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Measurement of the Diffuse and total reflectance of the paint material on Six Tile Samples from the Inner Surface of an Olympia Odos Motorway Tunnel Using UV/VIS/nIR Spectroscopy

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Method

Measurement of the Reflectance, and Transmittance of Materials Using Integrating Spheres

A system with two sources (one for the UV and the other for the visible/VIS and nIR spectrum area) is used for radiation from 200nm up to 800nm combined with a monochromating system and a photodiode array for receiving the diffused reflectance at the point of measurement. In both cases, the incident beam is inserted in a suitable fiber optic bundle. After the fiber optic bundle the beam is condensed to the measurement area using a lens system installed on external integrating sphere. In the case of the UV/VIS module the reflected power is injected into another optic fiber in order to be guided into the monochromating system and then to the Photo Diode Array (PDA).

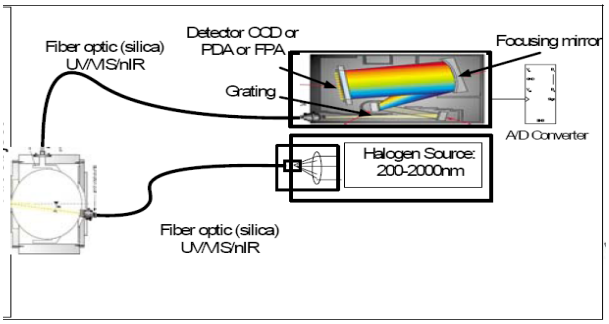


Figure 1 *UV/VIS/nIR spectroscopic device diagramme, Kind of measurements per point.*

The integrating sphere that was used is a 50mm diameter sphere. The internal surface of the sphere is covered with a high reflectance material of BaSO4 with reflectance value of the order of 91% to 98%. The sphere is equipped with four ports (**fig. 2**):

1. The illumination port in which the illumination is guided in the sphere targeting to the sample under illumination angle of 8°.
2. The sample port where the illumination is guided and were the sample under measurement id placed in order to be illuminated.
3. The measurement port where the receiving optical fibers are installed in order to guide the diffuse reflectance form the sample to the sensor.
4. The port (marked with blue line in **fig. 2**) which determines whether the total (diffuse) reflection ($\overline{R}_{tot}$) or the diffuse refection ($\overline{R}_{diff}$) will be measured. Using a light trap (black coated area) installed in this port, which is actually the area where the specular reflection is guided, the diffuse reflectance only is measured while installing in the port high reflectance material like the one that the sphere has the total reflectance is measured.

The total reflection coefficient $\overline{R}_{tot}$ and the diffuse reflection coefficient $\overline{R}_{diff}$ are measured in the wavelength band from 400nm to 700nm. Ten measurements of $\overline{R}_{tot}$ and $\overline{R}_{diff}$ from each sample. For each wavelength the average value of the $\overline{R}_{tot}$ and $\overline{R}_{diff}$ is calculated. The total reflection factor R_{tot} and the diffuse reflection factor $\overline{R}_{diff}$ are the average value of the total reflection coefficient $\overline{R}_{tot}$ and the diffuse

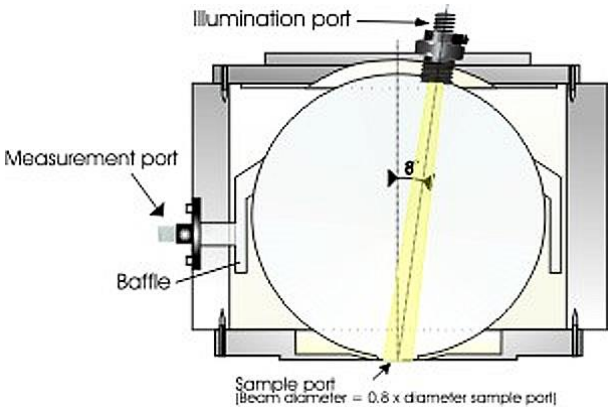
reflection coefficient $\overline{R}_{diff}$ respectively in the specific wavelength band:

$$R_{tot} = \frac{1}{\lambda_{700} - \lambda_{400}} \times \int_{400}^{700} \overline{R}_{tot}(\lambda_t) d\lambda_t$$

$$R_{diff} = \frac{1}{\lambda_{700} - \lambda_{400}} \times \int_{400}^{700} \overline{R}_{diff}(\lambda_t) d\lambda_t \quad (1)$$

Where λ_t is the wavelength.

The wavelength resolution (step) of the measurement is less than 1nm.



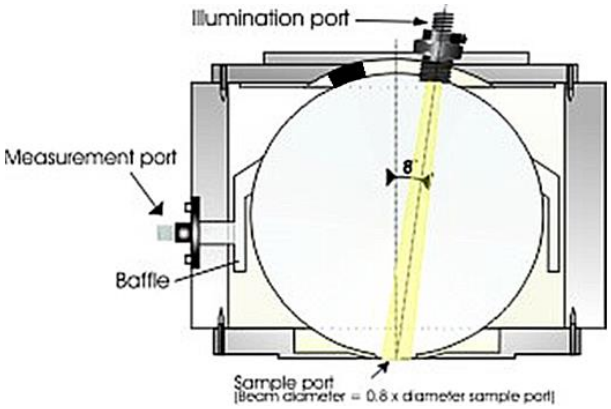


Figure 2 *Integration sphere used.*

Total reflectance measurements

Based on this analysis the results of the measurements of the six samples were produced. For each sample the reflection coefficient and the reflection factor are provided for the total and for the diffuse reflectance. The values of the standard deviation and the uncertainty according to ISO 17025 is also provided extracted from the reflection coefficient values for each wavelength and in total as a scalar value.

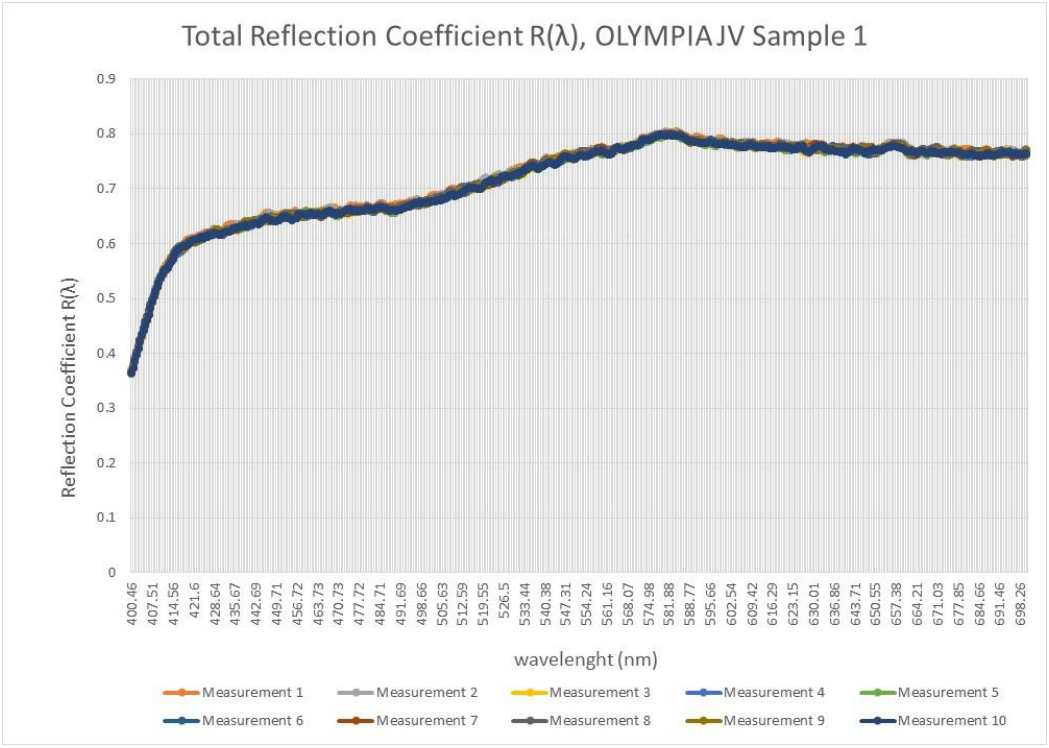


Figure 1 *Total reflection coefficient ($\overline{R}_{tot}$) measurement of the paint layer of Sample 1 from 400-700nm, according to ISO17025 and ASTM E-903 – 12, ASTM E-903 – 96 standards.*

R_{tot}	Standard Deviation R_{tot}	Uncertainty R_{tot}
0.7145	0.002627	0.001662

Table 1 *Total reflection factor ($\overline{R}_{tot}$) measurement of the paint layer of Sample 1 (Figure 3), according to ISO17025 and ASTM E-903 – 12, ASTM E-903 – 96 standards.*

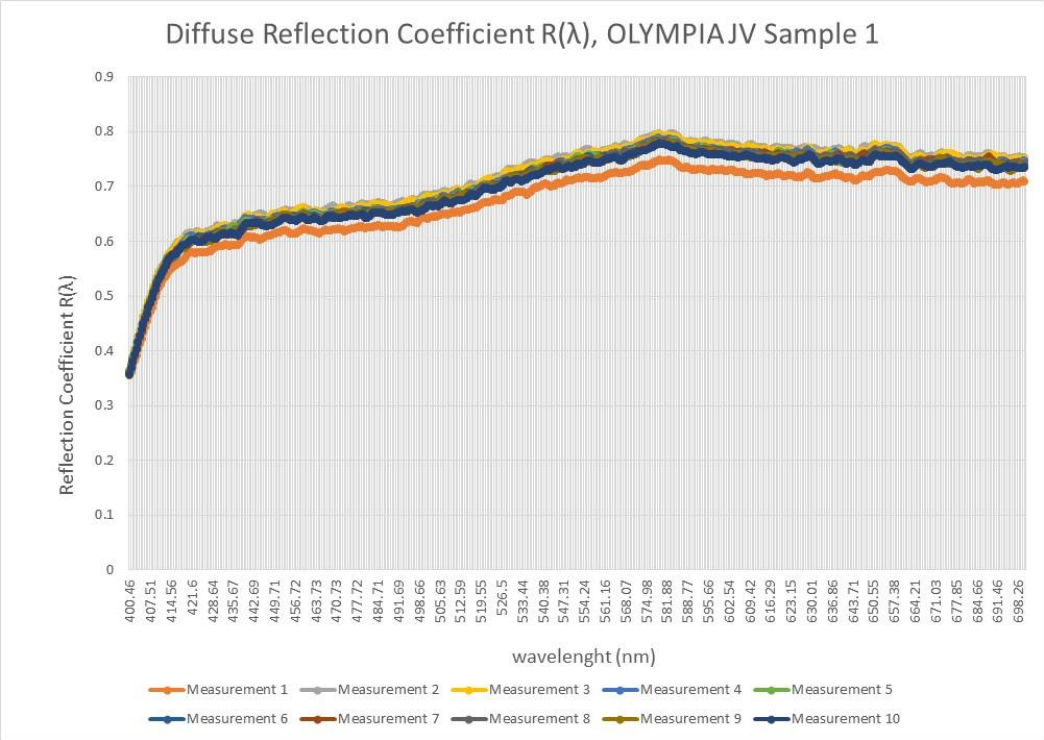


Figure 4 *Diffuse reflection coefficient ($\overline{R}_{diff}$) measurement of the paint layer of Sample 1 from 400-700nm, according to ISO17025 and ASTM E-903 – 12, ASTM E-903 – 96 standards.*

R_{diff}	Standard Deviation R_{diff}	Uncertainty R_{diff}
0.6984	0.011784	0.007453

Table 2 *Diffuse reflection factor ($\overline{R}_{diff}$) measurement of the paint layer of Sample 1 (Figure 8), according to ISO17025 and ASTM E-903 – 12, ASTM E-903 – 96 standards.*

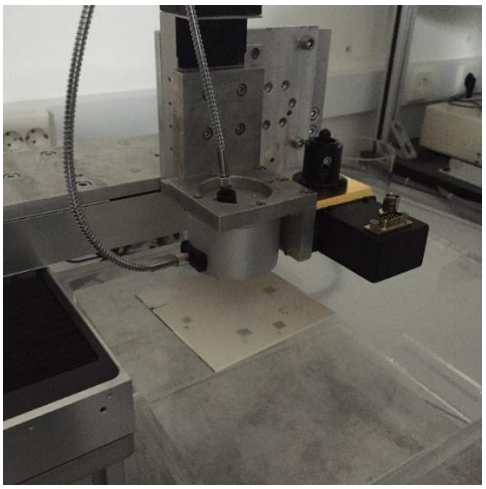
Sample	R_{tot}	Standard Deviation R_{tot}	Uncertainty R_{tot}
1	0.71453	0.00263	0.00166
2	0.69040	0.00202	0.00128
3	0.72331	0.00218	0.00138
4	0.72390	0.00211	0.00134
5	0.72426	0.00457	0.00289
6	0.74136	0.00206	0.00130

Table 3 *Total reflection factor ($\overline{R}_{tot}$) measurement of the paint layer of all the Samples, according to ISO17025 and ASTM E-903 – 12, ASTM E-903 – 96 standards.*

Sample	R_{diff}	Standard Deviation R_{diff}	Uncertainty R_{diff}
1	0.69841	0.01131	0.00716
2	0.71293	0.01505	0.00952
3	0.71514	0.01344	0.00850
4	0.72971	0.00546	0.00346
5	0.71861	0.01524	0.00964
6	0.71937	0.00690	0.00436

Table 4 *Diffuse reflection factor ($\overline{R}_{diff}$) measurement of the paint layer of all the Samples, according to ISO17025 and ASTM E-903 – 12, ASTM E-903 – 96 standards.*

Areas of the tunnel from which the tiles were acquired according.



Scanning of the paint layers on the tiles using the UV/VIS/nIR spectrophotometer equipped with the integration spheres.