data should be reliable, but the resolution, gain, and reflectance values can be off. The PerkinElmer and the SOC-100 also have gains that may or may not equal each other. A formal test plan was not utilized in the measurements of these samples. In the future, a more standardized process will be set-up for the collection of data.

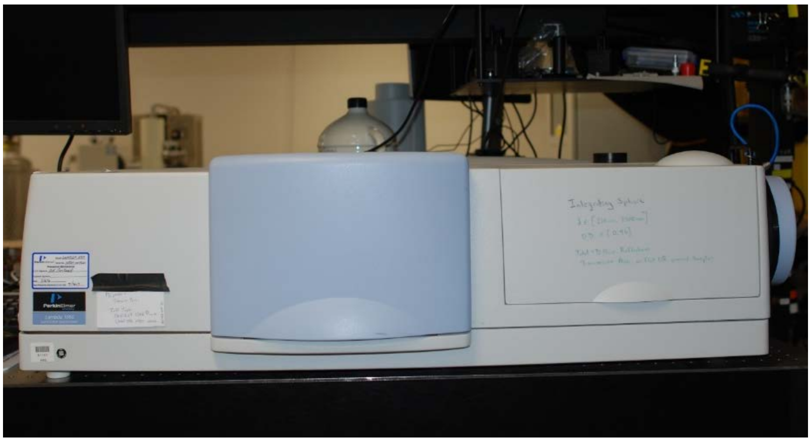

Figure 2: PerkinElmer 1050

The PerkinElmer instrument, shown in Figure 2, is a UV/Vis/NIR spectrophotometer that is capable of measuring paints, coatings, glass, fabrics and other materials. It offers a fast scan rate at high resolution (less than 1 nm if desired) and changeable integration times. It uses two lamps including a tungsten-halogen and deuterium lamp as well as two detectors including a PMT and lead-sulphide (Pb-S). The operable range is 175 nm to 3300 nm. All the measurements are taken from 250 nm – 2500 nm at neat normal incidence specular reflectance.

Figure 2: PerkinElmer 1050 Integrating Sphere

The PerkinElmer comes with a compartment space seen on the right hand side in Figure 2 above, which allows user to add or change the measurement module. The module that was used for the measurement is the Integrating Sphere Module. This image from PerkinElmer shows the inside of the integrating sphere. The integrating sphere can be used to measure reflectance or transmittance of any sample. As the surface roughness increases, the scattering increases as well. The integrating sphere allows user to measure the correct reflectance of materials with various surface roughness.

The SOC-100 measures specular and hemispherical diffuse reflectivity over the spectral range of 2.0 to 25 microns for incidence angles ranging from 7 to 80 degrees. Only hemispherical diffuse reflectance data will be presented in this paper. Due to the fact that samples were taken at different times using different methods, some samples were not measured using the other components. Not all samples were measured using the same spectral interval as well. Some samples are only measured from 2.0 to 13 microns.

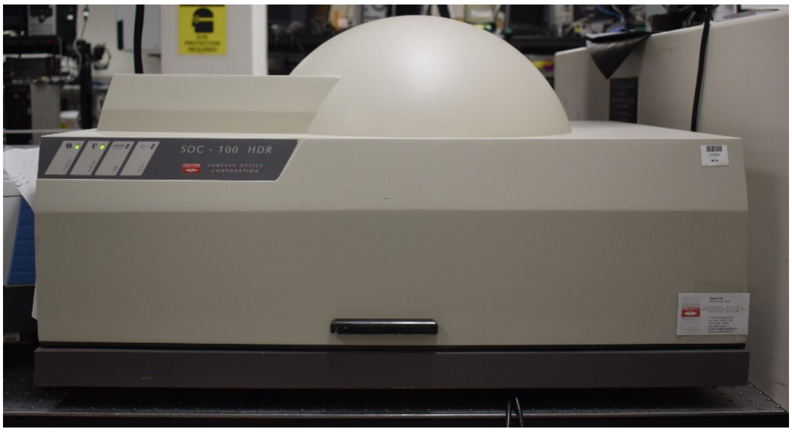

Figure 3: SOC-100

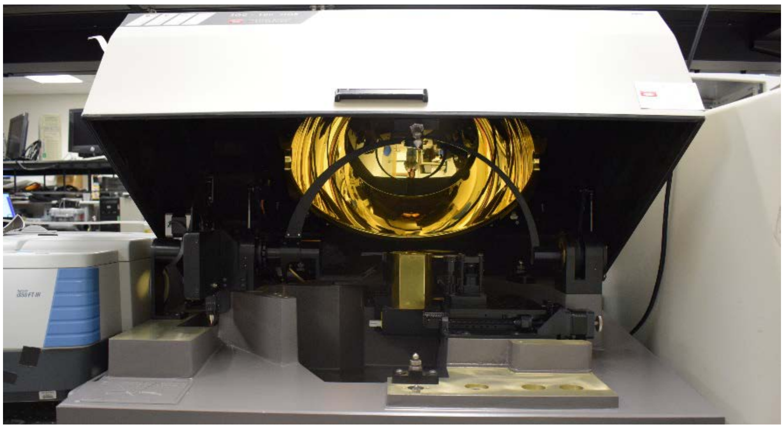

Figure 4: SOC-100 gold sphere

A schematic layout of the reflectometer is shown in Figure 5. Radiation from the source at one focus of a hemi-ellipsoidal mirror is collected and directed onto the sample at the other focus. The sample is illuminated over a full hemisphere. An overhead mirror collects radiation scattered at the chosen incident angle. This is equivalent to illuminating the sample in a narrow cone at chosen incident angle and collecting the radiation scattered into a full hemisphere. The collected radiation is then directed into a Nicolet FTIR spectrometer to measure the reflectance as a function of wavelength. The positioning of the collection mirror and the beam blocker (when used) are automatically controlled by the instrument software. Figure 4 shows the internal optical components of the SOC-100. The incident angle presented for the measurements are at 30 degrees. This was chosen because not all samples were measured closer to incident, so the measurement that they all did have in common is presented.

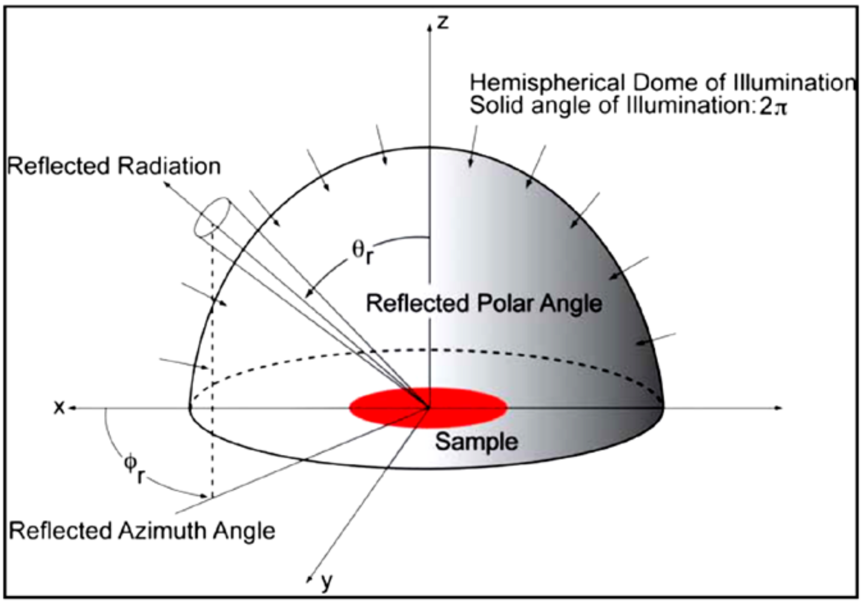

Figure 5: SOC-100 gold sphere

4.0 RESULTS AND COMPARISONS

Results and comparisons will be shown in this section. It should be noted that the following specifications were not closely monitored or known: coating density, coating thickness, details about how the paint or coating was applied, sample age, and specific formulation. Most of the samples were acquired directly from the vendors, and the vendors did not disclose the specific information. This could be due to protecting their proprietary paint or coating and preventing competition. Most of the vendors are commercial vendors who are trying to sell their product. Results will be listed in alphabetical order. Due to the fact that only a dozen samples are presented in this paper and the paint or coating process vary from one to the other, not comparisons for certain coating processes were made. The only comparison done is for reflectance measurement. This may be unfair to some of the coatings that are meant to be used in different applications than the darkest matte paints. However, this is just an initial gathering of data. Samples from all processes will be collected in the future.

The first sample that is presented is called Acktar Spectral Black from a company called Acktar based out of Israel with some U.S vendors. Acktar Spectral Black is a vacuum deposited coating on smooth aluminium. These samples were created for Lawrence Livermore National Laboratory and were sent to us for measurement. Below is a plot from the PerkinElmer.

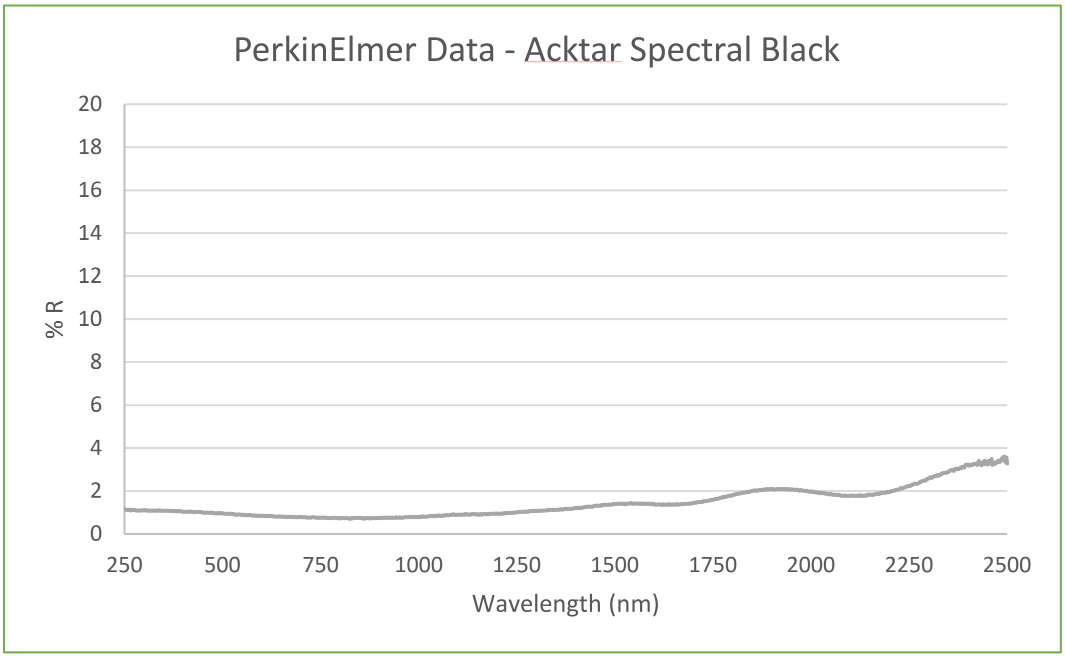

Figure 6: PerkinElmer spectral measurement of Acktar Spectral Black

Below is the measurement from the SOC-100:

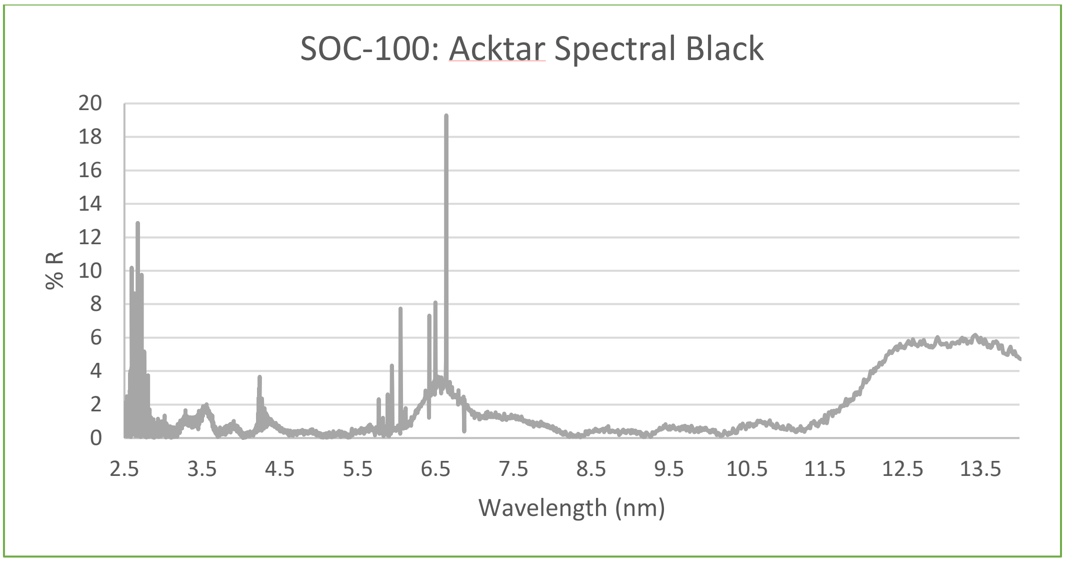

Figure 7: SOC-100 spectral measurement of Acktar Spectral Black

Avian Black-S is a two part water-based urethane paint made by Avian Technologies, LLC. It is available upon request and can purchased by the quart, gallon or custom. Avian will also coat whatever samples/background are sent in to them as well. The coating is fairly weather resistant and the coating has been used in many field applications including on blackbodies. The samples that were measured is dated to 2011. The measurement on Avian's website is dated to 2012. The formulation was not expected to change. Below is the measurement found on Avian's website. They noted that adding more coats of the paint can decrease the coatings' reflectance to around 2% reflectance and even lower by spraying the paint from a longer distance to get a rougher texture.

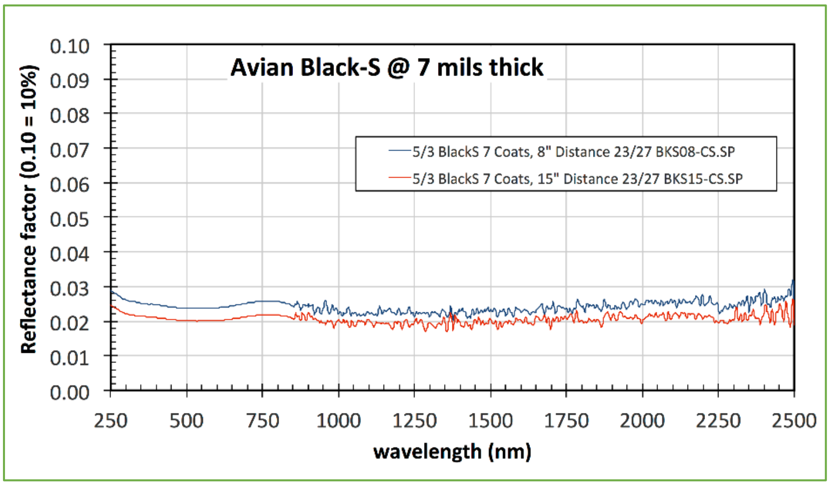

Figure 8: Spectral measurement for Avian Black-S as found from Avian's website

Below is what the PerkinElmer measured. It is not as flat as what Avian measured, but the 2% reflectance sample's average percent reflectance is roughly 2%. A 5% reflectance from Avian was also measured. The slope is not ideal for some applications.

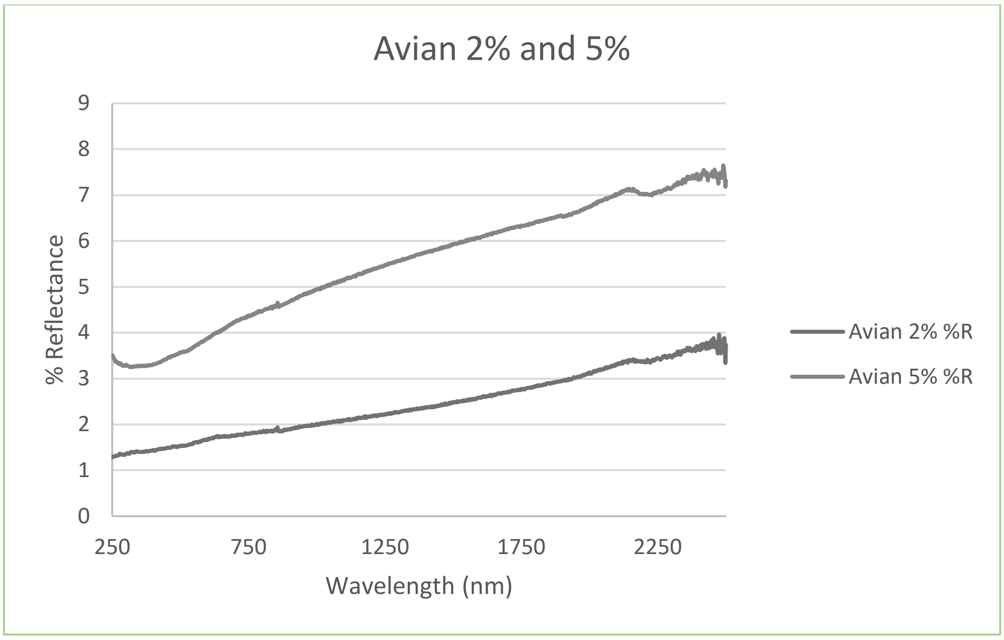

Figure 9: PerkinElmer spectral measurement for Avian Black-S

Below is a plot from the SOC-100:

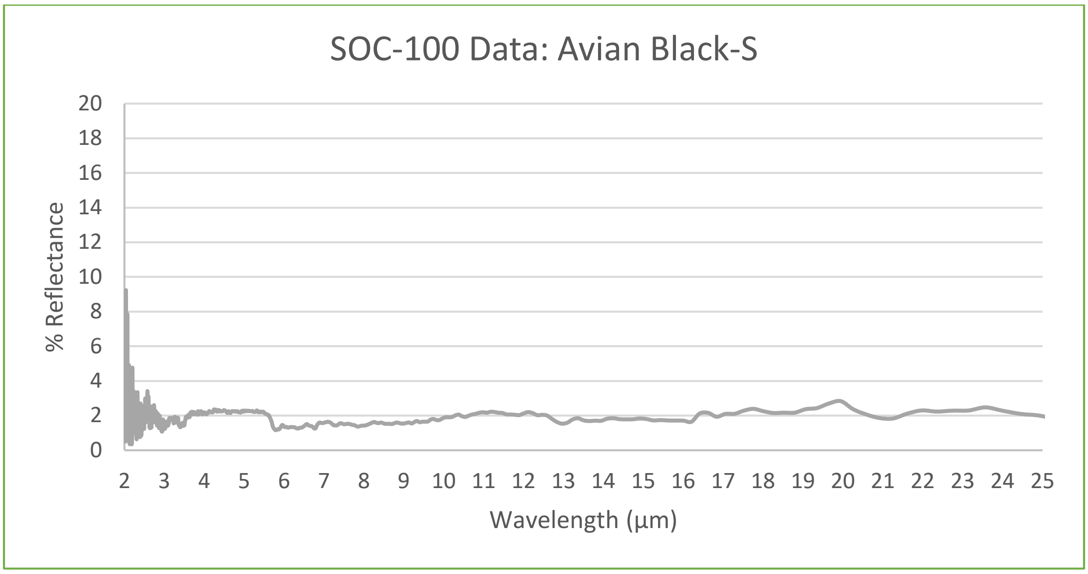

Figure 10: SOC-100 spectral measurement for Avian Black-S

BLACK 3.0 is an acrylic paint that was produced by an artist named Stuart Semple and a group of artists with funding raised from a Kickstarter to create the darkest black paint. This idea came about when another artist had created a black paint and copyrighted it, so no other artists could use it. Semple vowed to create this paint and ban that one artist from using it. BLACK 3.0 is sometimes called the Vantablack of the paint world. The distinction that needs to be made is that it is not actually the Vantablack paint or coating. Vantablack has recently been popularized as the blackest paint and coating, which is why anything in reference to a black paint or coating might be called Vantablack. Vantablack is not presented in this paper due to the unavailability of it while these samples were being collected.

BLACK 3.0 can be purchased for about 20 USD. However, due to popular demand, it is almost guaranteed to sell out as soon as it is released. Everyone who pledged at least 25 USD to the Kickstarter in the beginning received one bottle without waiting. For this paper, one bottle was acquired through the means of pledging to the Kickstarter. The paint was applied in three coats in our laboratory using a sponge paintbrush on smooth aluminum. Below is a picture found on the official website of the paint applied on regular canvas and compared to other popular black artist paints.

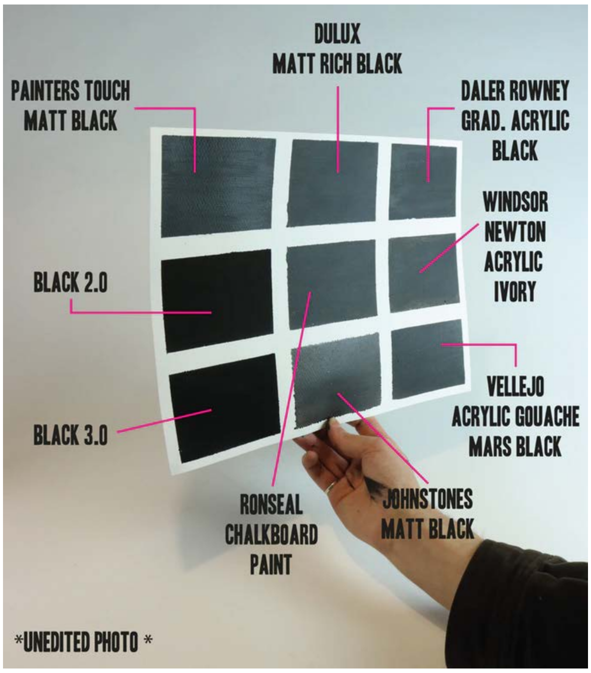

Figure 11: Example of BLACK 2.0 on paper

The plot below is also found on the official website. Since this is an artist paint, only the visible region was looked at. Note that this is also a measurement for BLACK 2.0 and it is believed that BLACK 3.0 should be darker. To see that, the PerkinElmer data is shown in Figure 12.

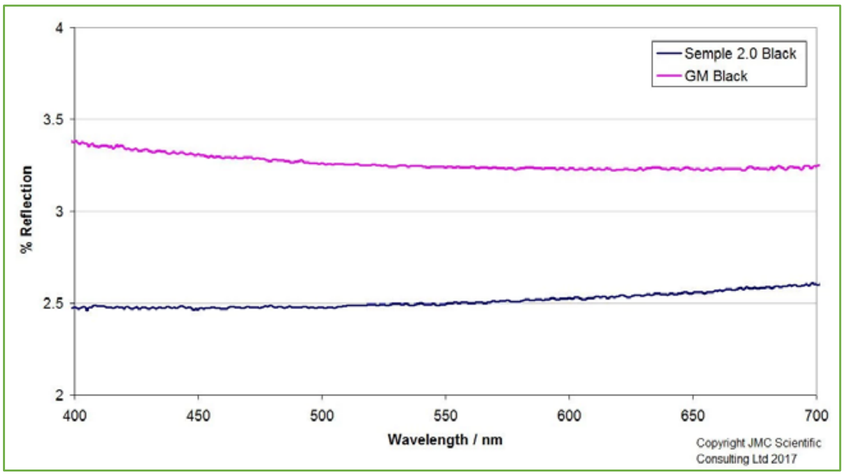

Figure 12: Reflectance as measured by Semple

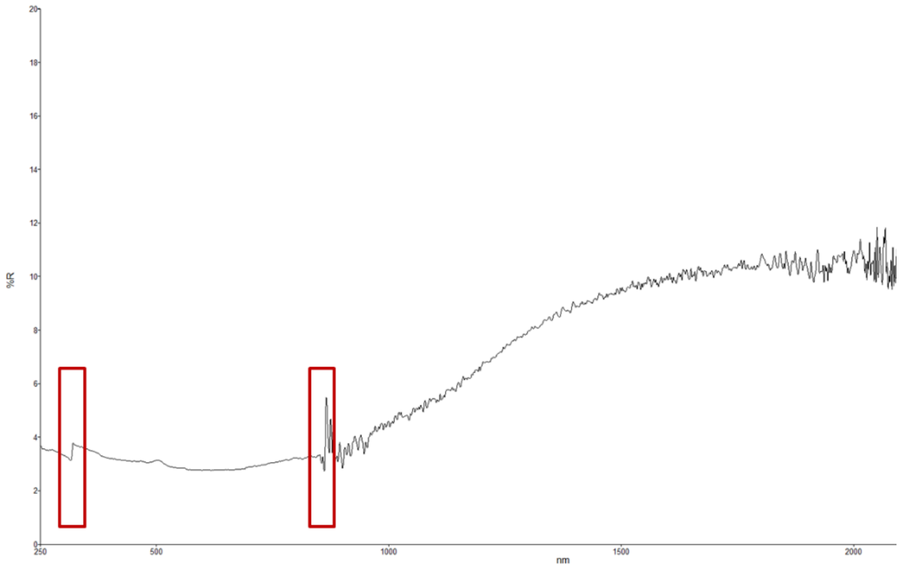

Figure 13: PerkinElmer spectral reflectance for BLACK 3.0

The highlighted regions is where the PerkinElmer changes detectors. This sometimes causes a slight shift in the measured spectrum. However, as seen, it is a minor shift. Overall, BLACK 3.0 is seeing roughly 3% reflectance in the visible region, which is comparable to the one posted on their website.

Below is a plot of the SOC-100 measurement.

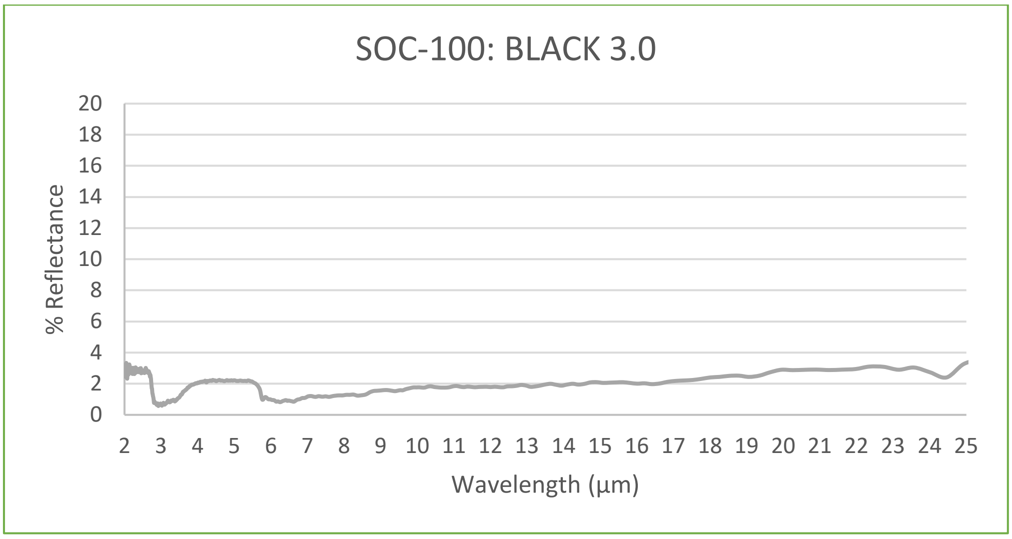

Figure 14: SOC-100 spectral reflectance for BLACK 3.0

The reflectance data for the current U.S Army Military Standard Coating/Paint will be shown but will not be named in this paper. No other information can be disclosed due to the nature of this paper.

Plot of its spectral reflectance in the PerkinElmer is shown below.

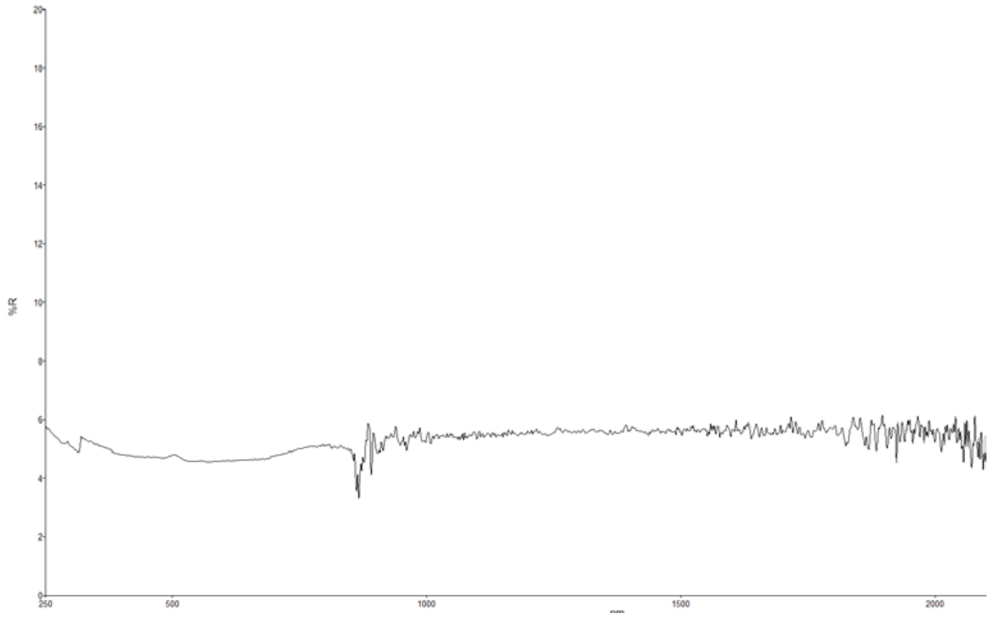

Figure 15: PerkinElmer spectral reflectance for Current Military Paint/Coating

Plot of the SOC-100 data is shown below.

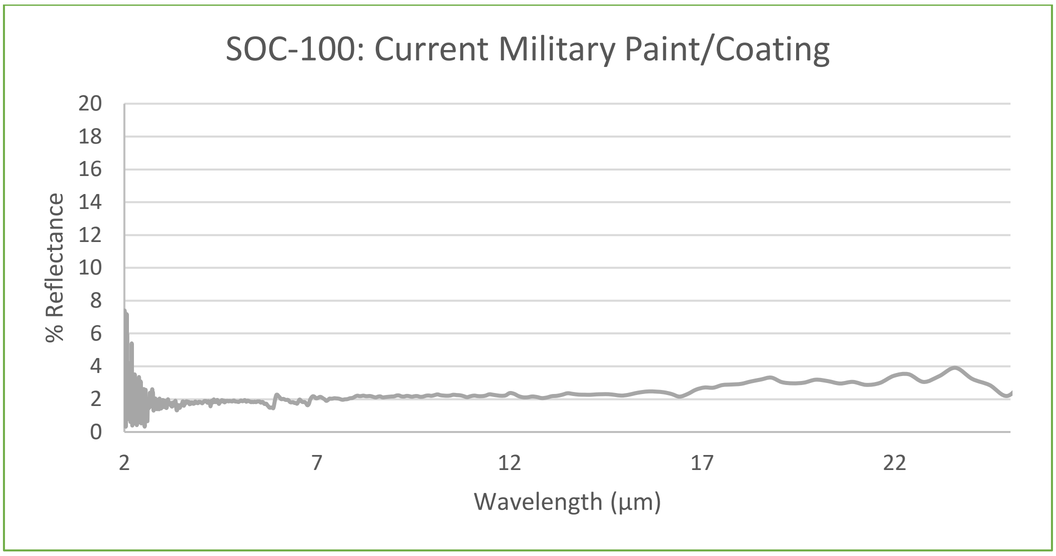

Figure 16: SOC-100 spectral reflectance for Current Military Paint/Coating

It is fairly flat around 2% with some less than smooth features. However, depending on the application, the flattest or smoothest paint and/or coating might not be necessary.

Electroless nickel boron black is a black nickel on silica blasted aluminium. Black nickel coatings have been around for many years and they have been applied to blacken surfaces of optical instruments from the UV to the IR. A military specification, MIL-P-18317, describes this coating and many plating vendors have a version of black nickel that meets this specification.

Plot of its spectral reflectance in the PerkinElmer is shown below. As seen, it does not have a particularly low reflectance value and trends upwards towards 30% in the short-wave infrared.

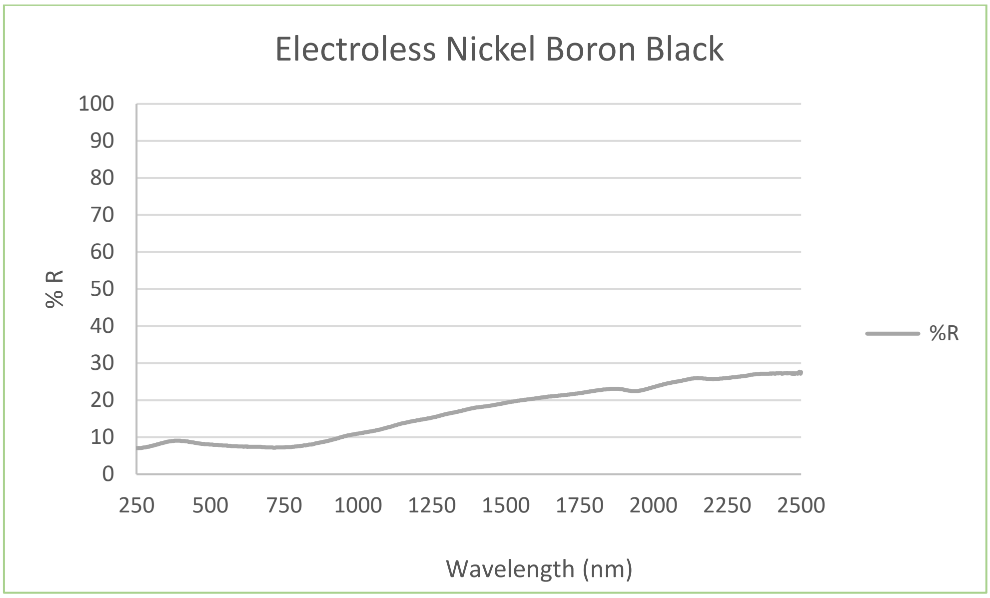

Figure 17: PerkinElmer spectral reflectance for Electroless Nickel Boron Black

In the SOC-100 measurement, a lot of unexplainable peaks were seen. At first, it was suspected to be a malfunctioning of the instrument itself. However, correct measurements were validated using known samples. Returning to this one kept yielding the same features. It must be in the material itself. Our guess is that it is a feature of using silica, but further analysis will have to be done to make a conclusion.

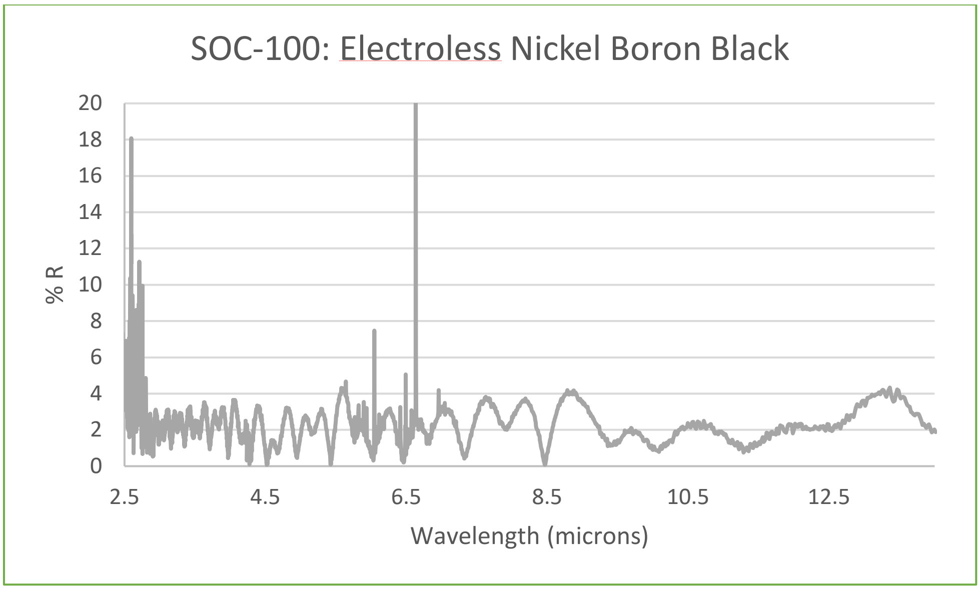

Figure 18: SOC-100 spectral reflectance for Electroless Nickel Boron Black

Fountain plating is a black nickel coating on media blasted aluminium deposited by Fountain Plating of West Springfield, MA. Unlike some other black nickels, this coating has a matte not shiny finish and its colour is black not grey. The coating has proven to be good in vacuum. This coating has been discontinued by Fountain Plating.

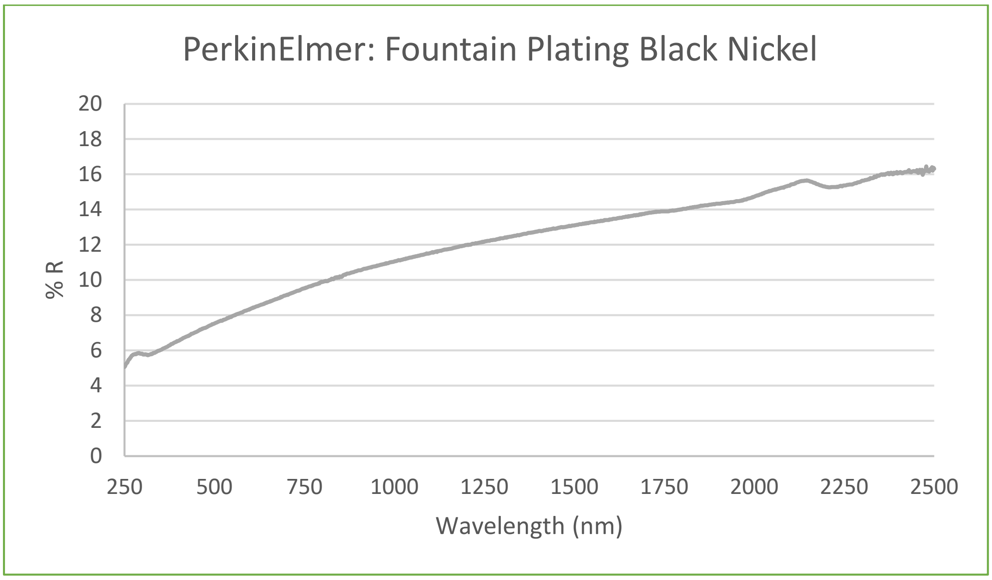

Figure 19: PerkinElmer spectral reflectance for Fountain Plating Black Nickel

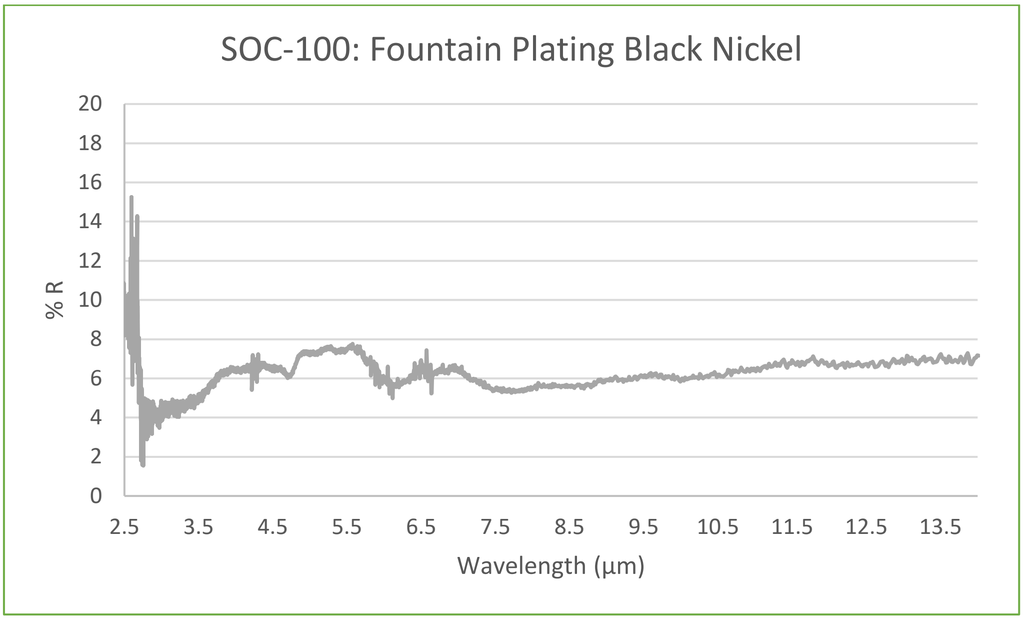

Figure 20: SOC-100 spectral reflectance for Fountain Plating Black Nickel

Krylon Ultra Black is a spray paint that is available commercially with prices less than 10 USD. It is most commonly in form of a spray paint and it is weather resistant, which finds good use on fielded targets.

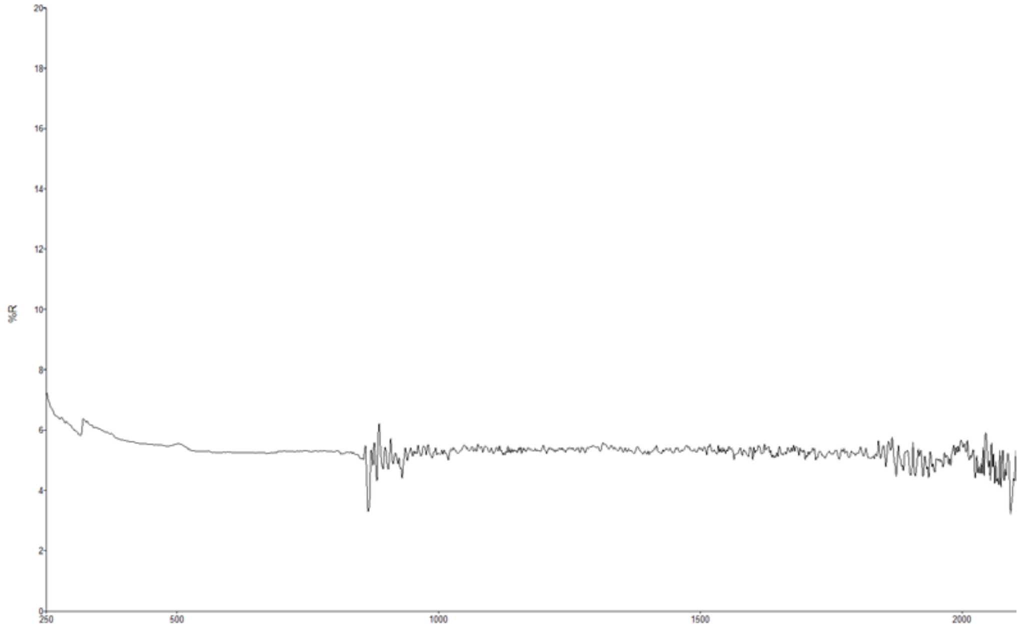

Figure 21: PerkinElmer spectral reflectance for Krylon Ultra Black

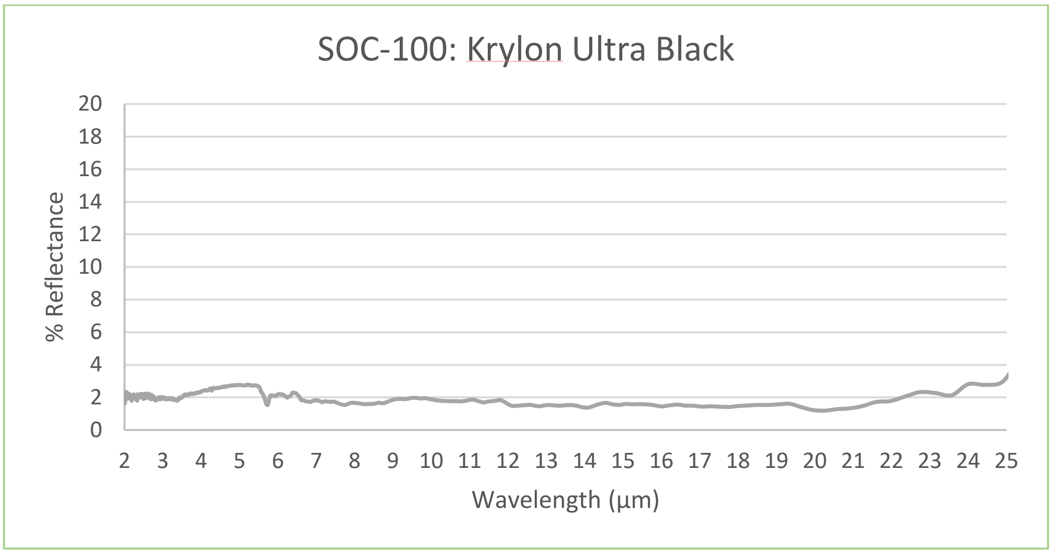

Figure 22: SOC-100 spectral reflectance for Krylon Ultra Black

Optical black anodized coating results from an oxide process but not organic dyes are used, so it is vacuum compatible and should not outgas. This particular sample was made by Pioneer Metal Finishing.

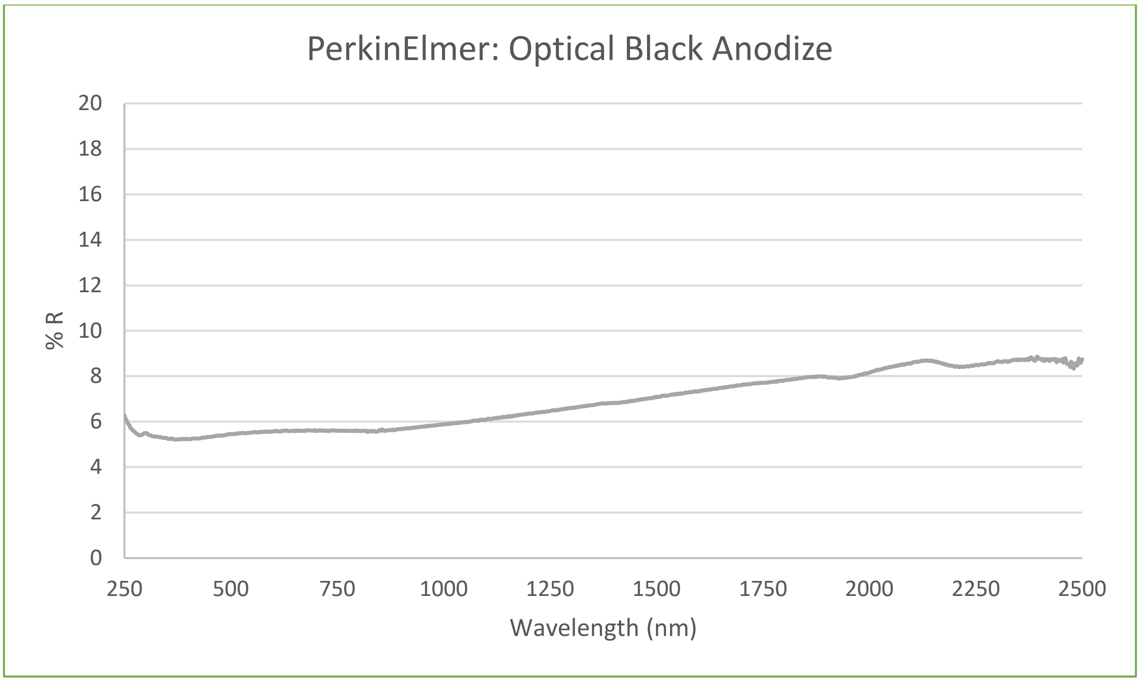

Figure 23: PerkinElmer spectral reflectance for Optical Black Anodize

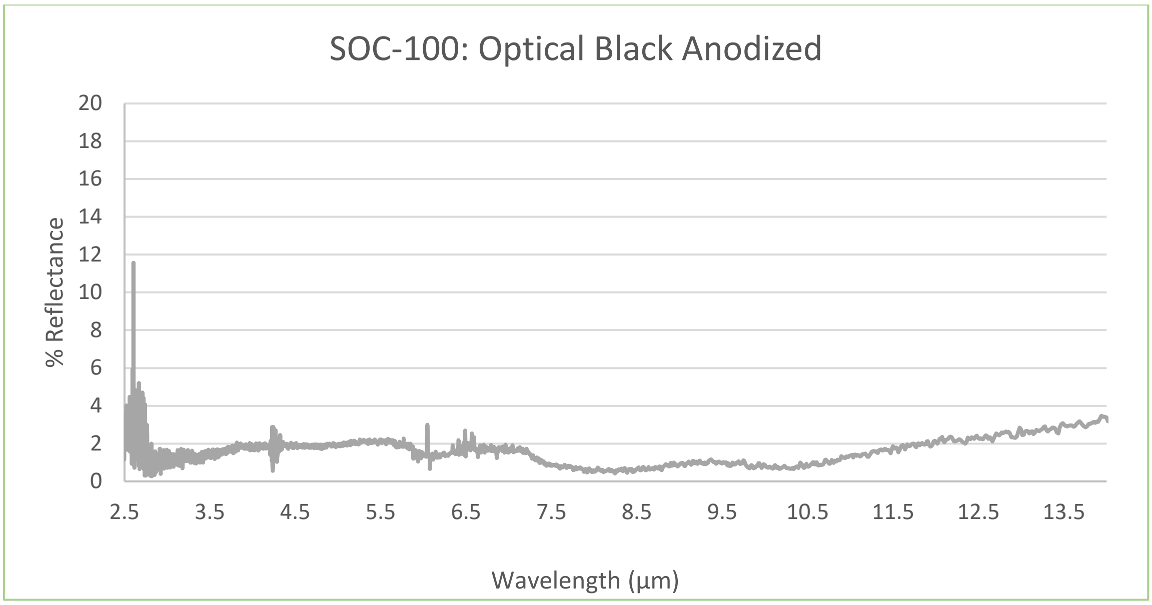

Figure 24: SOC-100 spectral reflectance for Krylon Ultra Black

Permaflect 5% is an optical coating made by Labsphere. No additional information about the coating could be found publically. Coated samples are commercially available with a one-by-one meter square starting at around 3,800 USD. Labsphere says that it is durable and high lambertian. Below is a measurement from their website.

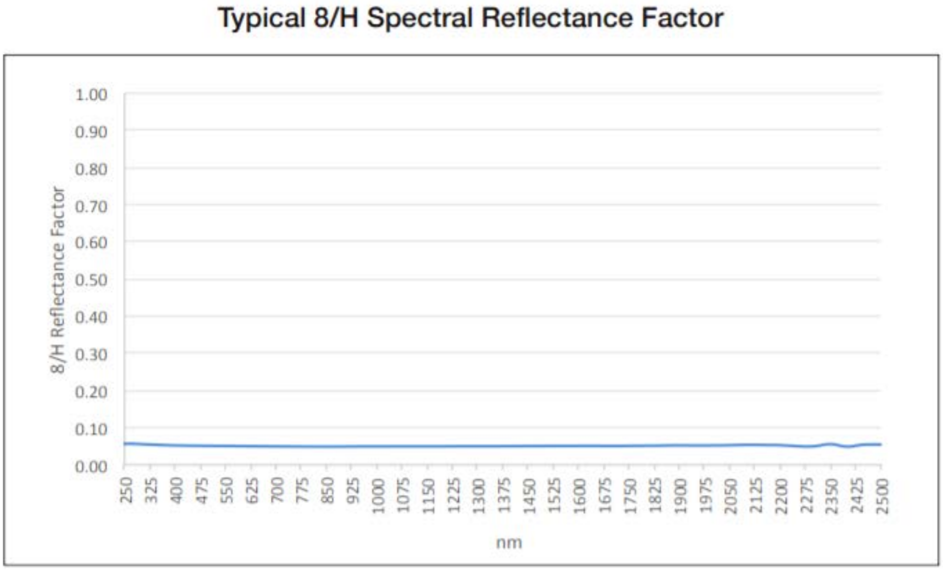

Figure 25: Spectral reflectance for Permaflect 5% as found on Labsphere's website

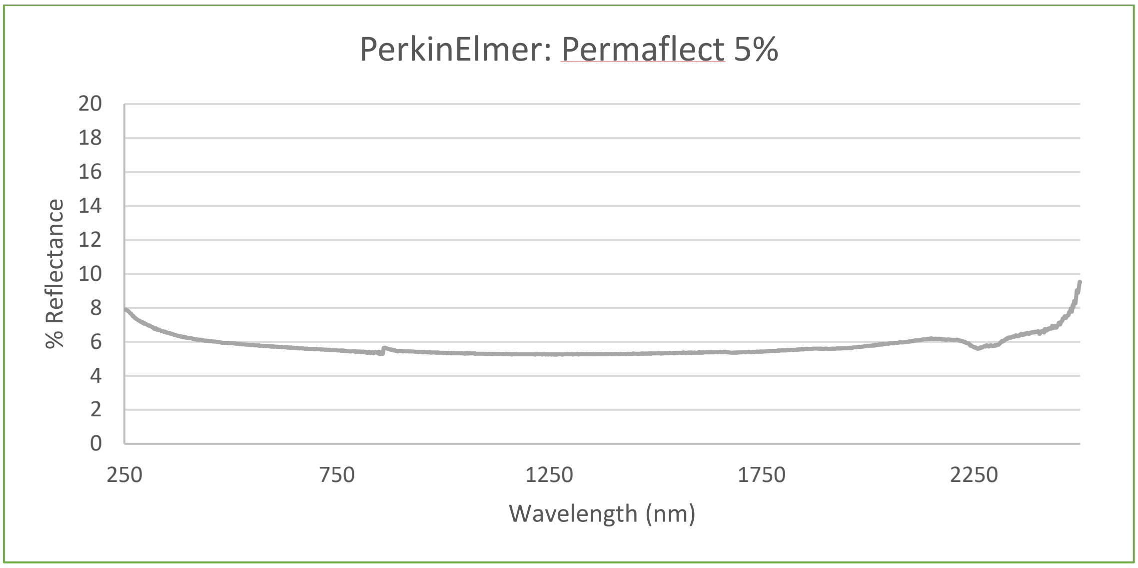

Figure 26: PerkinElmer spectral reflectance for Permaflect 5%

The SOC-100 spectral reflectance is shown below in Figure 27. It appears that the sample roughness or material is introducing a lot of characteristics in the short-wave bands and longer bands.

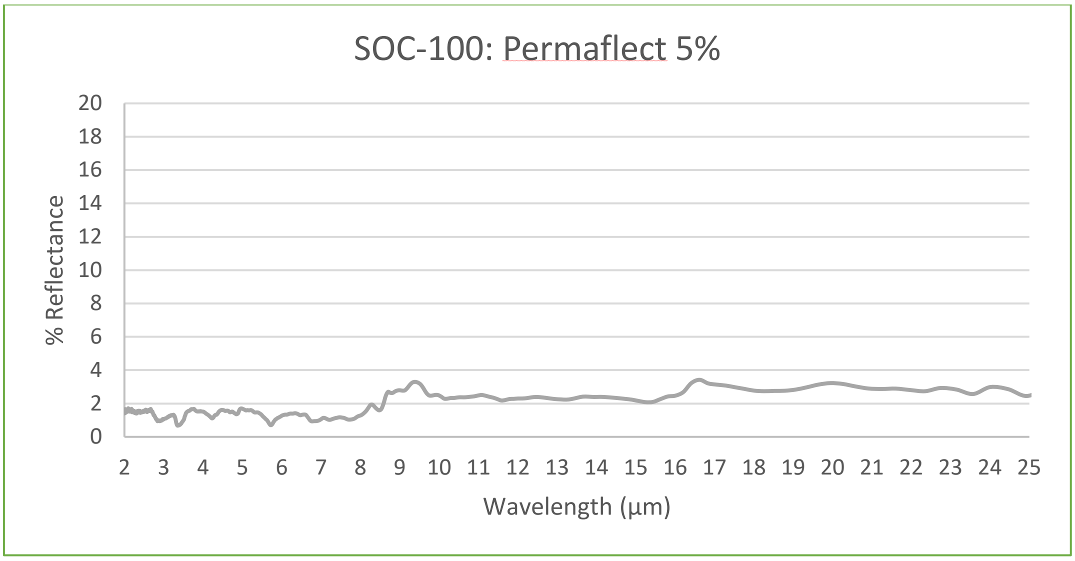

Figure 27: SOC-100 spectral reflectance for Permaflect 5%

The final sample that is presented here is a coating create by Vince, a colleague here at NVESD. Vince's coating is through a nano carbon coating process. No other information will be disclosed because the final formulation has not been established and this coating has not been published or shown anywhere else.

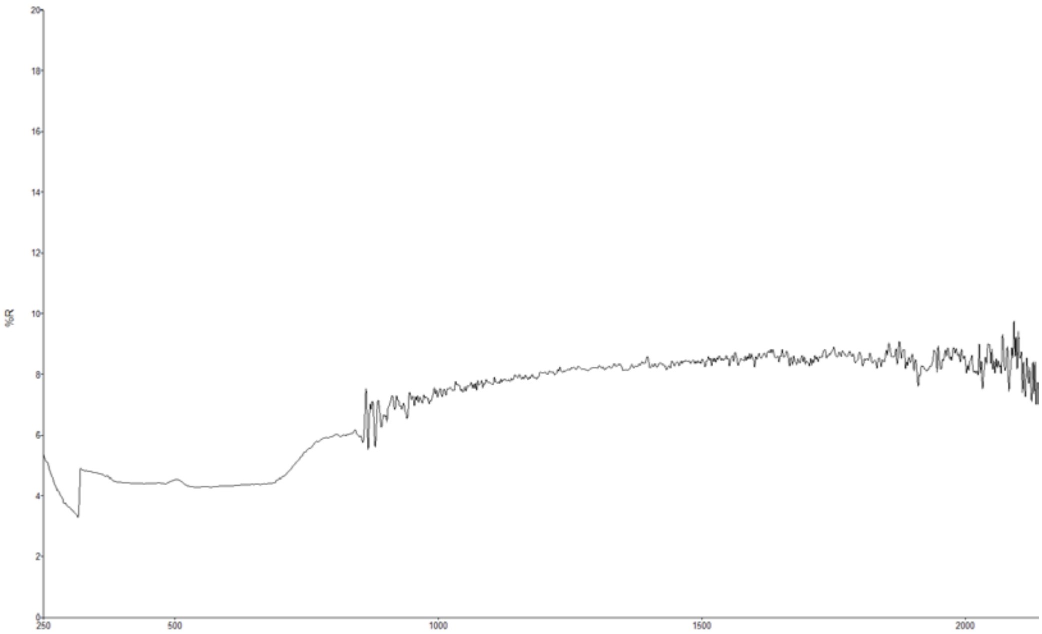

Figure 28: PerkinElmer spectral reflectance for Vince's Coating

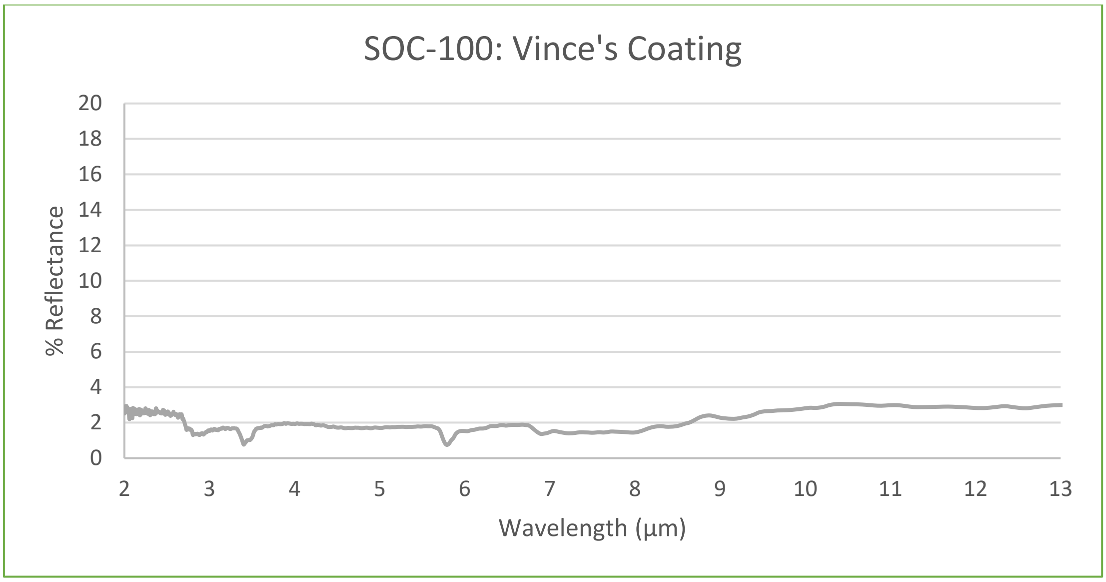

Figure 29: SOC-100 spectral reflectance for Vince's Coating

To compare the samples, only samples taken at the same time using the same instrument settings will be compared. VIS-SWIR comparisons from PerkinElmer measurements were made for Avian, BLACK 3.0, the Current Military Coating, Krylon, Permaflect, and Vince's Coating shown below in Figure 30.

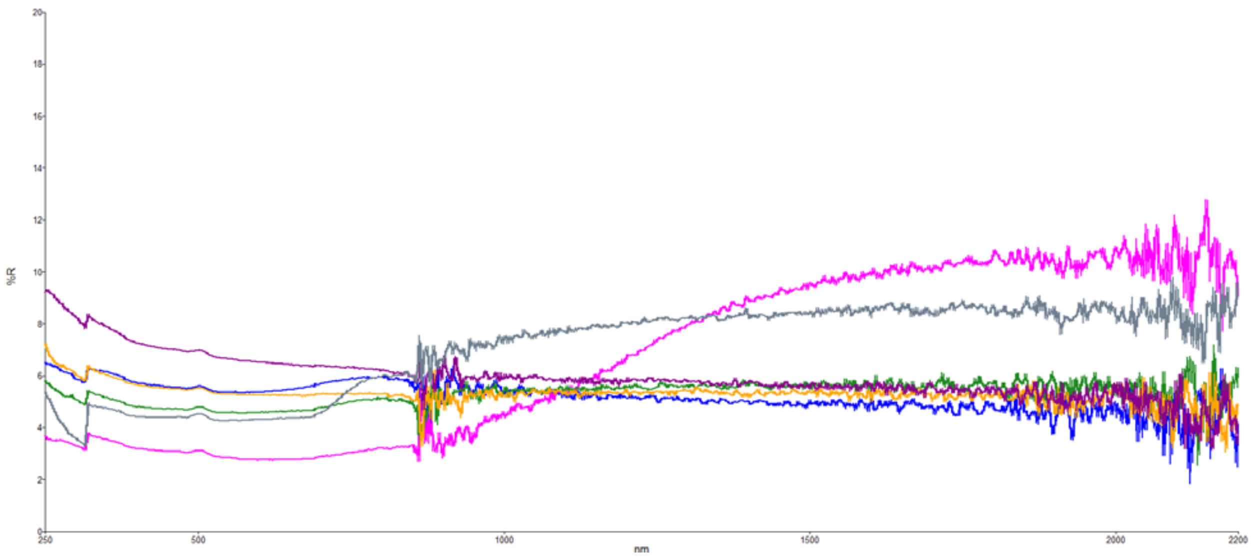

Figure 30: Comparisons of some samples measured by the PerkinElmer

In the visible region, it appears that the most matte paints and coatings have the lowest reflectivity percentages. From the bottom to the top, it is: BLACK 3.0, Vince's Coating, the Current Military Coating, Krylon and Avian (comparable), and Permaflect. It should be noted that the two darkest paint and coating are both the most fragile physically and not weather resistant or durable. The Current Military Coating, Avian, and Krylon are all have been used in fielded applications and have been developed to be weather resistant. Permaflect is also said to be weather resistant but we have no demonstrated that. In the short-wave, it appears that BLACK 3.0 no longer holds the lowest reflectivity but turns out to have the highest reflectivity amongst all the samples shown here. The Current Military Coating, Avian, and Krylon still appear to have fairly low reflectivity.

For the comparisons of SOC-100 shown below, comparisons will be made from 2.5 – 13 microns and 13 – 25 microns because of the fact that not all samples were measured out to 25 microns. For better visualization, the plot was set from 0 - 20 percent reflectance in Figure 31.

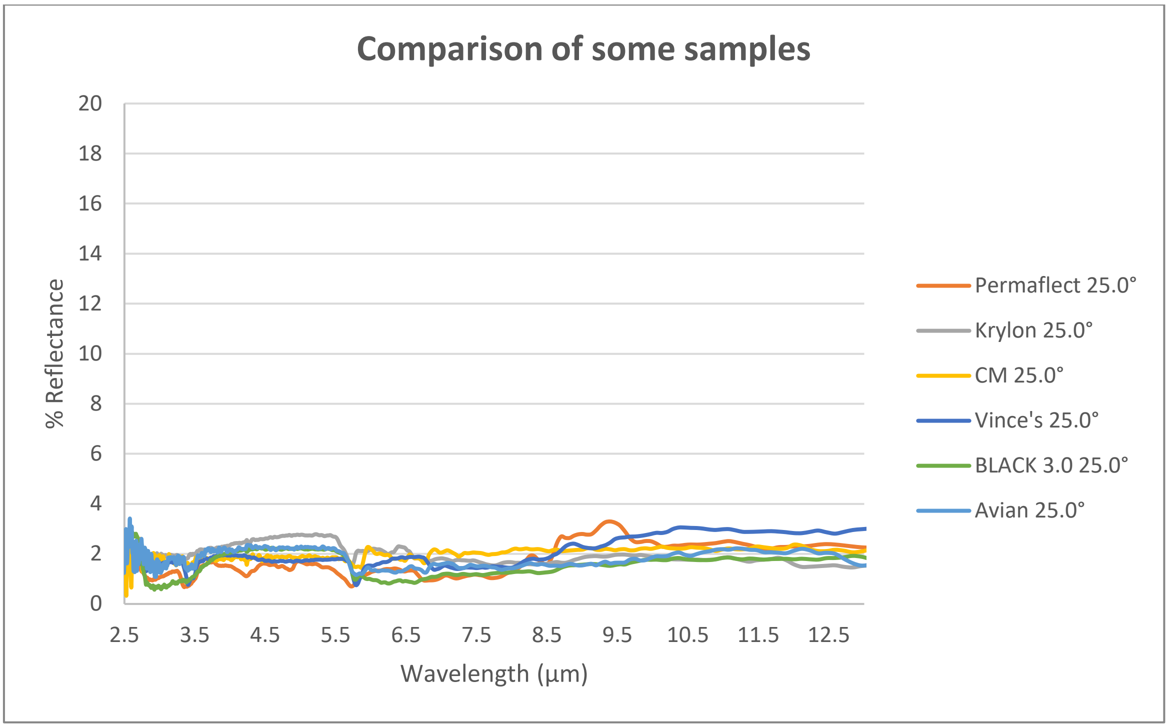

Figure 31: Comparisons of some samples measured by the SOC-100 from 2.5 – 13 microns

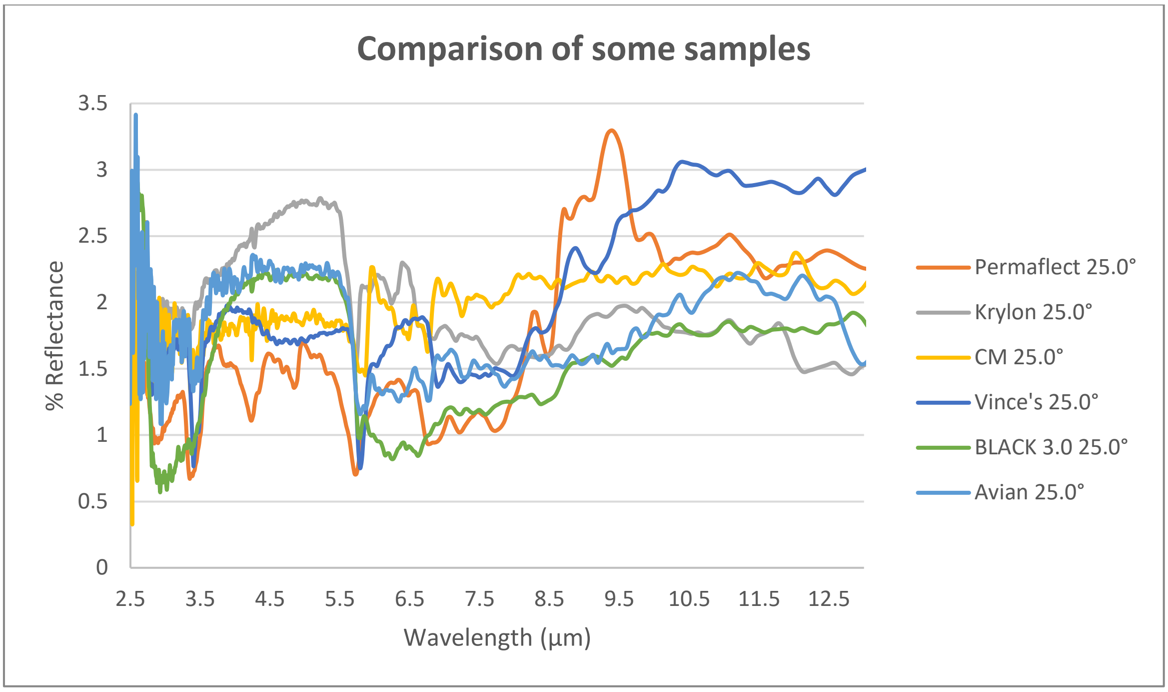

Figure 32: Comparisons of some samples measured by the SOC-100 shown from 0 – 3.5% reflectance

From 0 – 3.5 percent reflectance, more features in the materials are seen in Figure 32. These features can be considered negligible depending on applications as they range from 1.5 to fractions of a percent. The two features seen at roughly 3.5 and 5.7 microns is suspected to be aluminum, which is the background that a lot of these samples were placed on.

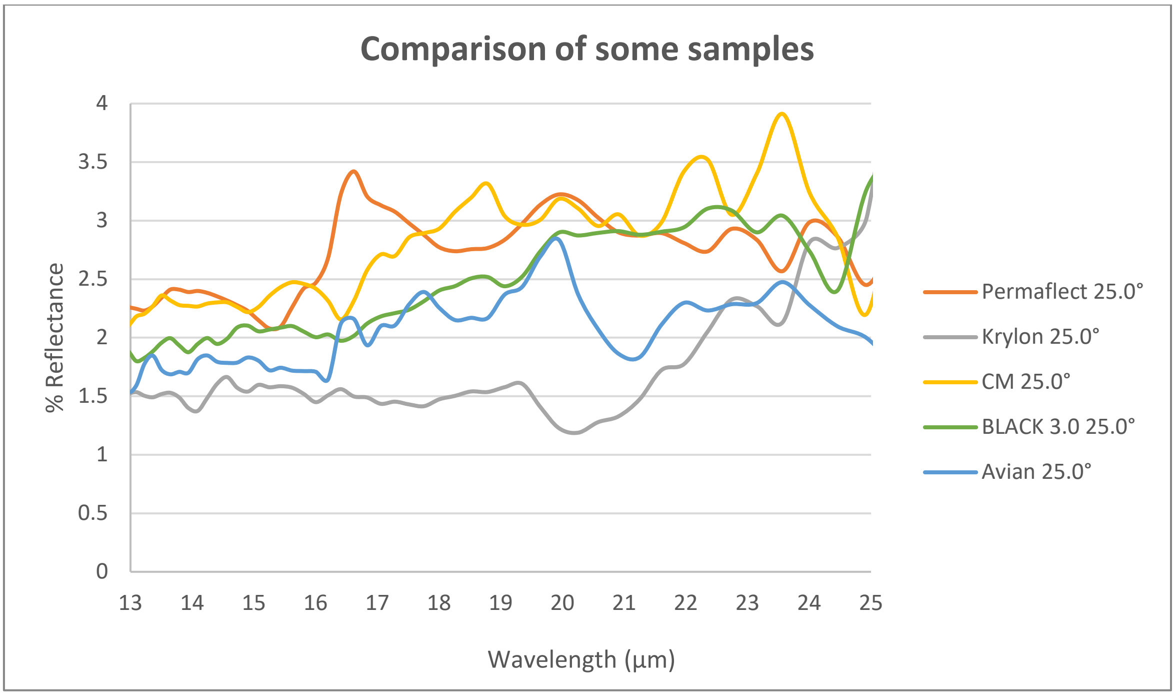

Figure 33: Comparisons of some samples measured by the SOC-100 from 13 – 25 microns

From 13 – 25 microns, it appears that Krylon has the lowest reflectivity. However, since they are all under roughly 3 percent with less than 1-2 percent variations, it is hard to rank the paints and coatings.

5.0 CONCLUSIONS

Future work to be done for this topic will be building a database of black paints and coatings and categorize the samples. Better characterization of the background and coating will be captured as well in order to understand the features introduced into the spectrum. Finally, a standard for making measurements and collecting data (eg. samples) will be set, so that each sample is measured in the same fashion and hopefully all samples have similar thickness and density for fairness. The paints and coatings are created and applied in different ways, introducing different characteristics into the final product. Krylon and Avian have comparable reflectivity and spectra in the visible-near infrared and are both durable, weather resistant, and idea for field applications. The two darkest paint and coating in the visible region are also the most physically fragile and are not weather resistant.

In conclusion, from a brief analysis of several paints and coatings, it is clear that not all paints are created equally, whether it is physically or spectrally. Most black paints and coatings will look visibly black to the human eye but may look very different across the spectrum. However, the results also show that black paints and coatings are application driven. Maybe the paint or coating with the lowest reflectivity might not be necessary for applications such as ones in the field while fragile paints and coatings can be utilized under protection in the laboratory. There is also many trade-offs that should be considered when picking a paint or coating as well and those trade-offs will be explored in more details in future work.

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7.0 BIBLIOGRAPHY

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