



## Chapter 6, Wet Road Surfaces, a Challenge for Road Users... and for Measurement

Enoch Saint-Jacques, Roland Brémond

### ► To cite this version:

Enoch Saint-Jacques, Roland Brémond. Chapter 6, Wet Road Surfaces, a Challenge for Road Users... and for Measurement. Radiometry of wet surfaces, EDP Sciences, pp.63-72, 2023, 10.1051/978-2-7598-2931-6.c007 . hal-04444217

**HAL Id: hal-04444217**

**<https://hal.science/hal-04444217>**

Submitted on 7 Feb 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## **Wet road surfaces, a challenge for road users... and for measurement**

Enoch Saint Jacques & Roland Brémond

Université Gustave Eiffel, Dpt CoSys, PICS-L Lab

It is necessary to consider the reflection properties (or BRDF) of road surfaces to optimize public lighting or automotive lighting performance. However, the latter is based today on BRDF of dry surfaces. What happens when the road is wet? This paper first presents the BRDF of road surfaces and their use in lighting performance computations. We then outline why and how a wet road surface impairs the lighting performance and poses a challenge to road users. We will equally emphasize on the challenge posed by the BRDF measurement of wet road surfaces and monitoring of their wetness. An approach is proposed for characterizing wetness by describing the time course of road samples specularity during the drying of a road sample. These measurements have been conducted on the University Gustave Eiffel's in-lab gonireflectometer.

### **The BRDF of road surfaces**

Road lighting is intended to increase the visual perception of objects in road scenes and thus contributes to comfort and safety of road users at night. Ensuring adequate luminance levels on the pavement is therefore necessary. The luminance distribution not only depends on the photometric properties of light sources, but also on those of pavements. Hence, reflection properties of pavements have to be considered when designing a road lighting installation.

These properties depend on material and texture; it can be specified by means of a set of luminance coefficients. The luminance coefficient  $q$  is defined in road lighting community as the ratio between the luminance  $L$  of a point on a surface, and the horizontal illuminance  $E$  on this surface, at the same point, caused by a light source [1]. It varies with both the lighting and the viewing directions. It is also referred to as the Bidirectional Reflectance Distribution Function (BRDF). In other words, this coefficient depends on 4 angles. For road lighting applications, the reference angles are defined as follow (see Fig. 1), with an explicit reference to the road axis for  $\delta$ :

- $\alpha$ , viewing angle;
- $\beta$ , angle between the lighting plane and the viewing plane;
- $\gamma$ , lighting angle;
- $\delta$ , angle between the viewing plane and the road axis.

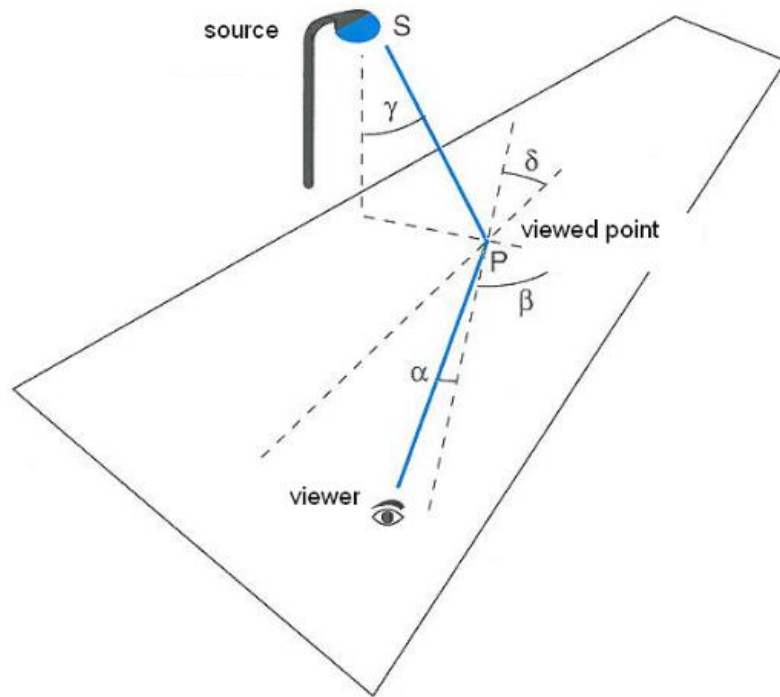


Figure 1: BRDF reference angles for road lighting applications.

For road lighting purposes, when taking into consideration a standardized height of a motorist (1.5 m from the road surface) looking ahead the road in his vehicle, the CIE (Commission Internationale de l'Eclairage) recommends to consider the BRDF for a single observation angle of  $1^\circ$ . Moreover, as the road surface is supposed to be isotropic,  $\delta$  can be set to  $0^\circ$ . Under these conditions, the BRDF solely depends on  $\beta$  and  $\gamma$  [1].

The complete reflection properties of road surfaces can thus be described in a two-dimensional table, in which luminance coefficients are given for a number of combinations of  $\beta$  and  $\gamma$ , the boundaries of which define the solid angle  $\Omega_0$ . For convenience, these tables are given in terms of reduced luminance coefficients  $r$  where:

$$r = q \cos(\gamma)^3$$

Indeed, the observed luminance at point P (cf. Fig 1), expressed in terms of luminaire's characteristics, thanks to Bouguer's law, can be written as follows:

$$L = qE = qI \cos \gamma \frac{1}{SP^2} = qI \cos \gamma \left( \frac{\cos \gamma}{H} \right)^2 = qI \frac{\cos^3 \gamma}{H^2} = r \frac{I}{H^2}$$

where  $H$  is the luminaire height and  $I$  is the luminous intensity of the luminaire.

An example of geometries measurements is given in Fig. 2 (where given  $r$ -values have been multiplied by  $10^4$ ).

beta tan gamma	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390
0,25	411	411	411	411	411	411	411	411	411	411	379	368	357	357	346	346	346	335	335	335
0,5	411	411	411	411	403	403	384	379	370	346	325	303	281	281	271	271	271	260	260	260
0,75	379	379	379	368	357	346	325	303	281	260	238	216	206	206	206	206	206	206	206	206
1	335	335	335	325	292	291	260	238	216	195	173	152	152	152	152	152	141	141	141	141
1,25	303	303	292	271	238	206	184	152	130	119	108	100	103	106	108	108	114	114	119	119
1,5	271	271	260	227	179	152	141	119	108	93	80	76	76	80	84	87	89	91	93	95
1,75	249	238	227	195	152	124	106	91	78	67	61	52	54	58	63	67	69	71	73	74
2	227	216	195	152	117	95	80	67	61	52	45	40	41	45	49	52	54	56	57	58
2,5	195	190	146	110	74	58	48	40	35	30	27	24	26	28	30	33	35	38	40	41
3	160	155	115	67	43	33	26	21	18	17	16	16	17	17	18	21	22	24	26	27
3,5	146	131	87	41	25	18	15	13	12	11	11	11	11	11	12	14	15	17	18	21
4	132	113	67	27	15	12	10	9,4	8,7	8,2	7,9	7,6	7,9	8,7	9,6	11	12	13	15	17
4,5	118	95	50	20	12	8,9	7,4	6,6	6,3	6,1	5,7	5,6	5,8	6,3	7,1	8,4	10	12	13	14
5	106	81	38	14	8,2	6,3	5,4	5,0	4,8	4,7	4,5	4,4	4,8	5,2	6,2	7,4	8,5	9,5	10	11
5,5	96	69	29	11	6,3	5,1	4,4	4,1	3,9	3,8										
6	87	58	22	8,0	5,0	3,9	3,5	3,4	3,2											
6,5	78	50	17	6,1	3,8	3,1	2,8	2,7												
7	71	43	14	4,9	3,1	2,5	2,3	2,2												
7,5	67	38	12	4,1	2,6	2,1	1,9													
8	63	33	10	3,4	2,2	1,8	1,7													
8,5	58	28	8,7	2,9	1,9	1,6	1,5													
9	55	25	7,4	2,5	1,7	1,4														
9,5	52	23	6,5	2,2	1,5	1,3														
10	49	21	5,6	1,9	1,4	1,2														
10,5	47	18	5,0	1,7	1,3	1,2														
11	44	16	4,4	1,6	1,2	1,1														
11,5	42	14	4,0	1,5	1,1															
12	41	13	3,6	1,4	1,1															

Reflection table R2

class RII

$Q_0 = 0.07$

Figure 2: r-table of a R2 pavement [1].

Given the complexity of conducting such measurements, the CIE has also defined two parameters that simplify the description of a road surface, based on the fact that most surfaces can be well characterized by their specularity (shininess)  $S_1$  and their lightness (or degree of whiteness)  $Q_0$  which corresponds to the average luminance coefficient.  $Q_0$  and  $S_1$  are usually computed from r-table of typical road surfaces as:

$$Q_0 = \frac{\int_0^{\Omega_0} q \, d\Omega}{\Omega_0}$$

and

$$S_1 = \frac{r(0^\circ, 2)}{r(0^\circ, 0)}$$

(the corresponding r-values are found for instance in the table of Fig. 2, which gives r-values for various values of  $\beta$  and  $\tan \gamma$ ). The parameters  $S_1$  and  $Q_0$  are then used to classify road surfaces (e.g. R-classifications, see Fig. 2 and Table 1), and those classifications are then used to design lighting installations according to road lighting performance standards [2].

Table 1: Thresholds on  $S_1$  for the R-classification of a road surface [1].

Class	$S_1$	Surface
R1	$S_1 < 0.42$	Diffuse
R2	$0.42 \leq S_1 < 0.85$	Slightly specular
R3	$0.85 \leq S_1 < 1.35$	Moderately specular
R4	$1.35 \leq S_1$	Very specular

## **Wet road surfaces**

All these considerations have been designed for dry road surfaces. Moreover, when the road is wet, water modifies the photometric properties of road:

- the degree of lightness ( $Q_0$ ) goes down, i.e., the pavement is darker,
- and the specularity ( $S_1$ ) goes up.

Lighting performance is impaired as:

- the uniformity of luminance goes down,
- the overall luminance levels are lower,
- and the mirror reflections generate glare.

This impairment of lighting performance is all the more problematic that all road lighting performance computations today are done with respect to a dry surface whereas roads can be wet a significant part of the year (over 30% in France).

Moreover, glare from headlamps increases dramatically during rain and wet conditions, raising an additional need for improved knowledge on the reflection properties of wet road surfaces. Indeed, as the illumination pattern of LED-based headlamps can be tuned in real time, counter-measures could be enacted to limit glare from headlamps in wet conditions. But in-vehicle sensors cannot directly measure the specularity of the road, and such applications would need explicit models of the specularity from the wet state of the road.

In order to take the wet nature of a road surface into account for lighting performance calculations, the first step is to agree on a definition or a characterization of a wet road surface. Indeed, “wetness” depends on the amount of water on the surface and on the road material. The optical mechanisms are two-fold. Sub-scattering by water inside the material increases absorption, making the material appears darker. Conversely, reflection by the film of water over the macrotexture is more directional and the surface looks more like a mirror. The problem is that “wetness” varies in time depending on the intensity of the rain, the drainage quality and meteorological conditions (wind, temperature and humidity) after the rain has stopped. Thus, “wetness” should be specified along with wet photometric properties of the road surface. Literature [3] hints at three modes: wet, humid, dry.

## **BRDF measurement of road surfaces and wetness monitoring**

Few data exist on wet road surfaces. For road lighting, CIE proposes [4] W-class standard r-tables (which are derived from a few measured road surfaces on Nordic countries). There is no obvious correspondence between dry and wet classes as road surfaces with almost any combination of classes for dry and wet conditions can be met with in practice [4]. Muzet et al. [5] have measured some r-tables with an in situ gonio-reflectometer named COLURROUTE (Fig. 3). Some BRDF have also been measured with a lab gonio-reflectometer at the University Gustave Eiffel, formerly LCPC (unpublished data).



*Figure 3: The Coluroute in situ r-table measurement device (©CEREMA).*

For automotive lighting, Hubert et al. [6] have implemented the CIE [4] wetting device. However, although CIE [4] proposes standard wet conditions, a full monitoring of wetness properties of road surfaces during the BRDF measurement has not been achieved to date.

The CIE recommends a standard wetness. To monitor the “degree of wetness”, measurements be done after a 5mm/h rain followed by 30 minutes of drying [4]. This could become impractical if the measurements take time. Indeed, the measurement of an r-table in the lab typically takes more than one hour. The solution could then be to monitor and maintain “wetness” all along the measurements.

Some systems do exist. The Aquasens system (Fig. 4), based on [3], which was originally designed to characterize the friction between a tyre and a wet road surface; a patented method has also been proposed by Brochard and Khoudair [8].



*Figure 4: the Aquasens wetting monitoring system on-board a trial vehicle [7].*

However, the monitoring system may interfere with the photometric measurements, especially for a gonio-reflectometer with rotating arms in the whole hemisphere of reflection.

Three strategies could be devised to monitor the “wetness” of a road surface.

- The first one is to find an experimental setup which does not hinder the measurements and allows for a knowledge of the state of wetness anytime, thanks to which the measured luminance coefficient can be associated with a particular level of wetness at a given time. This setup can ensure measurements all along the drying time.
- A second approach is to maintain the measured surface at a constant wetness level all the time thanks to a setup consisting in watering the surface and controlling it, e.g. by means

of a water pump, or a closed-loop regulation. Measurements can then be done at this stable state.

- The third strategy is to reproduce the “typical” drying time course of the road surface in laboratory. This approach implies being able to describe and simulate the phenomenon (e.g., using of a controlled ventilator).

### Measurements of the “wetness” with UGE’s in-lab gonio-reflectometer

From the preceding statements, one can realize that the critical aspect in a wet road surface is the impact of the wetness level during the measurements. That is why, in order to better understand the impact of water evaporation on the BRDF, we have measured the specularity coefficient  $S_1$  as a function of time during the drying of a wet road surface.

The measurement was done on the in-lab gonioreflectometer of University Gustave Eiffel (Fig.5) which was specifically designed for BRDF measurements of road surfaces. Saint-Jacques et al. [9, 10] give a detailed description of the functioning of our gonioreflectometer and the evaluation of its performance.

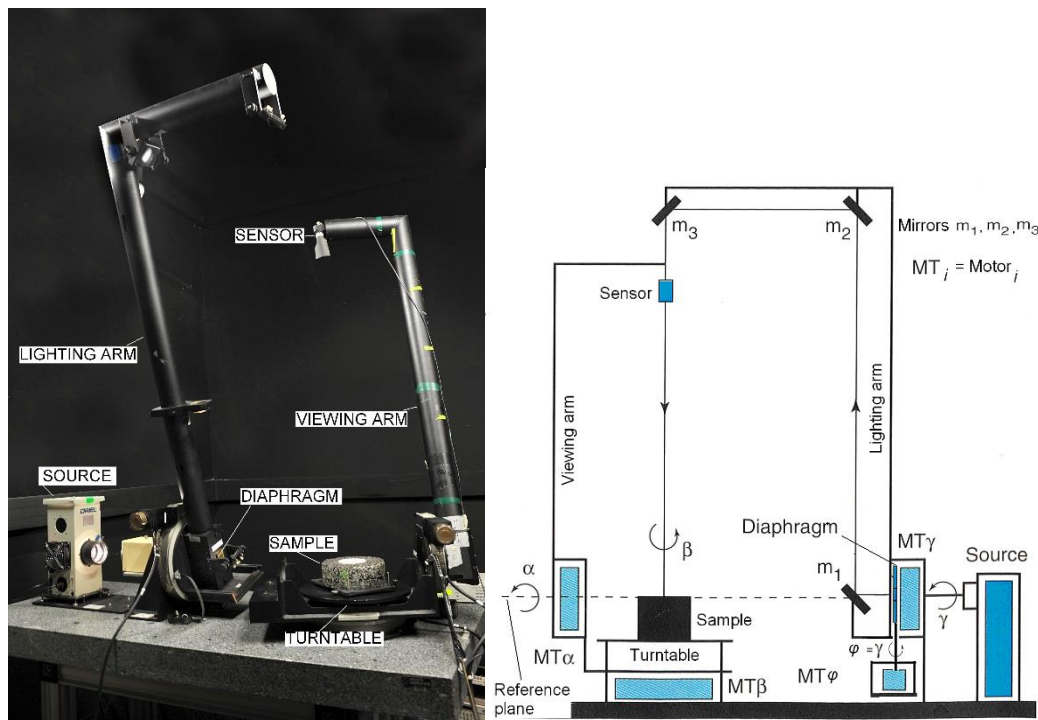


Figure 5: The gonioreflectometer of UGE: Photo (Left) and diagram (Right). To get an idea of its size, the longest part of each arm measures around 150 cm.

In an exploratory study, samples of road surface have been wetted with water from a sponge.  $S_1$  is indeed a good predictor of the wetness as it increases with the “level” of wetness [4].  $Q_0$  could also be relevant because it decreases with the “level” of wetness but, for practical reasons, as opposed to a relatively fast measurement of  $S_1$  (only two geometries are needed), in order to compute  $Q_0$ , one needs to measure the whole r-table which could be time-consuming and thus run against our aim to monitor the wetness level. Fig. 6 presents the results of the evolution of  $S_1$  on three different types of pavements: a light grey pavement, a white one and a black one.



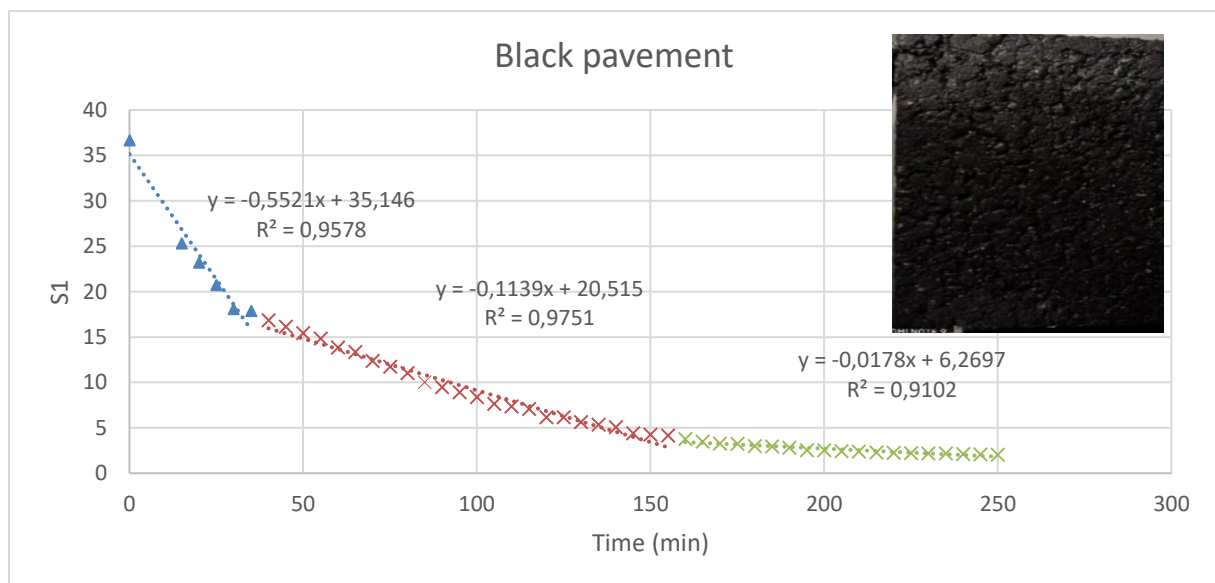
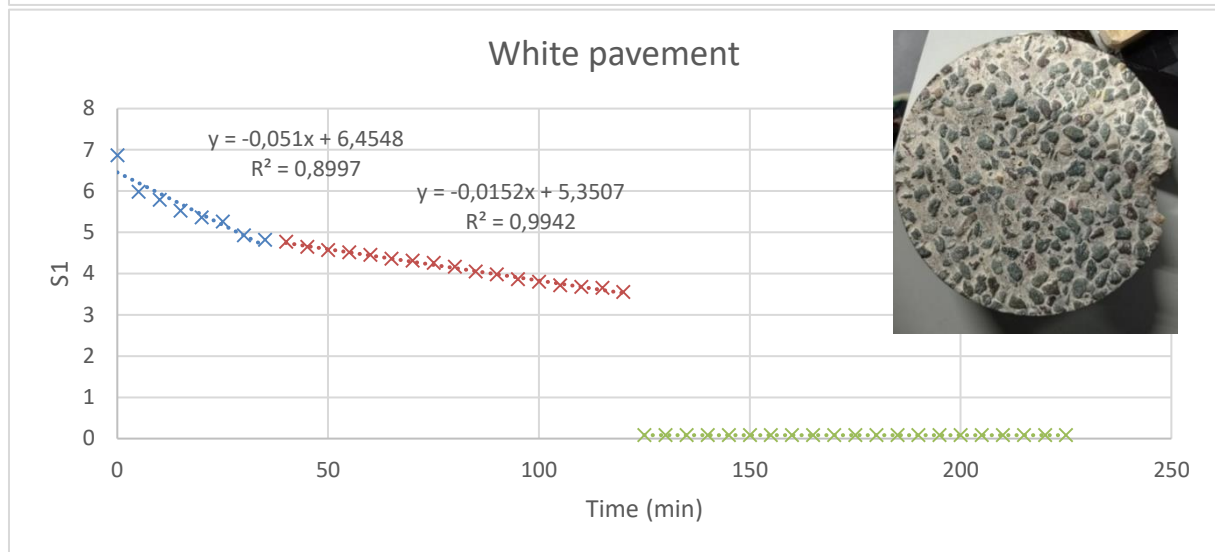
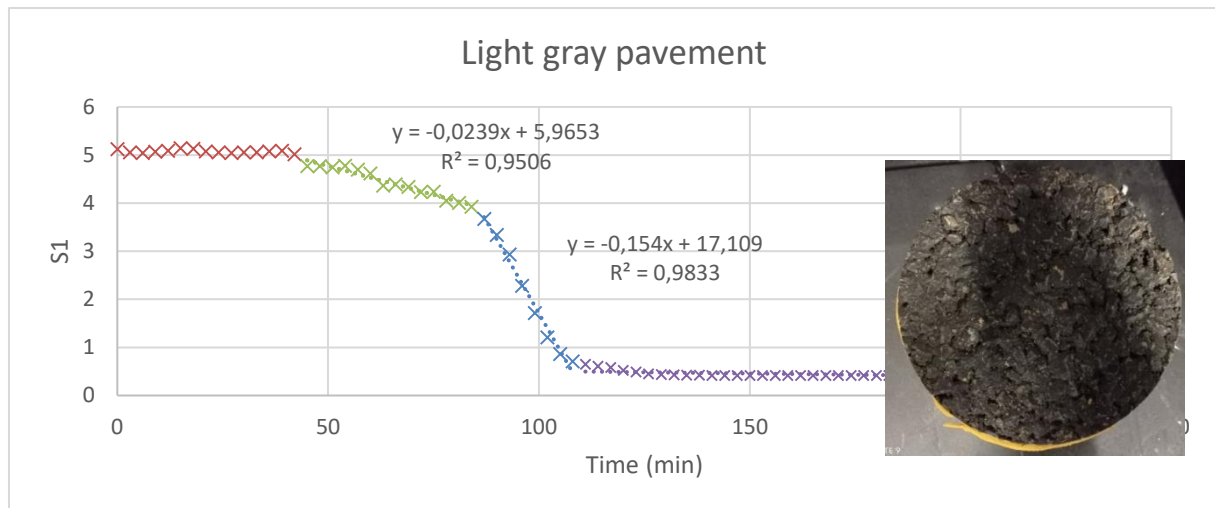


Figure 6: Evolution of  $S_1$  function of time of three road samples (respective photos inserted at top-right of graphs).



These preliminary results do confirm that the wetter the surface, the higher the value of  $S_1$ . One can distinguish three to four phases in the evolution of  $S_1$ . The first one (seen only on the light grey sample during the first 45 minutes) can be described as a “flooded” state (wherein a film of water covers the surface). That is why  $S_1$  seems to be constant. This phase is not present for the other two samples, probably due to a slightly different wetting protocol on that sample which was measured first and several months apart from the other two.

Apart from the flooded phase, several remarks can be made out of these data. First, the general shape is as expected, with a decrease in  $S_1$  with time, that is, during the drying of the road surface. This observation holds for all three types of road surfaces, suggesting that the specularity  $S_1$  may be considered, providing that a model is available, as a predictor of the wetness level of the road surface.

However, the curves in Fig. 6 also show that a general model of  $S_1$  with time will probably not be easily available, as the shape of the data differs depending on the road surface. The light gray road surface shows a sigmoid pattern, with 3 phases that can be labelled as “wet”, “humid” and “dry”. This 3-phase framework can be found in the two other road surface samples, but the sigmoid shape does not appear. These results call for a typology of these drying  $S_1$  functions, which should be conducted on more road samples for a better understanding of their drying behavior. The important point here is that the relevant criterion which needs to be controlled during drying is specularity, rather than physical amount of water, because specularity impacts visibility and glare on the road.

## Conclusion

The current classification of road surface reflection properties are based on sampled measurements on dry road surfaces, known as r-tables in the CIE vocabulary. The road surface classification is then based on two features computed from these r-tables, the lightness  $Q_0$  and and the specularity  $S_1$ . Road lighting is then designed based on these coefficients.

New technologies of smart lighting allow tuning the light source photometry, both in road lighting and in automotive lighting. This raises the possibility to take wet road surfaces into account in the tuning of these lighting systems. But before this goal can be reached, a better knowledge of wet road surfaces BRDF is needed.

In this paper, an overview of the problems with measuring the BRDF of wet road samples have been reviewed. An approach was proposed in order to describe the time course of road samples specularity during the drying of a road sample. We have seen that when using a simple experimental protocol, different road samples behave differently in terms of the time course of the specularity during drying. A simple model does not seem available, and future research is needed to propose a classification of road samples in terms of this time course.

This classification would be useful in order to predict the evolution of specularity during the period of drying, after the rain stopped, in a way consistent with each type of road surface. This prediction, in turn, may be useful for any adaptative lighting system, either automotive, road or urban lighting.

## References

1. CIE (1984). CIE 066:1984. *Road Surfaces and Lighting*. Vienna: CIE.
2. CEN (2015). EN 13201 :2015. *Road lighting*. Standard CEN.
3. Holzwarth, U. Eichborn (1993). *Non-contact sensors for road conditions*. Sensors and Actuators A, 37-38:121-127.
4. CIE (1979). CIE 047:1979. *Road Lighting for Wet Conditions*. Vienna: CIE.

5. V. Muzet, L. Windenberger, Y. Guillard (2007). *Mesures des caractéristiques photométriques de dalles de Gneiss et de pavés de Grès avec Coluroute*. LRPC de Strasbourg, Rapport technique 2006-77-004.
6. R. Hubert, M. Canestrelli, J.-P. Richard (1987). *Caractéristiques photométriques des revêtements routiers sous éclairage des projecteurs de véhicule à l'état sec et à l'état mouillé*. LCPC, Rapport technique 1.20.034-085.
7. D. Prevost, V. Cerezo, M.T. Do, C. Chabanon (2012). *On-board estimation of water depth using low-cost sensors*. SURF 2012 (7<sup>th</sup> Symposium on Pavement Surface Characteristics), France. hal-00851142.
8. J. Brochard, M. Khoudeir (2007). *Device for evaluating the state of wetting of a surface*. Patent Application US 2010/0045984-A1.
9. E. Saint-Jacques, C. Villa, E. Dumont (2017). *Characterisation of the reflection properties of road surfaces using an in-lab gonireflectometer*. In Proc. CIE 2017, Jeju, South Korea.
10. E. Saint-Jacques, C. Prévost, C. Villa (2019). *Evaluation of the performance of a road surface gonireflectometer*. In Proc. CIE 2019, Washington DC, USA.