

## 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

### 1. 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:

$$L = q \cdot E \cdot h \quad (1)$$

where  $q$  is luminance coefficient which is defined by four angles – the angle of observation from the horizontal plane, – the angle between vertical plane of light incidence and vertical plane of observation, – the angle of light incidence from the upward vertical, – the angle between the road axis and the vertical plane of observation [6]. The angle is usually neglected and the angle is considered constant  $1^\circ$  (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 and angles:

$$r = q \cdot \cos^3 \quad (2)$$

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:

$$Q_0 = \frac{1 \int_0^{\Omega_0} q d\Omega}{\Omega_0} \quad (3)$$

Where  $\Omega_0$  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:

$$S1 = \frac{r(0,2)}{r(0,0)} \quad (4)$$

The specular factor  $S2$  is defined as follows:

$$S2 = \frac{Q_0}{r(0,0)} \quad (5)$$

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	$0.42 \leq S1 < 0.85$	0.58	0.07
R3	$0.85 \leq S1 < 1.35$	1.11	0.07
R4	$S1 \geq 1.35$	1.55	0.08
C1	$S1 < 0.40$	0.24	0.10
C2	$S1 \geq 0.40$	0.97	0.07

## 2. MEASUREMENT METHOD

The current paper presents the experimental results for the reflection characteristics of typical for Bulgaria pavement. The measurement samples have been cut out of existing roads 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]. The optical system of the illuminant is constructed in a way so that from a distance of 1.5 m it gives a light spot with a diameter of 350mm and the ratio  $E_{min}/E_{max}$  is greater than or equal to 0.8; the optical system of the luminance meter is designed as not – focused and is coupled with pole and aperture diaphragms, ensuring viewing angle of  $1^\circ$  (with opportunity for change of from  $0.5^\circ$  to  $45^\circ$ ). The system ensures measurement with accuracy for  $0.01^\circ$  and positioning of the sample on the rotating table with accuracy up to  $0.1^\circ$ . A 50W, 12V halogen incandescent lamp has been used as a light source, having maximum intensity of 2350cd.

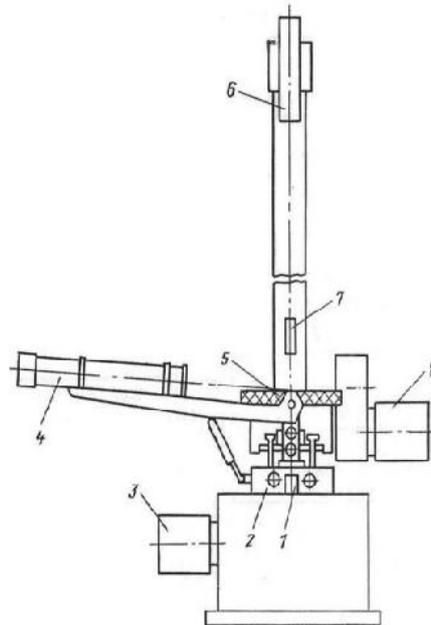


Fig. 1 Structure of the gonioreflectometer used for pavement reflectance: 1 and 7 detectors for start position; 2-rotating table on which the sample 5 is placed; 3 and 8 – step electrical motors; 4 – luminancemeter; 6 – luminaire

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,  $\theta = 45^\circ$  and the luminance meter was fixed at  $\phi = 180^\circ$ . The luminance of an ideal diffuse reflecting surface with  $\rho = 1$  is:

$$L_0 = E / \pi \cdot \rho_0 = 1 / \pi \cdot \rho_0 \cdot I_0 / R^2 \quad (6)$$

where  $I_0$  is the intensity of the light of the luminaire,  $R$  is the distance between the luminaire and the reflective surface and  $\rho_0 = 1$  sr.

The luminance of the real diffuse surface is:  $L_0 = \rho_e E / \pi \cdot \rho_0 = \rho_e / \pi \cdot \rho_0 \cdot I_0 / R^2$ . The value  $1/L_0 = \pi / \rho_e$  is constant, so the luminance coefficients of the asphalt samples depend on their luminance  $L_{asp}(\theta, \phi)$  and  $\rho_e$ :

$$q(\theta, \phi) = \rho_e / \pi \cdot L_{asp}(\theta, \phi) / L_e(\theta), \text{ where } L_e(\theta) = L_e(\theta = 0^\circ) \cos \theta \quad (7)$$

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  $\theta$  and  $\phi$ .

### 3. RESULTS

The r-tables have been measured for 21 pavement samples. The calculated  $Q_0$ ,  $S_1$ ,  $S_2$  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 C I and C II.

Table 2 Typical for Bulgaria pavements with different wearing period

Number	Period of wearing	$q_r$	$Q_0$	$S_1$	$S_2$	R class	C class
1	1 year 6 months	0.0298	0.0738	1.1939	2.5111	C II	R III
2	1 year 6 months	0.0264	0.0778	1.5434	2.9372	C II	R IV
3	1 year 6 months	0.0270	0.0716	1.5588	2.6314	C II	R IV
4	1 year 6 months	0.0280	0.0619	1.1281	2.2032	C II	R III
5	1 year 6 months	0.0256	0.0574	1.4286	2.2173	C II	R IV
6	New pavement	0.0090	0.1051	5.0227	11.944	C II	R V
7	2 years	0.0241	0.0804	1.9289	3.3649	C II	R IV
8	7 months	0.0294	0.0634	0.7755	2.156	C II	R II
9	2 years	0.0255	0.0777	1.7344	3.0367	C II	R IV
10	7 months	0.0216	0.0719	1.4862	3.2994	C II	R IV
11	7 months	0.0232	0.0673	1.4487	2.8782	C II	R IV
12	7 months	0.0267	0.0615	0.9145	2.2873	C II	R III
13	7 months	0.0204	0.0672	1.6732	3.2765	C II	R IV
14	2 years	0.0344	0.0717	1.1358	2.0726	C II	R III
15	2 years	0.0309	0.0714	1.2573	2.3264	C II	R III
16	3 years	0.0514	0.0900	0.467	1.76	C II	R II
17	3 years	0.0645	0.0970	0.393	1.52	C I	R I
18	3 years	0.0664	0.1010	0.386	1.52	C I	R I
19	3 years	0.0558	0.0890	0.443	1.59	C II	R II
20	3 years	0.0798	0.1440	0.703	1.79	C II	R II
21	3 years	0.0598	0.0860	0.346	1.44	C I	R I

Figures 2, 3, 4 show the reflectance of three chosen asphalt samples. The first one is for small grains asphalt-concrete sample number 13, the second one is for sample 14 and the third – for sample 15. These samples were chosen, because they are representative and show the most commonly used pavement in Bulgaria – class CII.

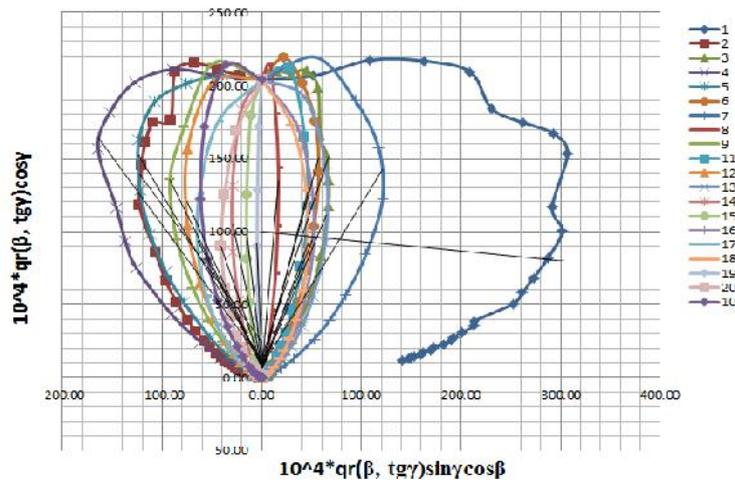


Fig. 2 Reflectance characteristics of sample 13 from Table 2

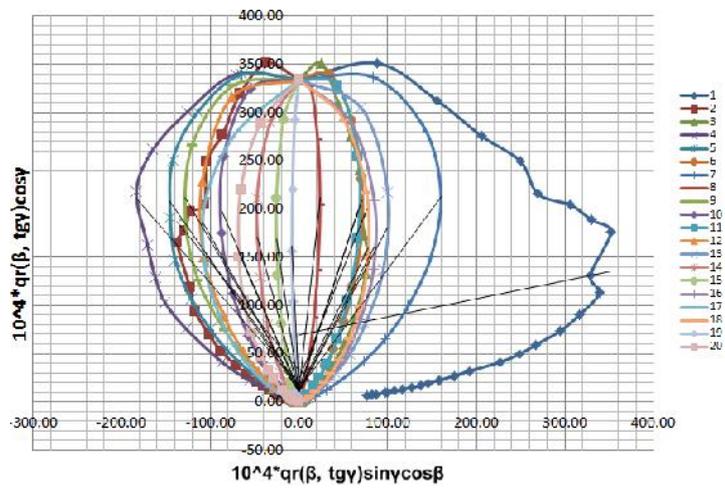


Fig. 3 Reflectance characteristics of sample 14 from Table 2

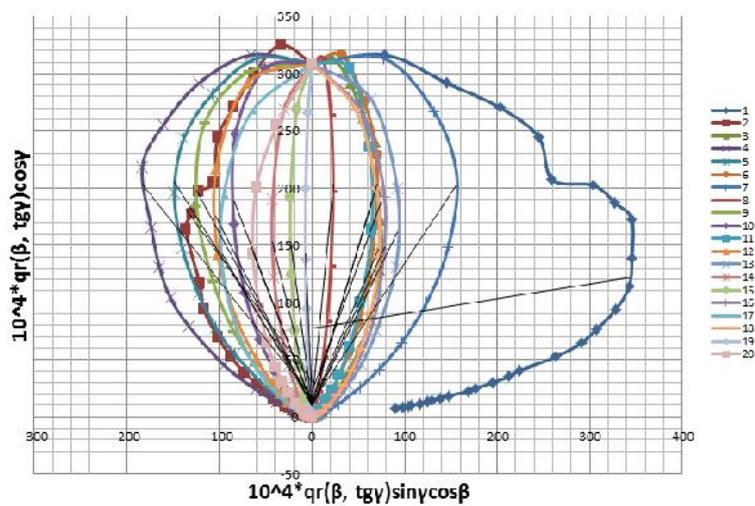


Fig. Reflectance characteristics of sample 15 from Table 2

#### 4. 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  $S_1$  is higher than the standard values given in the standard, while the values of the general illuminance coefficient  $Q_0$  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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