THE DEGRADATION RATE OF RETROREFLECTIVE MATERIALS

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Abstract
The paper is focused on the comparison of retroreflective levels of traffic sign materials. These samples were exposed to the accelerated natural weathering. Ten types of tree colours have been installed on the test desk on the building flat roof for 16 months. The coefficient of retroreflection was measured by handled retroreflectometer and subsequently was found out the degree of degradation. It was found out that the degradation rate for different types of retroreflective materials is unequal. The lowest difference between measurement was observed for white 3M 4090 film – about 1%, the highest was found for blue samples OR 5710 and 3M EGP films - about 17%. The degree of degradation in terms of colour is the lowest for white and the highest for blue.

Keywords: *retroreflectivity; traffic signing; safety; maintenance.*

INTRODUCTION

Traffic signs should be visible and readable for all age groups of drivers because signs provide important traffic information and increase safety on roads *(Baratian-Ghorghi, Zhou, Jalayer & Pour-Rouholamin, 2015)*. It is especially important for elderly drivers because they need 8 times more light to respond adequately to a traffic sign than younger drivers. The brightness of signs is also crucial for drivers who have various eye defects. According to the European health interview survey, 19.7% of the respondents have reported eye problems (even if they use glasses or contact lenses) *("Ústav zdravotnických informací a statistiky ČR," 2016)*. The impaired ability of aged drivers to accommodate the eye to different luminance level, a relatively high percentage of drivers with eye defects, poor weather conditions and darkness might significantly affect the visibility of a traffic sign.

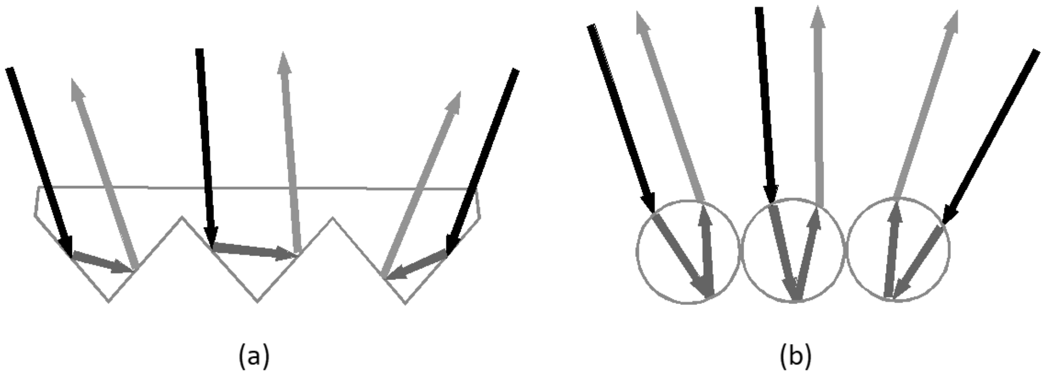

Fig. 1 Compositions of retroreflective sheeting. (a) Microprismatic type is consisted of prisms. (b) Glass bead type is consisted of small glass spheres. *(Source: Authors' work)*

Visibility of traffic signs at night, when about 50% of road accidents occur *(FHWA, 2008; National Safety Council, 2018)*, is ensured with special retroreflective sheeting upon the signs. This type of sheeting increases the brightness of the signs by reflecting light from the car headlights directly toward the driver *(Austin & Schultz, 2009)*. Nowadays, there are two main types of retroreflective sheeting, glass bead and microprismatic (Fig.1). They do not only have different structural units – glass spheres or prisms – they also have different tendencies to deterioration in the course of time *(Brimley & Carlson, 2013; Oloufa, 2017; Ré, Miles & Carlson, 2011; Rizenbergs, 1974; Sørensen, 2011)*.

Taking into account the degradation rate of retroreflective sheeting makes it possible to create a predictive model thus optimize the maintenance activities and replacement of road signs *(Babić, Babić, &*

Macura, 2017; Wolshon, Swargam, & Degeyter, 2002). Maintenance programs allow traffic signs not only to be visible enough but also to cut down the expenses of road agencies *(Bischoff & Bullock, 2002; Jackson, Carlson, Ye & Jackson, 2013)*.

The goal of this article is to determine the degradation rate of different types of retroreflective materi-als after accelerated natural weathering.

MATERIALS AND METHODS

The study encompassed 30 samples of white, red and blue retroreflective sheeting commonly used in signing production in the Czech Republic. The Tab. 1 represents all the test samples with dimensions 210 (mm) by 297 (mm) produced by different manufacturers - 3M, Avery Dennison (AD) and Oral-ite (OR). The samples were placed on the test desk that was installed on the flat roof of the Faculty of Engineering of CULS Prague. It was inclined at an angle of 45° and was oriented face to the south for the accelerated natural weathering *(ČSN EN 12899-1 Stálé svislé dopravní značení - Část 1: Stálé dopravní značky, 2003)*. Samples were exposed to natural weathering for sixteen months. Due to natural weathering the results similar to the degradation rate of the in-service traffic signs can be provided (Ke-tola, 1999).

Tab. 1 Test samples according to the manufacturer, type and colour. W – white, R – red, B – blue; GB – glass bead, M – microprismatic.

Class*	Number of sheeting	Manufacturer and serial number	Colour			Type
			W	R	B	
RA1	1	3M 3200	X	x	x	GB
	2	AD 1500	X	x	x	
	3	OR 5710	X	x	x	
	4	3M EGP	X	x	x	M
RA2	5	3M 3930	X	x	x	
	6	AD 6500	X	x	x	
	7	OR 5910	X	x	x	
	8	3M 4090	X	x	x	
RA3	9	AD 7500	X	x	x	
	10	OR 6910	X	x	x	

* - according to *(EN 12899-1 Fixed, vertical road traffic signs, 2007)*

Before putting out the sheeting samples, the measurements of their coefficient of retroreflection were made according to the standards *(ČSN EN 12899-1 Stálé svislé dopravní značení - Část 1: Stálé dopravní značky, 2003; EAD 120001-00-0106 Microprismatic retro-reflective sheetings, 2016)*. The measure-ment of the retroreflective films was carried out by a certified measuring device - retroreflectometer Zehnther 6060, which allowed to set the coefficient of retroreflection in compliance with the require-ments of *(ČSN EN 12899-1 Stálé svislé dopravní značení - Část 1: Stálé dopravní značky, 2003)*. The device also provided with information about the average value of three measurements of each sample. The mean value was used for further analysis.

In the Czech Republic, there is not common unified standard for measuring of different retroreflective sheeting materials. For example, glass bead sheeting should be tested according to *(ČSN EN 12899-1 Stálé svislé dopravní značení - Část 1: Stálé dopravní značky, 2003)* and microprismatic retroreflective materials – in accordance with the European Technical Assessment *(EAD 120001-00-0106 Micropris-matic retro-reflective sheetings, 2016)*. RA1 and RA2 glass bead materials are measured according to these technical regulations with observation angle $\alpha = 0.2°$, 0.33° and 2° and illumination angle $\beta_1 = +5°$, +30°, +40°. RA3 film is measured with observation angle of 0.33°, 1°, 1.5° and illumination angle + 5°, + 20°, + 30°, +40°. The identical measurement was carried out with the chosen illumination angle $\beta_1 = 5°$ and the observation angle $\alpha = 0.33°$ to compare the test samples. A summary of the minimal performance requirements for chosen illumination and observation angles of retroreflective sheeting is presented in Tab. 2.

Tab. 2 Requirements for minimal values of coefficient of retroreflection ($cd{\cdot}lx^{-1}{\cdot}m^{-2}$) for different colours and retroreflective classes according to *(ČSN EN 12899-1 Stálé svislé dopravní značení - Část 1: Stálé dopravní značky, 2003)*

	Colour		
Class	White	Red	Blue
RA1	50	10	2
RA2	180	25	14
RA3	300	60	19

In order to determine the rate of degradation of individual samples, repeated measurement of the samples was carried out 16 months after exposing them to natural weathering. According to the standards *(ČSN EN 12899-1 Stálé svislé dopravní značení - Část 1: Stálé dopravní značky, 2003; EAD 120001-00-0106 Micro-prismatic retro-reflective sheetings, 2016),* the samples were always cleaned before the measurement in order to avoid the influence of dirtiness. To specify the results, the meteorological conditions during this period were taken from the meteorological station that is located approximately 300(m) from the measuring spot.

Tab. 3 Determination of the scale of retroreflective degradation

D (k)	% loss of retroreflection
1	<5
2	5–10
3	11–15
4	> 15

The average values of the first and second measurements of each individual sample were compared by calculating the difference between these two values. The result was presented in a percentage. In order to determine the degree of degradation D(k) of each reflective material, all the results were divided into 4 groups (Tab. 3). Group number 1 corresponded to a decrease in retroreflection up to 5%. Group number 2 corresponded to a decrease in retroreflection from 5 to 10%. Group number 3 corresponded to values of results from 10 to 15%. The difference between the two measurements above 15% is represented by group number 4.

RESULTS AND DISCUSSION

According to the meteorological station, during the period of time the daily temperature fluctuated from -9°C to 30°C, the daily humidity - between 45% and 95%. Global radiation ranged from 1,500 to 22,500 ($kJ{\cdot}m^{-2}$ per day). The barometric pressure was between 953 and 988 (hPa). Daily rainfall ranged from 0.0 to 17 (mm per day). The scale of meteorological data is wide here but average values are not presented in the paper because they would not describe measuring conditions with higher preciseness. They represent usual nowadays continental conditions of the central Europe. Nevertheless, these meteorological conditions have led to the deterioration of the retroreflection level that is presented in Tab. 4 as D (k). This table also shows the average values of retroreflection coefficient of two data sets of measurements ("before" – the first measurement and "after "– the second measurement) that could be used for future researches.

The analysis of Tab. 4 shows that a total of 70% of white test samples can be included in group number 1. 20 % of all white retroreflective sheeting corresponds to group number 2 and only OR 5710 has lost 11.63% of retroreflection and corresponds to group number 3. According to the class division of all white samples, RA2 and RA3 have shown the loss of retroreflection up to 5%.

Regarding the red colour, 50% of all the samples correspond to group number 1, 20% to group number 2, the rest of the samples shows the deterioration of retroreflection above 10%. The highest retroreflection loss is observed in 3M 3200 film with retroreflection loss of 16.5%.

Tab. 4 The average values of measurements of retroreflection coefficient ($cd \cdot lx^{-1} \cdot m^{-2}$) and the degree of degradation of different types of sheeting. W – white, R – red, B – blue, b – before, a – after.

		Number of sheeting									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
W	b	85±3	73±3	109±4	132±5	678±28	414±17	530±22	769±32	422±17	434±18
	a	79±3	74±3	97±4	118±5	649±27	400±16	585±24	763±31	417±17	426±17
	D(k)	**2**	**1**	**3**	**2**	**1**	**1**	**1**	**1**	**1**	**1**
R	b	16±1	16±1	19±1	23±1	125±5	66±3	127±5	129±5	100±4	102±4
	a	14±1	15±1	16±1	22±1	118±5	59±2	125±5	127±5	88±4	99±4
	D(k)	**4**	**1**	**3**	**2**	**2**	**1**	**1**	**1**	**3**	**1**
B	b	1*	7*	8*	9*	43±2	33±1	64±3	52±2	30±1	43±2
	a	1*	7*	6*	8*	41±2	30±1	63±3	48±2	28±1	42±2
	D(k)	**1**	**1**	**4**	**4**	**1**	**2**	**1**	**2**	**1**	**1**

* - deviation is negligible, because is less than 0.4

Regarding the red colour, 50% of all the samples correspond to group number 1, 20% to group number 2, the rest of the samples shows the deterioration of retroreflection above 10%. The highest retroreflection loss is observed in 3M 3200 film with retroreflection loss of 16.5%.

Concerning the blue colour, group number 1 includes 40% of samples, 30% belong to group number 2, the rest relates to group number 4. Specifically, the retroreflection coefficient of a blue sample of the 3M 3200 film is between 1.1 - 1.2 ($cd \cdot lx^{-1} \cdot m^{-2}$), which is below the requirements of *(ČSN EN 12899-1 Stálé svislé dopravní značení - Část 1: Stálé dopravní značky, 2003)*. According to the class division, the loss of retroreflection above 15% is found in 75% of the RA1 film samples. However, this comparatively high percentage of deterioration does not mean that the coefficient of retroreflection of all samples will decrease in the same range during their whole service life.

Tab. 5 Comparison of authors' results with the results from study *(CHEN & JIANG, 2016)*

		Authors' results 16 months %		**(CHEN & JIANG, 2016)** 156 months %	
Colour	Class	minimal value	maximal value	minimal value	maximal value
White	RA1	7	12	12	21
	RA2	1	4	15	29
	RA3	1	2	2	9
Red	RA1	3	17	10	26
	RA2	2	10	12	40
	RA3	3	12	1	43
Blue	RA1	5	18	1	9
	RA2	2	10	11	15
	RA3	2	4	0.1	15

Looking at the average D(k) values in terms of colour, white samples show the lowest value since the degradation rate of the retroreflective materials is 1.4. The red samples show the average value of

D(k) 1.9 and for the blue samples, the average D(k) is 2.2. Looking at the average value of D(k) for different classes, the lowest value was presented by the microprismatic films RA3 and RA2 - the average value of D(k) is 1.33. The highest material degradation rates are shown for the RA1 film samples with D(k) equal to 2.58.

Almost all test samples after natural weathering have met the minimal requirements that are presented in Tab.2. Only the 3M 3200 blue sheeting did not meet the requirements of the standard, but even the new one.

In the Tab. 4 some coefficients of retroreflection were higher for the second measurement than for new sheeting samples. It can be explained that points for measurements were selected randomly and the microstructure of retroreflective films is not uniform as well.

The results of current study have been compared with the results of study *(CHEN & JIANG, 2016)* because of the same division of retroreflective materials. However, unlike to this research, *(CHEN & JIANG, 2016)* investigated 230 traffic signs for 13 years in Beijing, China. The minimal and maximal values of degradation rate for different types of retroreflective materials were used for comparison and are presented in Tab. 5. The analysis of Tab. 5 shows that there is no linear dependence on signs deterioration. Over a tenfold period of time, the average degradation rate has tripled. These results cannot be final as there are many factors that can affect the measurement. These factors include the environmental conditions around the traffic signs (*Khalilikhah* & Heaslip, 2015) and ambient temperature and humidity during the measurement *(Khrapova, 2019)*.

CONCLUSIONS

The goal of this paper was to determine the degradation rate of ten types of retroreflective sheeting commonly used on the traffic signs in the Czech Republic. In order to fulfil the main aim of the research two sets of data measurements were made - before and after accelerated natural weathering. The results of the measurements were compared, and the degree of degradation was found. After analysis, it was found that samples of red and blue R A1 were assessed as unstable because the deterioration of the retroreflection level was more than 15% after 16 months of natural weathering. It was also found that the 3M 3200 blue sheeting did not meet the requirements of the standard. The high level of degradation of retroreflective material was observed for the red 3M 3200 sheeting with 16.5% of deterioration, blue samples OR 5710 and 3M EGP films had the highest loss - about 17%.

According to the results of the carried out research, it can be assumed that some types of retroreflective sheeting will not meet the minimal retroreflection requirements before the end of their service life. The comparative analysis showed that degradation rate is not a linear function, it decreases in time. The experiment will continue, as the approved part of doctoral thesis, for several more years to prove that there is no constant degradation rate for different types of retroreflective films. The future results can support the design of the more accurate model of retroreflection degradation.

ACKNOWLEDGMENT

The authors gratefully acknowledge that the present research was supported by the Internal Grant of Faculty of Engineering, CULS Prague (grant number IGA 2018: 31150/1312/3120). Also, we would like to express an enormous thank to employees of ŘSD ČR and companies Značky Praha (Ing. Petr Hajoš), Araplast (Ing. Josef Šmerda) a Bizett (p. Jan Kavalír) for provision of some samples of retroreflective films, data and for cooperation.

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