Glow-In-The-Dark Concrete Topping-Based Road Marking

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***Abstract*— The road infrastructure has experienced relatively gradual changes in comparison to the rapid advancements in vehicle safety technology. Retroreflective devices, such as Bott's dots, have long been utilized for lane separation and edge detection. Despite their diverse shapes and sizes, these devices heavily rely on external light sources for reflection. However, the emergence of Glow-in-the-Dark (GiD) material introduces an innovative solution capable of storing and emitting energy in visible light, presenting a promising alternative to retro-reflectivity. This research focuses on the development and testing of GiD concrete-based markers designed specifically for lane separation and edge detection. These markers not only enhance driver alertness but also provide visible light without necessitating external light sources. The study not only demonstrates the durability performance of the presented prototype but also includes a comprehensive cost comparison with traditional Bott's dots. Moreover, the potential applications of GiD-based raised pavement markers extend beyond road infrastructure to encompass architectural and aesthetic designs in diverse settings, such as buildings, parks, walkways, and bicycle lanes.**

***Keywords*— glow-in-the-dark, raised pavement markers, performance testing, nanophospor strontium aluminate, SRN test**

I. Introduction

Road safety is a serious concern around the world [1]. Modern vehicles are equipped with advanced features such as sensors, cameras, and cruise control to assist drivers during their journeys. Despite these technological advancements, road safety remains a pressing issue, with traffic accidents resulting in significant human and material costs each year [1]. Efforts have been made to address this issue through the implementation of traffic safety laws and regulations, aimed at reducing road fatalities [1, 2]. However, it is unlikely that the global objective of halving traffic-related fatalities by 2030 will be achieved [2]. Currently, road accidents claim the lives of more than 1.2 million people annually and cause injuries to 50 million others [3, 4]. To tackle this problem, road safety policies cover various aspects, including road users, vehicles, roads themselves, and socioeconomic factors [5, 6].

One specific challenge to road safety is low lighting conditions, particularly during nighttime driving [7, 8]. Although street lighting is commonly installed on roadways, its limited brightness and range often restrict drivers' lines of sight. As a result, drivers may fail to adjust their speed to account for reduced visibility, increasing the risk of accidents [7, 9]. Studies have shown that the likelihood of accidents occurring at night is 1 to 1.5 times higher compared to daytime, and the rate of road deaths per kilometer is approximately three times higher during nighttime [10, 11]. Therefore, it is crucial to thoroughly examine the factors contributing to severe nighttime road accidents in low-light settings and develop precise control mechanisms to ensure driver safety during night driving. Previous research has focused on investigating the relationship between road conditions and safe nighttime driving, with a particular emphasis on lighting systems and their impact on traffic safety. These studies have demonstrated that accidents are more prevalent at night compared to daytime and that deploying effective lighting systems on roads can extend the visible range provided by car headlights, reducing fatalities and improving overall safety [12-15].

In recent years, some developing countries have implemented glowing roads as a strategy to enhance road safety. For instance, the Netherlands has transformed road markings into luminous elements that glow in the dark, eliminating the need for external illumination [16, 17]. Research has been conducted to evaluate the advantages and disadvantages of using photoluminescent road coatings on different types of asphalt, considering aspects such as illuminance and texture decay, which can affect friction levels [17]. However, the existing methods of implementing glowing roads have limitations, such as the dependence on electrical current to excite the Glow-in-the-Dark (GiD) material and concerns regarding durability and performance under harsh environmental conditions [18].

This research aims to address these limitations by proposing an intelligent road strategy that utilizes Nanophosphor Strontium Aluminate or GiD powder materials as reflecting materials on the road surface. The primary objective is to enhance the visibility of roadway markings during nighttime or low-light conditions. Furthermore, previous studies have often overlooked the importance of considering the color and shape of the pavement markers. Therefore, this research adopts the trapezoidal shape commonly used for raised pavement markers and selects the yellow color based on guidelines for their usage [19].

By exploring the potential of GiD materials and taking into account the specific shape and color of pavement markers, this study seeks to contribute to the improvement of road safety and visibility, particularly during nighttime and low-light conditions.

II. Related Works

Numerous studies have examined reflective raised pavement markers (RPMs), focusing on installation procedures, durability, retro-reflectivity, costs, and optimum spacing. However, there has been a limited number of studies in the past three decades that have specifically investigated the safety effectiveness of RPMs. Road safety is a crucial concern for governments worldwide, motivated by humanitarian, health, and economic factors. The World Health Organization (WHO) reports that road accidents lead to approximately 1.3 million fatalities annually and cause 30 to 50 million non-fatal injuries [19]. To address this global issue, proactive interventions such as urban and transport planning, safer road design, road safety audits, and internationally harmonized laws have been implemented [20, 21]. European countries' efforts in identifying high-risk areas, enhancing road design, and enforcing traffic regulations have resulted in a significant reduction in accidents [22].

A study conducted by the Georgia Department of Transportation (DOT) evaluated the safety effects of reflective raised pavement markers in Georgia. These markers were installed on the centerlines of 662 horizontal curves with a curvature of over 6 degrees. Additional delineation devices, including warning signs and chevron markers, were also installed, potentially influencing the study outcomes [23]. Previous studies on pavement marking safety, such as Miller's analysis in 1991, have shown the benefits of edge lines. Even on rural two-lane roads with low traffic volumes, the use of edge lines resulted in significant benefit-cost ratios, ranging from 17:1 to 60:1 [24]. Bali et al. conducted a study on delineation treatments for rural two-lane highways, observing a 36% reduction in crashes with the addition of edge lines and centerlines [25].

Polymer addition in asphalt pavement has been studied for its overall performance enhancement and potential contribution to road safety. Radium polymer materials, when used as reflective materials, have shown positive outcomes in improving road safety under low illumination circumstances [26]. Utilizing glow-in-the-dark (GITD) sealants on concrete surfaces offers an energy-efficient alternative to traditional streetlights. GITD powder, deriving its luminescence from sunlight, can provide increased visibility on the road, potentially improving road safety [27, 28]. However, challenges such as the glow duration during rain events and the risk of accidents when drivers turn off their headlights to rely solely on glow-in-the-dark lines have been noted [30, 31].

Recent research introduces a glow-in-the-dark concrete-based raised pavement marker that eliminates the need for retroreflection and electroluminescence. By incorporating Nano powder, the glow intensity of the marker increases, and the glow duration remains unaffected after a 5-minute charge [32]. These advancements hold promise in improving road safety and reducing dependence on streetlights.

III. Methods

The researchers gathered the materials used for developing the specimens that were tested. Cement, which is a binding substance used in construction to solidify and bond materials together, was purchased from a local supplier. Grade 100 Portland cement was specifically used in this study. Fine aggregates, typically natural sand, were utilized to ensure the durability of the concrete. Water, an essential component in the concrete production and curing process, played a crucial role in determining the strength and quality of the concrete used. It was important for the water to be of drinking quality and free from impurities.

Fig. 1. Epoxy Resin and Hardener

In addition, epoxy resins were employed in the study due to their high performance and suitability for extreme conditions. These resins can be customized by adjusting the resin, modifier, and crosslinking agent to meet specific requirements. The ratio of epoxy resin to hardener used in this study was 2:1. To introduce the glow-in-the-dark effect, glow-in-the-dark (GiD) powder was incorporated. This powder is cost-effective and can be charged by various light sources, such as sunlight or white light bulbs, and it exhibits luminescence under black light. Three types of GiD specimens were created, each with different percentages of GiD powder: 5%, 10%, and 15%.

Fig. 2. GiD Powder

Fig. 3. Plastic Molder

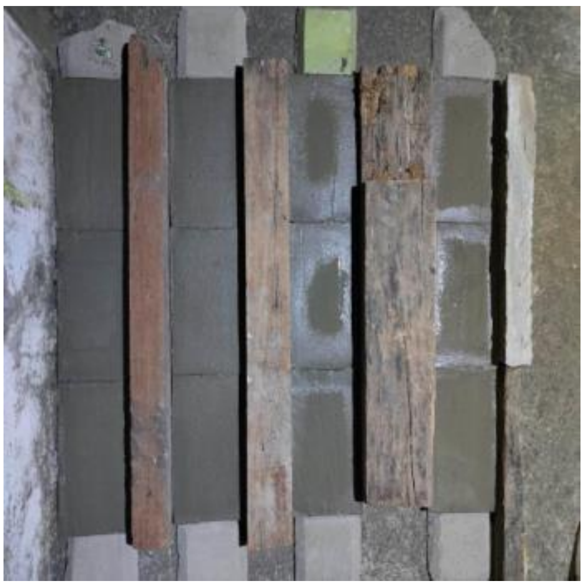

Fig. 4. Curing of Trapezoidal Concrete

Fig. 5. Mixing of Epoxy Resin and GiD Powder

The plastic molder, shown in Fig. 3, played a key role in shaping the epoxy resin in the cured concrete specimens. The molder, made of plastic, served as a container for the mixture of epoxy resin, hardener, and Glow Powder. This mixture was poured into the concrete specimen inside the molder. Subsequently, the specimen was left to cure and harden, resulting in a solid block that could be easily removed from the mold after a 24-hour curing period.

In the preparation phase, the necessary materials were acquired to create the product. The cement was purchased from a local hardware store in Caggay, Tuguegarao City, Cagayan. Additionally, sand was collected from an ongoing construction site near the hardware shop and sieved using a No. 18 Mesh. Fig. 4 illustrates the production and curing process of the trapezoidal concrete used for the body of the specimen.

The Epoxy resin and GiD powder were obtained from a local supplier. A mixture of epoxy resin and hardener was prepared in a ratio of 1:2. Three sets of epoxy mixtures were prepared for the 5%, 10%, and 15% GiD mixtures. The GiD powder was then combined with the epoxy resin mixture and thoroughly mixed until the desired consistency was achieved, as shown in Fig. 5. This solution of GiD epoxy resin was prepared to ensure even distribution within the concrete.

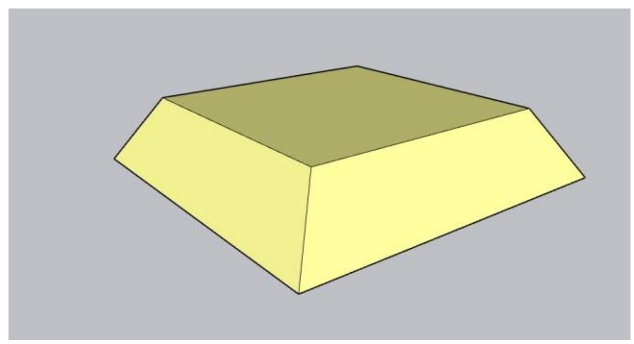

Fig. 6. Glow-in-the-dark concrete topping-based road marking

The final design of the proposed prototype for the Glow-in-the-dark (GiD) RPM is a two-way trapezoidal form, as shown in Figure 9. It has a base measurement of 100 mm, a top length of 75 mm, and a height of 15 mm. This specific design was chosen to provide drivers with visual feedback on tire vibration, both during the day and at night when the GiD material becomes visible. It is important to note that while the GiD RPM can be manufactured in various sizes and shapes, the focus of this research is to establish a proof of concept for the GiD RPM.

To assess the applicability of the developing prototype under real-world conditions, glow-in-the-dark testing was conducted. The objective of the experiment was to evaluate the intensity and duration of the prototype's glow. According to the study on Research Advances in Human-Eye-Sensitive Long Persistent Luminescence Materials, the minimum light level detectable by the human eye emitted from the prototype was specified as 0.32 mcd/m2 [33]. To measure the intensity and duration of the glow-in candles per square meter (mcd/m2), a photometer, depicted in Fig. 7, was utilized.

Before the test, all samples were placed in a dark cover without any visible light for 24 hours. Subsequently, each sample was excited using a UV flashlight, as shown in Fig. 8. The glow duration and intensity of each sample were recorded. The choice of a UV flashlight as the excitation source was based on the reasoning that its spectral irradiation closely matches that of the sun in terms of spectral irradiance versus wavelength of light, thus replicating real-world lighting conditions.

Furthermore, the distance of the light source was adjusted to ensure uniform coverage of the entire surface of the GiD RPM. Three samples with different percentages of GiD material addition (5%, 10%, and 15%) were tested with an excitation time of 5 minutes. The glow-in-the-dark effect was measured after three different durations: 5 minutes, 10 minutes, and 15 minutes. After switching off the flashlight, the photometer was placed on top of the samples after a 30-second interval.

Fig. 7. Photometer

Fig. 8. UV Flashlight

The Traffic Safety Division conducted an extensive review of the skid performance of commercially available RPMs. The study involved testing 14 different types of samples using the British Pendulum Number (BPN) test, as shown in Fig. 9. The researchers found that the RPMs exhibited an average skid resistance number (SRN) of 40, which falls below the desired value of 65. This lower SRN could potentially lead to loss of vehicle control when driving over the RPMs in wet and windy conditions.

Based on this information, the objective of the current study is to develop a GiD-based RPM that can perform better in SRN tests. To achieve this, the developed prototype was evaluated under three environmental conditions: (a) sandy, (b) wet, and (c) dry. The evaluation was conducted following ASTM E303-93(2018) standards (ASTM, 2018b). The purpose of the test was to assess the performance of the prototype under each weather condition while simulating speeds of up to 50 kph.

Fig. 9. Skid Resistance Number Tester

Fig. 10. ASTM D4280 Compressive Strength Machine

The developed GiD RPM prototype underwent fatigue testing according to the ASTM D4280 standard (ASTM, 2018a), as shown in Figure 13. The purpose of this test was to assess the performance of the prototype when subjected to flexural compressive loading caused by the passage of vehicle tires [34]. The objective was to simulate the real-world conditions in which the GiD RPM is exposed to compressive forces generated by passing vehicles.

During the test, the applied compressive force was gradually increased until the cracking condition was reached. This loading process aimed to replicate the field conditions and evaluate the prototype's ability to withstand the anticipated compressive loads experienced when vehicles pass over the GiD RPM. The test allowed for the assessment of the prototype's durability and its ability to withstand repeated loading cycles without significant damage or failure.

IV. Results and Discussion

Glow-in-the-Dark (GiD) testing was conducted on the Glow-in-the-Dark raised pavement markers, as shown in Fig. 11, to assess their glow duration and intensity. The results revealed that the GiD markers containing a 5% GiD component exhibited an average maximum intensity of 251.67 mcd/m^2 and a duration of 4 hours after the loss of luminosity. For the markers with a 10% GiD component, the average maximum intensity was 301.33 mcd/m^2, and they maintained their glow for 6 hours after the loss of luminosity. Lastly, the markers with a 15% GiD component had an average maximum intensity of 393.33 mcd/m^2 and a duration of 8 hours after the loss of luminosity.

The findings indicate that increasing the GiD component from 5% to 10% resulted in a 19.73% increase in intensity, while further increasing it from 10% to 15% led to a 23% gain in intensity. Moreover, the duration of emitting light from the GiD RPM significantly influenced the glow intensity. Previous studies have suggested that beyond a GiD component of 30.53%, the performance gains become negligible relative to the associated cost increase [34]. Therefore, it can be inferred that a GiD proportion of 15% is desirable in terms of achieving the desired glow intensity and duration.

Fig. 11. Glow-in-the-dark concrete topping-based road marking

During the analysis of light emission duration by the markers, it was observed that as the concentration of GiD increased from 5% to 15%, the duration of light also increased as shown in Fig. 12. Specifically, the markers with a 15% GiD concentration demonstrated the longest duration of light, lasting up to 8 hours. In contrast, the markers with a 5% GiD concentration had a shorter duration of light, with a maximum of 4 hours. This finding suggests that a higher concentration of GiD contributes to a more prolonged and sustained illumination, enhancing the overall effectiveness of the markers.

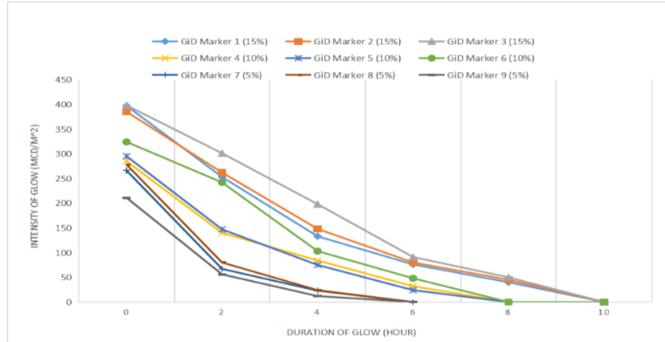

Fig. 12. Chart for Glow-in-the-Dark testing results

Skid resistance testing was performed to assess the performance of the Glow in the Dark (GiD) raised pavement markers (RPMs) under different environmental conditions. A total of three samples were tested for each condition. The skid resistance number (SRN) testing indicated that RPMs need to achieve a minimum SRN value of 65, as specified by the ASTM E303-93(2018) standard, to prevent vehicles from losing control in wet and windy conditions. The results obtained from the testing of the developed RPM prototype, presented in Table I, demonstrate its satisfactory performance across all weather conditions.

TABLE I. Skid Resistance Number Test at 50 kph

Trial	Wet (Skid Average)	Dry (Skid Average)	Sandy (Skid Average)
1	33.5	92.5	46.5
2	39	114.5	47.5
3	46	117	50.5

Fatigue testing was conducted on the Glow in the Dark (GiD) raised pavement markers to assess their durability under loading conditions. The tests were performed according to the ASTM C-39-M-01 standard, aiming to replicate the actual traffic-induced loading experienced by the markers. Table 2 provides a summary of the fatigue testing results, including the average maximum load capacity (kN) and the average maximum strength (MPa) required to induce failure.

TABLE II. Skid Resistance Number Test at 50 kph

Specimen	Average Maximum Load Capacity (kN)	Average Maximum Strength (MPa)
GiD Marker 5%	21.67	1.196
GiD Marker 10%	123.33	6.807
GiD Marker 15%	52.5	2.9

The majority of the GiD markers exhibited excellent fatigue resistance, demonstrating their ability to withstand significant forces before failure. Notably, the GiD marker with a concentration of 10% demonstrated the highest maximum strength. It is important to mention that this marker was the first specimen tested, and an adjustment was made during the fatigue test.

V. Conclusion

In conclusion, the study highlights the promising performance of Glow-in-the-dark (GiD) concrete topping-based road markings in improving road safety. The research demonstrates that the concentration of GiD in raised pavement markers significantly affects the duration and intensity of the emitted light, with higher concentrations resulting in longer and brighter illumination. However, it is important to consider environmental factors such as surface conditions, as the markers may experience reduced skid resistance in the presence of sand and water. The study also emphasizes the positive impact of higher GiD concentrations on fatigue resistance, allowing the markers to withstand greater loading before failure. Glow-in-the-dark concrete topping-based road markings show great potential in enhancing visibility and skid resistance, thereby improving safety on the roads, even in challenging weather conditions. Nonetheless, further research and real-world testing are needed to validate their performance and identify opportunities for further refinement.

Based on the findings, it is recommended that transportation agencies consider implementing Glow-in-the-dark concrete topping-based road markings as a viable solution to enhance road safety. These markings can offer improved visibility and skid resistance, particularly in low-light conditions and adverse weather. However, it is crucial to conduct additional field trials to evaluate their performance in real-world scenarios and assess their long-term durability. Furthermore, collaboration with manufacturers and suppliers is advised to optimize the GiD concentration and develop standardized guidelines for installation and maintenance. Continuous monitoring and evaluation of these markers' performance are also recommended to ensure their effectiveness and address any potential challenges that may arise. By embracing these recommendations and investing in further research, transportation agencies can enhance road safety and provide safer driving experiences for motorists.

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