Applied Optics in the Development of Smart Road Markings

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Abstract. Road markings (RM) consist of two distinct layers: the paint layer and the retroreflective layer. Together, they function as system and are essential features for road safety. Recent studies have been centred on elevating these systems to a smarter level, imbuing them with novel functionalities, increasing their visibility, service life and road safety. These new capabilities encompass photoluminescence, anti-aging, self-cleaning, and thermochromism. The aim of this study is to review the advancements and highlight potential opportunities for RM, the materials employed, functionalization techniques, and the key outcomes achieved.

1 Introduction

Road markings (RM) act as guidance feature for drivers, helping them stay on travel paths and constitute a valuable visual element for road safety. RM consist of two layers that work as a functional system. The base layer (paint layer) adheres to the road surface, enhancing daytime visibility through contrasting colors with the pavement surface, and establishing adhesion to the second layer. The second layer comprises retroreflective material, glass beads (GB), which enhance night visibility and protect the underlying layer from abrasion [1].

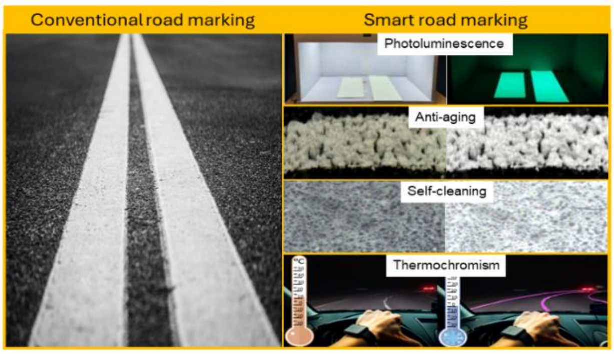

Fig. 1. Conventional and smart road markings.

Smart materials for new capabilities already exist in road engineering, especially in pavements. Concerning RM, the efforts are mostly focused on their main components and parameters (luminescence and retroreflectance). However, the literature reports advances concerning the functionalization of smart RM by the application of semiconductors, thermocapsules, photoluminescent materials, among others. Therefore, the main objective of this work is to assess the literature on RM that possesses additional abilities beyond the conventional ones (Figure 1), aiming to enhance visibility conditions, service life, and road safety.

2 Photoluminescent capability

Night visibility affects road safety. Since RM are seen by drivers according to the principle of retroreflectivity (passive lighting), it results in poor visibility in the absence of external light sources. Luminescent materials (LM) towards "active lighting" improve road safety during dark conditions. They emit light after absorbing photons from sunlight or vehicle headlights [2]. When incorporated into RM paints, LM extend visibility beyond the range of headlamp beams and in unlit areas [3].

Bi et al. [2] incorporated 10-30 (w%) of strontium aluminate ($SrAl_2O_4$) into RM paint and it resulted in photoluminescence ability without compromising basic requirements. Giuliani and Auteliano [4] concluded that $SrAl_2O_4:Eu^{2+},Dy^{3+}$ produced luminescence 5hours–6hours above 1mcd/m2. Villa et al. [3] evaluated photoluminescent paints (LuminoKrom®) and concluded that they could increase the visibility distance beyond the headlamp beams during the first few hours of the night.

Luminescent RM offer an alternative for improved nighttime visibility, and opportunities in this field include increasing the active lighting time and wear issues [5].

3 Anti-aging capability

Photodegradation resistance and some aging factors affect RM durability. Pereira et al. [6] incorporated 0.10, 0.25 and 1.00 (wt.%) of lignin into RM. It did not cause

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significant changes in chemical, flexibility, and no-pick-up time properties. However, two indicators of aging (the reduction in the band associated with the C-O of the ester group and the carbonyl group C=O) increased by up to 27% and 92%, respectively, after UV irradiation, while decreased by 40% for the unmodified paint.

Hadizadeh et al. [7] modified cold plastic RM paint by the addition of benzoyl peroxide (BPO) 0.5, 1.0, 1.5 and 2.0 (wt%) and evaluated the aging resistance by the color difference (ΔE) after exposure to accelerated weathering. The results showed that low BPO contents had minimal impact on the paint curing. Higher ΔE values were observed for samples with 0.5 and 2.0 wt.% (2.32 both), while the lowest ΔE were found for a 1.5 wt.% (1.16).

TiO_2 reflects and absorbs UV light, shielding composite materials from UV aging. Its incorporation into RM is an opportunity for enhancing anti-aging, as it has been attested in other binders [8].

4 Self-cleaning capability

Semiconductors, such as TiO_2 and zinc oxide (ZnO), when exposed to UV and humidity, present oxidation capacity, degrading dirt, organic compounds, and inorganic substances (self-cleaning). This capability has been studied on pavements, mortars, and glasses. Reza Omranian et al. [9] functionalized asphalt mixtures with TiO_2 and assessed potential for soot removal. After UV exposure, soot coverage was observed (from 65.3% to 7.2%) at increased TiO_2 concentrations. Rocha Segundo et al. [10] sprayed TiO_2 and ZnO particles over asphalt mixtures and attested these surfaces photodegrade organic pollutants and remove dirt particles through the Lotus effect by water repellence.

Self-cleaning RM by the incorporation of nano-TiO_2 represents a promising technology for road infrastructure. Since daytime visibility is a key factor, this property has the potential to prolong the service life of RM and increase road safety by maintaining their visibility and high contrast with the pavement surface for longer.

5 Thermochromic capability

Thermochromic materials (TM) can change color due to temperature variation and undergo this process at a specific transition temperature (TT). TM ensure applications in aerospace, military, textile, and construction fields [11]. In road engineering, TM are mainly applied to asphalt pavement for temperature variation control (mechanical performance of asphalt pavements) and heat absorption reduction (Urban Heat Islands mitigation) [12].

TM can provide a potential ability for RM when incorporated into the paint layer. When the TM are specifically designed with a TT around 0 °C, the RM paint can serve as a color-based sensor, by alerting the drivers (through color changing) about the presence of ice on the pavement. This can improve road safety, providing feedback to encourage drivers to adopt safer behavior and increasing visibility in snowy conditions.

6 Conclusions

This work provided a review on new capabilities for RM. The photoluminescence and anti-aging abilities have already been developed in some studies, presenting promising results in terms of increased durability and visibility conditions. The self-cleaning and thermochromism abilities represent an innovative potential opportunity already applied to other road engineering elements, but not yet to RM. In this regard, these novel abilities have the potential to increase the service life of RM, improve both day and night visibility, and effectively alert drivers to hazardous road conditions.

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