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Advancements and research in modern wall materials

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Abstract. Wall structures are commonly seen in everyday life, with brick masonry and concrete being the most frequently used materials. However, in the face of natural disasters such as earthquakes, floods, or other extreme situations, these buildings may collapse, leading to serious casualties and significant property damage. This paper aims to discuss the research and development of new wall materials and explore the compressive strength and seismic performance of modern wall materials in natural disasters. It is found that modern wall materials have witnessed significant improvement in seismic performance, making them especially suitable for meeting lighting needs during nighttime earthquakes. The research and development of self-luminous Glass Fibre-Reinforced Plastic (GFRP) composite materials can provide lighting during power outages, enhancing residents' sense of security. In addition, inspired by bioluminescence, specifically the light-emitting mechanism of fireflies, a new type of self-luminous material has been developed through the reaction between luciferin and luciferase. It offers an environmentally friendly and efficient lighting solution during blackouts.

Keywords: wall, seismic resistance, luminous material

1. Introduction

Walls are among the most essential components of buildings. Their quality has a direct impact on the overall safety and durability of a structure. However, traditional wall materials have exhibited various shortcomings under special circumstances. For instance, rural tile-roofed houses in the past typically suffered severe damage during a magnitude 2 earthquake, making them almost uninhabitable. According to design principles, buildings should withstand major earthquakes without collapsing, sustain only repairable damage during moderate quakes, and remain undamaged in minor tremors. Moreover, due to rainwater erosion, many walls have begun to show signs of decay, indicating poor waterproofing performance and reflecting inadequate corrosion resistance [1]. In addition, most walls are made of brick masonry, which has low compressive, tensile, and shear strength, as well as poor ductility. Under seismic forces, shear diagonal cracks or X-shaped cracks often appear below windows or across entire wall sections. Severe damage can also occur at other locations, such as column heads and column bases, detracting from the appearance of buildings. Hence, it is necessary to develop new wall materials with enhanced seismic resistance, durability, corrosion resistance, waterproofing, and environmental friendliness.

Traditional wall materials, including clay bricks, concrete blocks, and gypsum boards, have long been used in construction but exhibit notable limitations such as poor thermal insulation and insufficient seismic resistance. In contrast, modern wall systems increasingly adopt lightweight and prefabricated materials, which provide advantages in seismic performance, reduced structural footprint, lower carbon emissions, and enhanced architectural aesthetics. Recent advancements have further expanded the functionality of wall materials. For example, Phelan [2] demonstrated that Glass Fibre–Reinforced Plastic (GFRP) composites can be engineered with self-luminous properties that remain stable under varying humidity, temperature, and ultraviolet exposure, while posing no harm to human eyes or contributing to light pollution. Such luminescent walls may also help mitigate psychological distress after earthquakes by providing calming illumination. In parallel, Terlizzi [3] highlighted the superior mechanical strength, thermal efficiency, and sustainability of innovative GFRP applications in curtain wall systems, underscoring their potential as advanced wall materials that integrate structural safety, environmental responsibility, and user-centered design.

Given this research context, this paper aims to compare the advantages and disadvantages of both traditional and modern wall materials. Meanwhile, to respond to disasters such as nighttime earthquakes, it puts an emphasis on the luminous function of the new-type, modern wall material. It is expected that this study can promote innovation in architectural design and construction through the discussion of safer wall materials in the architecture industry.

2. Evolution process of building materials for walls

2.1. The primitive stage

In primitive society, humans primarily lived in caves or nests, and the building materials they used were mostly natural. For example, they dug into the earth or carved stone to create shelters, and constructed huts using felled trees and bamboo. Materials such as soil, wood, stone, and thatch were among the earliest wall materials. Soil could be directly used to build simple earthen walls; wood was used to create fences or serve as a structural framework; and stone was stacked to form stone walls. These materials were relatively easy to obtain and met basic living needs. However, they exhibited low durability and stability.

2.2. The stage of brick and stone application

The stage of brick and stone application in ancient China marked a significant transition in construction technology, characterized by the widespread use of fired clay products and innovative binding materials. As early as the Western Zhou period, ridge tiles and flat tiles were produced from clay, and by the Warring States period, fired bricks had emerged as durable and weather-resistant building units. Their adoption not only improved the structural longevity of walls, city defenses, and monumental architecture but also set the foundation for the flourishing of masonry techniques in subsequent dynasties. Parallel to the evolution of bricks and tiles, the development of binding agents played a decisive role in ensuring the integrity of brick-and-stone constructions. Lime was introduced during the Zhou Dynasty and became widely applied in monumental projects such as the Great Wall across the Qin, Han, and Ming periods. More significantly, sanhetu, a composite material composed of lime, sand, and clay—often reinforced with organic additives like sticky rice or egg white—appeared during the Northern and Southern Dynasties and gained extensive use from the Han Dynasty onward. Dai et al. [4] emphasized that sanhetu possessed excellent waterproofing, high strength, and long-term durability, enabling its application in city walls, bridges, tombs, and even rammed-earth dams during the Qing Dynasty. This combination of fired bricks, stone masonry, and advanced binders represented a mature stage of construction that greatly enhanced both the structural stability and functional resilience of ancient Chinese buildings.

2.3. The stage of conventional wall materials development

Traditional blue bricks were widely used in China before the mid-nineteenth century, being recognized for their relatively high strength, durability, and visually appealing appearance. The Nanjing Ming City Wall, the world's longest, largest, and best-preserved Ming-era city wall, stands as a representative example, showcasing the extensive application of blue bricks in walls, floors, and roofs [5]. With the advent of red bricks—primarily made from clay and fired through simpler, lower-cost techniques—construction practices shifted in modern times. Red bricks, characterized by good thermal insulation properties and moderate strength, became widely adopted in wall construction for various types of buildings. Aesthetically, the warm tones of red bricks blend harmoniously with loess landscapes, whereas the elegant tone of blue bricks complements distant greenery, reflecting the distinct visual qualities of both materials [5].

2.4. The stage of new-type wall materials development in modern construction

Since the 20th century, concrete blocks have gradually become an important wall material. Concrete blocks are block-shaped materials mainly made from cement, sand, and gravel through the process of mixing, molding, and curing. This type of material possesses advantages such as high strength, good durability, and ease of construction, and is widely used in non-load-bearing and load-bearing walls of a building. Panelling materials have developed, including fiber-reinforced calcium silicate boards, glass fiber-reinforced lightweight porous cement partition strips, autoclaved aerated concrete panels, gypsum wallboards, metal-faced sandwich panels, and others. These materials are lightweight, thermal insulation, soundproofing, and fire-resistant, accelerating the construction process and increasing the level of industrialization [6].

New types of brick materials have emerged, such as porous bricks, hollow bricks, autoclaved sand-lime bricks, and autoclaved fly ash bricks. While maintaining a certain level of strength, these materials reduce weight and improve thermal insulation performance, contributing to energy and resource conservation.

Environmentally friendly and energy-saving materials have been applied. As people's requirements for environmental protection and energy efficiency are becoming stricter, new types of environmentally friendly and energy-saving materials have constantly emerged, such as wall materials made from industrial waste, construction debris, and other discarded materials, as well as new types of composite materials with good thermal insulation performance.

3. Analysis of luminous walls

3.1. Case analysis

In recent decades, multiple earthquake events, including the Tangshan earthquake, the Wenchuan earthquake, and the recent earthquake in Dingri County, Xizang, have indicated that the seismic performance of wall structures is of great importance. Compared to traditional brick masonry, modern wall materials demonstrate better seismic performance and can satisfy the requirement of withstanding major earthquakes without collapsing, sustaining only repairable damage during moderate quakes, and remaining undamaged in minor tremors. The GFRP composite materials demonstrate excellent tensile strength, shear resistance, and corrosion resistance. Stretched or extruded GFRP materials can replace steel reinforcement in reinforced concrete, as well as in roof structures and bridge construction, thereby reducing the need for reinforcing bar (rebar) and enhancing load-bearing capacity and durability of the structure [7].

Conventional lighting methods, such as flashlights and mobile phones, have limited battery life. When nighttime earthquakes cause power system failures, the limitations of conventional lighting methods would affect residents' movements and rescue efficiency. Therefore, in the event of a power outage, walls can provide basic lighting if they are coated with a new material that has self-luminescent properties. It plays a more effective role, especially in special settings such as tunnels.

3.2. Fabrication and application of self-luminescent GFRP composite materials

GFRP composite material is expected to see increasingly widespread use for its properties of lightweight, high strength, corrosion resistance, and fatigue resistance. It can reduce costs while improving efficiency. Meanwhile, this new type of material is environmentally friendly because of its low energy consumption and low carbon dioxide emissions. According to Phelan et al., even when reaching the usable limit, it does not cause damage to mechanical loads, and the structural integrity of this multifunctional design is ensured. The fabrication of self-luminous GFPR composite material can be carried out using wet layup, vacuum molding, injection molding, filament winding, pultrusion, and other methods. The material uses epoxy resin R180 as the matrix, with an appropriate amount of hardener and luminescent powder added. Figure 1 shows the typical Scanning Electron Microscope (SEM) image of self-luminous powders.

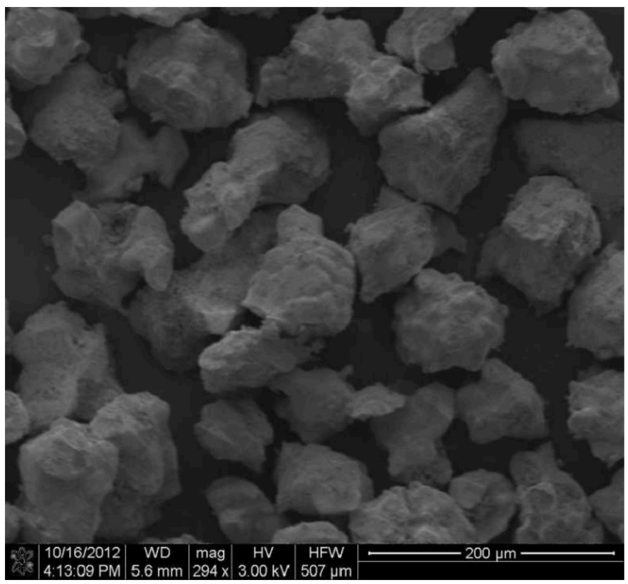

Figure 1. SEM image of self-luminous powders

An essential component for achieving self-luminescence is the use of self-luminous powder as an additive in the matrix system [8]. The powder is a crystalline aluminate compound with a specific gravity ranging from 0.25 to 3.6 g/cm^3. The particle size is selected based on the specific requirements of each region and wall application, and the size range is carefully controlled. To achieve sufficient brightness and reduce fading time, the self-luminous powder must be thoroughly mixed with the epoxy resin at an appropriate percentage to achieve sufficient brightness and reduce fading time. Over time, the brightness gradually decreases as the material is left unused.

This function is relatively new for GFRP composite material. Therefore, relevant research on the material strength, luminous intensity, and duration of illumination is limited. By leveraging the properties of modified translucent resin and glass fibers, the resulting GFRP components or structures can function at night without the need for external lighting. In the daytime, self-luminous powders under the protection of resin are exposed to the sunlight, absorbing solar energy. At night, the energy stored in the material is released in the form of light. During the wet layup process, the fibers are well encapsulated by the epoxy resin and, with the presence of the self-luminous lens, maintain a good distance from other potentially interfering components. These particles appear to be insufficiently embedded within the epoxy resin and tend to accumulate selectively in specific regions of the glass fibers. The ultimate goal of self-luminous wall materials is to release light in the event of a power outage, enhancing residents' convenience. The appearance is visually pleasing. The emitted light causes no harm to human eyes and provides a comfortable visual experience.

3.3. Principle and application of bioluminescence

The major principle behind firefly bioluminescence is that luciferin undergoes an oxidation reaction with oxygen, catalyzed by the enzyme luciferase, releasing light energy. At the tip of a firefly's abdomen, there are light-emitting organs filled with phosphorus-containing luminescent substances and enzymes. When the firefly breathes, luciferin reacts with the inhaled oxygen to form luciferase. These phosphorus-containing substances and enzymes produce a faint, flashing light in the abdomen, making the firefly resemble a tiny glowing bulb. Therefore, referring to the lighting mechanism of fireflies, luciferase can be mixed with building materials in a certain proportion to fabricate a new type of self-luminous material, providing an environmentally friendly and efficient lighting solution for power outages (see Figure 2).

The chemical reaction of firefly bioluminescence can be presented as follows:

$$Luciferin + ATP + O_2 \rightarrow Oxyluciferin + AMP + PPi + light \quad (1)$$

The lighting process is highly efficient, and almost all of the energy is released in the form of light, with only a small portion converted into heat. This reaction is up to 95% efficient, preventing the firefly from overheating during light emission. In addition, the firefly's light organ contains a reflective layer that amplifies the brightness, making its flashes more noticeable.

Figure 2. Effects of mixing luciferase with wall materials

4. Discussion

This paper mainly discusses the limitations of conventional wall materials, including issues of insufficient seismic strength, low tensile, bending, shear, flexural, torsional, and compressive strengths, as well as poor corrosion resistance. Following this, a new type of wall material with a self-luminous property is introduced, aiming to provide lighting for residents in the event of power outages. Meanwhile, the material is both visually appealing and harmless, causing no harm to human eyes. However, it is worth noting that different types of wall materials vary in load-bearing capacity, so careful consideration is needed when determining the amount of material to use.

This new type of wall material is made from translucent resin, glass fiber layers, and self-luminous powder. Compared to conventional wall materials, it demonstrates superior corrosion resistance and can maintain its ability to emit light at night even during earthquakes. Additionally, the application of wet layup has allowed self-luminous GFRP composites to be produced without compromising their load-bearing capacity. However, whether using firefly luciferase or GFRP composites, the proportion of materials must be strictly controlled. At the present stage, both self-luminous materials remain insufficient in luminescence duration, which urgently needs to be extended through technological improvements.

5. Conclusion

This study has traced the historical evolution of wall materials from primitive natural resources to brick-and-stone masonry, conventional bricks, and the emergence of modern lightweight and composite systems. While traditional materials such as clay bricks and concrete blocks have long served as the backbone of construction, their limitations in seismic resistance, durability, and environmental performance highlight the urgent need for innovation. The comparative analysis demonstrates that modern wall materials—particularly Glass Fibre–Reinforced Plastic (GFRP) composites—offer significant improvements in structural strength, corrosion resistance, and sustainability.

A distinctive advancement is the integration of self-luminescent functionality into wall materials. Inspired by both engineered GFRP composites and the natural mechanism of firefly bioluminescence, these new systems can provide stable illumination during nighttime power outages caused by earthquakes or other disasters. Beyond enhancing safety and rescue efficiency, such luminescent walls contribute to psychological comfort and resilience in post-disaster environments.

Nevertheless, challenges remain. Current luminous materials face limitations in brightness duration, uniformity of luminescence, and scalability of fabrication. Moreover, the balance between mechanical load-bearing performance and optical properties requires further refinement. Future research should therefore focus on optimizing material composition, extending luminescence persistence, and validating large-scale applications in real-world seismic scenarios.

Overall, the advancement of self-luminous wall materials represents not only a technological innovation but also a paradigm shift toward multifunctional, disaster-resilient architecture. By merging structural safety, environmental sustainability, and human-centered design, these new materials hold promise for shaping the next generation of wall systems that safeguard both lives and living quality in the built environment.

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