DEVELOPMENT OF AN OBJECTIVE TEST METHOD TO DETERMINE THE COLOUR OF COLOURED ASPHALTS

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ABSTRACT

Nowadays coloured bituminous pavements are more and more applied to our roads. Mostly they are used in rural environments to increase safety and livability. Since the expression of a colour is different for every individual, coloured roads form quite often a point of discussion between contractors and clients. The perception of colour depends on a variety of parameters: the observer is an important factor but the incidence of light and the distance between the observer and object also have a great influence. In this investigation a research method was developed to objectively determine the colour of coloured asphalts using two different types of spectrophotometers: one with a 45°/0° geometry and one with a d/8° geometry. Several coloured roads and cores were investigated using these two spectrophotometers and the results were analyzed.

Keywords: colour, spectrophotometer, asphalt

1. INTRODUCTION

In the current Belgian prescriptions RAL colour charts are used to determine the colour of asphalt pavements. The RAL colour charts form a collection of colours mostly used in paint industry and are a good tool to determine the colour of a smooth homogeneous surface (e.g. a painted wall). Once the surface becomes textured and inhomogeneous, like an asphalt pavement, the use of colour charts is not to be recommended and led to several discussions between contractors and clients.

Unlike length or weight, there is no physical scale for measuring colour, making it unlikely that a certain colour will be expressed in the same way by different people. Colour can only exist when three components are present: an observer, an object and light and its perception is influenced by many factors:

- The observer: a coloured asphalt layer can seem different for different observers
- The state of the object: a bituminous pavement can be wet or dry, clean or dirty, less or more compacted … In each state different colours will be observed
- The light source: an asphalt layer can look yellow ochre on a sunny day while it may seem dark grey on a cloudy evening.
- The distance between the object and the observer
- The angle under which the object is observed
- …

To set free of all of these factors a research method was developed to objectively determine the colour of a coloured asphalt pavement using a spectrophotometer

2. SPECTROPHOTOMETERS

The devices on the market that are able to measure colour can generally be divided into two groups: colorimeters and spectrophotometers. Since spectrophotometers have more possibilities and a better accuracy, two types of spectrophotometers were evaluated during this research project:

- a BYK-Gardner spectro-guide 45/0 gloss (45°/0° geometry)
- a BYK-Gardner spectro-guide sphere gloss (d/8° geometry)

2.1. Principle of a spectrophotometer

The principle of a spectrophotometer is simple: the device is placed on an object, its light source illuminates the object and the reflected light is measured by its observer.

2.1.1. Light source versus illuminant

A light source is a physical emitter of radiation that can be characterized numerically by a spectral power distribution curve. Each spectrophotometer has a built-in light source. Since different light sources will make a colour appear differently, the CIE (International Commission on Illumination) has codified the spectral power distribution curve of different types of white light sources and called them "illuminants". One of the commonly-used standard illuminant is the D65 illuminant, its spectral power distribution curve can be found in figure 1. D65 corresponds roughly to a mid-day sun in Europe and is also called the daylight illuminant. There are no actual D65 light sources, only simulators. The spectrophotometer's built-in light source may or may not match any of the CIE illuminants. Instead, the instrument determines the data for measurements under the selected illuminant through calculations based on the data actually measured under the instruments light source and the illuminant's spectral distribution data stored in the instrument's memory. In this research a D65 illuminant was used for all measurements.

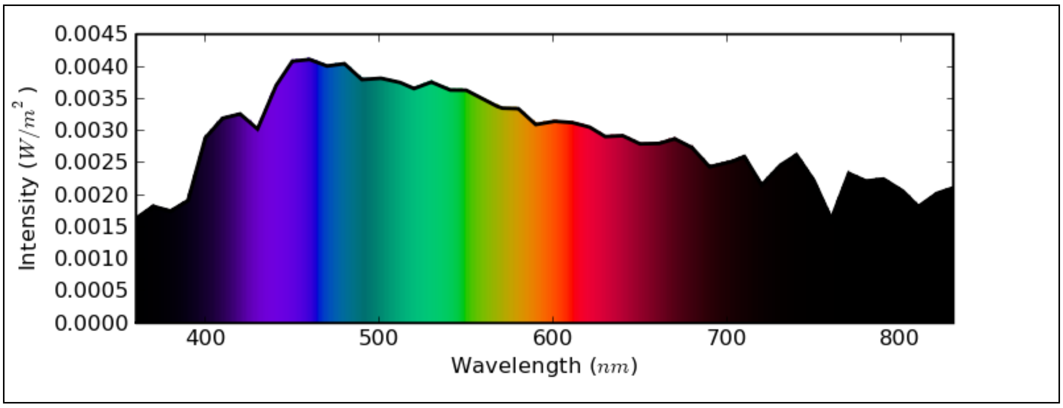

Figure 1: Spectral power distribution curve of a D65 illuminant [1].

2.1.2. Observer

The spectrophotometers used in this investigation offer the possibility to choose between a 2° and a 10° observer (see figure 2). In 1931 the CIE defined a standard observer using a 2° field of view due to the belief that the colour-sensitive cones in the eye resided within a 2° arc of the fovea. In 1964, however, research showed that cones were present in a larger area of the eye than previously believed and the 10° standard observer was defined. The 10° observer is mostly used because it gives a better correlation to the visible judgement and will also be used in this research.

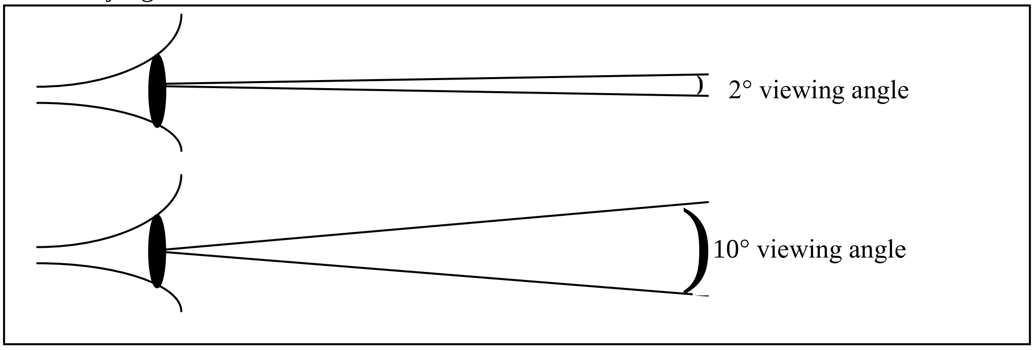

Figure 2: Schematic representation of the 2° and 10° standard observer.

2.1.3. The L*a*b* colour space

This colour space, shown in figure 3, was defined by CIE and will be used in this research to express colour. L*, a* and b* are dimensionless quantities where L* indicates the lightness and varies between 0 (light) and 100 (dark), a* and b* are the chromaticity coordinates and generally vary between -100 and +100: +a* is the red direction, -a* is the green direction, +b* is the yellow direction and –b* is the blue direction. The centre of the sphere is achromatic. As the absolute values of a* and b* increase, the saturation of the colour will also increase.

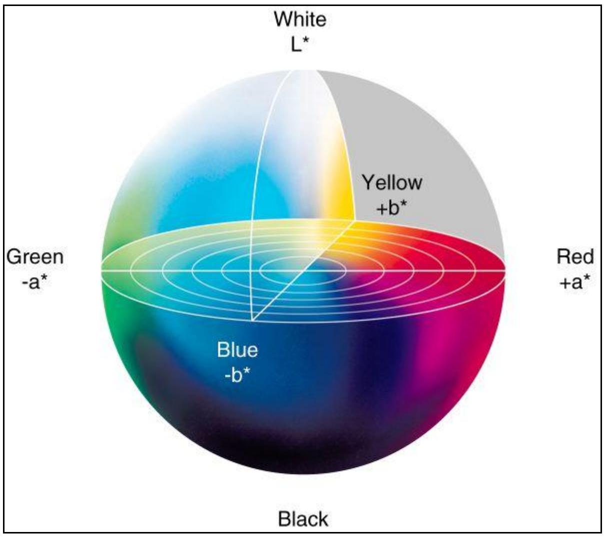

Figure 3: L*a*b* colour space [2].

2.2. Spectrophotometers with a 45°/0° geometry

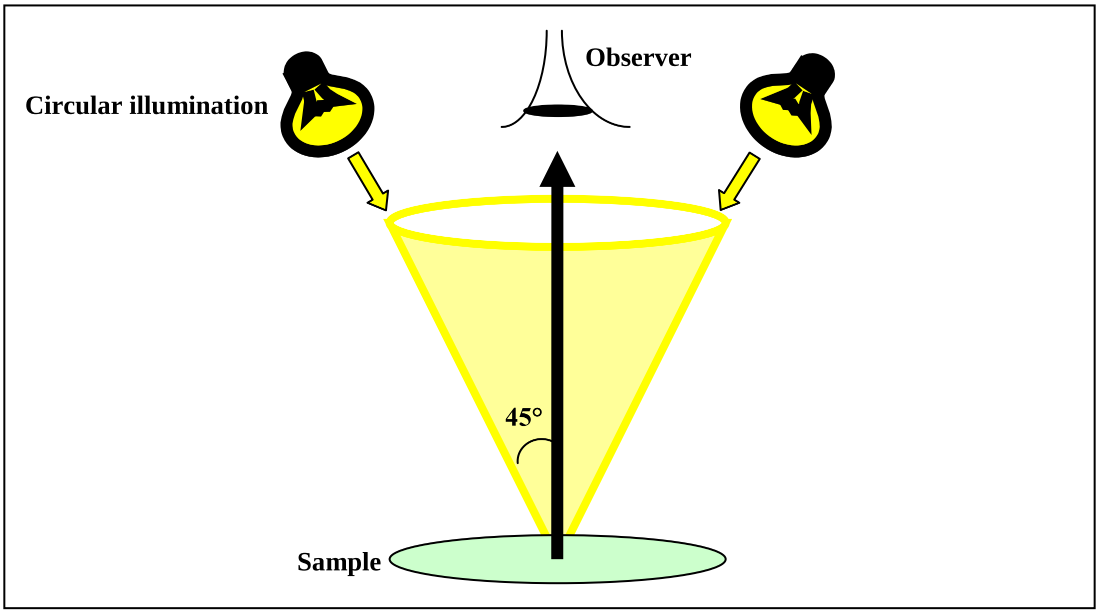

Figure 4: Schematic representation of a spectrophotometer with a 45°/0° geometry.

The 45°/0° geometry refers to the geometry or optical design of the spectrophotometer. The first angle, 45°, refers to the angle of illumination and the second angle, 0°, is the angle of viewing. These angles are both relative to the perpendicular to the surface of the sample being measured. The spectrophotometer used in this research has a circumferential illumination which means a sample is illuminated using many lights in a ring around it at 45° from its normal. The advantage of this circular illumination is that the measurement is independent of the direction of the sample. Spectrophotometers with a 45°/0° geometry "see" colour in the same way the human eye does. They are suitable for measuring differences in appearance of samples, including effects of colour, gloss and texture. This also means that two samples with a different texture that are equally pigmented will have different colour coordinates.

2.3. Spectrophotometers with a d/8° geometry

The "d" in the d/8° geometry refers to "diffuse" which is the method of illumination, and the 8° is the angle of viewing, relative to the perpendicular to the surface of the sample being measured. The d/8° geometry is also known as the "sphere" geometry. As shown in figure 5 the light source illuminates the white coated inside of a sphere (Ulbrecht sphere) and the incident light is scattered many times to obtain diffuse illumination of the sample. Because of this diffuse illumination a sample with a structured surface is homogeneously illuminated and there will be no shadows on it. For this reason a sample will have nearly the same colour coordinates independently its surface: a glossy, mat or structured sample will have the same colour coordinates if the pigmentation is equal.

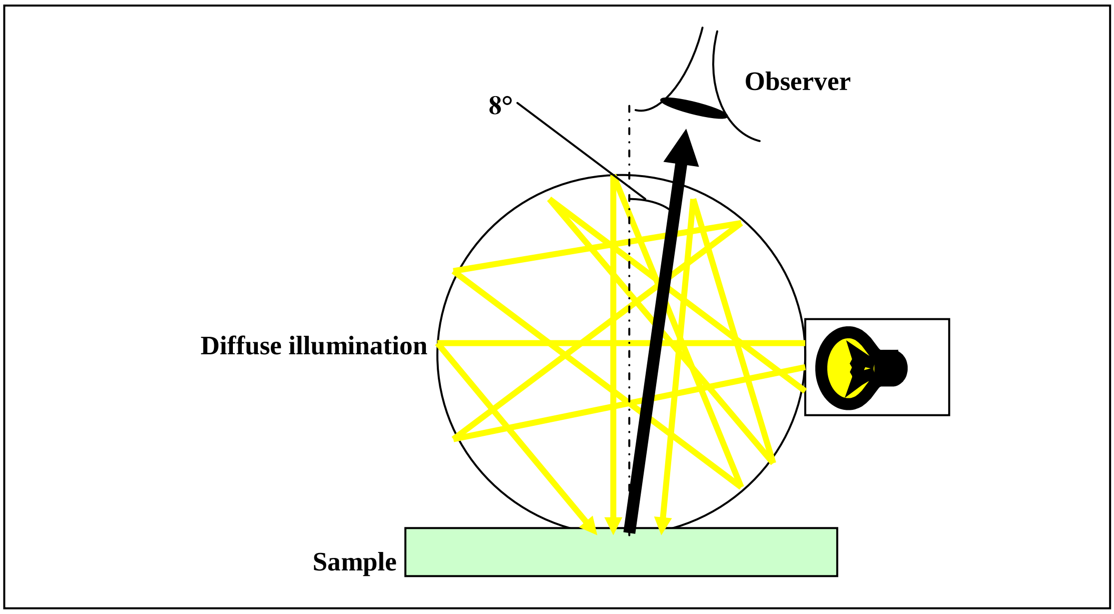

Figure 5: Schematic representation of a spectrophotometer with a d/8° geometry.

3. DEVELOPMENT OF A TEST PROCEDURE TO OBJECTIVELY DETERMINE THE COLOUR OF COLOURED ASPHALT PAVEMENTS

3.1. Measurements on cores

3.1.1. Test procedure

To develop a test procedure to determine the colour of asphalt cores we had 37 cores to our disposal with a diameter around 10 centimetres. These 37 samples were measured with both types of spectrophotometers (the 45°/0° and d/8° geometry). Although a wide variety of colours (grey, green, red, brown,…) was covered, the majority of the cores (14 in total) had a red-brown colour. Since asphalt is a very inhomogeneous material and because the measurement area of our spectrophotometers is limited to a circle with a diameter of 11 millimetres, several measurements per sample are required. We decided to start with 16 measurements per core as shown in figure 6 and to reduce the number of measurements after analysing the first results. Before measuring, each sample was cleaned thoroughly with a brush. In table 1 some typical measurement results and their standard deviations are summarised. The L*, a*, b* values in this table represent the mean of 16 measurement points per core.

Table 1: Typical measurement results for measurements with two types of spectrophotometers on cores

Colour of the core	Spectrophotometer	L*	a*	b*	σ_{L*}	σ_{a*}	σ_{b*}
Green	45°/0°	33.2	-5.6	11.8	1.2	0.5	1.7
	d/8°	33.0	-5.4	10.4	1.0	0.4	0.9
Red-brown	45°/0°	31.7	19.5	13.1	1.3	0.5	0.3
	d/8°	32.2	18.9	12.5	1.3	0.7	0.2
Dark grey	45°/0°	31.5	2.4	8.7	0.8	0.4	0.7
	d/8°	31.5	2.2	8.4	1.0	0.2	0.6
Light grey	45°/0°	42.1	1.4	9.9	1.4	0.1	0.2
	d/8°	42.3	1.1	9.5	1.1	0.1	0.2

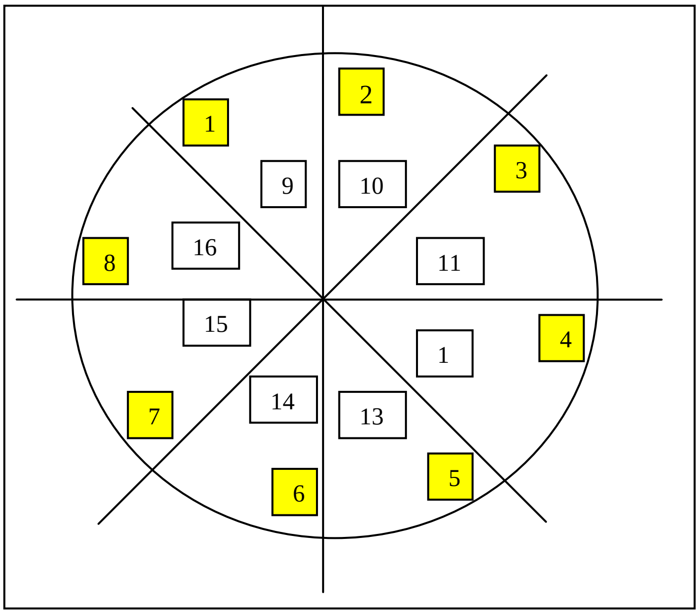

Figure 6: Schematic view of the measurements executed on each sample.

3.1.2. Reduction of the number of measurements per sample

In order to verify whether a reduction from 16 measurements to 8 or 4 measurements per core is possible, the measurement points depicted in figure 6 were subdivided as follows:

- two series of 8 points:
  - series 1: points 1 until 8
  - series 2: points 9 until 16

- four series of 4 points (one point per quadrant):
  - series 1: points 1, 3, 5 and 7
  - series 2: points 2, 4, 6 and 8
  - series 3: points 9, 11, 13 and 15
  - series 4: points 10, 12, 14 and 16

For each core and for each series of measurement points (1 series of 16, 2 series of 8, and 4 series of 4 points) the relative standard deviation (RSD) of L*, a* and b* was calculated as a measure for the precision. The relative standard deviation is expressed as a percentage and is defined as 100 times the quotient of the standard deviation and the average of an array of measurement points. In total 37 values for the RSD_{L*}, RSD_{a*} and RSD_{b*} were obtained per series of measurement points. For each parameter the mean of these 37 values and their dispersion (expressed by the standard deviation on RSD) were calculated as shown in table 2. Based on table 2 we can conclude that a reduction of 16 measurement points per core to 4 will lead to a similar average precision and dispersion. However, in the future additional cores will be measured to verify whether this conclusion is correct.

Table 2: Mean RSD for L*, a* and b* of the 37 measured cores and its dispersion

	Spectrophotometer	**Average RSD_{L*}**	**Average RSD_{a*}**	**Average RSD_{b*}**	σ_{RSDL*}	σ_{RSDa*}	σ_{RSDb*}
16 points	45°/0°	4%	7%	5%	2%	4%	3%
	d/8°	5%	6%	5%	2%	4%	3%
8 points series 1	45°/0°	4%	7%	5%	2%	5%	3%
	d/8°	5%	6%	4%	3%	3%	3%
8 points series 2	45°/0°	4%	6%	4%	3%	4%	3%
	d/8°	5%	6%	4%	3%	5%	3%
4 points series 1	45°/0°	3%	6%	4%	2%	5%	4%
	d/8°	4%	6%	4%	3%	4%	3%

4 points series 2	45°/0°	4%	6%	4%	3%	4%	3%
	d/8°	5%	6%	4%	4%	4%	3%
4 points series 3	45°/0°	4%	6%	5%	2%	4%	4%
	d/8°	5%	6%	4%	4%	5%	3%
4 points series 4	45°/0°	4%	6%	5%	3%	5%	3%
	d/8°	4%	6%	4%	3%	6%	3%

3.2. Measurements on site

3.2.1. Test procedure

To measure the colour of pavements its surface must be dry and clean. Mostly a dry cleaning of the measuring area with a brush was sufficient. In case of severe contamination a wet cleaning can be required. After a wet cleaning the measuring area must be dried with a hair dryer and before any measurements are executed the area should have the same temperature as its environment.

Coloured asphalt mixtures are applied to roads, bicycle paths, footpaths but also to squares like parking zones, recreation areas,… Since the geometry of a square is completely different, this case is treated separately in the test procedure. Small and large areas also ask for a different approach, therefore the test procedure will consider four cases:

- Case 1: determining the colour of a road, a bicycle path or a footpath with a length ≥ 50 m
- Case 2: determining the colour of a road, a bicycle path or a footpath with a length < 50 m
- Case 3: determining the colour of a square with a surface ≥ 2500 m²
- Case 4: determining the colour of a square with a surface < 2500 m²

For cases 1 and 2 two different test procedures were defined, tested and compared as will be described in paragraphs 3.2.1 and 3.2.2.

Case 1: determining the colour of a road, a bicycle path or a footpath with a length ≥ 50 m: test procedure 1

If the investigated site is longer than 50 meters, five square areas of 20 cm by 20 cm are measured over the total width of the lane and this every 50 meters as shown in figure 8. Per square four measurements, in each corner of a wooden frame, are made (see figure 9). In total 20 measurements per 50 meters were made. In case of a road with car traffic, we decided to place squares 2 and 4 in the wheel tracks (as depicted in figure 8). The coordinates of every measured point are noted.

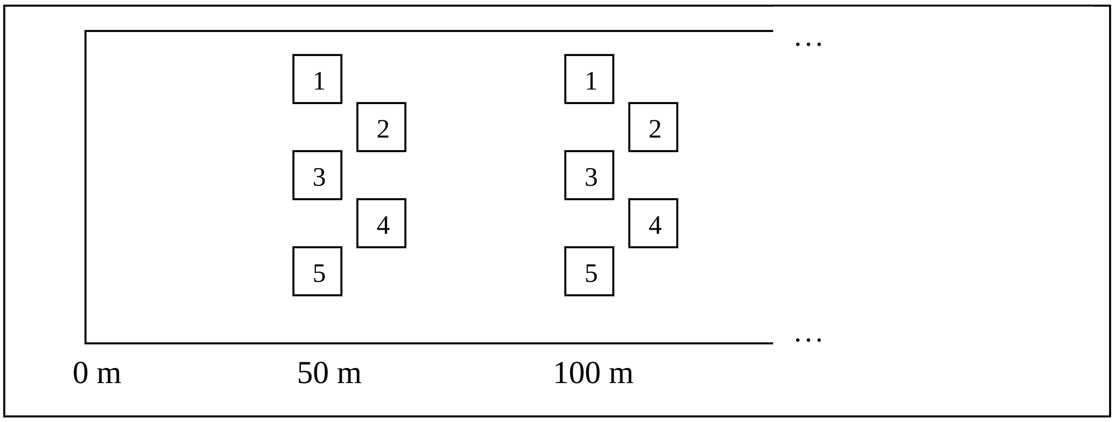

Figure 8: Schematic overview of a test procedure 1 for the case of a road, a bicycle path or a footpath with a length ≥ 50 m

Figure 9: Per area of 20 cm by 20 cm, 4 measurements are made: one in each corner of a wooden frame.

Case 1: determining the colour of a road, a bicycle path or a footpath with a length ≥ 50 m: test procedure 2

Every 10 meter a square area of 20 cm by 20 cm is measured over the total width of the lane as shown in figure 10. Per square four measurements, each in each corner of a wooden frame, are made (see figure 9). In total 20 measurements per 50 meters were made. In case of a road with car traffic, square 2 and 4 (as depicted in figure 10) are placed in the wheel tracks. The coordinates of every measured point are noted.

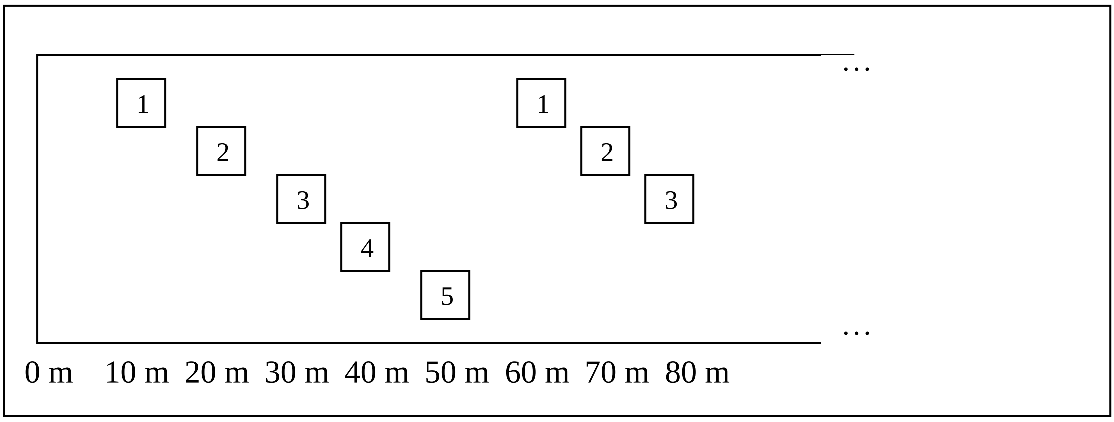

Figure 10: Schematic overview of test procedure 2 for the case of a road, a bicycle path or a footpath with a length ≥ 50 m

Case 2: determining the colour of a road, a bicycle path or a footpath with a length < 50 m: test procedure 1

In this case the total length, L, of the lane is measured and five areas of 20 cm by 20 cm are measured over the total width of the lane at the length coordinate $\frac{L}{2}$ as shown in figure 11. Per square four measurements, one in each corner of a wooden frame, are made (as depicted in figure 9). In total 20 measurements are executed.

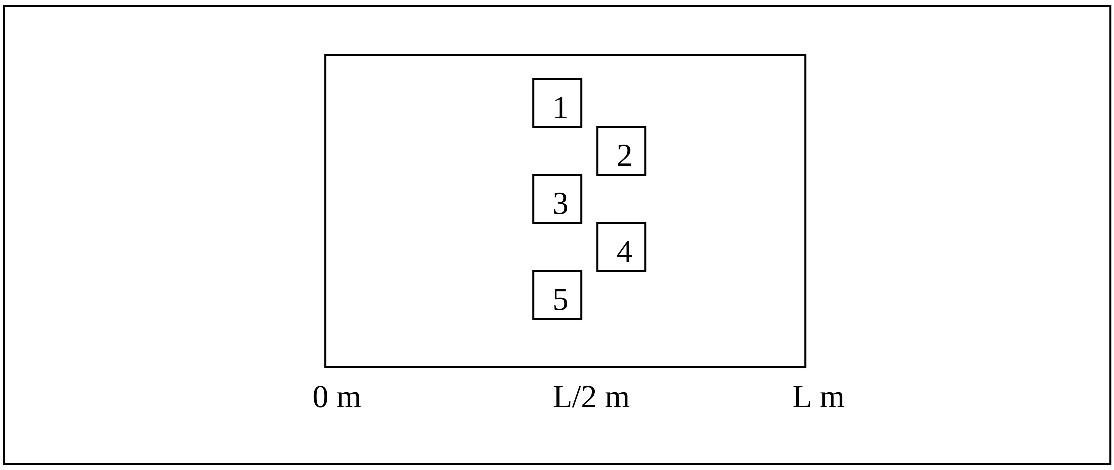

Figure 11: Schematic overview of test procedure 1 for the case of a road, a bicycle path or a footpath with a length < 50 m. The total length of the lane is defined as "L".

Case 2: determining the colour of a road, a bicycle path or a footpath with a length < 50 m: test procedure 2

In this case the total length, L, of the lane is measured and five areas of 20 cm by 20 cm are measured over the total width of the lane as shown in figure 12. Per square four measurements, one in each corner of a wooden frame, are made (as depicted in figure 9). In total 20 measurements are executed.

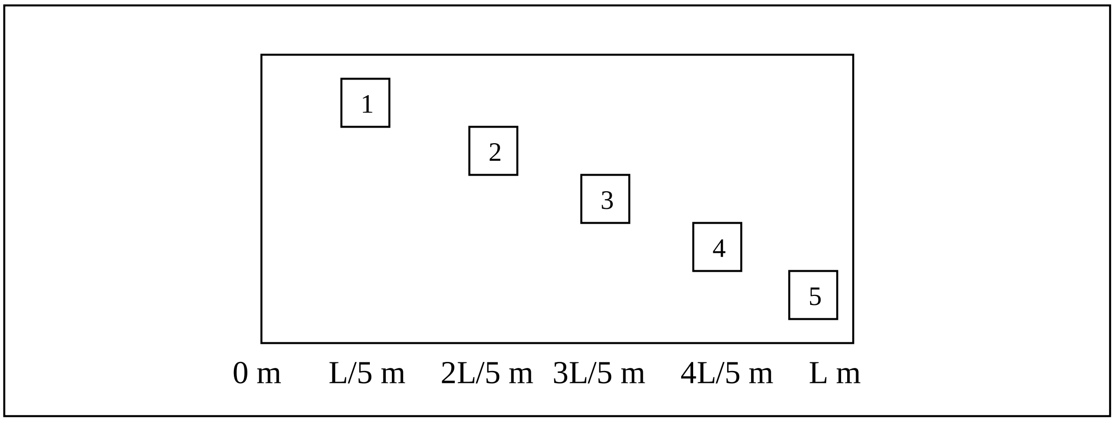

Figure 12: Schematic overview of test procedure 2 for the case of a road, a bicycle path or a footpath with a length < 50 m. The total length of the lane is defined as "L".

Case 3: determining the colour of a square with a surface ≥ 2500 m²

The total surface, S, of the square is measured and is divided by 500 m²:

$$x = \frac{S}{500m^2}$$

Subsequently x is rounded off to a natural number, n, which is the number of sub squares in which the square should be subdivided. Per sub square five areas of 20 cm by 20 cm are measured as shown in figure 13. Per area four measurements, one in each corner of a wooden frame, are made (as depicted in figure 9). In total 20 measurements per sub square are executed.

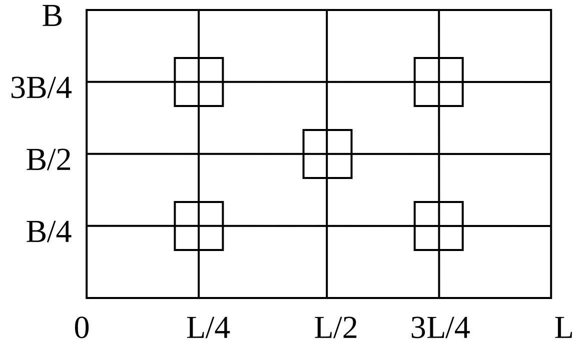

Figure 13: Schematic overview of the test procedure in case of a square, "L" represents the length and "B" the width of the sub square (case 3) or square (case 4).

Case 4: determining the colour of a square with a surface < 2500 m²

If the total surface (L x B) of the square is smaller than 2500 m², five areas of 20 cm by 20 cm are measured as shown in figure 13. Per area four measurements, one in each corner of a wooden frame, are made (as depicted in figure 9). In total 20 measurements are executed.

3.2.2. Comparison of test procedures 1 and 2 for the determination of the colour of a road, a bicycle path or a footpath

Four different sites were investigated using the two different test procedures as mentioned in paragraph 3.2.1:

Table 3: Overview of tested sites to compare procedures 1 and 2

Site	Colour	Length	Location	Case	# points measured
1	Ochre	55 m	Ieper	1	20
2	Grey	80 m	Vilvoorde	1	20
3	Ochre	150 m	Villeneuve d'Ascq	1	60
4	Ochre	40 m	Ieper	2	20

The comparison of procedure 1 and 2 was made for sites with 20 measurements on the one hand (site 1, 2 and 4) and for sites with more than 20 measurements on the other hand (site 3).

In figure 14 the relative standard deviation is depicted for sites 1, 2 and 4. This figure clearly shows that the RSD for procedure 2 is systematically higher than for procedure 1. In most cases the RSD for procedure 2 is even twice as high as for procedure 1.

The relative standard deviation for site 3 is depicted in figure 15. The differences between the relative standard deviation for procedure 1 and 2 are very small with exception of the RSD for a* measured with the d/8° spectrophotometer.

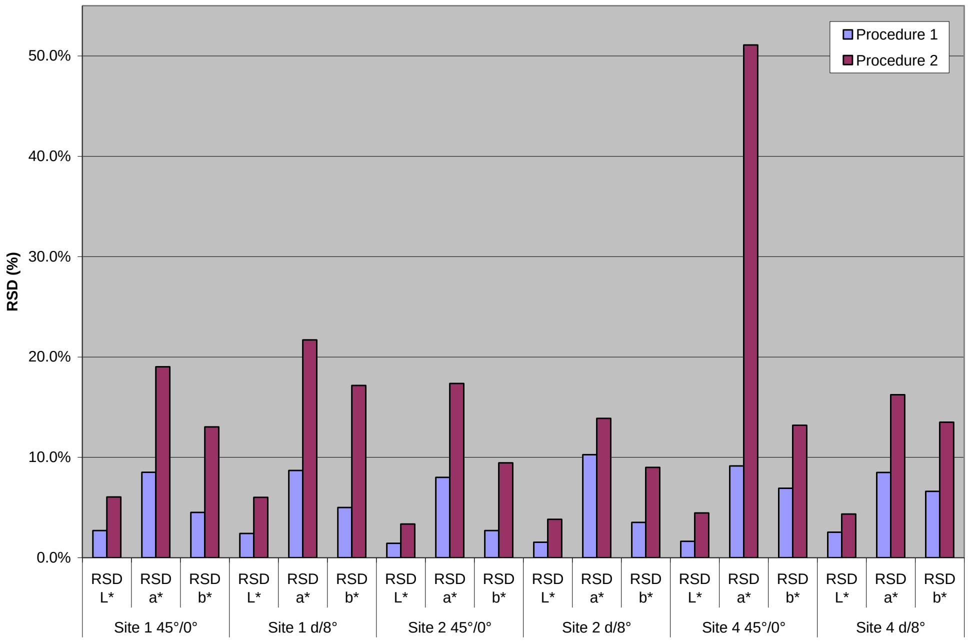

Figure 14: Precision of test procedures 1 and 2 for sites where 20 measurements were executed

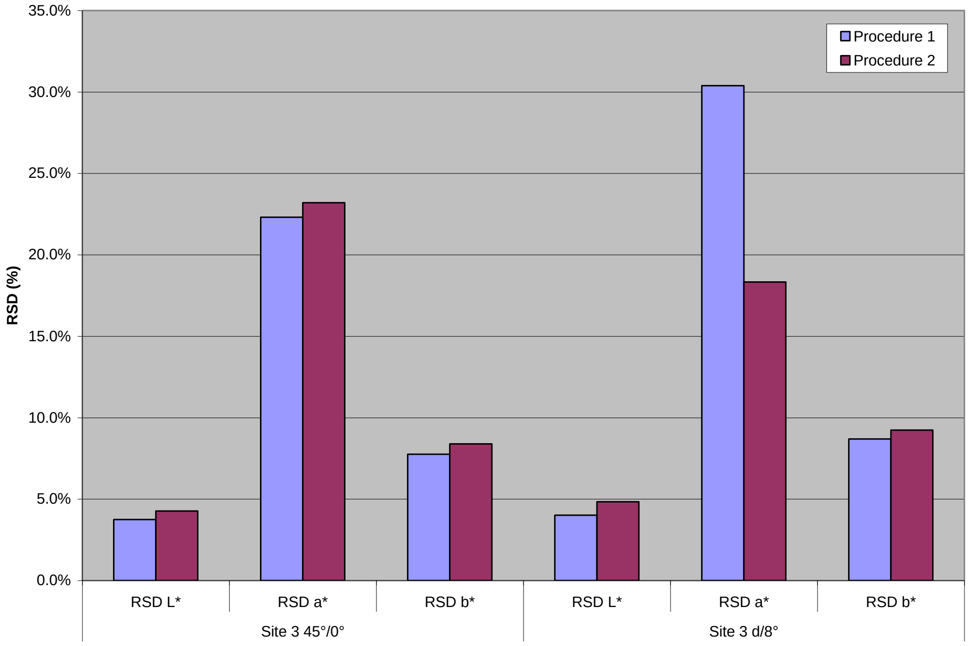

Figure 15: Precision of test procedures 1 and 2 for sites where more than 20 measurements were executed

Table 4 gives an overview of the mean RSD of L*, a* and b* for sites where 20 points were measured and for sites where more than 20 measuring points were taken.

- For sites with 20 measuring points the difference in mean precision between procedure 1 and 2 is very large: the precision of procedure 1 is higher than the precision of procedure 2
- For sites with more than 20 measuring points the difference in mean precision is negligible, except for the mean precision of a* measured with the d/8° geometry.

Table 4: Overview of the mean RSD of L*, a*and b* for sites where 20 measurements and more than 20 measurements were executed

	Site with 20 measuring points (sites 1, 2 and 4)		Sites with more than 20 measuring points (site 3)	
	Procedure 1	Procedure 2	Procedure 1	Procedure 2
Average RSD_{L*} 45°/0°	2%	5%	4%	4%
Average RSD_{L*} d/8°	2%	5%	4%	5%
Average RSD_{a*} 45°/0°	9%	29%	22%	23%
Average RSD_{a*} d/8°	9%	17%	30%	18%
Average RSD_{b*} 45°/0°	5%	12%	8%	8%
Average RSD_{b*} d/8°	5%	13%	9%	9%

For small sites the best precision for procedure 1 can be explained by the fact that in procedure 1 the measurements are executed in a limited area of the site, while they are more dispersed over the whole site in procedure 2. So it can be concluded that for small sites procedure 1 does not cover all the possible hues over an entire site. Therefore procedure 2 is preferred above procedure 1.

For large sites procedures 1 and 2 lead to nearly the same precision and measurement results (with exception of the RSD of a* measured with the d/8° geometry), therefore both procedures can be used for large sites. The dispersion of the measurement results is site dependant and a measure for the homogeneity of the sites colour. In this research only one large site was measured. Additional large sites will be measured in the future to confirm these results.

3.2.3. Reduction of the number of measurements

In the previous paragraph two test procedures for case 1 and 2 were compared investigating four sites (see table 4). In order to verify whether a reduction of measurement points is possible, the measurement results of these four sites and two additional sites which could be classified under case 4 were examined:

Table 5: Overview of tested sites with a square geometry.

Site	Colour	Surface	Location	Case	# points measured
5	Ochre	160 m²	Ieper	4	20
6	Red	325 m²	Vilvoorde	4	20

As described previously, in each case a wooden square of 20 cm by 20 cm is used to measure a site. This square is placed on the pavement's surface and four measurements were executed: one in each corner of the square. In this section we will verify whether it is possible to reduce the number of measurements per square from four to one in the case of a field measurement. Therefore the measured points were subdivided into four series of one measuring point per frame:

- series 1: only point 1 was taken into account (bottom left corner of the square)
- series 2: only point 2 was taken into account (bottom right corner of the square)
- series 3: only point 2 was taken into account (top left corner of the square)
- series 4: only point 2 was taken into account (top right corner of the square)

For each site the precision (expressed by the relative standard deviation) of the measured L*, a*, b* values was than determined for series 1 to 4 and compared to the precision of L*, a*, b* in case of four measurements per square. Analysing these results led to the following conclusions

- The precision of the colour coordinates depends on L*, a* and b*: the precision for the measurement of L* is the highest and for a* is the smallest.
- In general the differences in precision between 1 or 4 measurements are rather small. This indicates that the differences in hue of a whole site are far more important than of a certain place in a square.
- Reducing the number of measurements per square form 4 to 1 would however lead to larger dispersions in some cases.
- The precision and dispersion is site dependant.

4. CONCLUSIONS

In this study a test method is presented to objectively determine the colour of coloured asphalts. The method makes use of a spectrophotometer. The device can be used on cores as well as on site.

After analysing the first measurement results on 37 different cores it was shown that 4 measurements per core are sufficient to have a good precision. In the future additional cores will be analysed to confirm this conclusion.

In the case of measurements on field, two procedures to measure roads, bicycle paths and footpaths were compared. Procedure 1 is based on a measurement at five rather concentrated locations, every 50 metres. Procedure 2 takes measurements at regular distances dispersed over 50 m and repeated every 50 m. Procedure 2 was found more appropriate for small sites, for large sites both test procedures were comparable.

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