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ROAD SURFACE REFLECTION PROPERTIES OF TYPICAL FOR BULGARIA PAVEMENT MATERIALS

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Abstract
The luminance of asphalt road surfaces is a function of the horizontal illuminance and the reflection properties of the surface at any point. The reflection properties of the road surfaces depend on their physical condition, age and type (components and roughness of the surface). The current standards and recommendations are based on the luminance of the road surface and its distribution along the road. This distribution depends to a great degree on the reflection properties of the road. The existing standard tables of reflection of the road surfaces are not valid for all the road conditions. The cracked and old surfaces are typical for Bulgaria, which means that the reflection tables, given by the standard will not lead to a proper design of street lighting systems. The aim of the current investigation is description of the real reflectance characteristics of typical for Bulgaria road surfaces, according to their age, fracture of the materials and condition.

Keywords: road surface reflectance properties, reflection characteristics of surfaces.

INTRODUCTION

The safety of the road traffic at nighttime is decided by the illumination of the road surface. With proper lighting, people and objects on the road are made visible, thus ensuring their detection by drivers. The contemporary quality criteria for street lighting require minimum luminance of the roadway ensured, matching the type of the illuminated street. As it is well known the calculation of the average luminance on a road with a given geometry of the lighting installation is possible only if the reflection characteristics of the road surface are known. Road lighting standards in Europe give values of the average road surface luminance, overall luminance uniformity ratio, longitudinal uniformity ratio, disability glare and surround ratio [1, 2, 3, 4]. The luminance of a given point on the road can be calculated if the luminous intensity in the direction of the point and the reflection characteristics of the road surface are known. The luminous intensity depends on the luminaires' light distribution curve and their luminous flux. The road surface reflection is a function of the physical state of the road and its nature as well as on the direction of its illumination and the conditions of observation [5]. The different pavements can have different reflection characteristics which depend on the texture of the surface and its age, materials included in the pavement, binding materials and paving method. Reflection characteristics change with the weather conditions and also alter with the change of their physical state (when holes or cracks occur, also when they are worn out). With the change of the reflection properties of the road surfaces their luminance also changes. The distribution of the luminance L on the roadways, illuminated by stationary lighting systems is determined by the arrangement and height of the poles, light distribution of the luminaire and reflection properties of the pavement. It can be calculated using the formula:

$$L = q.E_h \tag{1}$$

where q is luminance coefficient which is defined by four angles α – the angle of observation from the horizontal plane, β – the angle between vertical plane of light incidence and vertical plane of observation, γ – the angle of light incidence from the upward vertical, δ – the angle between the road axis and the vertical plane of observation [6]. The angle δ is usually neglected and the angle α is considered constant 1° (because of the viewing height of the drivers 1.5m and the important for detecting obstacles area of 60 – 160 m ahead of the driver) [6].

The reflection characteristics of road surfaces are given by set of reduced luminance coefficients r, arranged in tables for different combinations of β and γ angles:

$$\mathrm{r} = \mathrm{q}.\cos^3\gamma \tag{2}$$

These tables give description of the reflection characteristics of roadways. In order to obtain general information on the road surface reflection properties, the general illuminance coefficient and specular factors S1 and S2 are introduced. They can be defined using the following equations:

$$Q_0 = \frac{1\int_0^{\Omega_0} q d\Omega}{\Omega_0} \tag{3}$$

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Where Ω_0 is the solid angle, from the point source on the surface, containing all directions from which light is incident that are considered in the averaging process.

The specular factor S1 is a ratio between the reduced luminance coefficients r (0,2) and r(0,0), that are generally large respectively for specular and diffuse reflection:

$$S_1 = \frac{r(0,2)}{r(0,0)} \tag{4}$$

The specular factor S 2 is defined as follows:

$$S_2 = \frac{Q_0}{r(0,0)} \tag{5}$$

These properties of the road surfaces are unique and change with time. They can be measured for real roads but this is a hard work and it is rarely done. CIE has defined r-tables for road surfaces, classified according to their reflectance properties [5, 7]. The standard r tables date back from the 1960s, so actualization has to be considered. Also the fractures of the pavement materials, used in the different countries differ, which will also lead to changes in their reflectance properties.

The CIE publication 30-2 gives a classification of the road surfaces into four representative classes – R1, R2, R3, R4 with standardized r-tables [5]. Another classification introduces the C-classes – C1 and C2 that are also generalized and standardized [7]. Based on the class and the Q_0 value of the road surface, the luminance of the road can be calculated and the street lighting system designed.

Table 1 Classification of road surfaces according to CIE 30-2, 1982 and CIE 66, 1984

Class	S1 limit	S1 standard	Normalized Q_0
R1	S1<0.42	0.25	0.10
R2	0.42≤S1<0.85	0.58	0.07
R3	0.85≤S1<1.35	1.11	0.07
R4	1.35≤S1	1.55	0.08
C1	S1<0.40	0.24	0.10
C2	S1≥0.40	0.97	0.07

MEASUREMENT METHOD

The current paper presents the experimental results for the reflection characteristics of typical for Bulgaria pavement. The measurement samples are with size, ensuring that the reflection will be representative for the whole hemisphere above the sample (360x180mm or diameter of 150mm). The measurement has been carried out using a specially constructed gonioreflectometer [8]. Its constriction, as shown on figure 1 consists of the following elements: two vertical half-arcs, a horizontal circular rail ring and a horizontal sample holder. All the elements of the gonioreflectometer are painted in matt black paint. The vertical half arc mounted on the circular rail ring supports the light source and allows zenith movement of the latter and also azimuth rotation around the sample. The second vertical half-arc is stationary and is mounted on the inside of the circular rail ring and it supports the zenith movement of the spectroradiometer or the luminancemeter. In the middle of the horizontal arc, a rotating sample holder is mounted, which allows azimuth movement of the sample.

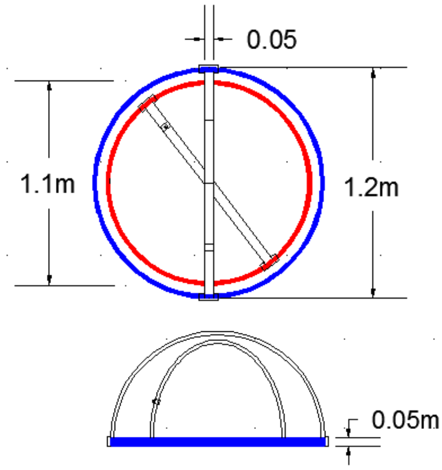

Fig. 1 Structure of the gonioreflectometer used for pavement reflectance

A 25 W, 12V halogen incandescent lamp is used as a light source. In order to avoid illumination inhomogenities of the light spot, projected by the lamp, the incoming light intensity at different angles is measured for a net of measuring points with a calibrated luxmeter. For illumination from nadir, the special distribution of the light intensity is very homogenous, while from other different angles - 60º, 40º, the area closer to the light source is brighter than the area on the opposite side of the sample. If the center of the detector of the luminancemeter or radioreflectometer is always aimed and coincide with the center of the light spot, produced by the light source, the error from inhomogeneity will be negligible. This illumination inhomogeneity has to be estimated, because the light source considered doesn't emit parallel light rays.

Before the measurement, the gonioreflectometer has been calibrated according to the procedure described in [8]. Diffuse surface with known reflection has been used, designed especially for calibration of the reflectometer. The reflectance coefficient of the diffuse surface is $\rho_e = 0.9383$. For the aim of calibration the diffuse surface has been lit by the luminaire of the gonioreflectometer, $\gamma = 45°$ and the luminance meter was fixed at $\beta = 180°$. The luminance of an ideal diffuse reflecting surface with $\rho=1$ is:

$$L_0 \frac{E}{\pi.\omega_0} = \frac{1}{\pi.\omega_0} . \frac{I_0}{R^2} \tag{6}$$

where I_0 is the intensity of the light of the luminaire, R is the distance between the luminaire and the reflective surface and $\omega_0 = 1$ sr.

The luminance of the real diffuse surface is: $L_0 = \rho_e E/\pi.\omega_0 = \rho_e/\pi.\omega_0 * I_0/R^2$. The value $1/L_0 = \rho_e/L_e$ is constant, so the luminance coefficients of the asphalt samples depend on their luminance $L_{asp}(\beta, \gamma)$ and γ:

$$q(\beta,\gamma) = \frac{\rho_e}{\pi} . \frac{L_{asp}(\beta,\gamma)}{L_e(\gamma)} \tag{7}$$

where $L_e(\gamma)=L_e(\gamma=0°)\cos\gamma$

The accuracy of the gonioreflectometer is estimated to be up to 15%, but correction factors are introduced and estimated, which leads to significant reduction of this value [8].

The aim of the measurement is to collect experimental data for the luminance coefficients for the specified in the standard 12301- 3 combinations of β and tanγ.

RESULTS

The r-tables have been measured for 21 pavement samples. The calculated Q_0, S1, S2 values of the samples are presented in Table 2. The results are calculated for each pavement sample and after that an average value has been taken as representative for the classes CI and C II.

Table 2 Typical for Bulgaria pavements with different wearing period

№	Period of wearing	q_r	Q_0	S_1	S_2	R class	C class
1	New pavement	0.0089	0.1051	5,0227	11,944	CII	RV
2	7 months	0.0200	0.0672	1,673	3,277	CII	RIV
3	1 year 6 months	0.0288	0.0738	1,194	2,511	CII	RIII
4	1 year 6 months	0.0273	0.0778	1,543	2,937	CII	RIV
5	2 years	0.0342	0.0717	1,136	2,073	CII	RIII
6	2 years	0.0310	0.0714	1,257	2,326	CII	RIII
7	3 years	0.0513	0.0900	0,467	1,76	CII	RII
8	3 years	0.0635	0.0970	0,393	1,52	CI	RI

Figures 2, 3, 4 show the reflectance of three chosen asphalt samples The first one is for small grains asphalto-concrete sample number 2, the second one is for sample 5 and the third – for sample 6. These samples were chosen, because they are representative and show the most commonly used pavement in Bulgaria – class CII.

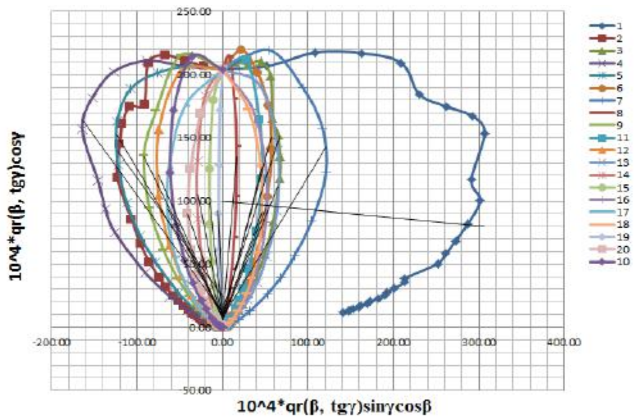

Fig. 2 Reflectance charactereistics of sample 13 from Table 2

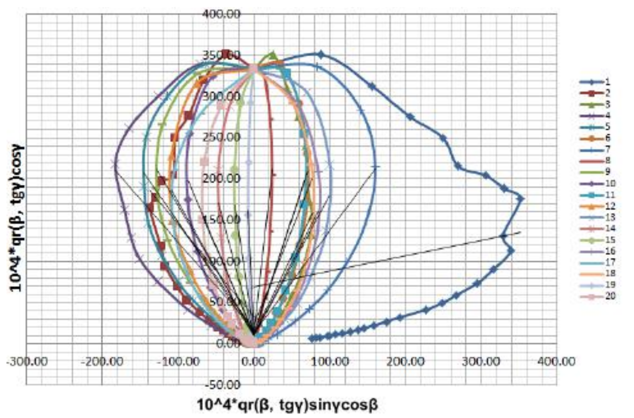

Fig. 3 Reflectance charactereistics of sample 14 from Table 2

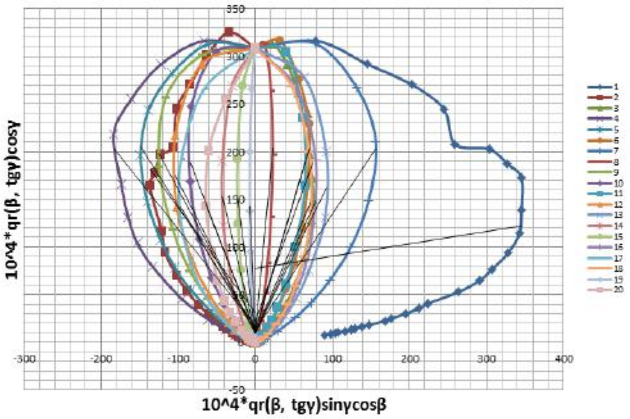

Fig. 4 Reflectance charactereistics of sample 15 from Table 2

CONCLUSIONS

From the results obtained by measurement of the reflection characteristics of typical for Bulgaria pavements, it is obvious, that both for class C I and C II the specular factor S1 is higher than the standard values given in the standard, while the values of the general illuminance coefficient Q0 are approximately the same.

For the design of street lighting systems, it is most appropriate to have the r-table of the pavement of the street considered. This way the best lighting decisions can be obtained. Since the measurement of the luminance coefficient is not always possible, calculation techniques can be used with data for the reflectance properties of the most common pavements for the country, where the design is taking place.

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