Design of reflective pavements for roads

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ABSTRACT

Agencies are increasing asking for more reflective pavements in case of non-ordinary situations. Roads become increasingly visible when using reflective pavements which adds to traffic safety in dark situations. Reflective pavements can be constructed by using white chippings in the mixture, by using a blanc bitumen and/or using white pigments. Although the primary goal is increasing traffic safety, sustainability relating to traffic and transport can also be improved because public lightning can be reduced in order to obtain equal safety levels or omitted completely.
Reflective pavements also adds to social safety in rural areas where normally dark areas exists. For instance in tunnels or on cycle paths. It is known that these type of pavements do help with face recognition at video controlled areas.
Within Road Engineering it is complicated to introduce new asphalt materials. Therefore this branch is producing and testing laboratory test samples. It takes considerable time before the bitumen skin has been sufficiently removed in normal traffic conditions for the tarmac to then show its true reflective values. On the lab samples this traffic processes should be replicated for creating the correct "test sample" road surface.
The paper focusses most importantly on luminance theory and luminance factors. We also discuss luminance contrast and we focus on methods to measure luminance quantities from laboratory prepared samples in such a way that the reflective potential for full-scale situations can be forecast. Further, the paper discusses the lab testing and lab samples treatment method. In order to create a proper series of test samples the specific reflective specifications were measured like Rl, Qd, Qo and S1. During the research different treatment methods of the samples were applied. Finally the results measured on samples were compared to full-scale constructed road sections. By analysing the results the team was able to select the most desirable asphalt surface treatment method for this particular application. The work resulted in the development of four standard reflective asphalt mixtures for KWS-Infra and a method that can be applied if a reflective pavement is designed for a specific purpose.

Keywords: Asphalt, Environment, Light Reflection, Safety, Sustainable urban and rural infrastructure

1. INTRODUCTION

Durability is hip, waste is not. It is probable, or so is thought, that wasting energy and raw materials will not return. All to save our earth as much as possible for future generations. Road builders in the Netherlands, want to help by making their primary process; developing, producing and processing asphalt roads in a more environmentally friendly manner. One of our innovations is lighter pavements (as in more reflective). These light reflecting pavements have as aim to save on public lighting by higher reflection, for example in tunnels, but also at night-time. In addition, it also reduces rutting because in the summer the asphalt stays cooler. The latter is also known as "heat Islands effect" [1, 2]. And, last but not least, reflective pavements improve public safety in inner city areas.
Lighter asphalt surfaces may be realised in various ways. Bitumen is naturally black and colours the pavement dark. There exists colourless bitumen where one can work with pigment and one can also choose to use lighter stone chippings used as aggregate in the asphalt mixture. For the sake of sticking to our high quality standards and to keep mixtures affordable, KWS has chosen to develop mixture variants with the latter option in mind; the use of light aggregates within the hot asphalt mixture.
Apart from roads for traffic, optimum reflection of pavements are also important for bicycle paths. Bicycles do often have worse lightning compared to motorcars and bicycles are currently seen as a week traffic category. Therefore they need extra attention and measures to improve their safety under all traffic circumstances. This is one of the reasons that in particular cases in the Netherlands we chose for reflective bicycle paths.

This article will focus in particular on the design of better light reflecting mixtures based on measurements of laboratory prepared samples. In the run up to this, we will briefly discuss the theory behind light reflection relating to traffic and transport and it's relation to public lighting and to what extent night visibility of the road by motorists is relevant for the coating of surfaces.

2. PROBLEM DEFINITION

Roads with asphalt as pavement material have a very long history. Bitumen, the binder in the asphalt, made from crude oil gives the different asphalt types their typical black colour, especially when they are just constructed and the bitumen skin on the chippings is not worn off by traffic. The Netherlands has a good illumination system on our public roads, a good thing to ensure safety, but it is, especially in these times where sustainability is important, important to consider that this also consumes lots of energy. The dimming of street lighting on motorways was already a political issue in the discussion at the end of 2013. Lightening the colour of the surface of the pavement is certainly not new. They worked around Hamburg in Germany and also in the Nordic countries for about 30 to 40 years with stronger light reflecting pavements to conserve energy in the first place but also with other objectives as mentioned, increase social security and resistance to rutting.
An aspect with regard to the development of new materials in the road construction branch arises because of the fact that those systems are part of the public domain and safety, therefore, must always be secured. This makes it unattractive to test new mixtures full-scale without hedging the security risks. For this reason, asphalt mixes for the full-scale application, are often tested under laboratory conditions. However, laboratory conditions do not perfectly mimic all effects such as the wear on the asphalt from traffic. At least the following mechanisms do affect the wear of the pavement surface caused by traffic, namely, grip, sound and light-reflection. The road must be loaded by real traffic in order to determine the reflective performance of the pavement surface and the bitumen from the aggregate particles skin should wear in order to obtain the appropriate in-use condition of the road surface. Measuring the reflective values can be done with the necessary techniques and tools from a laboratory measurement and translated into a real values. What methods and techniques KWS-Infra uses for this is discussed within this paper.
Reflective values of asphalt for traffic roads may vary depending on the intensity of the road use and the conditions under which reflective quantities for the pavements are measured. For example do we measure these under dry or wet conditions [3]. The parameters that reflect how reflective the pavement will be are the parameters Qo and S1, (respectively average luminance coefficient and mirror factor) in combination with the R-values table. The reflective properties of asphalt will vary greatly in the first 6 months of the pavement being in use. Fotios and others [4] acquired their reflection information for a large part through research that was done in the United Kingdom around 2000 and reported by Cooper[5] as well as research done in 1975 in Denmark and reported by Sorensen [6]. Both researchers contributed towards the BS5489-standard in the United Kingdom, which prescribes the luminance of pavements and roads. The public lighting system in the United Kingdom is designed based on reflective values which reflect the

reflective values of dry pavements. Depending on the used armatures and lights, it is indicated [7] that the difference between a most dark pavement and an in terms of optimal light reflective pavement could lead to 40% energy and cost reduction.
Apart from reflection of the road surface the contrast of the elements of the drivers surrounding is very important in what and how much the driver sees. The human eye is very sensible to slight differences in contrast for example between a medium dark surface and a slightly darker surface. So we can also make use of the quality of the human eye, and playing around with colours and reflection values of the building blocks by which the surrounding of an ordinary driver is designed ie. pavement, lighting attributes, housing, guide rail, traffic lights, fences, sidewalk tiles, etc. etc. Apart from reflection we will in this paper also briefly discuss brightness contrast and factors that influence contrast in designing roads for saver traffic and transport.

3. THEORY AND BACKGROUNDS OF LIGHT REFLECTION AND CONTRAST

Asphalt with a higher lightness reflects more light than a traditional darker asphalt at the same lighting level. However, apart from the lightness of the asphalt that plays its role also the micro- and macro texture does affect how the light will be reflected. In other words, how is the light reflected in the area (figure 1).

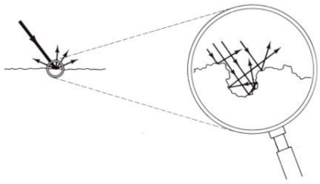

Figure 1: the light reflection of an optical rough surface as from an asphalt pavement caused by different (micro) surface orientations.

From an optical point of view it is about light reflection on rough surfaces and the surface orientation relative to the angle of the light incidence that deduces the reflection. Also important to that is the presence of holes of several millimetres (texture depth). A mixed and spread light reflection will be the result; a reflection in between completely mirroring and diffusing reflection.
In the framework of light reflection the photometric unity luminance [$cd \cdot m^{-2}$] is of significant importance. Luminance is a complex photometric unity that represents what the human eye can observe making use of brightness- and colour contrasts (figure 2a). Different factors determine the luminance, some of them are; the angles of observation and illumination , lighting- intensities, -distribution and -orientation and the reflective properties of the surface (figure 2b).

Figure 2a (left) en 2b (right): 2a. Luminance is a complex photometric quantity that represents what the human eye can observe. 2b. measuring luminance under a very small observation angle as the motorist sees a road.

On traffic roads, the reflective properties of asphalt are of direct importance. Also, the uniformity of the luminance as seen by the motorist is determined by the reflective properties of the asphalt. The reflective properties of the asphalt are therefore important under all circumstances and situations; in direct sunlight, when it' s cloudy, in the dark with and without public lighting, inside tunnels or otherwise darkened circumstances and in dry and wet situations. We can distinguish different types of lighting relevant for traffic and roads:

- Public lighting
- Headlight lighting
- Natural evening/night light (moon- and sky light)
- Natural day light (sun- and sky light)

We will discuss here the different luminance coefficients and luminance contrast.

3.1 The Luminance coefficient Qd or daylight visibility

The luminance coefficient Qd [$mcd \cdot m^{-2} \cdot lx^{-1}$] is the variable assigned to diffuse lighting. It is a measure for the reflectance of objects like a pavement in daylight (figure 3). The coefficient Qd is also called, but not limited to, daytime visibility [7]. Namely, the coefficient is also of importance in weak daylight during twilight and darkness. In these situations our visual senses are very sensitive caused by a large brightness range and contributes significantly to our visual perception. Imagine a white gravel road or foam of the sea breakers in the dark. One can percept these phenomena surprisingly clearly also at a visually weak daylight.

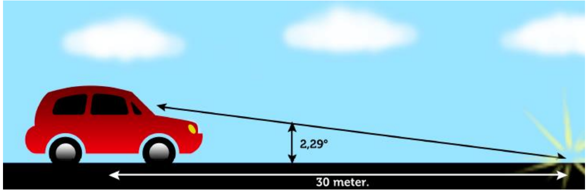

Figure 3: geometry for measuring luminance coefficient Qd or daylight visibility [8] diffuse sky light on a distance of 30 m in front of the car driver.

Daylight visibility Qd can also be applied for public lighting [8]. However, the later discussed method Qo is a more advanced method for public and tunnel lighting which takes also into account the degree of reflection (Sl) of the pavement (mirror factor).

3.2 Retro reflection coefficient Rl or night visibility.

The retro reflection-coefficient R1 [$mcd \cdot m^{-2} \cdot lx^{-1}$] for headlight lighting is a measure of the reflectivity of a pavement or mark for a motorist by their own headlights (figure 4). The retroreflection coefficient is called night visibility [8]).

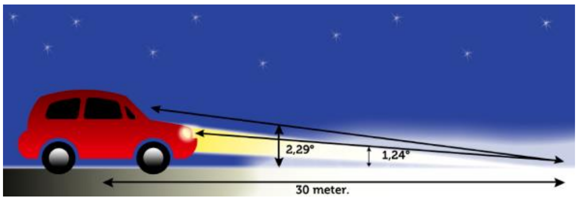

Figure 4: geometry for Retroreflection Rl coefficient or night visibility Rl [8] as a result of the own car lighting on a distance of 30 m in front of the car driver.

The retro reflection coefficient is of importance for roads without public lighting due to the so-called comfort luminance. This is the desired luminance of the asphalt in front of the motorist as a result of the reflection of the light of his own lighting. Most research studies about night visibility separate the road in front of the driver in different areas over a length of 90 meters. The comfort luminance indicates the visibility of the alignment of a road. Generally research shows that the motorist wishes higher luminance in the area of 90 meters in front of the car, than is achievable without public lighting and traditional dark pavement.

3.3 Average luminance coefficient Qo and specular factor S1

The average luminance coefficient Qo is introduced for road surfaces to create a comparable and easily useable quantity. This average luminance coefficient represents the road surface visibility, considered in collaboration with the mirror factor S1. The average luminance coefficient and specular factor are defined respectively as:

- Average luminance coefficient Qo: degree of lightness of asphalt [$mcd^{-2} \cdot lx^{-1}$].
- Factor S1: degree of specularity [-/-].

For the variables applies:

- Higher Qo means higher light levels on the pavement which becomes reflected towards the motorist.
- Higher S1 factor means the asphalt is more specular and shiny.

The Qo lighting measurement methodology makes it possible to calculate public lighting based on a so-called reflection table (R-table).

3.4 Contrast

Visual sense is very sensitive to brightness contrast. It is possible the create enough brightness contrast between for example road and roadside walls or middle conductor in order to create more safety on roads under both dry and wet conditions. Thanks to the higher luminance adaption it is possible to reduce the lighting power and still guarantee good visibility on public roads. Luminance-contrast can also serve as a way of marking of conflict zones on roundabouts and intersections.
The challenge in the near future of light reflecting asphalts is to achieve an optimisation of lightness in terms of power saving caused by parameters like asphalt texture and reflection quantities. In other words, a profound synergy between asphalt innovation and lighting techniques with preservation of civil functional properties of the road pavement and even improving the safety levels of the road.
Contrast values can be calculated and judged using the theory of Michelson [9, 10]:

$$K = (L_{max} – L_{min})/ (L_{max} + L_{min})$$

In which:

- K = contrast value
- L_{min} = minimum luminance value of contrast surface
- L_{max} = maximum luminance value of contrast surface

It is presumed that in current circumstances minimum K values of 0.3 ($k>0.3$) guarantee enough perceptibility of inter-faces and limitation lines. By knowing this one can use this concept to improve visibility in creating safer traffic conditions.

4. MEASURING LIGHT REFLECTION ON LAB PREPARED SAMPLES.

Test specimens manufactured in the laboratory have, as well as new manufactured pavements have in practice, a neat bitumen skin around the stone chippings. The desired reflective properties arise after this bitumen skin has been worn away by a certain amount of traffic. Because bitumen skins on laboratory prepared samples do not get worn down by traffic, the bitumen skin must then be removed in an artificial way.
It is still a bridge too far to make predictions, based on theory and modelling, in what quantity the improved reflectiveness of the stone chippings will add to the light reflecting properties of the completed paved road section. This implicates that asphalt lab. samples must still be made and on these samples lighting measurements must be taken to determine the light reflecting properties. Also, we should do this the empirical way.
It is the target of KWS, after a new asphalt mixture with reflective properties is launched, within a short period of time to be able to forecast light reflection properties of the new mixture underpinned by reflective measurements. This should be done based on laboratory manufactured samples. KWS has therefore initiated the following steps:

1. Performing light reflection measurements on a real (pilot) pavement.
2. Performing light reflection measurements on laboratory fabricated test specimens.
3. Determining the relationship between the full scale and laboratory scale measurements concerning light reflective properties.

The reasoning behind these steps is as follows: full scale measurements are expensive and time consuming and are only possible with sophisticated equipment and under specific circumstances. If the correlation between lab size and full scale measurements is to be determined, it is workable to use lab size test specimens to determine the reflective properties of the mixture and the mixture can be adjusted if needed. Different treatment methods of asphalt surfaces have been tested and the light reflective quantities of those surfaces have been judged both visually and by doing light reflection measurements (table 1). We will discuss the different treatment methods and the light reflective quantities deduced:

a. Sandblasting the outside of the lab. samples

A simple method to execute. A disadvantage, however, is that even though the lab. sample is visually as evenly sandblasted as possible, there will be spots where the sandblasting was more intensive. Several reflective measurements have been taken at the lab. sample surface and they indicated that the blasting process did not lead to a homogeneous treated lab. sample surface. This convinced us to judge the method as not representative enough for our purpose.

b. Brushing the outside of the lab. sample

Brushing the lab. sample surface with sand and a little quantity of dilutant to brush the bitumen skin of the lab. sample surface. This results in a lab. sample surface that is, visually judged, pretty comparable with drilled lab. samples from a road. This method seems therefore usable. A disadvantage is however, that the method is very subjective to the person who performed the treatment. Additionally, it proved that on s with higher amounts of bitumen in the mixture the method became quite labour-intensive before a representative lab. sample surface was realised.

c. Sawing the lab. sample and slightly blasting the sawed surface

Visual judgement of the outside of the gyratory compacted lab. samples proved that at the outsides the lab. samples are susceptible for segregation. This becomes increasingly clear by sawing the lab. samples and comparing the sawed surface to the original "outside" surface of the lab. sample (figure 5). Therefore we decided to take the sawed surface as a source for further testing.

Figure 5: Comparison of the sawed lab. sample surface (beneath) to the original "outside" surface (above). The lab. sample surfaces show that in the outside surfaces there is more segregation of particles compared to the sawed surfaces.

The sawed surface however is very smooth. But if we lightly sandblast the smooth sawed surface of the lab. sample and measure then light reflective properties of the sample it proves that this gives reflective quantities more closely to what is measured on real road surfaces applied to traffic. We could judge this by considering the S1 values. If a surface like an asphalt pavement is treated in a way that should be comparable to the way it is loaded by traffic, the mirror-factor S1 measured on both object surfaces should be comparable (within limits, see table 1). Because the lab. samples are blasted very lightly, this method is less subjective to human error in the sense that blasting a particular spot is not much heavier than on another particular spot. One could even imagine that this method can be further automated and therefore further uniformed.

Table 1: a comparison between the light reflecting quantities measured on lab. samples after different treatment methods and measure on real road asphalt.

	Treatment of asphalt cores # SMA 11B						
Luminance	1 sandblasting	2 brushing	3 sawing & slightly blasting	reference 1 (real road)	reference 2 cycle path	reference 3	unit
Rl	34	29	25	17	17	19	mcd.m-2.lx-1
Qd	97	118	135	80	97	83	mcd.m-2.lx-1
Qo	0.088	0.094	0.166	0.103	0,123	0.101	cd.m-2.lx-1
S1	0.150	0.236	0.395	0.647	0,363	0.601	-/-
	Treated asphalt material core round 150mm, SMA 11B 30 v/v% granusil						

The light reflecting quantities have all been measured on laboratory prepared lab. samples of 150mm in diameter and compacted using a Gyratory compacting machine.
As discussed, light reflecting properties (S1, Rl, Qo en Qd), have been measured on lab. samples after they underwent different types of treatment even as values measured on a real road with a minimum age of one year (table 1). The result shows that treatment method #3 does have the highest potential if we consider the specular factor S1 value as discussed earlier. The spread of the white stone chipping is nicely spread over the complete surface and the specular factor S1 is in between 0.30 and 0.70 as is commonly measured on real road surfaces[1].

d. Designed light reflecting mixtures designed by KWS-Infra/Infralinq

Designing reflective pavements has more or less to do with the volumetric amount of light reflecting stone material at the road surface and thus also at the surface of the lab. prepared samples. During the development of the light reflective pavements we found that about 30% of white stone chippings in the mineral fraction is enough to achieve Qo values of about 0.09 $cd.m^{-2}\cdot lx^{-1}$. This gives reasonable improvement of visibility however if one wants to go beyond that level one can add extra white material (until 100%) to reach Qo values of 0.10 to 0.11 $cd\cdot m^{-2}\cdot lx^{-1}$. This implies that designing the reflectibility of your pavement is playing around with the amount and type of white stone chippings in your mixture. If one uses only calcined stone chippings, the whitest ones but also soft, one should not go far beyond 30% of this material if bearing capacity of your road pavement by heavy loaded trucks is an issue.

KWS-Infra/Infralinq designed the next four light reflective asphalt mixtures;

a) A light reflecting dense stone mastic asphalt 11 (Qo>0.11),
b) A light reflecting dense asphalt concrete 11 (Qo>0.10),
c) A stone mastic asphalt 11 with minimum reflective properties (Qo>0.09), and,
d) A dense asphalt concrete 11 with minimum reflective properties (Qo>0.09).

As a reference we measured the reflection grades Y-brightness of raw materials used in road building engineering. The figures are as shown in table 2.

Table 2: Measured Y - Brightness of raw materials

Y- Brightness of the CIE tristimulus values XYZ (CIE)		
	Observed values (Y D65-45/0°-10°)	
	Dry	Wet
Artificial stone chippings (calcined)	~ 50	~ 40
Natural white stone chippings	~ 45	~ 30
Porphyry stone chippings	~ 20	~ 5

For commercial reasons the a and the b variant got the premium KWS brand name KonwéBright. They have been made using only white stone chippings as aggregate. Mixtures c and d do have a minimum of 70% of the aggregate of Mo-rene, Bestone or Porfier as a basic material stone chippings. Mixtures c and d contain a more ordinary stone chipping type, are therefore a bit cheaper but also a bit less reflective. The mixtures c and d have a Qo value of minimal 0.09 which is the minimum value that is normally requested in the Netherlands if road owners want improved light reflectiveness on roads. All mixtures do have a largest particle of 11 mm, which is what is asked for in ordinary contracts in the Netherlands.

5. AS AN ILLUSTRATION THE LIGHT REFLECTING CYCLE PATH AT BARENDRECHT

The agency of Barendrecht, a city in the southern part of the Netherlands, wanted to improve the safety at a frequently used cycle path in dark conditions. They focused on visibility and decided to check if reflecting pavement surfaces could help them in reaching their goals. If such a reflecting pavement would be applied not only visibility and safety would improve but simultaneously one could apply a different, less energy consuming public light source.
The majority of the cycle paths in the Netherlands are applied with a dark asphalt concrete as a pavement and often such paths are enclosed by banks of grass especially in rural areas.

[1] The range of specular factors S1 for real trafficked asphalt pavements, between 0.30 and 0.70, are the results of a wide range of light reflecting measurements done by co-author D. Hetebrij of Light Surface Control.

In such situations, in the dark, with little or no public lighting, visibility can be poor and under such conditions it is hard to see where to ride; this can easily lead to unsafe situations (figure 6). In such conditions it is not only the luminance but also contrast between different objects, originated by the colour and reflection values of them, that could improve the situation.

Figure 6: A public cycle path in the Netherlands with no public lighting in dark conditions. Alongside, the cycle path banks are grassland.

For a long time in the Netherlands quality criteria for the minimum lighting for pavements of cycle paths are available. However, considering those minimum values the colour of the pavement and the differences in reflection values of it are not taken into account. Figure 6 illustrates a public cycle path in the Netherlands with no public lighting in dark conditions. It is clear that in such situations using reflective pavements and/or using other road markers the visibility could be hugely improved and with that also the riding comfort of the cyclists.

For considering the safety of the cycle path situation in Barendrecht one should apart from the luminance calculations (Rl, Qd, Qo and S1, see table 1 column # 6) also analyse the contrast of different road elements.
Therefore we can compare two situations situation a). a dark asphalt road surface along a grass grown bank (figure 6), in relation to b). a light reflecting asphalt along a grass grown bank (figure 7). For both situations we estimate the contrast between the pavement and the grass grown bank as a human eye would observe at night. For that purpose we can use the K factor using Michelson formulae [9] see paragraph 3.4. Michelson formulae makes use off L (Luminance value) [$cd \cdot m^{-2}$]. If we assume diffuse reflection with Lambert distribution one can calculate L when diffuse reflection Y-brightness is known using the formulae:

$$L = Eh * \text{Y-brightness (d)}/\pi$$

From the formulae we can derive that for a situation value L (luminance) is proportional to Y-brightness. Knowing this we can calculate K factors if we know or can measure Y-brightness factors for dark and reflecting asphalt and grass grown banks. We know reflection values Y-brightness for dark and reflecting asphalt from measurements [10], the Y-brightness value for grass can be found in general handbooks [11]. Using this we come to the next Y-brightness values for the following materials (table 3):

Table 3: types of materials and corresponding Y- values.

Type of material	Y-brightness	Source
Traditional dark asphalt	7	measurements [11]
Light reflecting asphalt (Qo>0,1)	22	measurements [11]
Grass grown banks	6	handbook [12]

Table 4: calculated contrast values K based on Y- values.

materials			
material 1	material 2	contrast factor K	visibility level
Traditional dark asphalt	Grass grown banks	0,08	poor
Light reflecting asphalt (Qo>0,1)	Grass grown banks	0,57	very good

From table 3 and 4 and calculated K values for a dark asphalt road surface along a grass grown bank we can see that contrast visibility is relatively poor (K value of about 0.0 – 0.1) whereas a cycle path of reflective asphalt surface alongside a bank with grass improves the K value up to above 0.5. In general terms it is assumed that K values above

0.3 do give enough comfort visibility for easily detection by the human eye. We conclude that the light reflecting asphalt gives – bank with grass situation (k>0.3) enough comfort visibility whereas the dark asphalt – bank with grass situation (k ± 0.0) gives very poor comfort visibility. Figure 7 shows in daylight, a cycle path with a light reflective pavement surrounded by grass grown banks.

Figure 7: A public cycle path with a light reflecting pavement. Although the picture is taken in daylight one can see there is good contrast between the cycle path and the grass grown banks.

6. CONCLUSIONS

Visibility proves to be a very important aspect for motorists in gathering information during traffic situations. The motorist wants to travel save and comfortable from A to B. Light reflection is very closely related to visibility, safety and comfort whilst traveling by bike or car. It is therefore important to build up knowledge of light reflecting specifications of (asphalt) road pavements but also from the other road-building elements, like barriers, banks, middle or side conductors, footh- and cycle paths, etc. in order to enhance visibility effects while designing for the future motorists environment.

Apart from the light reflection from a single object it is also important to know the difference of light reflection from two adjacent materials, the luminance contrast. Measuring reflective properties of roads is complex because it changes from time to time, is dependent of the use of the road (more or less intensively) and dependent on the conditions, for example wet or dry. We discussed here a method that is used successfully in measuring light reflective properties on laboratory prepared asphalt samples, and we are able to forecast based on those properties, the light reflecting potential of the full-scale road pavement. We also discussed an example in which luminance contrast makes a difference.

A difficult step in this method was finding a way to treat the surface of the lab. samples in a manner which mimics the traffic load precisely. Based on a lot of luminance measurements we found that the treatment method of lightly sandblasting the sawed surface of the lab. samples proved to be the best method. The research shows that the mirror factor S1 is very useful in judging what the treatment method has done to the treated surface of the lab. sample and how comparable it is to a full scale road asphalt that is subjected to normal traffic conditions.

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