Field Study of Pedestrian Crossings Deterioration Over Time: Assessment of Microplastics Emission from Road Markings

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Abstract. The issue of road marking deterioration (loss of functional properties, followed by abrasion) is of profound importance, so appropriate maintenance of roadway infrastructure is required. When road markings are used past their intended functional service life, they can undergo abrasion, which negatively affects their visibility for drivers and also leads also to emission of microplastics. This study was undertaken to fill the knowledge gap related to the rate and extent of abrasion that could be expected from road markings exposed to heavy traffic after the loss of functional properties. Analysis of luminance loss over three years was utilised as an indirect measurement method. The outcome, based on assessment of three pedestrian crossings, indicated average abrasion of 2.1% per 1 million weight-adjusted vehicle passes when cold plastic, a durable material containing hard coarse fillers, was used. However, it could exceed 20% if paint, unsuitable for such jobs, was utilised instead. Thus, the polymer quantities released from the analysed zebra stripes during the three years of usage past their functional service life varied from 10.3 to 25.9 g per 1 million weight-adjusted vehicle passes. Such relatively large measured abrasion and emissions was a result of grossly negligent maintenance. Hence, appropriate selection of materials for a particular road and their correct maintenance were shown as necessary to not only assure visibility of the road markings for drivers, but also to minimise the emissions to minimise the environmental impact.

Keywords: service life · luminance · abrasion · retroreflectivity · environmental pollution

1 Introduction

Road markings (RM) are necessary basic road safety elements – they are used by both human drivers and by the machine vision technology utilised in driver assistance systems and as such are currently irreplaceable [1]. However, RM are deteriorating systems that require renewals, so they would maintain their functional properties. Upon reaching the end of functional service life, RM remain on the road and normally should be renewed

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(not replaced). Their extended use, past the intended and designed functional service life, leads to the decrease in visibility for drivers and then abrasion, which causes contribution to microplastic (MP) pollution.

There were reports about enormous emissions of MPs originating from RM, but closer examination revealed them to be fundamentally wrong [2]: in the theoretical estimates not only the functional parameters of RM, but also the protective role of the drop-on glass beads and the common practices associated with RM maintenance were disregarded. Several reports of finding RM particles amongst collected MPs were traced to either extraordinary abrasion conditions (like the use of studded tyres) [3, 4] or to unacceptably negligent maintenance (i.e. permitting for complete abrasion or crumbling instead of prompt renewal upon the loss of functional properties) [5, 6]. Based on field assessment in several countries, it has been demonstrated that at pedestrian crossings, which are the most used areas as all of the vehicles encroach on them, annual abrasion was $< 5\%$ (with the exception of Sweden, where studded tyres are used; abrasion there exceeded 20%) [7].

Whereas based on prior research it was possible to estimate the extent of complete loss of RM at a particular moment, absent was a systematic study to correlate the rate of abrasion (which can occur only after the loss of functional properties) with the traffic load. Hence, this effort was undertaken with the goals of providing the results from such assessment and proposing an easy methodology for this type of evaluations. For demonstration, periodically taken images of three pedestrian crossings were analysed for road marking erosion (i.e. complete abrasion) based on the loss of luminance, according to previously established methodology [7, 8]. The outcome was envisaged to be a clarification of the issue of RM deterioration for environmental scientists seeking apportionment of roadway sources of pollution, but foremost should assist road administrators in selecting optimum solutions to simultaneously maximise the benefits for drivers and minimise contamination of the environment.

2 Methodology

The evaluation protocol was explained in detail elsewhere [7]. The key assumption was that the marked area had much lighter colour than the area of underlaying roadway exposed due to a complete abrasion of RM.

Evaluation was done on representative ‘zebra’ pedestrian crossings at national road 2 in Poland, a two-lane section between towns Kałuszyn and Siedlce. Two of the assessed crossings were marked with structured cold plastic (a material designed for withstanding heavy traffic loads, containing hard coarse fillers) and one initially with paint (material of relatively low durability that should be used only on edge lines that are not heavily trafficked). Analyses were repeated at least twice a year for three years (but not necessarily all on the same day). One has to note that it is not known how long exactly the RM were in service before the analyses commenced; while it may be important and this weakness is acknowledged, for the presented assessment it was considered irrelevant because of the extended evaluation period. The annually average daily traffic, per data published recently by the road administrator, is provided in Table 1 (assumed was equal traffic in both directions). For easy comparison, the marking loss was expressed per 1 million of weight-adjusted vehicles per lane (MWAVL).

Table 1. Traffic load (per lane).

—	Crossings A and B	Crossing C
Light vehicles (≤3.5 t gross weight rating)	7703	7716
Heavy vehicles (>3.5 t gross weight rating and buses)	1621	1381
Weight-adjusted annually averaged daily traffic	20,667	18,764

3 Results

Pictures of one of the analysed pedestrian crossing at the beginning and at the end of the evaluation period are shown in Fig. 1 and Fig. 2, correspondingly; increase in the abraded area is clearly visible.

Fig. 1. Exemplary area (crossing B) at the beginning of analysis: circa 2% marking loss since last application (period on the road unknown).

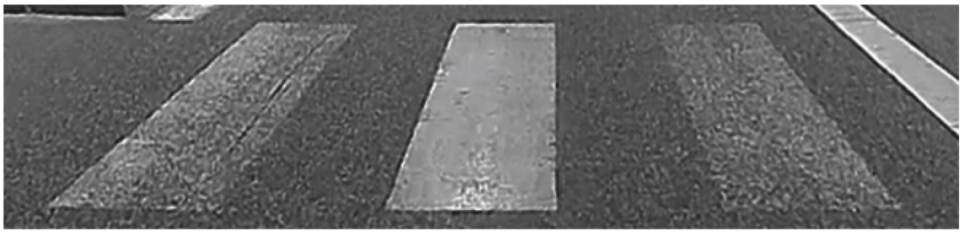

Fig. 2. Exemplary area (crossing B) after 3 years and 23.0 million weight-adjusted vehicle passes: circa 43% marking loss.

The results of the evaluation are summarised in Table 2 and visualised in Fig. 3. One should note the superior performance of cold plastic that was used to mark pedestrian crossings A and B, loss of 1.4–1.8% per MWAVL was measured, which corresponded to estimated polymer emissions of 10.3–12.9 g per MWAVL. At pedestrian crossing C, marked initially with paint, loss of 20.2% per MWAVL was measured (within just several months, average abrasion was 75.5%, but if one excluded the least-used 'zebra' stripe, on which almost no vehicles encroach, it was > 97%) for polymer release reaching 14.5 g per MWAVL. Subsequent switch to cold plastic resulted in significantly higher abrasion resistance; however, after another renewal the abrasion rate increased to 3.6% per MWAVL, which indicates that the renewal was not done properly (poor workmanship and/or use of a substandard material).

Table 2. Marking loss.

Period	MWAVL[(a)]	'Zebra' A[(b)]	Zebra' B[(b)]	'Zebra' C[(c)]	'Zebra' C[(b)]
Initial	0.0 / 0.0	0.6%	1.8%	75.2%	–
about 3 months	2.3 / 1.9	1.6%	4.6%	3.5%[(d)]	–
about 6 months	4.5 / 3.6	3.8%	12.1%	65.5%	–
about 1 year	5.8 / 5.5	8.4%	19.2%	75.5%	–
about 18 months	9.8 / 8.0	13.7%	24.6%	–	2.7%[(d)]
about 2 years	16.2 / 12.5	22.9%	33.8%	–	9.6%
about 30 months	20.5 / 14.7	31.1%	41.2%	–	1.0%[(d)]
about 3 years	23.0 / 20.5	33.5%	43.1%	–	22.1%
Average marking loss per MWAVL		1.4%	1.8%	20.2%[(d)]	1.5 / 3.6%[(d)]
MP emissions per MWAVL [g][(e)]		10.3	12.9	14.5[(d)]	10.9 / 25.9[(d)]

(a) First value applies to crossings A and B, second value applies to crossing C. (b) Marked with cold plastic. (c) Marked with paint. (d) Renewal was done. (e) Calculated assuming the material losses given herein and: cold plastic – applied at 3.5 kg/m^2 containing 20.5% of polymeric material, and paint – applied at 0.6 kg/m^2, containing 12.0% of polymeric materials

4 Discussion and Conclusions

Evaluation of pedestrian crossings for marking loss (i.e. complete abrasion) revealed that its rate was strongly correlated with the selection of materials for the RM. The use of properly applied cold plastic (a good choice for this type of location) resulted in average abrasion rate of 1.6% per MWAVL and mean MP release rate of 11.4 g per MWAVL. The selection of paint (a very poor choice for pedestrian crossing) resulted in abrasion rate more than ten times larger. Because life cycle assessments done on various types of RM revealed that the parameter controlling their sustainability was their functional service life, so appropriate materials selection is critical [9–11] which was demonstrated herein again.

Validity of this approach and consistency of the collected data was confirmed through comparison of the trendlines drawn through the data points (Cf. Figure 3), where almost parallel trendlines ($y = 0.015x - y = 0.018x$) and good data point fits, with $R^2 > 0.95$, were observed for crossings A and B. Similar result was also seen for the initial application of cold plastic at pedestrian crossing C. Because of apparently poor quality of its renewal, the subsequent slope was steeper ($y = 0.032$; loss 3.6% per MWAVL was measured instead of 1.4–1.8%). The differences between the most used and least used stripes were disregarded for this preliminary assessment, even though they were meaningful; this aspect may be needed for optimisation of the maintenance schedule.

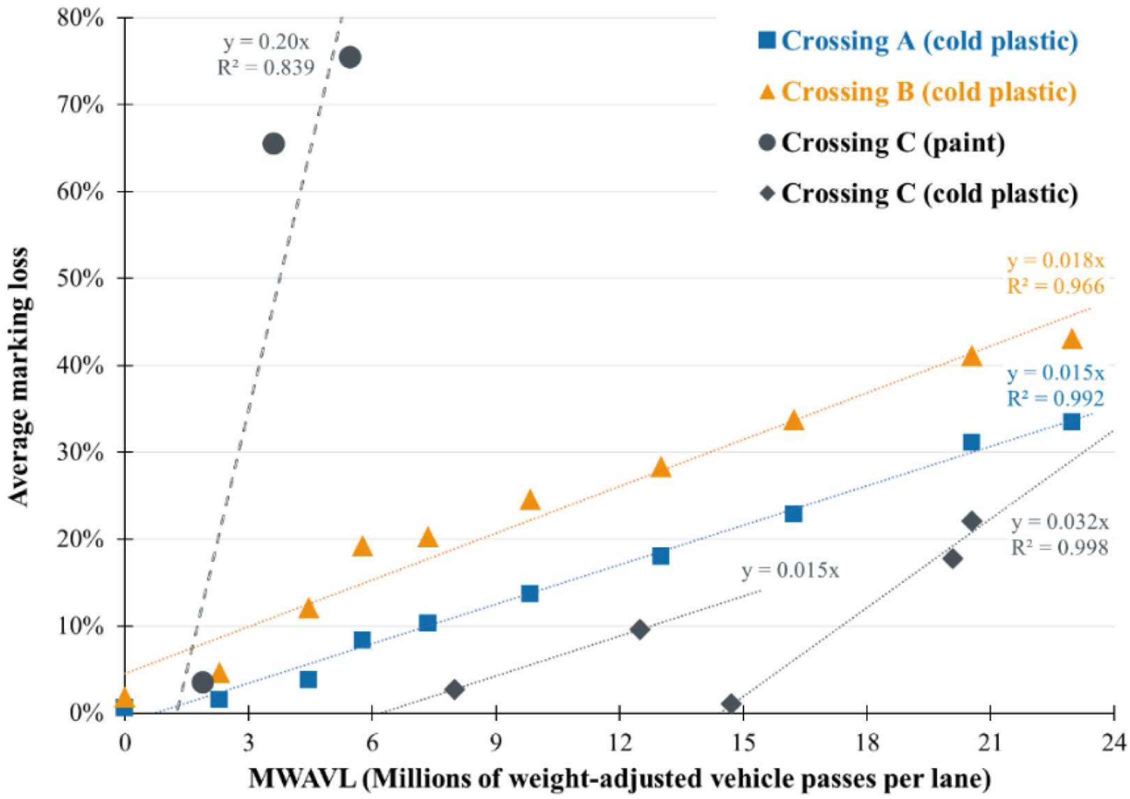

Fig. 3. Marking loss (abrasion) at the analysed pedestrian crossings as a function of traffic load.

From the perspective of MP emissions, this assessment indicated larger annual abrasion than was previously reported based on other field estimate [7]; however, herein very heavy traffic load was combined with grossly negligent maintenance – the RM were not renewed upon the loss of functional properties, but were permitted to be significantly abraded [2, 7]. The relatively high rates of marking loss should not be treated as an inherent weakness of RM and their propensity to undergo abrasion, but were a results of very poor maintenance practice (combined with erroneous choice of material in one of the cases).

One should additionally note that structured RM, such as those present on the pedestrian crossings marked with cold plastic, are providing much better visibility at night during rainy conditions [12], which should translate to an increase in road safety. Therefore, the measured grossly inadequate maintenance could be a factor contributing to very poor road safety in Poland. If the RM are simultaneously reflectorised with glass beads capable of furnishing retroreflectivity under wet conditions, additional benefits could be realised; successful use of such high-end RM at pedestrian crossings was recently reported [13]. Furthermore, it was calculated that the use of high-end materials for RM, despite their high unit costs, from a long-term perspective was not more expensive than low-end RM due to improved durability [14]. Because of enormous expenses associated with vehicular accidents, the use of inexpensive and readily available solutions like properly visible RM should bring meaningful social advantages, so it is surprising that some road administrators neglect such easy solutions to improve road safety.

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