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Effects of pavement lightness and colour on road lighting performance

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Introduction

Road lighting standards in Europe are mainly expressed in terms of various measures of road surface luminance distributions. These are average road surface luminance, overall luminance uniformity and longitudinal luminance uniformity [1]. The luminance of any point of road surface is a function of the illuminance on the road and the reflection characteristics of the road surface.

The reflectance properties of the road surface are highly dependent on the aggregate type used. The aggregate lightness and aggregate colour used for the pavement materials, on the other hand, are highly dependent on the aggregate regional availability and aggregate quality requirements in different countries. In view of the reflection properties of road surfaces, road lighting luminance calculations are based on the average luminance coefficient Q_0 and on a table of the reduced luminance coefficient (called the r-table). Each road surface has a unique r-table and average luminance coefficient Q_0 value, which change over time as different parts of the road wear differently. In principle these data can be measured for a real road, however, in practice this is very rarely done or even impossible at the design stage. In order to simplify the road lighting design system, CIE standard publication No: 30-2 "Calculation and Measurement of Luminance and Illuminance in Road Lighting" introduces different road surface classes to be used in road lighting design and calculations [2]. In the standard, road surfaces are classified into four classes (RI, RII, RIII and RIV) and luminance calculations are carried out using standard r-tables (R1, R2, R3 and R4) assumed to be representative of the reflection properties of the respective class. Also a C classification system using only two classes (CI and CII) has been introduced by the CIE [3]. All these classes are generalizations of various pavement materials that have similar reflection characteristics.

Hence, the CIE method requires that the class and the Q_0 value of the road surface are known at the design stage. The method further assumes that the standard r-table represents the individual road surface irrespective of temporal and local variations due to aggregate type used, ageing and wear.

CIE standard publication No: 30-2 recommends incandescent lamp with a high colour temperature to be used for measuring most of the road surface samples [2]. For deeply coloured road surfaces the influence of various light sources with different light spectrum should be tested separately. However, in road lighting design the same road surface standard classifications and the same Q_0 and r-table values are usually used for different roads, regardless of the light sources and the pavement materials (aggregate lightness and colour) used in practice. Thus, in reality, road lighting installations may result in significantly different road surface luminance values compared to the calculated and the designed values. Furthermore, it can also be argued that current road pavement types are not well characterized by the standard CIE road surface classes (R1, R2, R3 and R4) [4, 5].

This paper focuses on studying the effects of aggregate lightness and aggregate colour on reflectance properties of pavements. The main hypothesis of the paper is that the lightness and colour of the aggregate have a significant effect on pavement reflection properties and thus also have a major effect on the road lighting performance. Therefore these factors are very important in road lighting design and optimization and should be considered more carefully in the design process of the road lighting.

It can be argued that the same pavement can result having different reflection factors in different road lighting installations due its inhomogeneous spectral reflectance properties. For example pavements with slightly reddish aggregate can result in higher luminance levels when illuminated with high pressure sodium (HPS) lamps compared to the metal halide (MH) lamps due their higher spectral reflectance in the long wavelength region. On the other hand, pavements with greyish aggregate result in somewhat the same luminance levels regardless of the lamp spectrum as long as the illuminance level on the road surface is the same.

It can also be argued that by using light aggregate for road surface pavements, significant road lighting energy savings could be achieved due significantly higher reflectance of the light pavement materials.

1. Measurement set-up

In this paper the pavement measurements were done using seventeen different pavement samples and eleven different pavement types. For some pavement types (SMA 16 W with white aggregate, SMA 18 L with light, slightly reddish aggregate, SMA 8 G quiet asphalt sample with dark greyish aggregate and SMA 11) several samples with different pavement compositions were measured. The samples used in the measurements were mostly stone mastic asphalt (SMA) pavements. The Prall method, which follows the European standard EN 12697-16, was used for the wearing of the pavement samples [6]. Figure 1 show six different pavements used in the measurements. As can be seen from Figure 1 the measured pavements varied in aggregate lightness, colour and size.
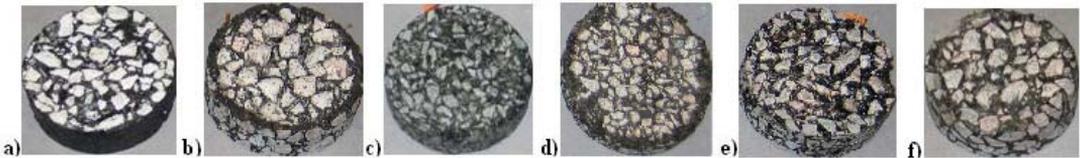

Figure 1: Pavement samples (ϕ100 mm) of six different pavements used in the measurements. a) SMA 16 W1 with white aggregate b) SMA 18 L2 with light slightly reddish aggregate c) SMA 8 G1, quiet asphalt sample with dark greyish aggregate d) SMA 8 Q2, Hilja, noise reducing quiet asphalt e) SMA 11 A f) SMA 16

The measurements and analysis were made using spectroradiometer CS-2000. The measurement angle between the sample and the spectroradiometer was set to 35° (α = angle of observation) and the measurement area covered most of the sample area. According to the studies of Gibbons and Adrian the luminance of the road surface behaves similarly to a Lambertian surface for observation angles approximately from 20º to 45º and Lambertian reflection can be used to model the reflection of light from road surfaces within these limits [7]. The spectroradiometer was placed on the same longitudinal axis as the pavement samples.

The measurements were made under Osram HCI-TS 70W/942 NDL metal halide (MH) lamp and Osram NAV-TS Super 70W (SON-TS Plus) high pressure sodium (HPS) lamp. White barium sulphate surface (ρ = 0.97) with homogeneous spectral reflectance was used as a reference. The angle β (angle between vertical plane of incidence and vertical plane of observation) and the angle γ (angle of incidence from the upward vertical) were set to 20º and 35º. All measurements were made using the same measurement geometry. Thus measurement results are comparable and relative calculations for different pavement samples can be made. For the part of the pavement samples the measurements were made using different β (90º, 55º, 35º, 25º, 20º, 13º) and γ (50º, 46º, 40º, 35º, 30º, 25º, 20º, 13º) values [3, 8]. The measurements were also made using wet road surface samples to study the changes in reflection properties of the wet pavement samples compared to the dry ones. The measurement accuracy of the spectroradiometer CS-2000 is ± 2 percent [9].

2. Results

Figures 2 and 3 show measured relative spectral reflectances of 17 pavement samples. For the most of the measured pavements the relative reflectances were higher for the long wavelength region. The results indicate that light sources with high output in the long wavelength region (for example HPS lamps) are more effective compared to ones with high output in the short wavelength region.

According to the results most of the measured pavements would result in different average luminance coefficient Q_0 value and r-table values depending on the light source used for the road surface measurement. This, on the other hand, means that in road lighting conditions the same road surface would result in various road surface luminance values if different light sources with different light spectrum are used. Thus, it can be argued that the aggregate colour is an important factor in road lighting optimization and should be taken into consideration in the road lighting design. Furthermore, some guidelines and recommendations regarding the use of different aggregate colours with different light sources could be added to road lighting standards.

As shown in Figure 2, three different samples of *SMA 16 W* with white aggregate resulted in highest relative spectral reflectance values. For *SMA 16 W* samples the reflectance values were higher for the long wavelength region, partly because of the fact that fine aggregate used for the pavement was reddish. When compared to the *SMA 16* with the same aggregate size, *SMA 16 W1, W2* and *W3* samples resulted in significantly higher spectral reflectance values due to differences in the aggregate lightness. Also *SMA 18 L* samples with light slightly reddish aggregate resulted in relatively high reflectance values compared to the *SMA 16* sample and most of the pavement samples shown in Figure 3.

Noise reducing quiet asphalt *SMA 8 G* samples (*G1* and *G2*) with dark greyish aggregate had very low spectral reflectance values. Because of the grey aggregate, the *SMA 8 G* samples also resulted in somewhat uniform spectral reflectance over all wavelengths. The *AB 20* asphalt concrete sample with grey aggregate had similar relative spectral curve shape as *SMA 8 G1*. However, for the *AB 20* the reflectance values were significantly higher compared to the *SMA 8 G1* due to differences in the aggregate lightness. The *SMA 11 New* sample, which consisted of a new SMA 11 pavement with very dark bitumen surface (no Prall-method wearing), resulted in the lowest reflectance values. However, at very low angles of observation, the luminance of the new pavement is usually higher than the luminance at high angles of observation, due to high specular reflection of the new pavement surface.
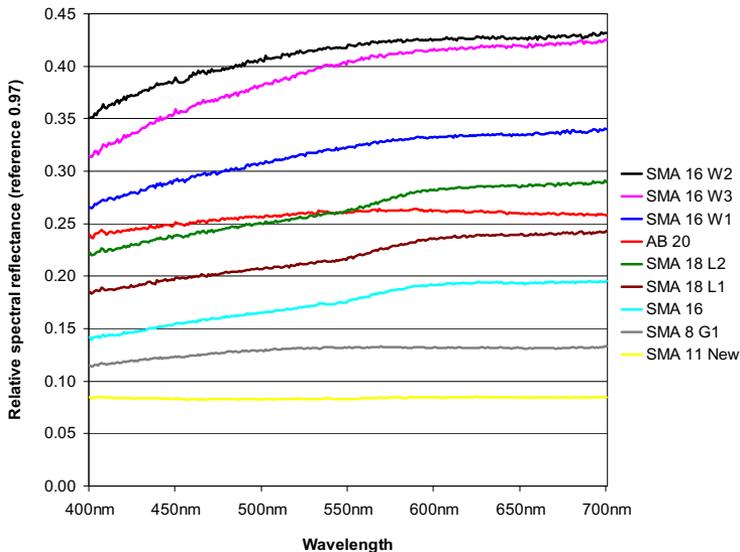

Figure 2: Relative spectral reflectances of nine different pavement samples measured under the MH lamp spectrum. White barium sulphate surface (ρ = 0.97) with homogeneous spectral reflectance was used as a reference. The angles β and γ were set to 20º and 35º

SMA 16, SMA 8, SMA 8 Q1 and *Q2*, *SMA 6*, *SMA 11 A, B* and *C* samples represent quite common aggregate types (lightness and colour) used for road pavements in Finland. Figure 3 shows that for all of these pavements the relative reflectance values of the long wavelength region were higher compared to those of the short wavelength region. The reflectance values of these samples were also significantly lower compared to the reflectance values of the pavement sample *SMA 16 W1* with white aggregate (Figure 3).
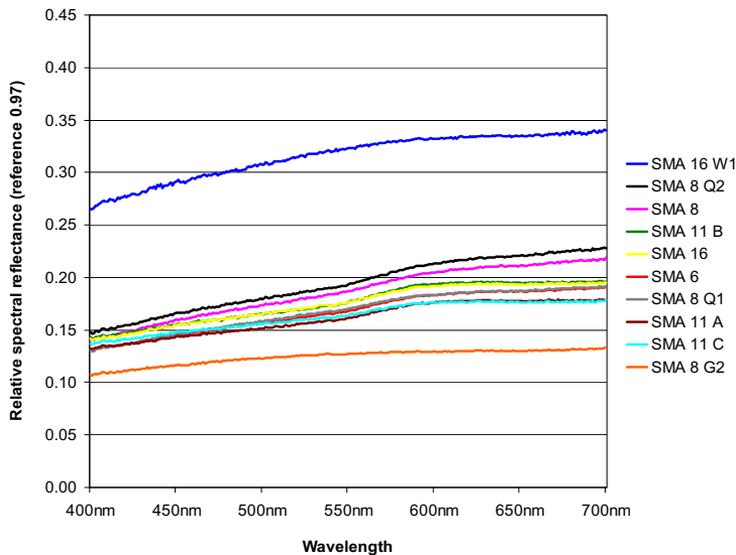

Figure 3: Relative spectral reflectances of ten various pavement samples. The samples are measured under the MH lamp spectrum. White barium sulphate surface (ρ = 0.97) with homogeneous spectral reflectance was used as a reference. The angles β and γ were set to 20º and 35º

Figure 2 shows the significant effect of aggregate lightness on the reflectance properties of the road surface pavement. All nine pavement types shown in Figure 2 could be used on similar roads. The reflection properties of these nine pavements are however, significantly different. Thus, very different road surface luminance values could result with the same road lighting installation depending on the pavement material used for the road surface. Therefore, it can be concluded that the pavement material lightness is a very important factor considering the energy consumption and the energy efficiency of the road lighting.

According to the results it can be argued that dark pavement types are not very suitable for use on illuminated roads due to their very low reflectances. At the same time the results indicate that by using light aggregate and light materials for road surface pavements instead of conventionally used pavement types, significant road lighting energy savings could be achieved due significantly higher reflectance of the pavement. This of course requires that quality factors of the light aggregate, such as for example wearing properties, are adequate for the road traffic use.

In Finland the use of white aggregate for road pavements is rather expensive and may result in triple aggregate costs. This is mostly due the fact that white aggregate has to be transported from other countries. In assuming that aggregate costs are about 15 % of the total pavement and paving costs, the white pavement would result in about 30 % higher total expenses compared to the conventional pavements. However, at the same time it is possible to achieve significant road lighting energy savings by using pavements with white aggregate instead of the conventionally used dark pavements. In addition, such energy savings could be achieved basically for the whole lifetime of the pavement.

Yet, despite the high energy saving potential, in Finland, the use of studded tyres at winter time sets very high wearing requirements to the pavements and thus not all white aggregates are suitable for the pavement use.

In wet conditions the luminance distributions of road surfaces change significantly compared to the dry conditions. Road surface areas with specular refection towards the observation point become very bright. On the other hand, the luminances of the darker areas of road surface decrease [10]. Figure 4 shows relative spectral reflectances of three different pavement samples (*SMA 16 W1* with white aggregate, *SMA 16* and

SMA 8 Q2 noise reducing quiet asphalt) in dry and wet conditions. No significant variations were found in the shapes of the relative spectral curves between dry and wet pavement samples. The results suggest that pavements which have higher reflectance values at long wavelength region still maintain the same feature when the pavement becomes wet.

The relative spectral reflectance values were lower for the wet pavement samples compared to the dry pavement samples. The reflectance of the wet road surface is however, highly dependent on the specular reflection towards the observation point and α, β, γ angles.

The results also indicate that when the road surface gets wet, the changes in the reflectance values of the road surface are different depending on the material of the pavement. For example, the reflectance values of the *SMA 16 W1* sample decreased less compared to the reflectance values of the *SMA 16* and *SMA 8 Q2*.

The measurement results of this paper show that also in wet conditions the aggregate lightness and the aggregate colour have significant effects on the reflectance properties of the road surface pavement.
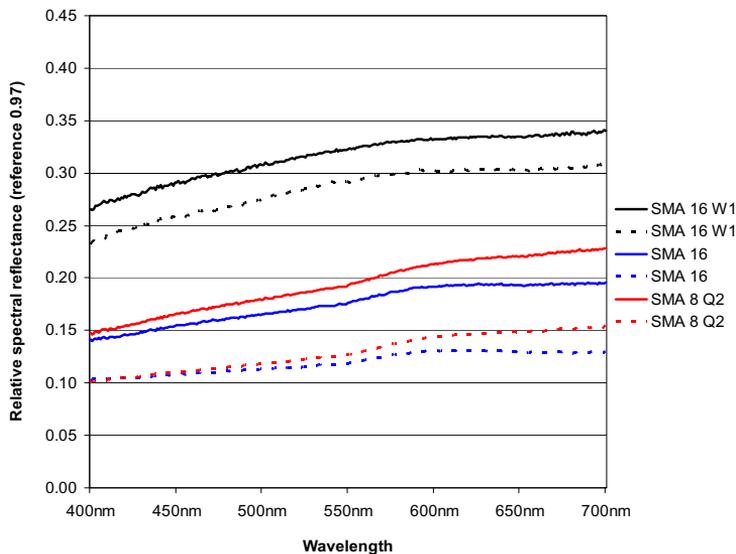

Figure 4: Spectral reflectances of SMA 16 W1 with white aggregate, SMA 16 and SMA 8 Q2 (Hilja) noise reducing quiet asphalt measured in dry and wet conditions. White barium sulphate surface (ρ = 0.97) with homogeneous spectral reflectance was used as a reference. The angles β and γ were set to 20º and 35º

Figure 5 shows relative luminances of eight different pavements measured under metal halide (MH) lamp and high pressure sodium (HPS) lamp. As expected, for the most of the measured pavements relative luminances were higher when illuminated with HPS lamps compared to the MH illumination.

The pavement sample of *SMA 16 W1* with white aggregate had 4 % higher relative luminance when illuminated with HPS lamp compared to the MH lamp. As shown in Figure 5 *SMA 16 W1* had significantly higher relative luminances than other pavements. When compared to the *SMA 8 G1* sample*, SMA 16 W1* resulted in almost three time higher relative luminances. This means that if *SMA 8 G1* is used for road pavement, luminaires would have to produce three times more light to achieve the same luminance levels on the road surface as in the case with *SMA 16 W1* pavement. The differences are even higher in the case with *SMA 16 W2* and *W3* samples.

In the case with *SMA 16* the relative luminance was 8 % higher when illuminated with HPS lamp compared to the MH lamp. For *SMA 18 L2* the corresponding value was 7 %. The relative luminances of the *SMA 8 Q2* (Hilja) varied the most (12 %).

The relative luminances of *SMA 8 G1* with dark greyish aggregate and *AB20* asphalt concrete with grey aggregate did not change significantly when illuminated with MH lamp and HPS lamp.
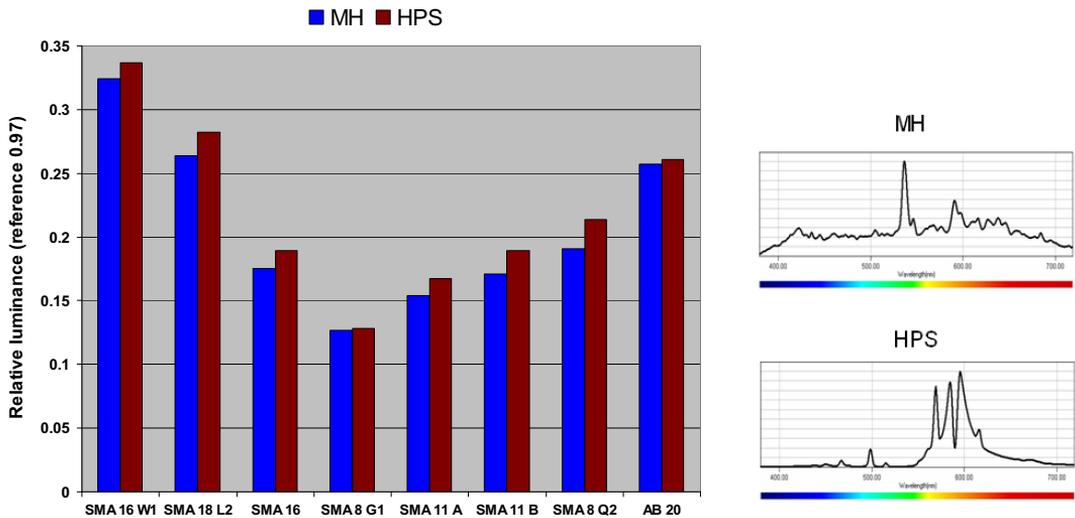
Figure 5: Relative luminances of eight different pavements and the relative spectral power distributions of Osram HCI-TS 70W metal halide lamp and Osram NAV-TS Super 70W high pressure sodium lamp. White barium sulphate surface with reflectance of 0.97 was used as a reference. The angles β and γ were set to 20º and 35º

For the part of the pavement samples the measurements were made using different β and γ values. Figure 6 shows an example of relative spectral reflectance variations of SMA 6 sample in relation to the parameters β and γ. No significant changes were found in the shapes of the relative spectral curves of the pavement samples. However, the reflectance values and the total reflectances of the pavement samples varied significantly depending on the β and γ values.
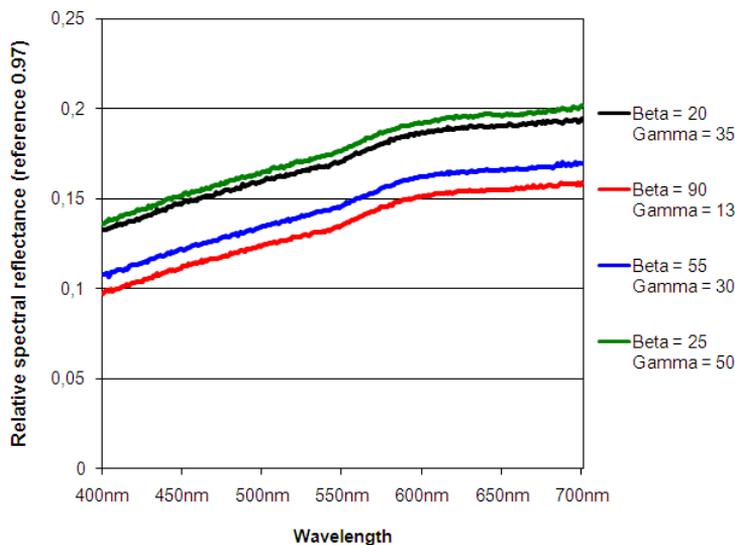

Figure 5: Relative spectral reflectances of SMA 6 sample measured with different β and γ values. White barium sulphate surface with reflectance of 0.97 was used as a reference.

3. Conclusions

The pavement measurements of this paper indicate that aggregate colour and especially aggregate lightness have a significant effect on pavement reflection properties. Stone mastic asphalt samples with white aggregate (*SMA 16 W1, W2* and *W3)* resulted in significantly higher reflectance values compared to the other pavement samples. Thus it can be argued that the aggregate lightness and the lightness of the pavement material are very important factors in road lighting design and optimization. Further research and extensive profitability calculations are needed to define the real benefits of light road surfaces compared to conventionally used road surface materials. Even then, it is quite clear that dark pavement types are not very suitable for use on illuminated roads due to their very low reflectances. This also applies on the roads without road lighting because the illumination of vehicle headlights is partly dependent on the reflectance properties of the road surface.

For the most of the measured pavements the relative reflectances were higher for the long wavelength region. The measurement results suggest that due to the higher content in the long wavelength region HPS lamps are usually more effective than MH lamps in terms of light reflected from the pavements.

No significant variations were found in the shapes of the relative spectral curves between dry and wet pavement samples. The measurement results indicate that also in wet conditions the aggregate lightness and the aggregate colour have significant effects on the reflectance properties of the road surface pavement.

In addition to the effects on the pavement reflectance properties, the lightness and colour of the pavement also affect luminance and colour contrasts of targets located on the road and thus have a role in defining the target visibility. At the same time the reflectance properties of the pavement define the spectra of the light reflected from the surface and thus have an effect on the visual performance at the mesopic light levels.

According to the measurement results it can be concluded that road pavement is a very important parameter in optimization and development of road lighting energy efficiency. Thus a more extensive cooperation between the road administration authorities and the road lighting experts is needed to be able to efficiently optimize road lighting performance. Furthermore, some guidelines and recommendations regarding the use of different aggregate colours with different light sources should be added to road lighting standards. One possible scenario could be that different countries would have their own road surface classes (modified CIE classes), which are defined based on the extensive field measurements of typical pavement materials used for road surfaces in these countries [5]. Also different Q_o values and r-table values could be introduced for different light sources used in road lighting.

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