Research reference Plastic

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Inhoud

1. Goal of the experiment

Plastic Scanner had assembled a box with bags of types of plastic. Each bag had four to six samples of the same type of plastic. These samples were gathered from commercial plastics. The identification of the types of plastic was read of the labelling. The goal of the experiment was to determine whether each sample is the type of plastic indicated on the label and whether the samples could be used as reference to the plastic scanner.

To be able to compare the measured data with the theory the reflectance of the samples needs to be determined. This can be done using the following equation,

$$R = \frac{I_s}{I_{ref}} \cdot 100\% \tag{1.1}$$

in which R is the reflectance in %, I_s is the intensity of the plastic sample in counts and I_{ref} is the intensity of the reference tile in counts.

2. Setup

The IR spectrum of the types of plastic can be measured with a spectrometer, a broadband light source and a fibre. The fibre is able to illuminate the plastic and detect the reflected IR spectrum. The equipment needed to execute the experiment are as follows:

- Avantes IR spectrometer (AVASPEC-NIR256-2.0TEC)
- Computer/Laptop containing AvaSoft8
- Halogen lamp (AVALIGHT-HAL)
- Optical multimode fibre with beam splitter (FDP-7UVIR400-2-VAR)
- Stand to hold the fibre
- Reference box C with plastic reference samples including three different types of reference tiles
- HHS reference tile

Figure 1 shows a schematic sideview of the placement of the equipment. The optical fibre is connected to the halogen lamp and the IR spectrometer. The detection side of the fibre is placed in a way that it can scan the plastic samples from above. The spectrometer is connected to a computer containing the AvaSoft8 software to read the detected data.

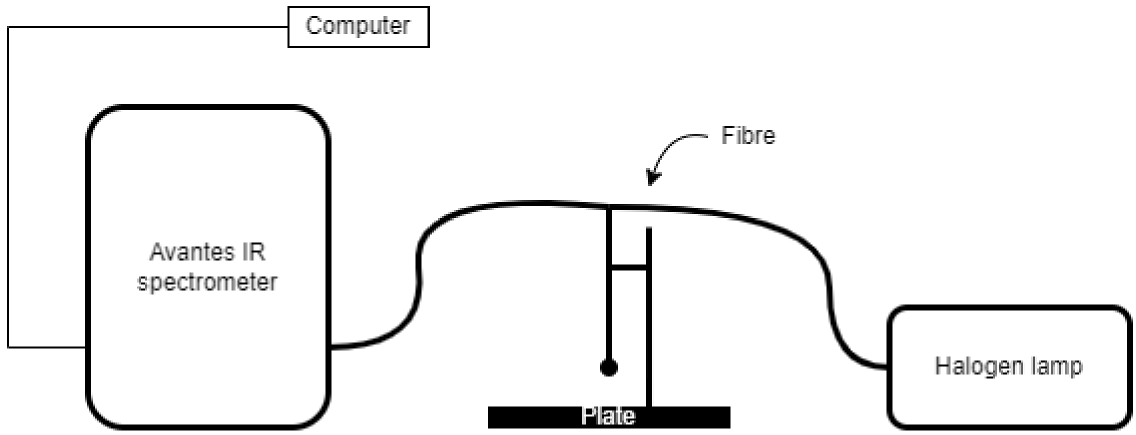

Figure 1: A schematic setup to identify the type of plastic via IR spectroscopy. A split fibre is attached to the Avantes spectrometer and the light source (halogen lamp).

The experiment can be conducted in a darkened or lightened room.

2.1 Accuracy analyses

Before measuring the reference tiles and the plastic samples, a dark measurement was made. The dark measurement was subtracted from the collected data of the plastic samples.

3. Method

The setup is build according to Figure 1. Before measuring, the integration time and average of the Avantes spectrometer are set. The integration time is set on a value around 100,000 ms and the average is set on a value of 2. The Dynamic Dark in the same settings is disabled. The range of the wavelength in which the spectrometer will measure are set from 800 nm to 1900 nm. A dark measurement is made and saved in AvaSoft.

First the reference tiles are measured. The reference tile is placed under the fibre ending with a distance in between of 10 mm. The tile is measured five times, where at each measurement a different location on the tile is measured. By measuring the tile five times at different locations, the repeatability can be determined. After measuring each reference tile, the plastic samples provided by Plastic Scanner are measured. Six different plastic types are present in reference box C, PET, HDPE, PVC, LDPE, PP and PS. Each bag consists of four to six samples of one type of plastic. Each sample of the plastic type is measured five times at different locations on the sample. The plastic samples are placed on top of the reference tile that will be used during the experiment. The samples are measured by pressing the 'Single measurement' button in the program.

The data is manually saved in Excel-documents and plotted using python.

4. Expected results

It is expected that the spectra of the scanned plastic will be the same as Figure 2. The spectra of the different types of plastic in Figure 2 are plotted with an offset.

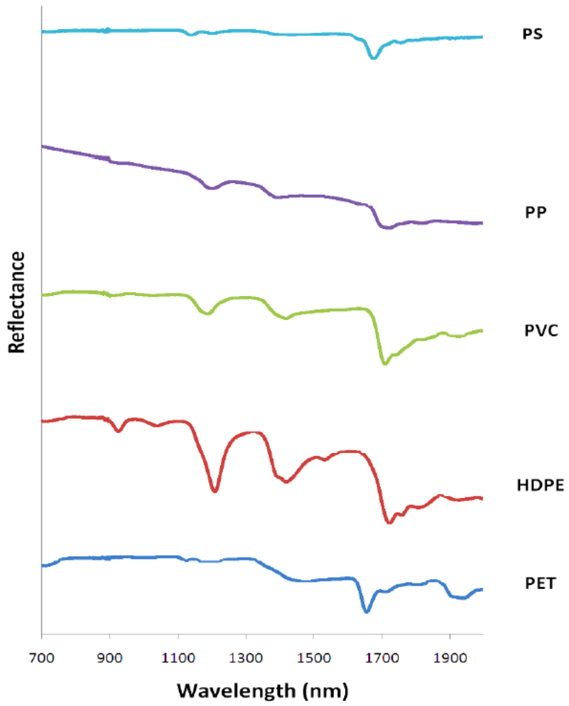

Figure 2: Expected progression of the five most common types of plastic over a wavelength range of 700 nm to 1900 nm [1].

It is also expected that the scanning location on the plastic has no effect on the measurement of the spectra.

5. Results

The experiment was conducted in the Lectoraat lab and Photonics lab at the Hague University. The measurements conducted in the Lectoraat lab were executed in an lighted room in which the sun had an effect on the measurements. The integration time was set on 140,000 ms and an average of 2. The measurements conducted in the Photonics lab were executes in a darkened room. The integration time was set on 105,000 ms and an average of 2. First the results of the reference tiles will be discussed, then the results of the plastic samples will be discussed.

The colours of the data in the figures do not always correspond with the colour of the plastic. The letters at the end of the sample code in the legends indicate the colour of the plastic sample.

Table 1: Explanation of the letters at the end of the sample code in the legends.

Letter	Colour
w	White
t	Transparent
g	Green
wt	White transparent
y	Yellow
gr	Grey
bl	Blue
r	Red
p	Purple

Reference tile

The results of the four different reference tiles are shown in Figure 5.

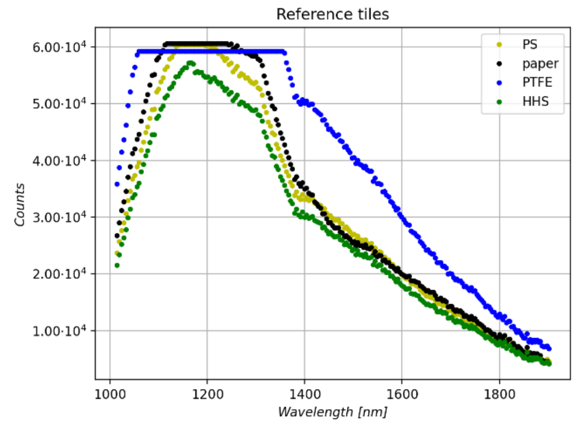

Figure 3: Measurement conducted in the Lectoraat lab. The settings of the Avantes spectrometer were set on a Integration time: 140,000 ms and an average of 2.

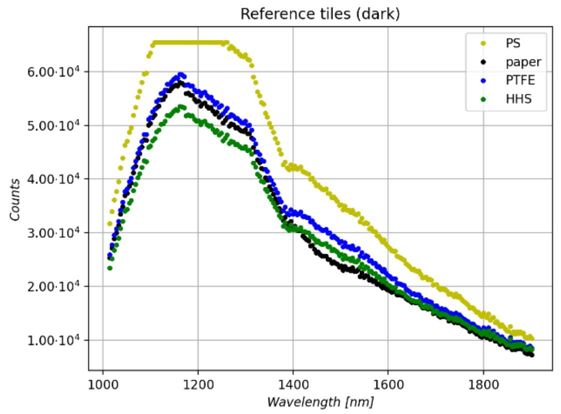

Figure 4: Measurement conducted in the Photonics lab. The settings of the Avantes spectrometer were set on a Integration time: 140,000 ms and an average of 2.

Figure 5: The counts of the four different reference tile plotted against the wavelength. PS refers to the reference tile provided by Plastic Scanner and HHS refers to the reference tile provided by The Hague University. Paper and PTFE refer to the material of the reference tile.

Figure 3 and Figure 4 show that the lighting in the measurement room has an effect on the intensity of the reflection. Both figures show saturated data, meaning that the integration time has to be altered to a lower value then 140,000 ms.

Colour measurement

Each type of plastic had four to six different colour samples. The reflection of each of these samples is represented per type. Each type of plastic shows the results of the measurements conducted in the Lectoraat lab and the Photonics lab.

PET

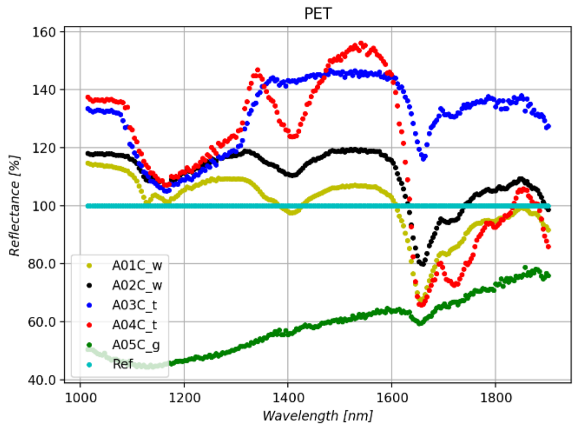

Figure 6: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140,000 ms and an average of 2.

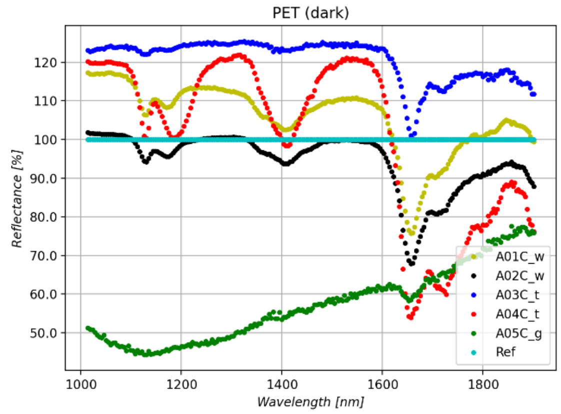

Figure 7: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105,000 ms and an average of 2.

The blue and red results in Figure 6 show a dip that is caused by saturated data. Both figures, Figure 6 and Figure 7, show an undefined spectrum in the green dataset, however the absorption dip around 1650 nm is still visible.

HDPE

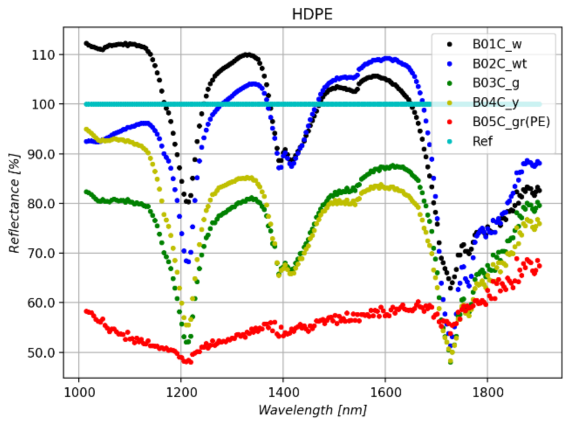

Figure 8: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140,000 ms and an average of 2.

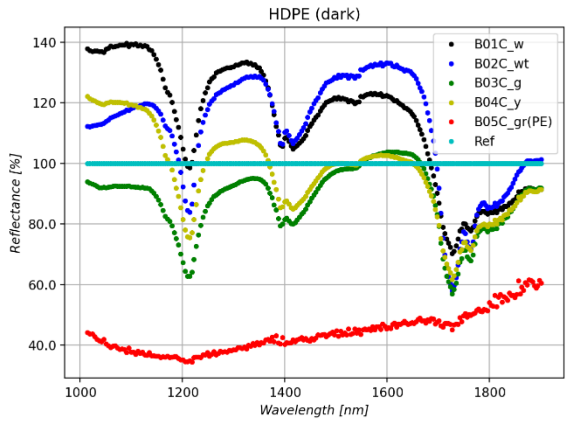

Figure 9: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105,000 ms and an average of 2.

The grey sample (red coloured line) of PE has an undefined spectrum compared to the other colours of HDPE. The absorption has decreased in a darkened room relative to a lightened room, as visible in Figure 8 and Figure 9. The intensity of the reflection has increased in a darkened room.

PVC

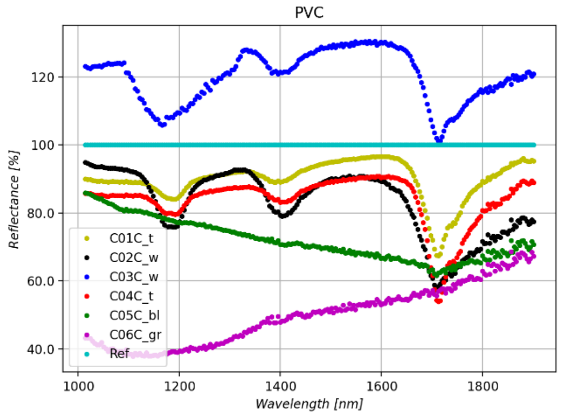

Figure 10: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140,000 ms and an average of 2.

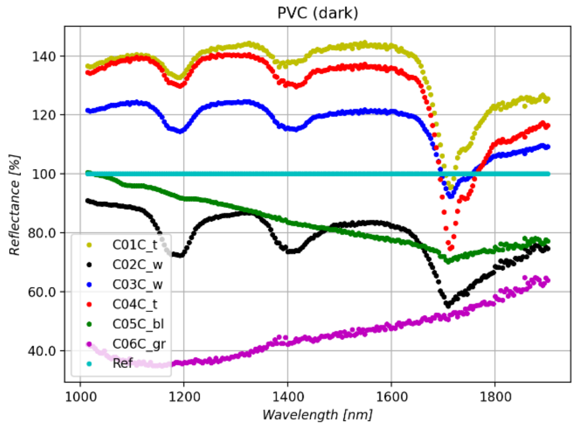

Figure 11: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105,000 ms and an average of 2.

Both figures show a more undefined spectra of the blue and grey sample of PVC (purple and green lines). The purple line, C06C, shows no absorption dips. The green line, C05C, shows a small absorption dip around 1700 nm. The blue line, C03C, shows a saturation dip around 1150 nm in Figure 10.

LDPE

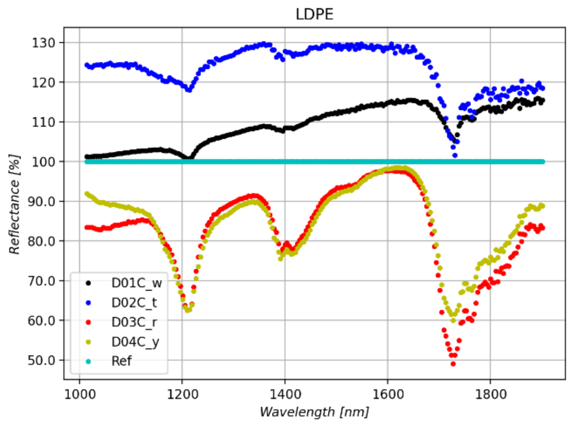

Figure 12: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140,000 ms and an average of 2.

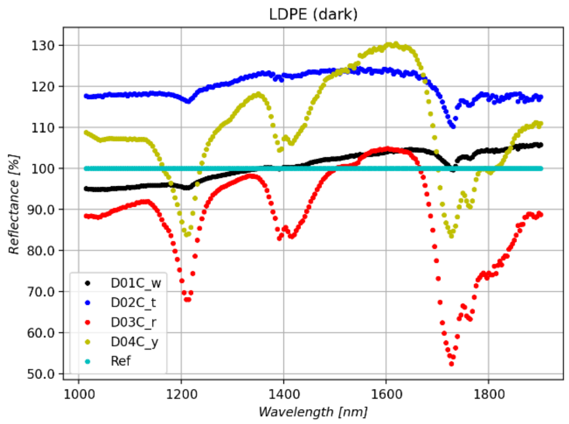

Figure 13: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105,000 ms and an average of 2.

As opposed to the previous plastic types, the light coloured samples have a less defined spectrum than the darker coloured samples. The dips of the LDPE plastic correspond with the dips of the HDPE plastic, as expected because of the similar molecule structure.

PP

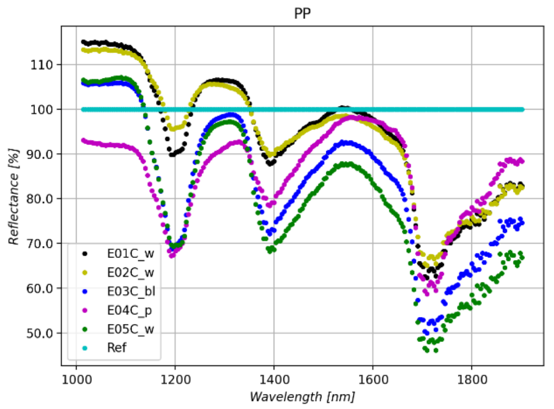

Figure 14: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140,000 ms and an average of 2.

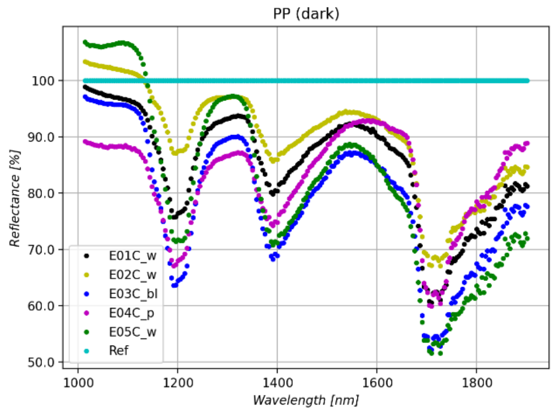

Figure 15: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105,000 ms and an average of 2.

The uniqueness of Figure 14 and Figure 15 is the well defined spectra and the reflectance. The lines lay close to each other, which ensures that the average does not deviate much from the original data. Both figures don't deviate from one another except for the decrease in reflectance in Figure 15, which can be the result of the darkened room.

PS

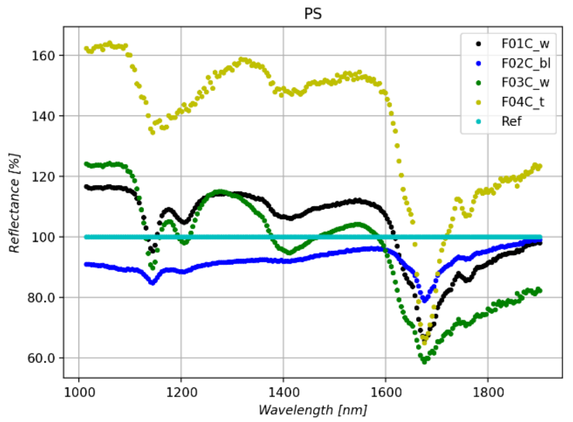

Figure 16: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140,000 ms and an average of 2.

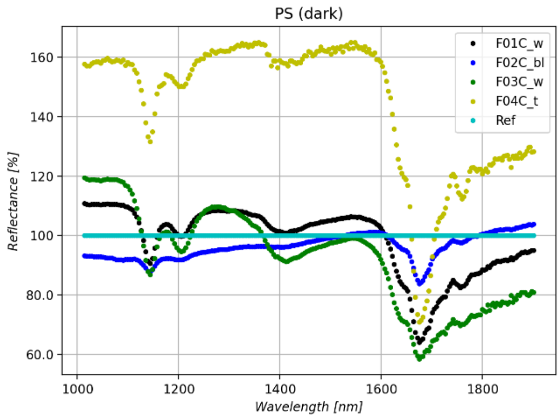

Figure 17: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105,000 ms and an average of 2.

With both measurements the transparent sample has a higher reflectance than the other coloured samples. As expected is the spectrum of the blue sample less defined. Sample F04C also has a saturation dip around 1150 nm in Figure 16.

All figures have colours that have a higher reflectance than 100%. A cause could be the low reflectance of the reference tile. It is also visible that the colour of the plastic affects the reflectance. The absorption becomes higher with coloured plastic and the defining dips become less visible. This means that these samples are not suitable as reference.

Repeatability Lectoraat lab

Each colour of the plastic samples of each type has been measured five times to measure the repeatability. These results are presented in this section. The results are sorted per type of plastic.

PET

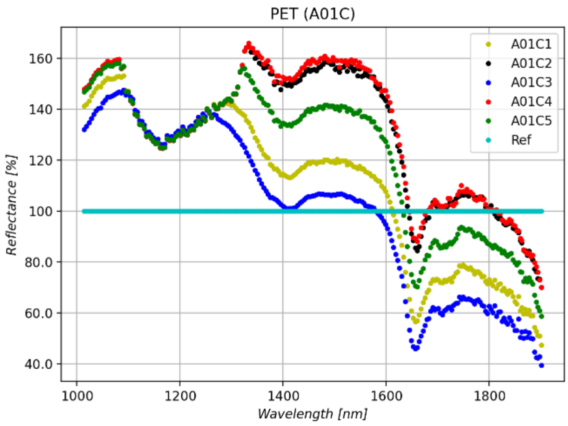

Figure 18: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

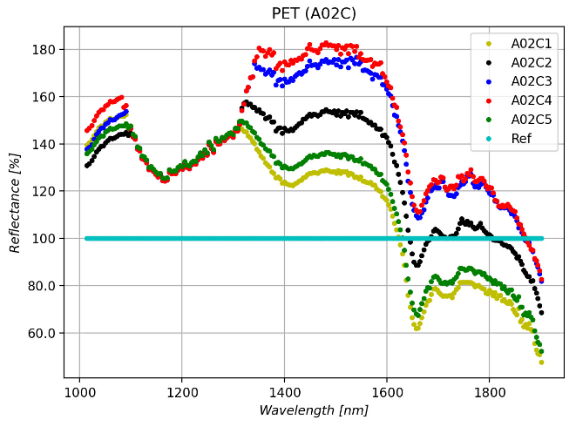

Figure 19: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

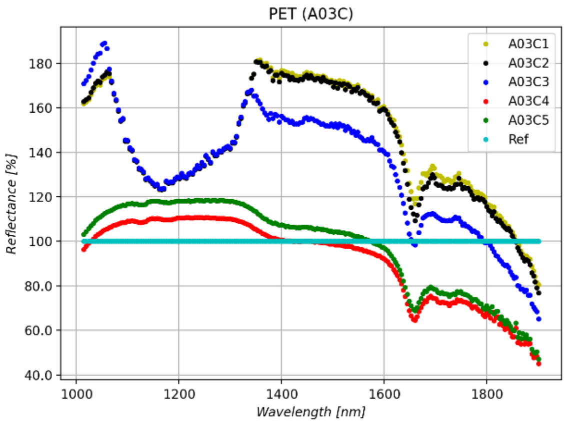

Figure 20: Measurement conducted in the Lectoraat lab of a transparent sample. Integration time: 140,000 ms and an average of 2.

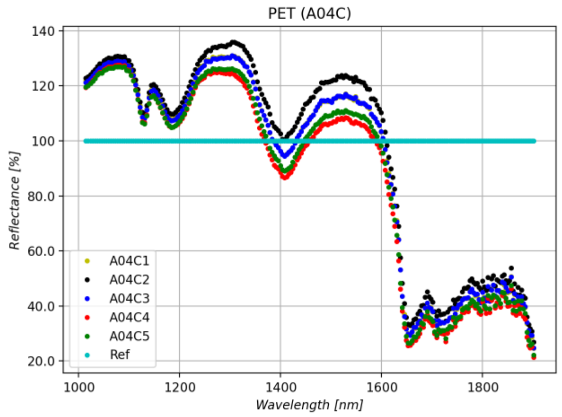

Figure 21: Measurement conducted in the Lectoraat lab of a transparent sample. Integration time: 140,000 ms and an average of 2.

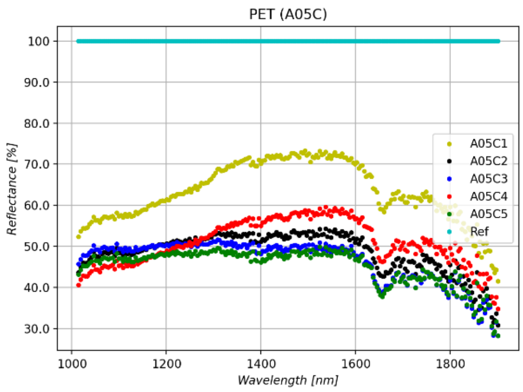

Figure 22: Measurement conducted in the Lectoraat lab of a green coloured sample. Integration time: 140,000 ms and an average of 2.

The dip shown in Figure 18, Figure 19 and Figure 20 are caused by saturation.

HDPE

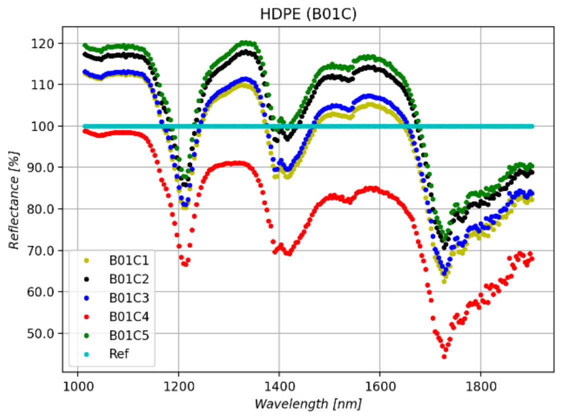

Figure 23: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

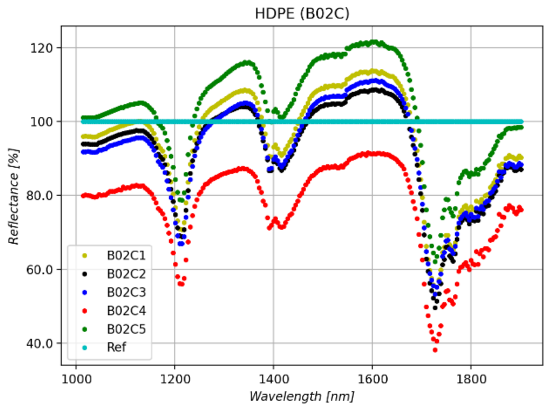

Figure 24: Measurement conducted in the Lectoraat lab of a white transparent sample. Integration time: 140,000 ms and an average of 2.

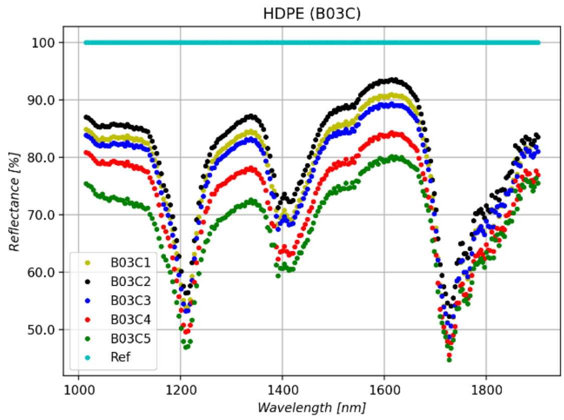

Figure 25: Measurement conducted in the Lectoraat lab of a green coloured sample. Integration time: 140,000 ms and an average of 2.

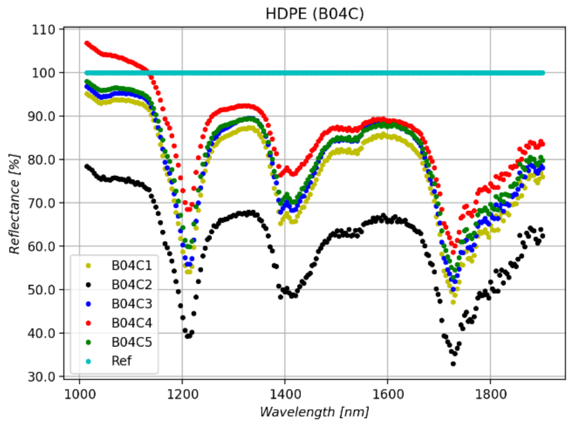

Figure 26: Measurement conducted in the Lectoraat lab of a yellow coloured sample. Integration time: 140,000 ms and an average of 2.

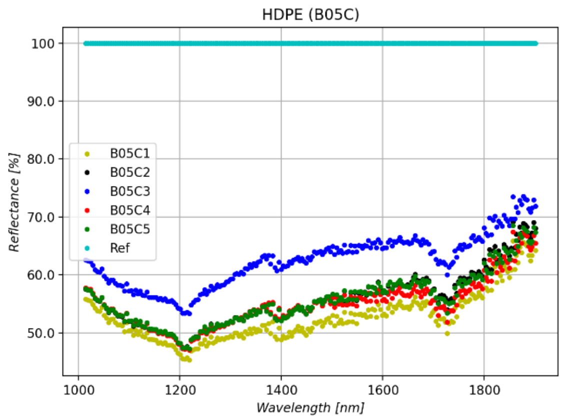

Figure 27: Measurement conducted in the Lectoraat lab of a grey coloured PE sample. Integration time: 140,000 ms and an average of 2.

Figure 27 deviates from the other four spectra of HDPE. A cause of this deviation could be the difference in plastic type. Figure 27 shows the spectrum of PE instead of HDPE. An other cause could be the colour of the plastic. The absorbance becomes higher and the spectrum less defined.

PVC

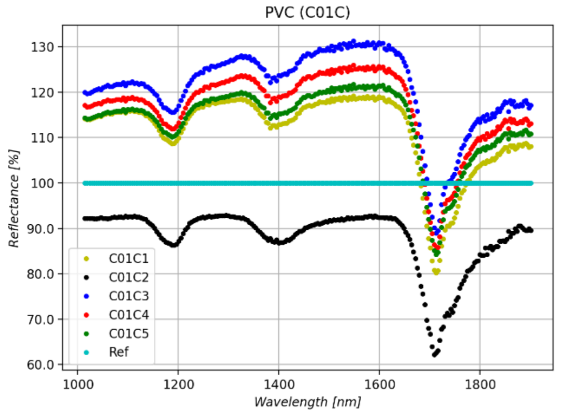

Figure 28: Measurement conducted in the Lectoraat lab of a transparent sample. Integration time: 140,000 ms and an average of 2.

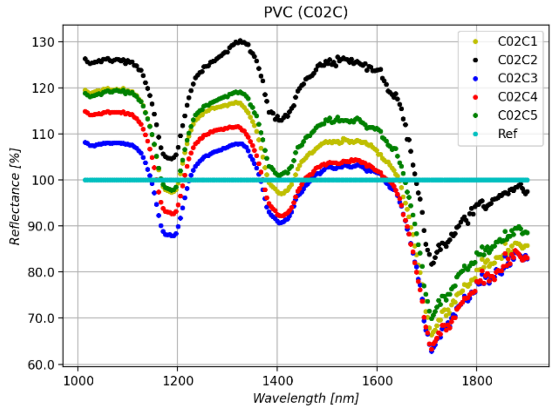

Figure 29: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

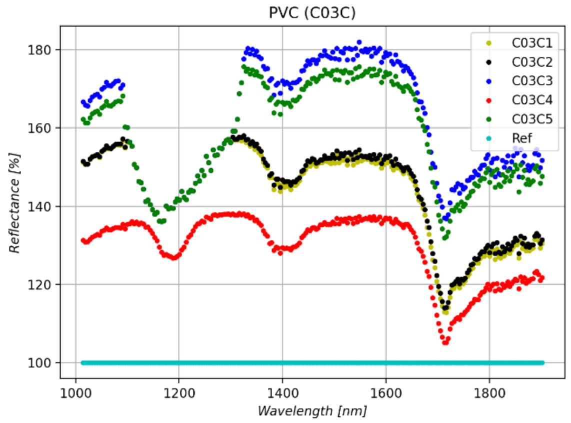

Figure 30: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

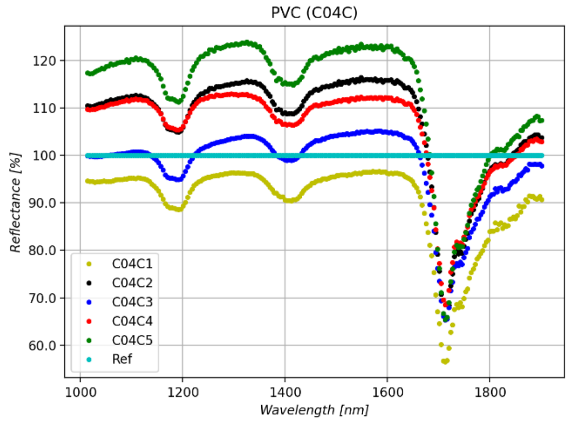

Figure 31: Measurement conducted in the Lectoraat lab of a transparent sample. Integration time: 140,000 ms and an average of 2.

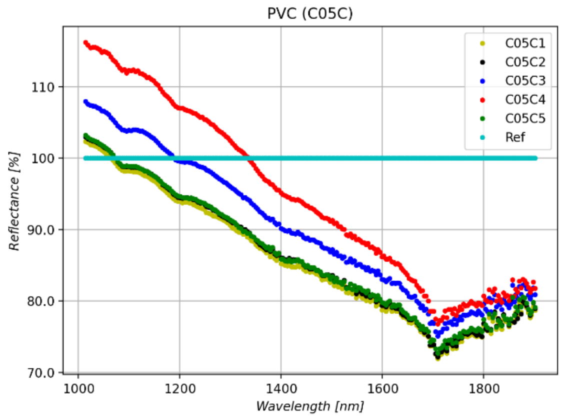

Figure 32: Measurement conducted in the Lectoraat lab of a blue coloured sample. Integration time: 140,000 ms and an average of 2.

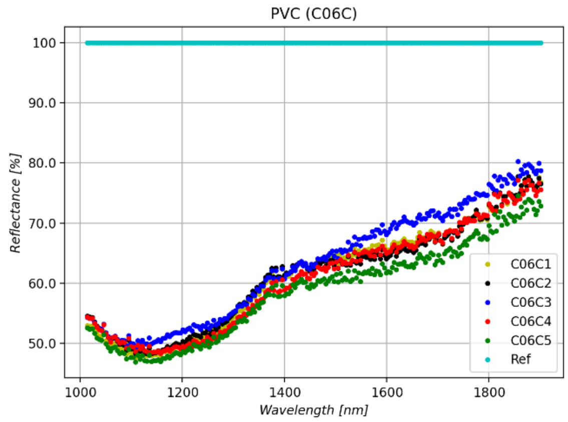

Figure 33: Measurement conducted in the Lectoraat lab of a grey coloured sample. Integration time: 140,000 ms and an average of 2.

It is uncertain if the last two samples can be identified as PVC, because of the deviation in the spectra compared to the previous four figures of PVC.

LDPE

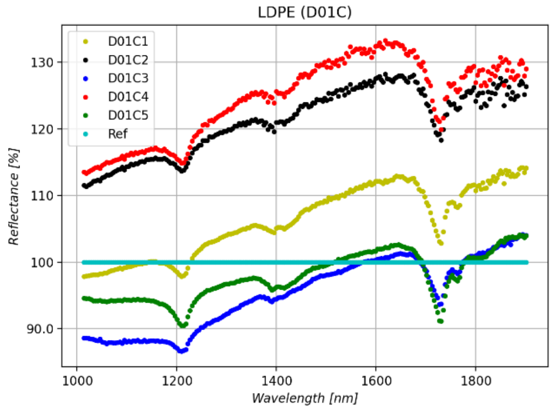

Figure 34: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

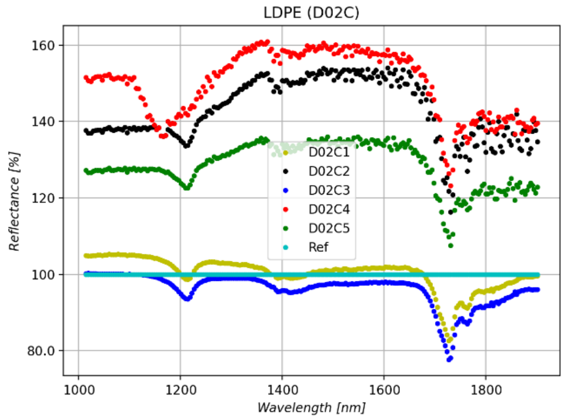

Figure 35: Measurement conducted in the Lectoraat lab of a transparent sample. Integration time: 140,000 ms and an average of 2.

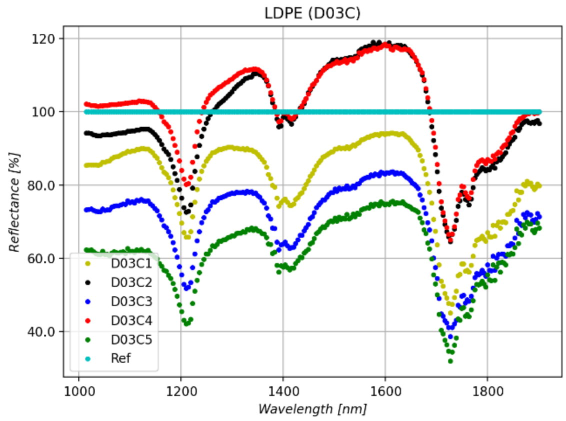

Figure 36: Measurement conducted in the Lectoraat lab of a red coloured sample. Integration time: 140,000 ms and an average of 2.

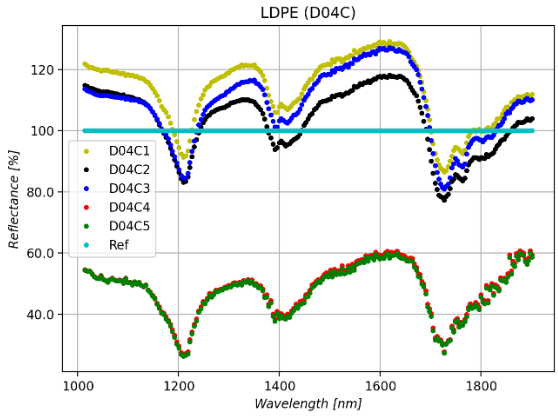

Figure 37: Measurement conducted in the Lectoraat lab of a yellow coloured sample. Integration time: 140,000 ms and an average of 2.

The intensity of the reflectance of the repeated measurements differentiate from each other. It would be expected that the lines would overlap for one of the samples.

PP

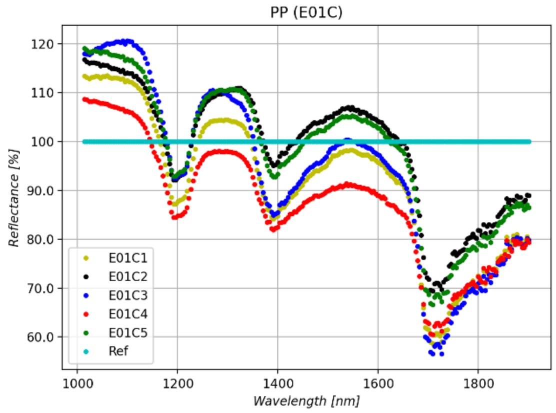

Figure 38: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

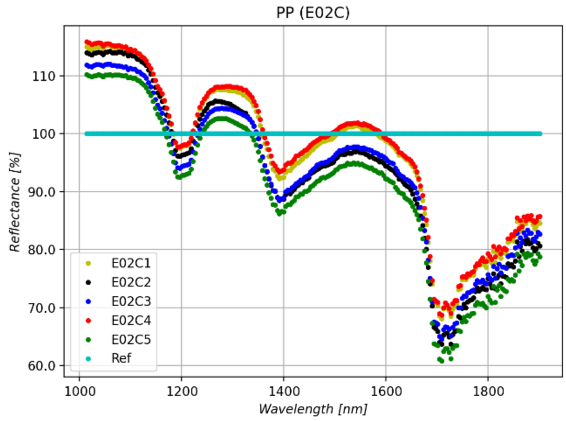

Figure 39: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

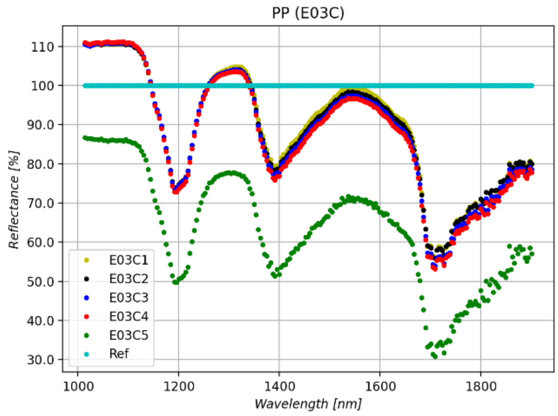

Figure 40: Measurement conducted in the Lectoraat lab of a blue coloured sample. Integration time: 140,000 ms and an average of 2.

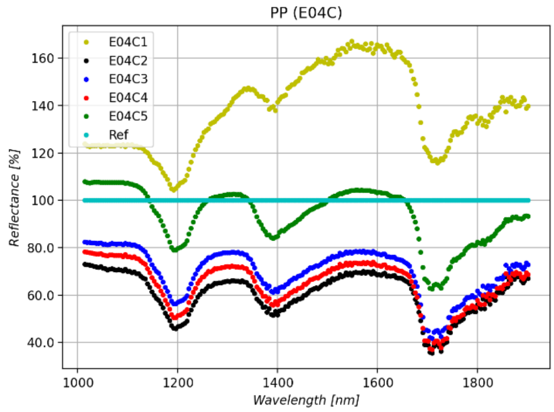

Figure 41: Measurement conducted in the Lectoraat lab of a purple coloured sample. Integration time: 140,000 ms and an average of 2.

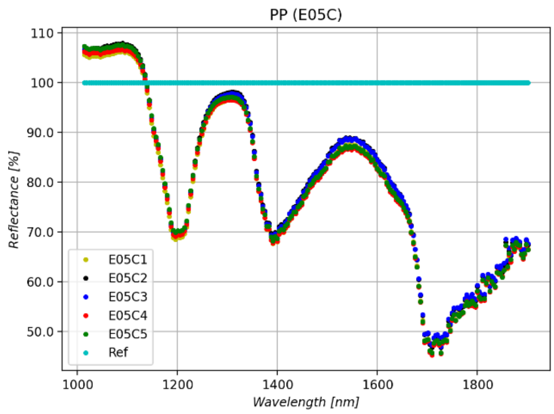

Figure 42: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

The repeated measurements overlap each according to expectations. The first and fourth measurement in Figure 41 have a higher reflectance than the other measurements. The reflectance of the fifth measurement in Figure 40 is lower than the other measurements.

PS

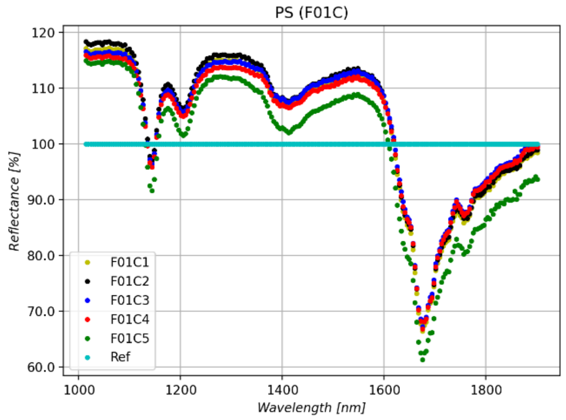

Figure 43: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

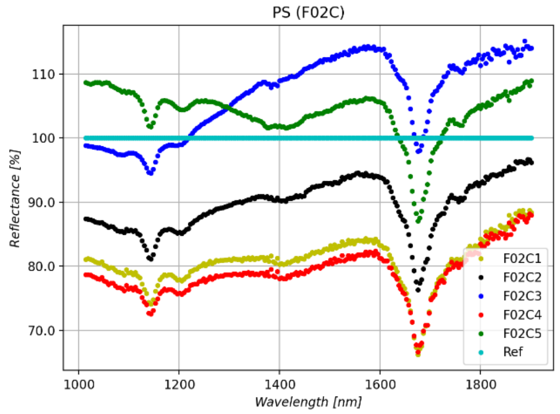

Figure 44: Measurement conducted in the Lectoraat lab of a blue coloured sample. Integration time: 140,000 ms and an average of 2.

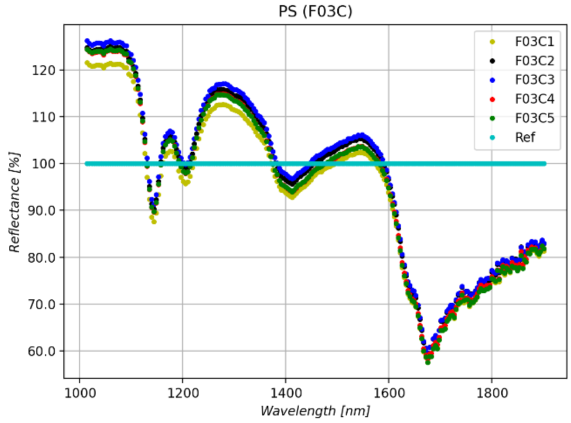

Figure 45: Measurement conducted in the Lectoraat lab of a white coloured sample. Integration time: 140,000 ms and an average of 2.

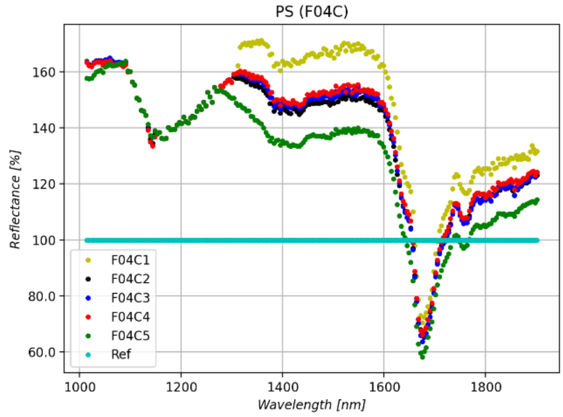

Figure 46: Measurement conducted in the Lectoraat lab of a transparent sample. Integration time: 140,000 ms and an average of 2.

The reflectance of the measurements in Figure 44 vary widely. A cause could be the difference in diffuseness of the surface of the plastic sample. Figure 46 shows a dip around 1150 nm which can be characterised as saturated data.

Repeatability Photonics lab

Each colour of the plastic samples of each type has been measured five times to measure the repeatability. These results are presented in this section. The results are sorted per type of plastic.

PET

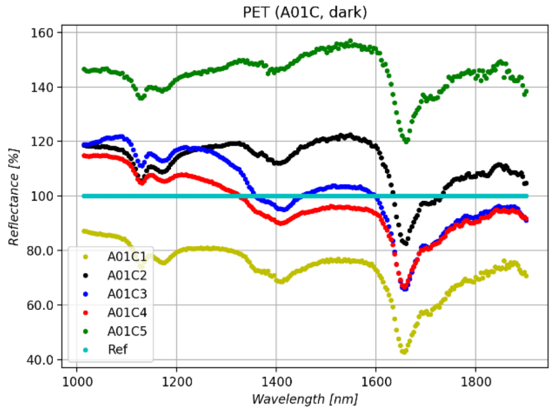

Figure 47: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

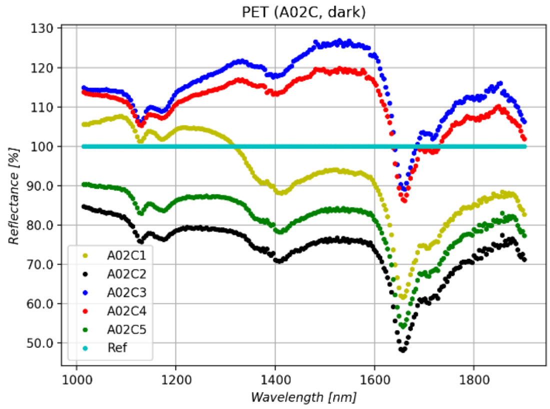

Figure 48: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

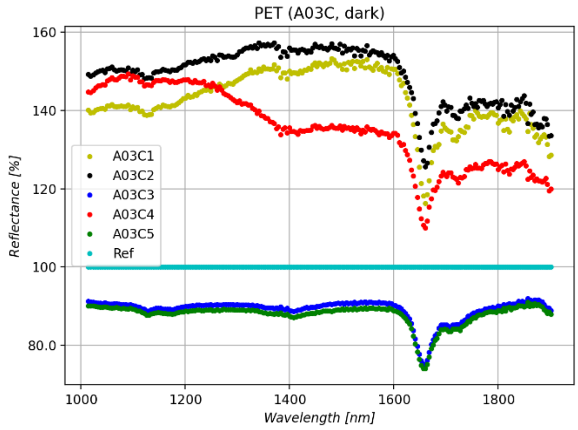

Figure 49: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105,000 ms and an average of 2.

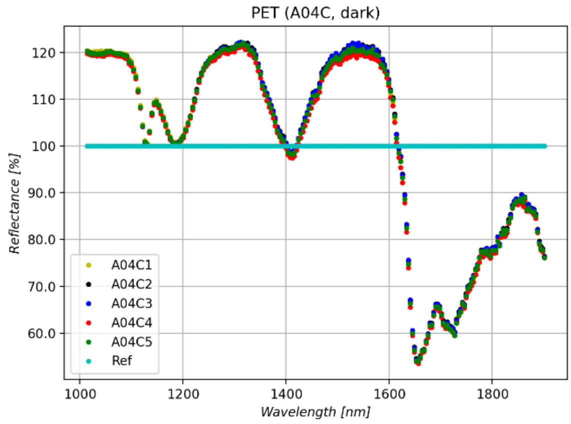

Figure 50: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105,000 ms and an average of 2.

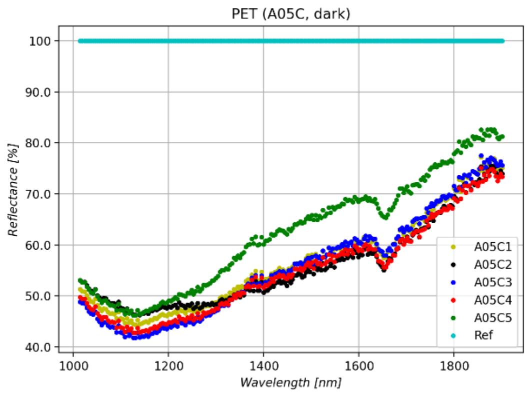

Figure 51: Measurement conducted in the Photonics lab of a green coloured sample. Integration time: 105,000 ms and an average of 2.

There is no saturation present in this data because of the lowered integrations time, therefore the dips in the wavelength range of 1100 nm to 1200 nm has become more clear.

HDPE

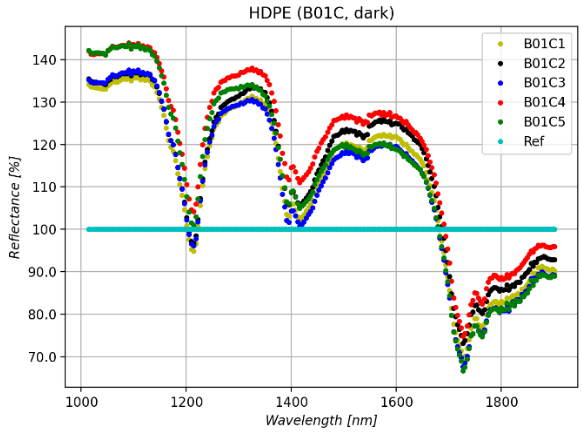

Figure 52: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

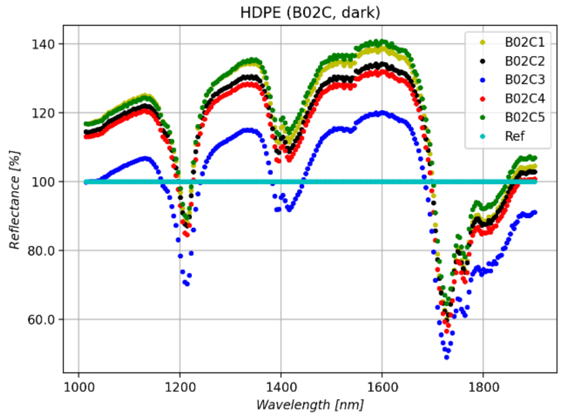

Figure 53: Measurement conducted in the Photonics lab of a white transparent sample. Integration time: 105,000 ms and an average of 2.

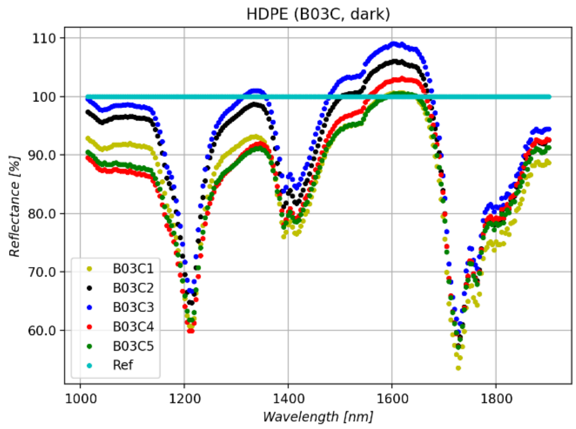

Figure 54: Measurement conducted in the Photonics lab of a green coloured sample. Integration time: 105,000 ms and an average of 2.

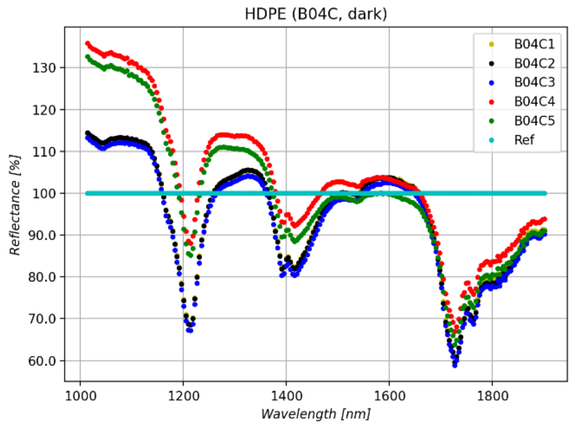

Figure 55: Measurement conducted in the Photonics lab of a yellow coloured sample. Integration time: 105,000 ms and an average of 2.

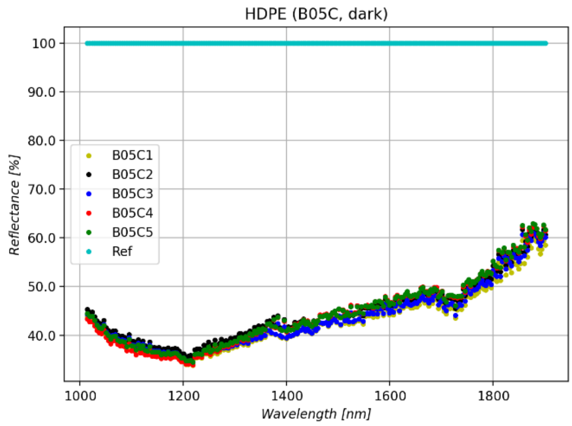

Figure 56: Measurement conducted in the Photonics lab of a grey coloured sample. Integration time: 105,000 ms and an average of 2.

The difference between the intensity of the reflectance of repeated measurements has decreased compared to the measurements in the Lectoraat lab.

PVC

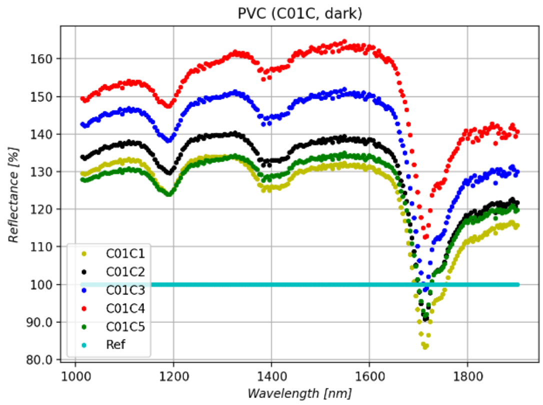

Figure 57: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105,000 ms and an average of 2.

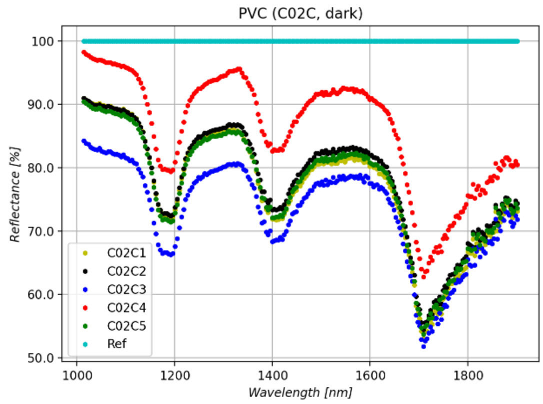

Figure 58: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

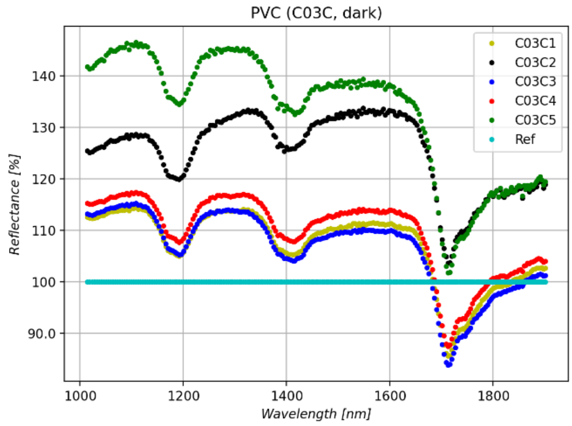

Figure 59: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

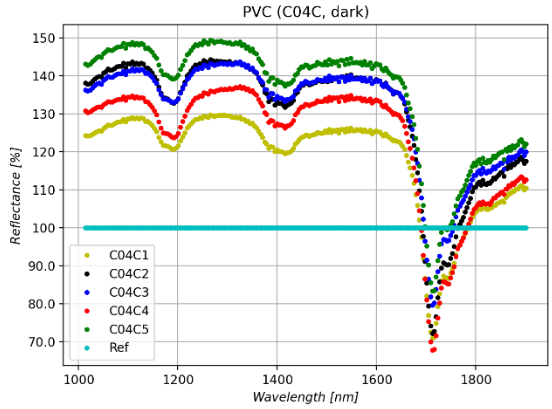

Figure 60: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105,000 ms and an average of 2.

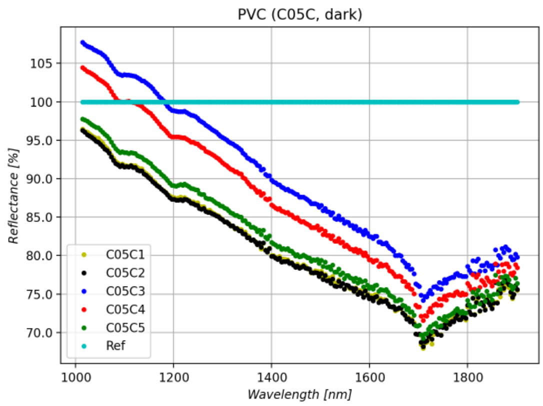

Figure 61: Measurement conducted in the Photonics lab of a blue coloured sample. Integration time: 105,000 ms and an average of 2.

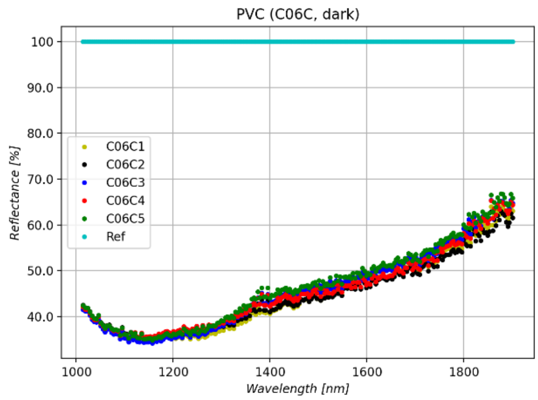

Figure 62: Measurement conducted in the Photonics lab of a grey coloured sample. Integration time: 105,000 ms and an average of 2.

As shown again the last two samples of PVC are not following the expected spectra for PVC.

LDPE

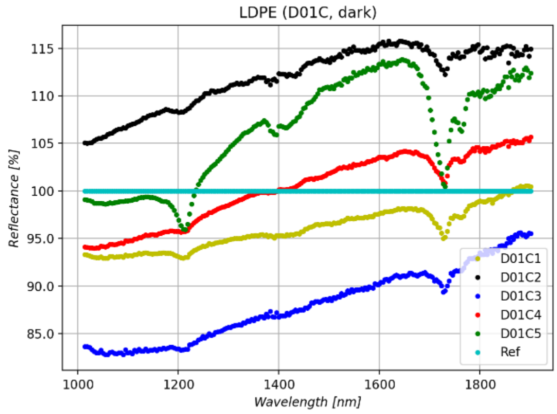

Figure 63: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

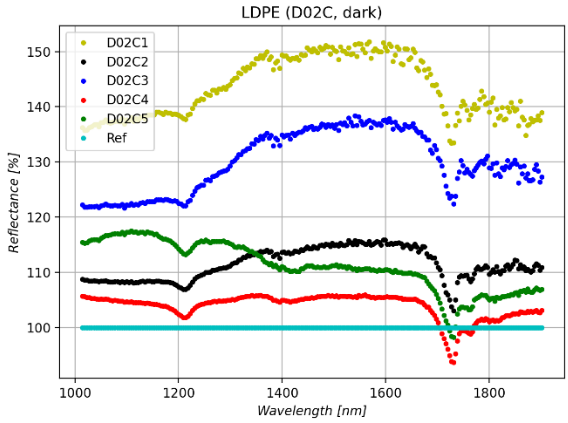

Figure 64: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105,000 ms and an average of 2.

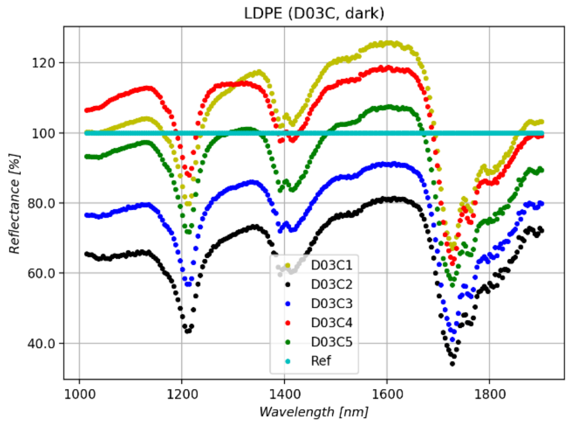

Figure 65: Measurement conducted in the Photonics lab of a red coloured sample. Integration time: 105,000 ms and an average of 2.

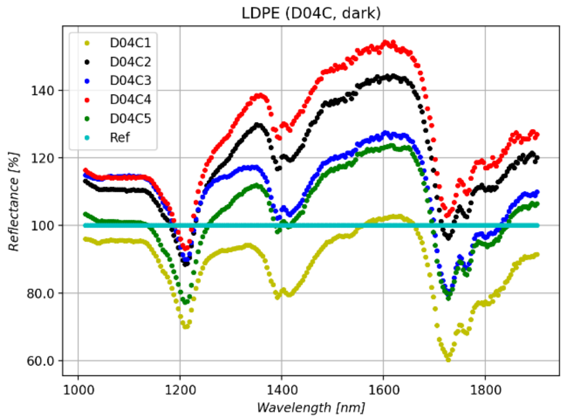

Figure 66: Measurement conducted in the Photonics lab of a yellow coloured sample. Integration time: 105,000 ms and an average of 2.

All figures show no difference in spectra compared to the measurements taken in the Lectoraat lab, except for the measurements of sample D01C. The dip around 1200 nm is less visible.

PP

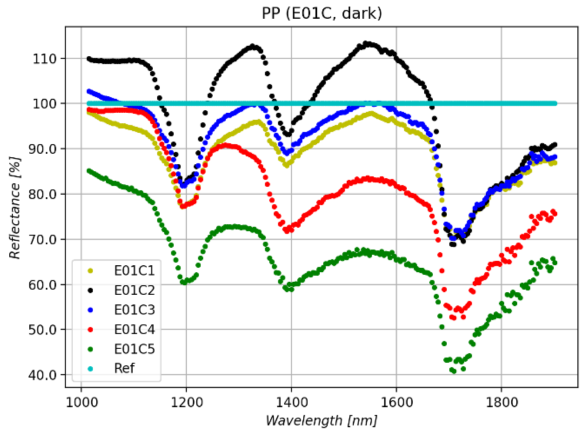

Figure 67: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

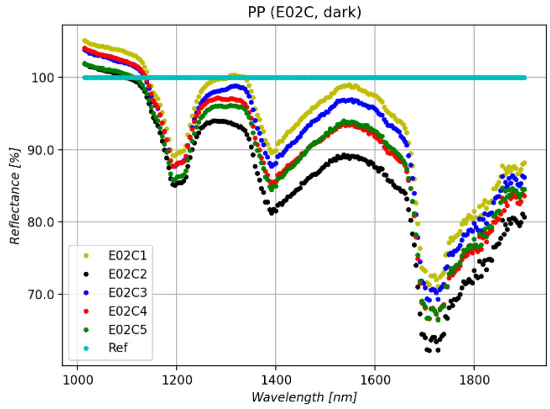

Figure 68: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

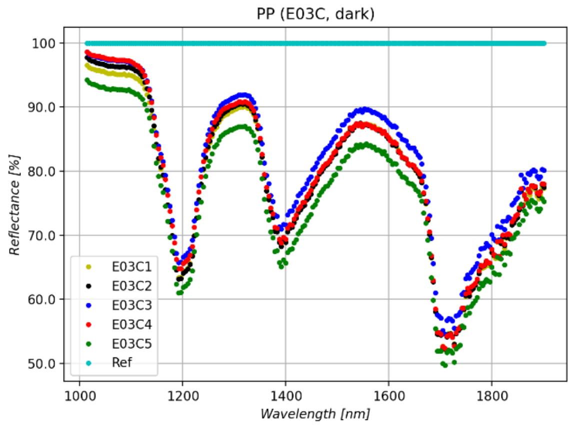

Figure 69: Measurement conducted in the Photonics lab of a blue coloured sample. Integration time: 105,000 ms and an average of 2.

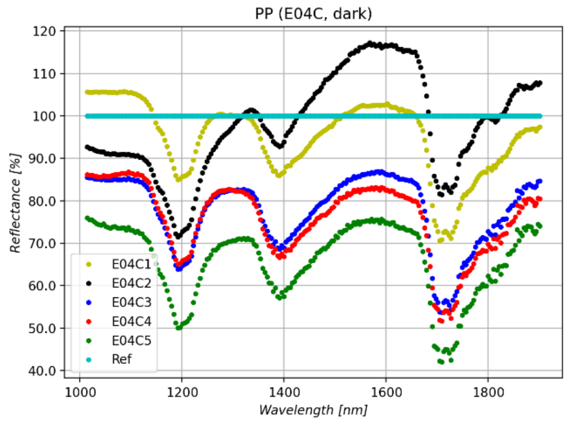

Figure 70: Measurement conducted in the Photonics lab of a purple coloured sample. Integration time: 105,000 ms and an average of 2.

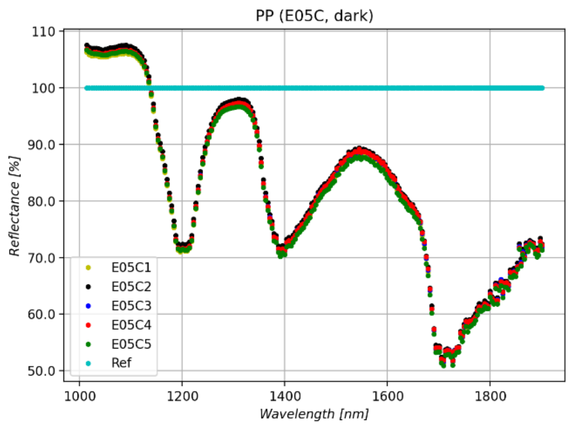

Figure 71: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

There are no major changes visible in the data measured in a darkened environment compared to the measured data in a lightened environment.

PS

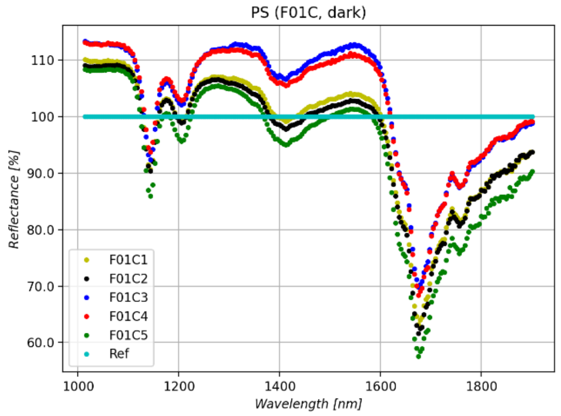

Figure 72: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

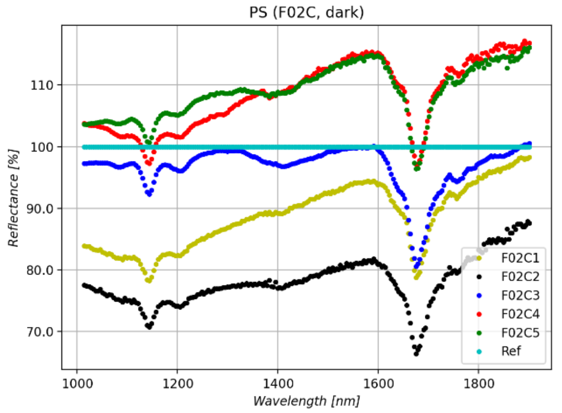

Figure 73: Measurement conducted in the Photonics lab of a blue coloured sample. Integration time: 105,000 ms and an average of 2.

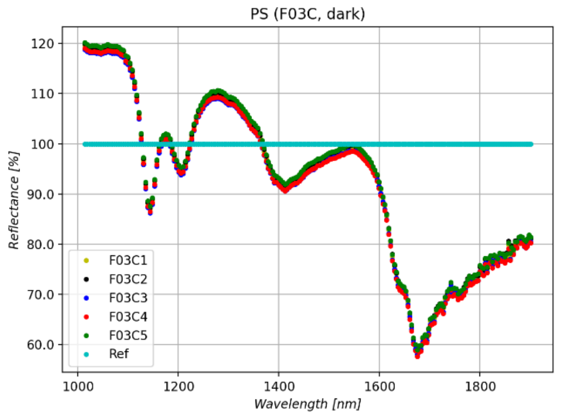

Figure 74: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105,000 ms and an average of 2.

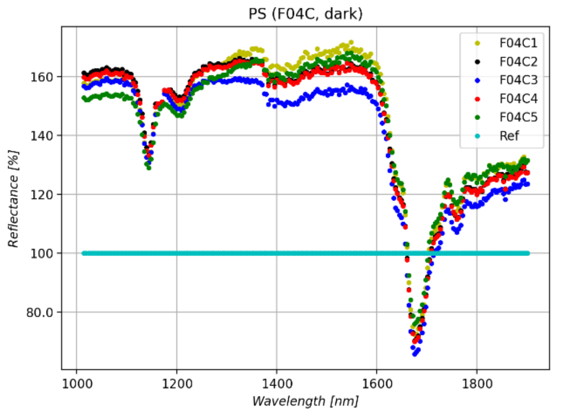

Figure 75: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105,000 ms and an average of 2.

All figures of PS show that it is not relevant where you scan the plastic to get a repeated measurement.

As seen in the figures of the repeatability (Lectoraat lab and Photonics lab), it is very important that the data is not saturated. The spectra of the types of plastic becomes more visible. Nevertheless, Figure 18 tillFigure 75 show that the scanning location on the plastic does not effect the course of the spectra of the types of plastic.

Plastics

Figure 76 shows the reflectance of the types of plastics plotted against the wavelength.

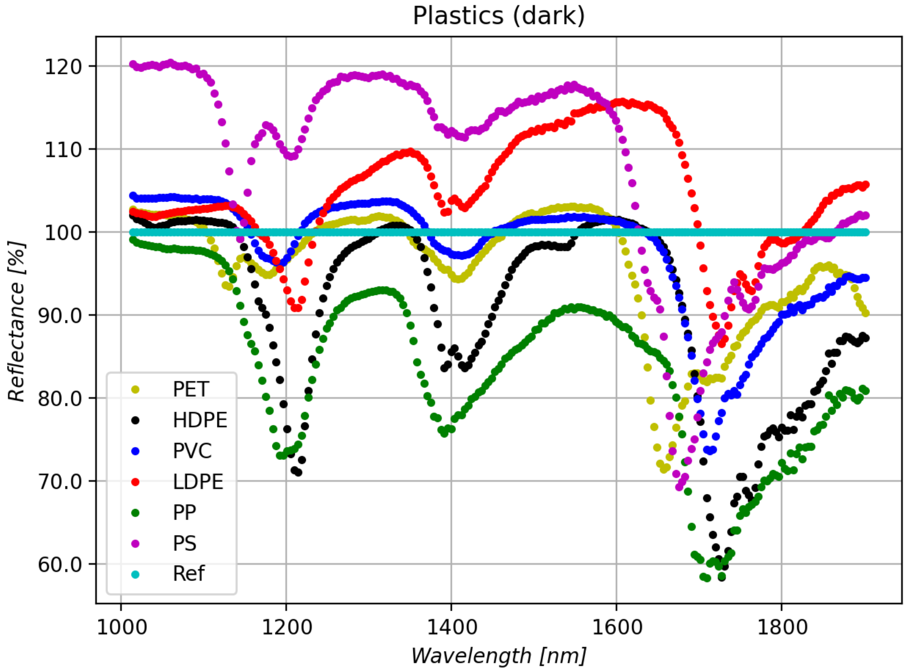

Figure 76: The reflectance of the different types of plastic plotted against the wavelength. Measurements conducted in a dark Photonics lab. The settings of the Avantes spectrometer were set on a Integration time: 105,000 ms and an average of 2.

A SNV filter should be used to show a better distinction between the spectra of the types of plastic. The filter will be applied to the repeatability data. The measured data of the types of plastic is placed next to the spectra of the theory to determine the correspondence with each other. The comparison is shown in Figure 77.

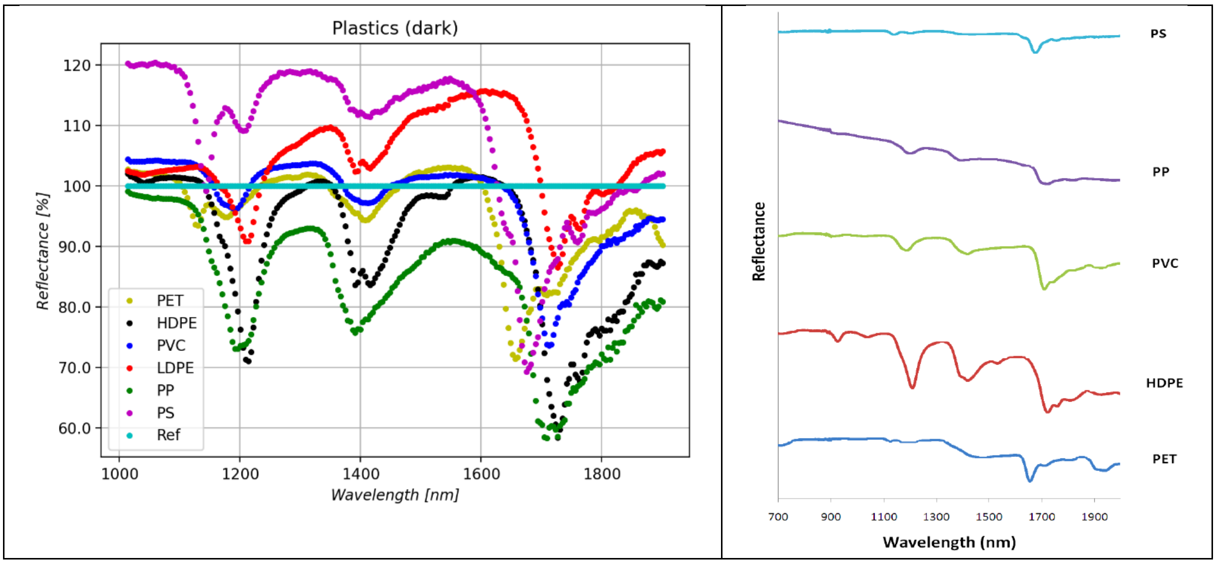

Figure 77: The measured spectra of six different types of plastic next to the spectra of the different types of plastic from the theory.

The spectra of the different types of plastic corresponds with the spectra in the theory.

6. Conclusion

Most plastic samples have a higher reflectance than 100%. This could be caused due to the mirroring layer on certain plastic samples. To prevent a higher reflectance than 100% the reference tile needs to become more reflective or the plastic samples more diffuse. The offset could also be a cause of the higher reflectance.

Some of the plastic samples measured in the Lectoraat lab have a saturated dataset, which is visible in the large dip around the 1150 nm. By decreasing the integration time the measured data does not become saturated and the spectra of the data becomes more defined. This can be seen in the data measured in an darkened environment where the integration was lowered from 140,000 to 105,000 ms.

The only difference between the measurements taken in a lightened and darkened environment is the intensity of the reflectance. The spectra of the types of plastic stays the same allowing the plastic to be identified. Not all samples can be used as reference because of the undefined spectrum. Samples B05C, C05C and C06C show a spectrum not comparable with the other spectra of the type of plastic.

Bibliography

[1] H. Masoumi, S. Mohsen Safavi en Z. Khani, „Identification and classification of plastic resins using near infrared reflectance spectroscopy,” *International Journal of Mechanical and Industrial Engineering,* pp. 213-220, january 2012.