THE COMBINATION OF RETROREFLECTIVE MATERIALS ON ROAD SIGNS

Lukáš Jan HRABÁNEK[1]

[1]*Department of Vehicles and Ground transport, Faculty of Engineering, Czech university of Life Sciences Prague*

Abstract
Combination of retroreflective materials from the perspective of optical performance is essential for temporary road signs placed in areas of road works while driving at night. The measurements of white traffic sheetings in the measured viewing angle α = 0.33° and the illumination angle β = 5° proved, that there are more significant optical differences in the tapes formally included in the RA2 class, as the two tapes 3M 3930 and OR 5910 have values of around 600 cd·lx $^{-1}$·m^{-2}. However, the third tape tested, AD 6500, only has values of around 405 cd·lx $^{-1}$·m^{-2}. Significant differences are seen in traffic sheetings formally classified as RA3, since the AD 7500 and OR 6910 samples have values of around 430 cd·lx $^{-1}$·m^{-2}. However, the third 3M 4090 traffic sheeting in the same formal class has values up to 764 cd·lx $^{-1}$·m^{-2}.

Key words*: *road works; traffic sheeting; retroreflective material; road signs.

INTRODUCTION
Road signs provide important traffic information and thus a safer road traffic environment through prohibitions, orders, warnings or otherwise (*Koyuncu & Amado, 2008*). The aim of putting on the key traffic signs, especially the priority or speed limit ones, is to increase road safety *(Baratian-Ghorghi, Zhou, Jalayer, & Pour-Rouholamin, 2015*) day and night and to improve the quality of road transport services (*International commission on illumination CIE, 1988*). The EUROSTAT statistical office's demographic surveys show that Europe is aging, as the relative ratio of persons over the age of 65 has increased for the European population from 10.5 % in 1970 to 15.9 % in 2005. By 2020, according to the medium-sized version of the United Nations projection, the share of European seniors can be expected to grow to 19 %. According to Eurostat data from 20 July 2017, persons over 65 will be 23.9 % in 2030, 27 % in 2040 (*Vácha, 2010*). Older drivers need 40 % more time and 8 times better light conditions to respond adequately to objects or traffic signs than younger drivers do.
If we different eye defects of drivers (according to the Institute of Health Information and Statistics of the Czech Republic based on the EHIS 2014 survey, 19.7 % of respondents reported impaired vision even while using their glasses or other visual aids) (*ÚZIS, 2016*), impaired abilities of quick accommodation of the eye for changes in the level of incident light of older drivers, poor weather conditions, bedazzlement by oncoming vehicles, driver fatigue and possible dirtiness of the road sign and windscreen, then we can better understand why night driving is dangerous and so that we need to ensure that traffic signs are visible in this period.
In the case of night driving, fatal accident rate is 2.5 fatal accidents per 1 million miles travelled (*FHWA, 2008*). While only 25 % of the total driving time is being performed at night, 50 % of fatal accidents happen during this time (*NSC, 2018*). The visibility of traffic signs is ensured by special retroreflective materials that reflect a certain amount of light back to the driver. Especially in the field of road works and traffic restrictions, the use of several types of special retroreflective materials (blind technology) of varying optical performance in one cross section is common, which, especially if combined, can cause the night traffic to miss important traffic information. Traffic signs provide drivers with important information (*M. Khalilikhah, Fu, Heaslip, & Carlson, 2018*). However, road signs are fully effective only if they are clearly visible. With retroreflective material, the traffic signs are visible also at night, even if they are not illuminated by external lights *(Majid Khalilikhah & Heaslip, 2016*).
The usage of retroreflective materials in the field of road works and traffic restrictions is regulated in detail by special technical regulations. They state that on the road signs, only traffic sheetings of RA2 class shall be used on motorways, first road class and local roads (*Ministerstvo dopravy ČR, 2015*). Furthermore it is possible to use RA1 class of retroreflective materials on other roads.

Nevertheless, the continuous higher optical performance in the field of retroreflective materials shows that the three existing classes of formal classification according to EN 12899-1*(“ČSN EN 12899-1,” 2003*) are insufficient and significant differences can be observed according to the measurements made.

Fig. 1 Combination of traffic sheetings on a traffic sign "Work" on a fluorescent substrate

Fig. 1 in the top row shows pictures of traffic signs taken at daytime. In the lower row, pictures of traffic signs as seen by the driver at night are shown. On the left, there are traffic signs where classes RA1 and RA3 are combined. In the middle a combination of RA2 and RA3 traffic sheeting is used. On the right a complete RA3 class sign is pictured. From the structural point of view the retroreflective materials are differentiated into ballotine (GB) and microprismatic (M). Ballotine materials are made of glass beads. This type of ballotine retroreflective materials has been used since 1930s, and it is no longer possible to increase its performance, since the values of the most powerful ballotine retroreflection materials are around 264 $cd \cdot lx^{-1} \cdot m^{-2}$. Especially for this reason, the more powerful, microprismatic traffic sheetings have been developed. Those have been used since the 1970s. In principle the surface of the microprismatic traffic sheeting is formed by prismatic reflectors. In some microprismatic traffic sheeting a rotational symmetry is being measured, i. e. to what extent the retroreflection is affected by the rotation of the traffic sheeting.

There are many studies dealing with retroreflection of traffic signs. Recently, there have been scientific articles such as the evaluation of background materials leading to increased visibility safety *(Obeidat, Rys, Rys, & Du, 2016*), basic retroreflective materials maintenance procedures for road signs, automatic retrieval of traffic signs retroreflection by mobile device LIDAR (*Ai & Tsai, 2016*), Traffic sign damage analysis (*Boggs, Heaslip, & Louisell, 2013*), Improvement of Traffic Signs Indicating Animal Occurrence (*Majid Khalilikhah & Heaslip, 2017*), Lifetime of Retro-Reflective Materials (*Unhola, 2016*), (Kai Sørensen, 2011). However, none of these articles have previously dealt with a possible combination of retroreflective materials in one cross section, although in practice it is a common problem and the appropriate combination has a major impact on visibility and thus road safety. Therefore the main aim of the research is to assess the combination of selected retroreflective materials to enhance understanding of their usage. From the perspective of road traffic safety it is desirable to introduce more classes within EN 12899-1, which would take materials of similar optical performance into account.

MATERIALS AND METHODS

The amount of 30 samples, were examined to determine optical properties of white, red, green and blue traffic sheetings with dimensions of 210 × 297 mm. All of them are produced by the three worldwide companies (3M, Avery Dennison and Oralite) and those are the most commonly used traffic sheetings in ordinary road traffic. Retroreflective materials produced by Nikkalite were not investigated, because they are not used by Czech traffic sign manufacturers. Samples that were displayed on the roof of the building of the Faculty of Engineering of the Czech University of Life Sciences in Prague, were repeatedly examined as a part of study (Fig.2). Retroreflection measurement results are limited by this factor, since the sample being examined can be made from a different quality retroreflection materials part during the manufacturing process.

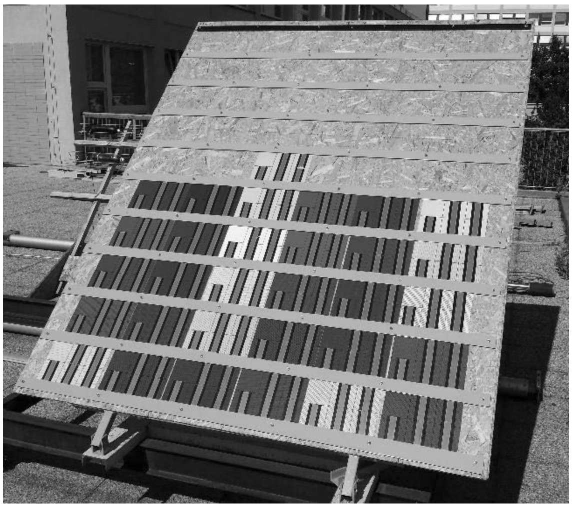

Fig. 2 Traffic sheetings exposed on the roof of building

Retroreflection measurement results are limited by this factor, since the examined samples can be produced of retroreflective materials of different quality during the manufacturing process or during the subsequent treatment of the traffic sheeting by the manufacturer of the traffic signs. The results of traffic sheeting sample measurements also do not promote or uphold the individual products not traffic sheeting manufacturer, but they are merely the basis for an article published in a scientific journal. From a formal point of view, the performance class RA1 according to ČSN EN 12899-1 is represented by the samples of 3M 3200, AD 1500, OR 5710 and 3M EGP type of microprismatic traffic sheetings. From the performance class RA2, the microprismatic traffic sheetings of the type 3M 3930, AD 6500 and OR 5910 were subject to measurements. The functional lifetime of RA1 traffic sheeting is 7 years. The functional lifetime of RA2 and RA3 traffic sheetings is 10 years. Ballotine traffic sheetings are tested according to ČSN EN 12 899-1 and microprismatic retroreflective materials according to European Technical Approval ETA *(“ČSN EN 12899-1,” 2003*). RA1 and RA2 class traffic sheetings are measured according to these technical regulations at an viewing angle α= 0.2°, 0.33° and 2° and in the illumination angle β1 + 5°, +30°, +40°. RA3 class traffic sheetings are measured at an viewing angle of 0.33°, 1°, 1.5° and + 5°, + 20 °, + 30°, +40° in the illumination angle. For uniform measurement conditions, the illumination angle β1 = 5° and the viewing angle α 0.33° were chosen to compare the traffic sheeting samples. The individual traffic sheeting samples have been clearly marked and exhibited since the beginning of August 2017. The individual traffic sheetings were consequently optically divided into six individual fields of approximately 0.1 m x 0.1 m. Before the taking of actual measurements, the individual traffic sheetings were always thoroughly cleaned with a cotton cloth so that possible dust and pollen particles would not distort the retroreflexion measurements.

RESULTS AND DISCUSSION

The actual measurements of the traffic sheetings were performed by a certified measuring device Zenther 6060 that is able to measure in three observation angles α = 0.2°, 0, 33° and 2° and in one illumination angle β1 = 5°, while according to the requirements of ČSN EN 12 899-1 the value of β2 = 0. The traffic sheetings were measured before being exposed on the roof of the building both horizontally and vertically to eliminate the effect of rotational symmetry, which can significantly affect the measured values for some types of traffic sheeting. Subsequently, measurements were undertaken after exposure to meteorological effects after 1, 4, 8, 12, 16 and 20 weeks.

The Table 1 shows the retroreflection values (R_A) of $cd \cdot lx^{1} \cdot m^{-2}$ for pre-exposure (A) and 20 weeks after exposure (B), including the minimum retroreflection values (R_A) required by technical regulations (C) and the retroreflection coefficient value (KR) that serves to determine possible combinations of traffic signs in one cross section from the point of their optical performance. The results of the white, red and blue traffic sheeting measurements are presented clearly in the Table 1. The most efficient out of the RA1 class ballotine traffic sheetings is the OR 5710, where the retroreflection value measured after 20 weeks, was exceeding 99.2 $cd \cdot lx^{-1} \cdot m^{-2}$. The lowest value after 20 weeks of measurement was detected for the AD 1500 traffic sheeting, 75 $cd \cdot lx^{-1} \cdot m^{-2}$.

The minimum value according to ČSN 12 899-1 for RA1 class is 50 $cd \cdot lx^{-1} \cdot m^{-2}$. None of the RA1 ballotine traffic sheetings tested has significantly differed in their optical performance according to previous measurements. The 3M EGP class RA1 type microprismatic traffic sheeting has a retroreflection value of about 125.5 $cd \cdot lx^{-1} \cdot m^{-2}$, which is the lowest value achieved among all examined microprismatic traffic sheetings. However, more significant optical differences are already apparent for traffic sheetings formally classified as RA2 class. Two of them, the 3M 3930 and OR 5910 traffic sheetings, have values of about 600 $cd \cdot lx^{-1} \cdot m^{-2}$, while the third tested sample, the AD 6500, achieves values of only about 400 $cd \cdot lx^{-1} \cdot m^{-2}$. Even more significant differences are seen in traffic sheetings formally classified as class RA3, as the AD 7500 and OR 6910 samples have values 418-427 $cd \cdot lx^{-1} \cdot m^{-2}$ and the third one, the 3M 4090 belonging to the same formal class achieved a value of around 764 $cd \cdot lx^{-1} \cdot m^{-2}$.

Tab. 1 Samples of white, red and blue traffic sheetings

Colour	White				Red				Blue			
R_A	$cd \cdot lx^{1} \cdot m^{-2}$				$cd \cdot lx^{1} \cdot m^{-2}$				$cd \cdot lx^{1} \cdot m^{-2}$			
Sample	A	B	C	KR	A	B	C	KR	A	B	C	KR
3M 3200 (GB)	85.1	82	50	1	16.9	16.2	10	1	1.1	0,6	2	-
AD 1500 (GB)	79	75	50	0.91	15.5	15.2	10	0.93	5.9	5.4	2	1
OR 5710 (GB)	105.9	99.2	50	1.2	18.7	17.7	10	0.95	7.5	6.2	2	1.14
3M EGP (M)	127	125.5	50	1.53	22.8	22.6	10	1.39	9.1	8.8	2	6.5
3M 3930 (M)	665	654	180	7.97	125.4	120.9	25	7.46	42.5	41	14	7.59
AD 6500 (M)	405	401	180	4.87	75.5	76.5	25	4.72	36.8	31.5	14	8.83
OR 5910 (M)	591.5	589.2	180	7.18	127	125	25	7.71	63.9	63.1	14	11.68
3M 4090 (M)	768.1	764	300	9.3	129	128	60	7.9	51.8	49.5	19	9.16
AD 7500 (M)	419.9	418	300	5.09	66	59.3	60	3.66	29.5	28.9	19	5.62
OR 6910 (M)	431	427	300	5.2	102	101	60	6.23	43	42.5	19	7.87

The obtained results of carried out measurements confirm significant differences in optical performance, especially among the traffic sheetings that are classified as RA2 and RA3 *(Unhola, 2016)*, *(Obeidat et al., 2016)*, *(Kai Sørensen, 2011)*. Thus, the current required values of the European standard EN12899-1 are insufficient and an adjustment should be made to create more formal classes as in the USA, that will have similar optical performance and design *(Carlson, et al., 2017*). Before the new standard becomes effective, it is therefore always desirable to identify the approximate values of the traffic sheetings with respect to their age before the application of the content of the sign. Most of the samples provided were screened using the ink. Several samples were produced by digital printing, respectively without modification by the manufacturer. Therefore, it would be desirable in further research to compare, on a larger number of samples, the extent to which the optical production process can be influenced by the traffic sheeting production process, since the production process also might have a significant effect on the possible combination of individual traffic sheeting types.

CONCLUSIONS

The combination of different retroreflective materials from the perspective of their optical performance on one temporary traffic sign is only possible when determining the retroreflection coefficient, which serves to simplify the determination of the appropriate combination of materials. The measurements indicate that in the area of temporary traffic signs, in terms of optical performance, no traffic sheeting should be used in one cross-section when the values of the difference of retroreflection constants are higher than 2.

The results of measurements taken of white traffic sheetings show that at the basic measured viewing angle $\alpha = 0.33°$ and the illumination angle $\beta = 5°$ for the RA1 class a combination of all ballotine traffic sheetings is possible, since their maximum optical performance ranges from 79-105 $cd \cdot lx^{1} \cdot m^{-2}$. The RA2 microprismatic traffic sheetings tested had an optical performance of 405 to 665 $cd \cdot lx^{1} \cdot m^{-2}$, thus a combination of 3M 3930 and OR 5910 traffic sheetings is possible. From the perspective of the RA3 traffic sheetings the optically most powerful traffic sheeting is the 3M 4090 type with a value of about 764 $cd \cdot lx^{1} \cdot m^{-2}$, that makes it impossible to combine with any other samples tested in the same class. The experiment will continue for next years and it might be assumed that with a longer period of external influences, the differences in retroreflection of different types of traffic sheetings will become more evident.

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Corresponding author:
Ing. Lukáš Jan Hrabánek, Department of vehicles and ground transport, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic, e-mail: hrabanek@tf.czu.cz