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A review on light-emitting concrete using waste glass aggregates: Progress, potential, and challenges

Nguyen Thanh Van [2,3], Huynh Tan Phat [2,3], Huynh Dac Tin [1,3], Nguyen Ngoc Tri Huynh [1,3*]

[1]Department of Silicate Materials, Faculty of Materials Technology, Ho Chi Minh City University of Technology (HCMUT)

[2]Department of Engineering Drawing, Faculty of Civil Engineering, Ho Chi Minh City University of Technology (HCMUT)

[3]Vietnam National University Ho Chi Minh City

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ABSTRACT

Light-emitting concrete (LEC) has recently gained significant attention as a multifunctional construction material that integrates sustainability, energy efficiency, and aesthetics. By incorporating phosphorescent powders and recycled waste glass aggregates, LEC not only emits light in dark environments but also promotes circular economy practices through the reuse of post-consumer glass. This review provides a comprehensive overview of the current research landscape surrounding LEC, including its historical development, material composition, fabrication methods, optical and mechanical properties, practical applications, and environmental benefits. Special emphasis is placed on recent innovations and experimental findings in Vietnam, where local materials and techniques have been adapted to optimize performance. Challenges such as alkali-silica reaction, durability of luminescent compounds, and the absence of standardization are critically discussed. Finally, future research directions are proposed, including smart integration with energy systems and potential for self-sensing or self-healing capabilities. The findings suggest that LEC represents a promising solution for sustainable urban development, particularly in contexts requiring low-energy illumination and resource reuse.

1. Introduction

As cities become smarter and sustainability becomes central to construction practices, light-emitting concrete (LEC) has emerged as a promising material for combining structural performance, aesthetic enhancement, and energy efficiency. LEC, typically made by incorporating phosphorescent materials into a cementitious matrix, offers the ability to absorb and re-emit light in the dark, enhancing visibility in low-light environments without relying on external energy sources. When combined with recycled waste glass as aggregate, LEC contributes further to green construction efforts by diverting waste from landfills and reducing reliance on natural aggregates. This review provides an overview of the development, characteristics, applications, and challenges of LEC, with a particular focus on its integration with waste glass and research progress. This paper aims to synthesize recent findings and identify current gaps in research, particularly those relevant to Vietnam's construction context.

2. Historical background and development

Luminous concrete or LEC was first introduced as an innovative material combining photoluminescent compounds, such as strontium aluminate with traditional cementitious matrices [1–4]. The idea gained momentum alongside advances in phosphorescent pigments and increasing global attention to sustainable building materials. Early implementations focused on decorative and safety features, but more recent studies have explored its structural performance and environmental benefits [5, 6]. The use of glass in concrete can be traced back to the 1970s, but the integration of glass waste with photoluminescent additives is a relatively recent development [7, 8]. Researchers have demonstrated that crushed glass, when processed and graded correctly, can act as either fine or coarse aggregate and significantly influence both the mechanical and optical behavior of LEC [9].

3. Material composition and fabrication techniques

LEC typically consists of Portland cement, phosphorescent powder (commonly strontium aluminate doped with rare-earth elements), and recycled waste glass aggregates (Fig. 1). Additional components may include pozzolanic materials, admixtures like superplasticizers, and mineral fillers [10]. Glass aggregates not only contribute to the sustainability of the mix but also enhance light transmission and distribution within the concrete. However, challenges such as the risk of alkali-silica reaction (ASR) and mechanical incompatibility between glass particles and the cement paste must be addressed. In some studies, microbial-induced calcium carbonate precipitation (MICP) has been used to coat glass particles

*Corresponding author: nnthuynh@hcmut.edu.vn
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with a protective calcite layer, improving interfacial bonding and mitigating ASR [11, 12].

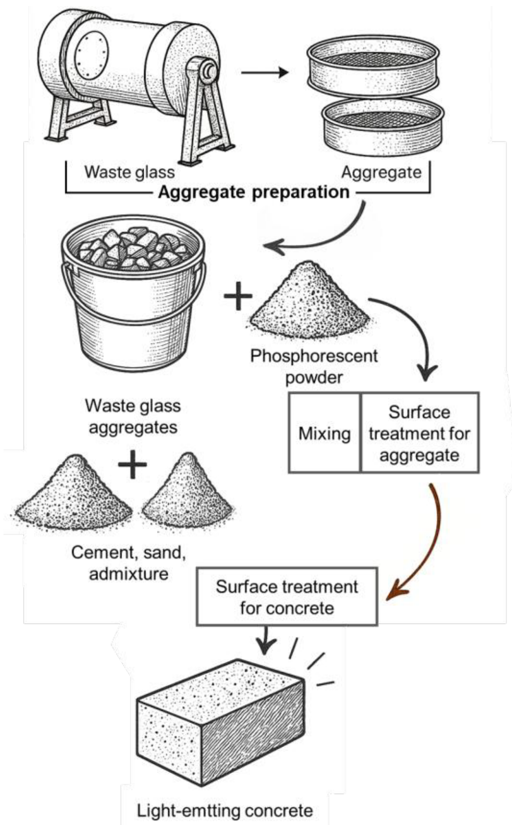

Figure 1. Fabrication process of light-emitting concrete using waste glass aggregates and phosphorescent powder.

Mixing methods and curing regimes are also critical. Uniform dispersion of phosphorescent particles and appropriate curing ensure adequate activation of luminescent properties and sufficient mechanical strength. In Vietnam, recent experimental research has highlighted how optimizing the particle size distribution of glass and surface treatment with MICP significantly prolongs light emission and enhances concrete integrity.

4. Optical and mechanical properties

The performance of LEC is primarily evaluated through its light emission intensity and duration, as well as traditional mechanical metrics such as compressive strength. The photoluminescent effect depends on the quality, concentration, and distribution of the phosphor, while emission duration tends to decrease with age due to environmental degradation and hydration product evolution [13–15]. Studies show that combining multiple sizes of glass aggregates results in denser packing and smoother surface finishes, which not only improve the aesthetic and optical response but also reduce voids, enhancing compressive strength.

Despite a slight reduction in strength compared to conventional concrete due to the lower mechanical performance of glass particles, optimized mix designs can meet structural requirements for non-load-bearing and decorative applications.

5. Applications in practice

LEC incorporating waste glass aggregate presents diverse applications, combining utility with aesthetics. To better organize and avoid repetition, the following subsections detail its main areas of use:

5.1. Construction and infrastructure

One of the most direct and practical uses of luminous concrete is in infrastructure particularly highways, bike paths, and pedestrian walkways. By providing low-level, sustained illumination after dark, this material improves safety for both vehicles and pedestrians without relying on conventional lighting systems. This is especially beneficial in areas with limited electricity access or where reducing light pollution is desirable [16–18]. For example, luminous concrete has been employed in highway expansion and emergency reconstruction projects.

5.2. Architectural and urban design

In architecture, luminous concrete offers designers a dynamic material for façades, interior surfaces, and landscape installations. The glow-in-the-dark effect adds visual interest and supports nighttime navigation. Applications include building skins that absorb sunlight by day and emit it by night, enhancing both form and function. Public spaces benefit as well, with glowing paths and edges that improve accessibility and orientation in low-light conditions [19, 20].

5.3. Decorative and landscape use

Beyond its structural role, luminous concrete also serves decorative purposes. Its integration into garden features, park furniture, and artistic elements can create visually engaging nighttime environments. For instance, concrete with embedded phosphorescent materials can highlight steps, planters, or gathering areas, contributing to both ambiance and safety. These elements are durable and require minimal maintenance, thanks to the longevity of modern photoluminescent pigments.

6. Environmental and sustainability considerations

Incorporating recycled glass helps reduce landfill waste and conserves natural aggregates. LEC contributes to energy savings by reducing the need for street lighting and offers low-maintenance, long-lasting light emission capabilities [22]. The environmental benefits are amplified when phosphorescent additives and recycled components are selected and processed with minimal carbon footprint. In Vietnam, growing interest in green building certification systems (e.g., LOTUS, EDGE) creates opportunities for LEC to be recognized as a value-adding material. Current efforts focus on optimizing waste glass preprocessing, developing local phosphor alternatives, and studying long-term durability in tropical climates.

7. Challenges and mitigation strategies

Despite the considerable progress in the development of LEC using waste glass aggregates, several technical and practical challenges remain. One of the most critical issues is the risk of ASR due to the high silica content of glass. ASR can cause expansion, cracking, and deterioration of concrete, significantly reducing its long-term durability. Addressing this issue requires a deeper understanding of the chemical interactions between alkalis in cement and reactive silica in aggregates, particularly under humid or wet conditions.

7.1. Addressing alkali-silica reaction

ASR is a well-known durability concern in concrete containing reactive silica-rich aggregates like recycled glass. In LEC, the use of uncoated glass particles can increase susceptibility to ASR, leading to premature cracking and strength loss. Traditional mitigation techniques include the use of pozzolanic additives like fly ash or slag to reduce available alkalis. However, these methods may not always be effective in aggressive environments.

7.2. MICP treatment for ASR prevention

Recent studies have explored the use of MICP as a novel treatment method to prevent ASR. MICP involves the use of bacteria such as Sporosarcina pasteurii, which induce calcium carbonate formation on aggregate surfaces through metabolic processes like urea hydrolysis. This calcium carbonate layer acts as a physical and chemical barrier, reducing the reactivity between the glass surface and cement paste. Experimental results in Vietnam have shown that MICP-treated glass aggregates significantly reduce ASR-induced microcracking and enhance the bond at the aggregate-paste interface (Fig. 2).

Integrating MICP into the concrete production process requires consideration of bacterial viability, uniform distribution, and curing conditions. Researchers have proposed protocols involving the pre-treatment of glass aggregates with bacterial solution and nutrients prior to mixing. This process promotes early calcite precipitation and strengthens the interfacial transition zone (ITZ). Moreover, MICP contributes to self-healing capabilities, as dormant bacteria can be reactivated upon crack formation, leading to in-situ crack sealing through continued calcite deposition.

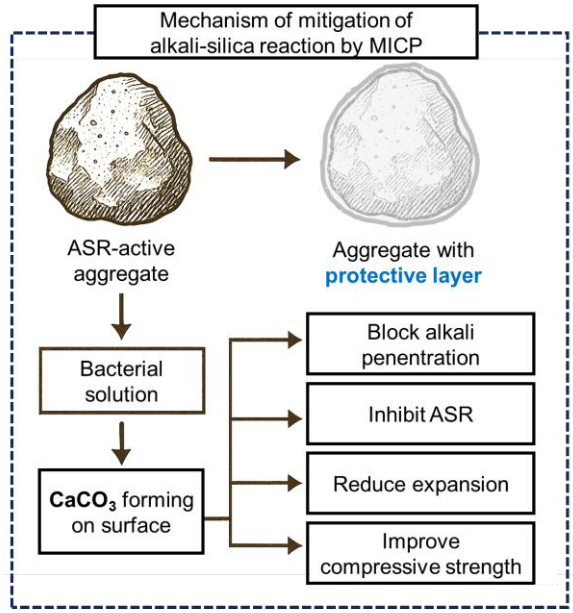

Figure 2. Mechanism of mitigation of alkali-silica reaction by MICP.

7.3. Durability of luminescent components

Another challenge is the long-term durability of photoluminescent powders. Exposure to moisture and ultraviolet (UV) light can degrade the luminescent intensity over time. Protective coatings or encapsulation techniques are being developed to extend the life of these materials when embedded in concrete. Moreover, uneven dispersion of phosphor can cause inconsistent lighting performance across the surface.

7.4. Lack of standardization and high production cost

Standard testing protocols for evaluating the optical performance and ASR resistance of LEC are still under development. This lack of standardization creates barriers to widespread implementation. Additionally, the higher cost of photoluminescent pigments and MICP processing remains a concern, particularly for large-scale applications. Research into local sourcing of materials and optimization of mix design is ongoing to improve cost-effectiveness.

8. Future directions

Emerging trends in LEC research include the development of smart sensing features, integration with fiber optics, and compatibility with self-healing concrete technologies. There is also growing interest in using LEC for climate-responsive design, integrating it with solar energy systems or as part of passive lighting strategies in green buildings. In Vietnam, collaborations between academic institutions and construction firms are beginning to form around circular economy goals, positioning LEC as both a functional and symbolic material of sustainable innovation.

LEC using waste glass aggregates represents a convergence of sustainability, material innovation, and functional design. While challenges related to durability, standardization, and cost remain, the progress in material science, particularly in Vietnam, points toward a bright future for this technology. Continued interdisciplinary collaboration and real-world deployment will be key to unlocking the full potential of LEC in the context of modern urban development.

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