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Yellow pedestrian crossings: from innovative technology for glass beads to a new retroreflectivity regulation

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ABSTRACT

Horizontal road markings are common and inexpensive road safety features, which are particularly needed and effective during night time driving, when the embedded glass beads provide retroreflectivity, which is perceived by drivers while other visual cues are limited. Worldwide, there are different standards for the minimum retroreflectivity levels: the most recent recommendation for coefficient of retroreflected luminance (R_L) from European Road Federation is 150 mcd/m^2/lx. Such level can be readily achieved and maintained in white paint, but not in yellow. In Switzerland, yellow colour is used for marking of pedestrian crossings, which necessitated lower R_L. The recently introduced premium type of glass beads was found to furnish R_L exceeding the requirements and simultaneously provides longer service life, which led to modification of the Swiss norms and increase of the minimum R_L from 60 mcd/m^2/lx to 150 mcd/m^2/lx for used markings. In addition, substantial R_L was achieved under the condition of wetness. The study has shown that shade of the yellow colour also played profound role in the on-road performance. This emerging technological advance has a potential to affect the road administrators' policies toward reflectorisation of horizontal road markings worldwide. Improved road safety can be realised by increasing the conspicuity of markings and, therefore, pedestrians. Furthermore, the measured increased durability can directly transfer into lesser environmental burden.

1. Introduction

Safety of pedestrians belongs to the critical focus areas in European Union because 68,371 pedestrians were reported to have been killed in road accidents between 2006 and 2015 (European Commission, 2018). During this period, on Swiss roads 663 pedestrians were killed, 6902 severely injured, and 16,811 lightly injured (BFU, 2018). In Europe, pedestrians constitute approximately 21% of all road fatalities and this percentage remains unchanged for the past decades (European Commission, 2018). In addition to personal and social burden, such death toll and injuries are associated with enormous financial expense. It was calculated that one road accident in Europe costs between 0.7 and 3.0 million euro, depending on the country (Wijnen et al., 2019). In Switzerland all road accidents in 2017 were calculated to cost 15,717 millions Swiss Francs (CHF); since there were 4199 recorded accidents with a person injured or a property damaged, average cost per case was 3,743,034 CHF (BFU, 2018). Thus, a solution for improved road safety would be highly advantageous and is stressed in various national and international policies (European Commission, 2010).

Horizontal road markings are common features seen on almost all modern roads. While the majority of markings serve to channel vehicular traffic on long road stretches, pedestrian crossings are marked to warn drivers of the area where people would be crossings. Indeed, an eyetracker study performed in the field demonstrated that zebra markings were the most frequently observed by drivers feature of pedestrian crossings (Bichicchi et al., 2017). Simultaneously, pedestrians are informed that while crossing on the 'zebra' they have a right of way over oncoming vehicles. In darkness, all types of horizontal road markings have to be reflectorised to be seen in vehicles' headlights, which necessitates the use of glass beads that are embedded in the paint layer and provide retroreflectivity (Pocock and Rhodes, 1952). Providing visibility at night is important because despite lower number of vehicles travelling in the darkness than during daylight, the reported number of accidents and their severity on unlit roads are significantly higher as compared to occurring in lit conditions (Plainis et al., 2006; Uttley and Fotios, 2017). Retroreflectivity is so critical that quality and service life (durability) of horizontal road markings are measured with coefficient of retroreflected luminance (R_L). The recent

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recommendation from European Road Federation (ERF) is to keep $R_L > 150$ mcd/m^2/lx at all times, which agrees with a report based on a visual assessment (Gibbons et al., 2012).

In majority of countries, pedestrian crossings are marked in white. However, in Switzerland, yellow colour is preferred because it is considered as attracting more attention and warning drivers. Statistical analysis demonstrated that the use of high visibility crosswalks led to a reduction in pedestrian-vehicle collisions even up to 37% (Feldman et al., 2010). While calling drivers' attention with yellow colour brings safety, the drawback of using yellow marking is reduced R_L. The current policies regarding retroreflectivity standards of road markings vary between countries and depend on the road and marking type, colour, and utilised materials. In the past, in Switzerland, which case is described herein, required was minimum initial R_L between 180 and 300 mcd/m^2/lx for white markings and 150 mcd/m^2/lx for yellow. After usage (which typically meant – after winter), between 100 and 150 mcd/m^2/lx was demanded for white and only 60 mcd/m^2/lx for yellow. As a consequence of the results achieved from evaluation described herein, Swiss authorities recognised the possible benefits and modified their R_L demands for yellow pedestrian crossings to require minimum initial R_L of 250 mcd/m^2/lx and 150 mcd/m^2/lx after usage, throughout service life of the markings specified at not less than 3 years. Contractors who won the maintenance tenders are responsible for keeping appropriately high R_L.

The scope of the described field trial was demonstration that with the newly available premium glass beads R_L of yellow markings can be increased beyond values typically achieved with standard glass beads. For the purpose of this experiment, it was reasoned that high R_L would make the crossing more conspicuous at night and the pedestrians could be better distinguished against the dark surroundings. No prior research was found that would attempt to correlate R_L of pedestrian crossings marking, either white or yellow, with road safety, or even address the perception of crossing R_L by drivers or by pedestrians. Nonetheless, retroreflectivity was recognised as one of the factors that may increase pedestrian safety (Basile et al., 2010). Several shades of yellow colour were evaluated to assess their effect on R_L and to select the best performer.

The achieved exceptional performance has a potential to affect various governmental policies toward road markings due to simultaneously measured meaningfully higher R_L and longer service life. Savings in materials consumption based on the improved durability scenario are provided to demonstrate the environmental advantage of using such technology.

2. Background

2.1. Safety at pedestrian crossings

A place where pedestrians cross the roadway is a conflict zone and minimising the number of such conflicts and their severity can be achieved with engineering controls. The most risky pedestrian crossings are those located mid-block, on bidirectional two-lane roads, such as are frequently present in villages (Olszewski et al., 2015). Majority of accidents involving pedestrians were reported to be occurring at marked crossings and the number of collisions taking place in darkness was, in relation to traffic load, significantly higher than during daytime (Uttley and Fotios, 2017). Removal of 'zebra' markings was also considered, with the reasoning that pedestrians crossing the road at marked areas may subconsciously feel too safe and thus become more vulnerable to inattentive drivers; however, a study did not confirm such hypothesis (Gitelman et al., 2017). Improvement in safety at pedestrian crossings was reported to be realised with the installation of refuge islands, appropriate warning signs, and increasing conspicuity of the crossing (Vignali et al., 2019).

Despite all of the knowledge and plethora of engineering controls that are being implemented, the number of pedestrians killed and injured at pedestrian crossings remains extremely high. The tested and proposed novelty, which has a potential to increase visibility of pedestrian crossings at night time in unlit locations, are 'zebra' markings with high retroreflectivity.

2.2. Road marking materials

Horizontal road markings are systems, comprising the base (colour) layer and the retroreflective (glass beads) layer and only co-operation of these two components provides a functional marking (Pocock and Rhodes, 1952). The base layer, which may be a waterborne or a solventborne paint, a thermoplastic mass, a cold plastic polymer, or other material provides adhesion to the road surface, gives the desired colour, and holds glass beads while the retroreflective layer furnishes R_L and protects the base layer from abrasion. Most frequently for marking roads are used paints, because of their broad availability, ease of use, and low unit price (Babić et al., 2015). However, paints are poorly suited for marking areas of high traffic load, because their relatively low durability causes the need for frequent renewals; consequently, their environmental friendliness is quite low due to high material consumption and the emissions of volatile organic compounds occurring during drying (Burghardt and Pashkevich, 2018). Paints are commonly used for renewal of structured road markings that have lost their R_L but the structure remained functional; this topic is beyond the scope of this article.

Pedestrian crossings, where all passing vehicles encroach on the marking, ought to be marked with durable thick-layer structured systems, such as those based on cold plastic. In such a material, as binder are used acrylate monomers and oligomers, which upon mixing with a peroxide initiator immediately prior to the application polymerise on the road surface to form a hard and durable layer. Cold plastic can be conveniently applied by hand spreading to achieve a stochastic structure, which makes it particularly useful for marking of pedestrian crossings. During application, glass beads are dropped-on to furnish retroreflection and to protect the base layer. Appropriate coating of glass beads is allowing for a chemical reaction with the polymerising acrylates to furnish their excellent adhesion. The irregular vertical structure of properly applied cold plastic permits for sheltering of some glass beads from the passing vehicles and snow ploughs and simultaneously improves water drainage, which allows for increased R_L under wet conditions. To achieve high skid resistance, which is critical for safety of both drivers and pedestrians, materials designed for pedestrian crossings contain appropriate anti-skid additives.

The yellow 'colour box' coordinates specified in EN 1436:2009 standard (European Committee for Standardization, 2009) are quite broad and encompass numerous shades. No literature reports describing evaluation of various yellow shades for horizontal road markings could be found. It must be added that modern yellow road marking materials are prepared without the use of toxic lead chromate pigment, which in the past was causing environmental contamination (Werkenthin et al., 2014); instead, organic pigments of high durability and low toxicity are utilised (Hunger, 2005).

2.3. Glass beads for road marking

Glass beads of various qualities and gradations are available from numerous manufacturers worldwide. Typical glass beads for road markings are prepared from recycled window glass and thus have refractive index (RI) 1.5. Current technology for their production limits their diameter to approximately 850 µm. Glass beads with larger diameters or with different RI can be prepared from virgin raw materials. Amongst those, high index glass beads (RI 1.9), despite very high R_L that they provide are not suitable for typical horizontal road markings due to low scratch resistance; they are used mostly for airport markings or other niche applications. All glass beads for road markings should be free from lead, antimony, and arsenic to meet Class 1 requirements of