International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

PO187

**EXPERIMENTAL INVESTIGATION OF PAVEMENT LIGHT
REFLECTION CHARACTERISTICS IN WET CONDITIONS**

Kriangkrai Pattanapakdee et al.

DOI 10.25039/x46.2019.PO187

from

CIE x046:2019

**Proceedings
of the**

29th CIE SESSION

Washington D.C., USA, June 14 – 22, 2019

(DOI 10.25039/x46.2019)

The paper has been presented at the 29th CIE Session, Washington D.C., USA, June 14-22, 2019. It has not been peer-reviewed by CIE.

© CIE 2019

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from CIE Central Bureau at the address below. Any mention of organizations or products does not imply endorsement by the CIE.

This paper is made available open access for individual use. However, in all other cases all rights are reserved unless explicit permission is sought from and given by the CIE.

CIE Central Bureau
Babenbergerstrasse 9
A-1010 Vienna
Austria
Tel.: +43 1 714 3187
e-mail: ciecb@cie.co.at
www.cie.co.at

EXPERIMENTAL INVESTIGATION OF PAVEMENT LIGHT REFLECTION CHARACTERISTICS IN WET CONDITIONS

Pattanakdee, K.¹, and Chotigo, S.¹

¹ Department of Electrical Engineering, Faculty of Engineering,
King Mongkut's University of Technology Thonburi, Bangkok, THAILAND

patkriangkrai@gmail.com

DOI 10.25039/x46.2019.PO187

Abstract

Road lighting effects on traffic accidents and varies with pavement materials and weather conditions. In conditions of wet, poor uniformities and glare due to high specular reflection have been found and negatively effect on visual performance of drivers. To improve light quality, the adaptive roadway luminaire which has multi light distributions which are suitable for dry and wet road surfaces is proposed. However, wet conditions is very complicated because of its dynamic characteristics. The pavement light reflection properties in wet conditions were studied in this paper. Three various materials and aging having concrete, rough asphalt and fine asphalt were extracted to do the experiments in the laboratory by using the modified gonio-reflectometer. The results showed the different of dynamically changing of specular factor (S1) and the major r-values of various pavement materials in wet conditions. They can be divided into three stages. Moreover, changing of the reflected light colour are disappeared over wet surfaces.

Keywords: Pavement, Light Reflection, Wet Condition, Luminance Coefficient, Specular Factor

1 Introduction

Road lighting certainly impacts on traffic accidents and varies with pavement materials and weather conditions (WANVIK, 2009 and JACKETT, 2013). Generally, luminance level and light uniformities are significantly considered in a road lighting design (CIE 132, 1999). However, they are required in only dry pavement conditions. In conditions of wet pavements, poor uniformities and glare due to high specular reflection of wet surface have been found and negatively effect on visual performance of drivers (EKRIAS et al, 2007).

Many solutions were proposed to reduce the severity of problems such as dimming, increasing the cross factor (VAN BOMMEL, 1976), using asymmetric light distribution (CLANTON & ASSOCIATES, 2014), and adjusting the road lighting pole. Although dimming of light output which is standard control of roadway luminaire can reduce the degree of very brightness and glare toward to vehicle driver, it cannot improve uniformity of luminance. Moreover, the reflected luminance from some points on road surface also be more decrease or they become dark areas. Dimming can mitigate glare problems but it cannot control the luminance uniformity in order to get better light quality. However, uniformity can be improved by reduction of luminous intensity in direction that reflect into driver's sight.

So, the roadway luminaire with adaptable luminous intensity distribution (LID) curve for dry and wet road surfaces are interested. The adaptive smart luminaire which has multi light distributions which are suitable for dry and wet road surfaces is proposed. The appropriate light distribution curves for a standard road configuration with the conditions of dry and wet road surfaces by the optimization of illuminance distribution function are studying. However, control of light quality in wet conditions is very complicated because of its dynamic characteristics. Luminance and uniformities are unstable while the surface is either becoming wetter or else it is drying. Therefore, the pavement light reflection properties in wet conditions and dynamically characteristics while they are drying were studied in this paper to investigate the change of specular reflections. The measured luminance coefficient at the selected angles may be applied to creating the approximated the r-tables in wet conditions for optimization of the appropriate light distribution curves.

2 Experimental method

In this paper, change of pavement light reflection properties during dynamic wet conditions are studied and the conditions of wet were investigated to classify into categories according to reflection properties impacting on the decreasing of luminance uniformities. Laboratory measurement by the modified gonio-reflectometer was used in the study.

2.1 Pavement sample

Nine samples of three different types of pavement materials (3 samples for each type) were extracted by coring drill with 15 cm diameter from the roads in KMUTT. They consisted of concrete samples, rough asphalt samples, and fine asphalt samples. Figure 1 shows the samples of road surfaces in this study. Before testing, samples were cleaned and painted with the matted black colour over all side areas to avoid the reflection of light during tests.

Figure 1 – Pavement Samples

2.2 Test equipment and method

The gonio-reflectometer modified from the rotating luminaire type of goniophotometer (EVERFINE GO-2000H) was designed and installed in dark room at Electrotechnology and Illumination Laboratory (E-LU), KMUTT as shown in figure 2. It was for investigating the reflection characteristics of the different road surfaces in dry and wet conditions. Moreover, the r-values for a specific set of combinations of β and $\tan(\gamma)$ were obtained.

Figure 2 – The Modified Gonio-reflectometer

Pavement sample was fixed on the support having installation of the imaging luminance meter (EVERFINE CX-2B). The observing angle (α) is set at 1° according to CIE 140 standard. For the light source, the calibrated 4,000K LED lamps with 24° of beam angle were used for emitting the light over the test sample. Moreover, the reflected light spectrums were measured by using the spectral radiance meter (Photoresearch PR-670) and were compared to the original spectrums of incident light.

Angle between vertical plane of light incidence and vertical plane of observation and angle of light incidence from the upward vertical were rotated by the servo motor. The angles were controlled in goniometer software according to the standard r-table. The average luminance and average illuminance over sample at any positions of β and γ angles were measured to calculate the reduced luminance coefficient (r). Figure 3 shows measurement of luminance and illuminance over pavement sample.

Figure 3 – Measurement of luminance and illuminance over pavement sample

The complete r-tables of all samples were tested in dry conditions, then the reflection parameters, which are the average luminance coefficient (Q_0) and the specular factor (S_1), were calculated according to CIE 144:2001. To investigate light reflection characteristics in drying state, sample was sprayed water onto its surface. Tests were started from wet in the inundated condition to 120 minutes with naturally drying in $25 \pm 1^\circ\text{C}$, 60-70% RH of surrounding conditions and air flow $< 0.2\text{m/s}$. Changing of specular factor (S_1) and the spectral power distribution of the reflected light versus time were investigated. The $r(0,2)$ and $r(0,0)$ were measured during drying together with the reflected light spectrum.

3 Results

3.1 Dry condition

In dry condition, samples were tested for the complete r-table with 396 R-values. Q_0 and S_1 were calculated to classified the light reflection properties of pavement samples as shown in figure 4. The specular factor (S_1) of concrete samples closed to rough asphalt samples ($0.56 < S_1 < 0.85$). They were in slightly specular group (R2) according to R-system classification in CIE standard. However, the rough asphalt samples had the average luminance coefficient (Q_0) less than the concrete samples around 2 times because of they were still in new condition having darker materials or lower reflectance. For the fine asphalt samples, they had very high specular factor ($S_1 > 1.74$) which was in very specular group and their average luminance coefficient were around 0.10 which was slightly higher than the concrete samples.

Figure 4 – light reflection properties of pavement samples in dry conditions

Figure 5 shows the comparison of the spectral reflected light for different types of road samples. The reflected lights of sample 1 from each pavement type were analysed the distribution of power spectrum by the spectral radiance meter. They were compared to the original spectrum of LED light source (4,000K). The results show that the concrete surface absorbed the short and medium wavelength light more than others surface materials. For the asphalts, they had little difference of spectrum distribution in only the blue light region.

Figure 5 – comparison of the spectral reflected lights from different types of pavement samples

3.2 Wet condition

Test results in wet conditions are showed in figure 6 and 7. When they were in the inundated wet condition, their specular factors are very low or approximately zero. In drying conditions, the results showed dynamically changing of specular factor (S₁) and the major r-values. They can be divided into three stages. Specular factor (S₁) is raised to the maximum point in the first stage. Next stage, it is declined and slightly become to dry specular factor in the last stage. The specular factor of rough asphalt surface is rapidly swung within 10 minutes with highest specular factor then slowly decrease to dry condition with quite long time (more than 2 hours). In case of concrete and fine asphalt pavements, the results showed longer rise and fall time, except shorter slightly decreasing period before dry condition. Their rise time and total drying period are approximated around 30-45 minutes and 60 minutes respectively. The r(0,2) of wet rough asphalt surface may be more than 12 times of r-value in dry condition. They are around 7 and 3 times for concrete and fine asphalt pavements respectively.

Figure 6 – dynamically changing of S1 with time during wet conditions of pavements

Figure 7 – variations of $r(0,0)$ and $r(0,2)$ during wet conditions of different pavements

The measurement results of the reflected light spectrum show the lightly decreasing of CCT due to absorption of short wavelength light. The maximum colour drift appears in concrete pavements. However, changing of the reflected light colour are disappeared over wet surfaces. The reduced luminance coefficients at the significant angles in each period of wet conditions show the different effects of pavement materials and wet levels.

4 Conclusion

The light reflection properties of wet surfaces were investigated by gonio-reflectometers. The test results of three type pavement materials showed differently changing of specular factor versus time in three stages. The rough asphalt samples have very high specular factor in short time and slightly decreasing in long time. The fine asphalt and concrete samples have longer rise time and lower specular factor. The drift of light colour by absorption of short light wavelengths do not show in the inundated wet condition. The reduced luminance coefficients at the significant angles present the different effects of pavement materials and wet levels. They may be created the approximated r -tables of wet conditions in the future works.

References

- WANVIK, P. O. 2009. Effects of road lighting: An analysis based on Dutch accident statistics 1987–2006. *Accident Analysis & Prevention*, 41(1), 123–128.
- JACKETT, M. 2013. Quantifying the Impact of Road Lighting on Road Safety – A New Zealand Study. *IATSS Research.*, 36, 139-145.
- VAN BOMMEL, W. 1976. Optimisation of the Quality of Roadway Lighting Installations, Especially under Adverse Weather Conditions. *JIES.*, 55, 99-104.
- EKRIAS, A., ELOHOLMA, M. and HALONEN, L. 2007. Analysis of Road Lighting Quantity and Quality in Varying Weather Conditions. *LEUKOS.*, 4(2), 89-98.
- CLANTON & ASSOCIATES, Inc. 2014. Seattle LED Adaptive Lighting Study. Report #E14-286.
- FREDERIKSEN, E. and SØRENSEN, K. 1976. Reflection Classification of Dry and Wet Road Surfaces. *Lighting Res. Technol.*, 8(4), 175-186.
- VAN BOMMEL, W. 2015. *Road Lighting: Fundamentals, Technology and Application*, 1st Ed. Springer.
- Commission Internationale de l'Éclairage, CIE 47:1979. *Road Lighting for Wet Conditions*. Vienna: CIE.
- Commission Internationale de l'Éclairage, CIE 144:2001. *Road Surface and Road Marking Reflection Characteristics*. Vienna: CIE.
- Commission Internationale de l'Éclairage, CIE 140:2000. *Road Lighting Calculations*. Vienna: CIE.
- Commission Internationale de l'Éclairage, CIE 132:1999. *Design Methods for Lighting of Roads*. Vienna: CIE.