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Study on properties and mechanisms of luminescent cement-based pavement materials with super-hydrophobic function

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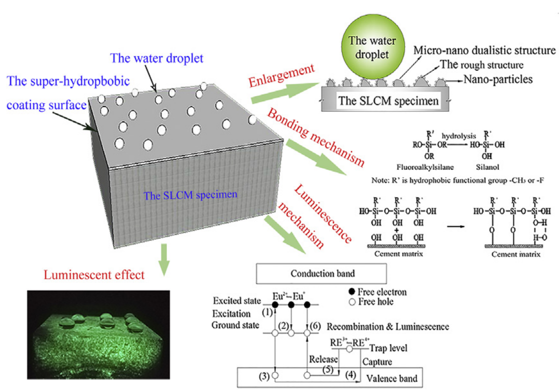
HIGHLIGHTS

- The luminescent cement-based pavement materials with super-hydrophobic function were prepared.
- The luminescent properties and hydrophobicity of SLCPM were studied via a series of tests.
- The practical application test were carried out in outdoor environment.
- Microcosmic appearance, luminescent and hydrophobic mechanism were analyzed theoretically.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, super-hydrophobic and luminescent cement pavement materials (SLCPM) were prepared, and the effects of the long afterglow luminescent materials and hydrophobic materials on luminescent properties and hydrophobicity of SLCPM were investigated. The results indicated that the mechanical performance of SLCPM was improved with the addition of luminescent powder (LP), but the opposite was true for the addition of reflective powder (RP). The superior luminescent properties of SLCPM could be found when the content of the LP was about 25% and the optimum content of the RP was maintained at 10%. The initial brightness could reach 96.56% of the maximum initial brightness after lighting for 30 min, which have more stable long afterglow performance and higher identification. The super-hydrophobic surface coating has excellent stability, self-cleaning performance and long-term stability, which can effectively reduce the liquid infiltration. After the test was finished, the surface contact angle and rolling angle could still reach 152.2° and 5.4°, respectively. It is concluded that doping appropriate LP can not only optimize the distribution of hydration products, but also improve compactness and initial brightness of SLCPM; while doping a large amount of RP can obviously reduce its strength due to its reaction with hydration products. These obtained results would provide a new thought on the design of the road pavement in low lighting environment.

1. Introduction

The long afterglow luminescent materials have attracted great interest with their potential application in various fields, including emergency lighting of low brightness, decorative landscaping and

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indicator due to some certain characteristics such as high brightness, long afterglow time, stable chemical performance and no pollution of radioactive. The continuous development of luminescent materials gives the scientists of cement-based materials a glimmer of hope to invent a type of luminescent cement-based materials which can storage energy during in the daytime and luminous at night [1,2].

The long afterglow luminescent materials can be classified into sulfide, aluminate, silicate and other matrix types according to its developing process and different matrix [3,4]. Recently, a large amount of results have been drawn from the researches to investigate the characteristics of the materials. The red emission came from the (Ca, Zn)TiO_3: Pr^{3+} phosphor is quite stable and long for a dark-adapted human eye, and shows no appreciable degradation in the optical properties when is prolonged exposed to surrounding [5,6]. Some researchers have been devoted to investigate the long afterglow luminescent materials $Sr_3Al_2O_6$: Eu^{2+}, Re^{3+} (Re = La, Ce, Pr, Nd, Sm, Gd, Dy, Er) via X-ray diffraction and fluorescence spectrophotometer and it has been found that the Eu^{2+} ions are easier to occupy low-coordination crystallographic site [7,8]. Some scholars have also focused on the photoluminescence properties of the long-lasting phosphorescence materials co-doped Eu^{2+} and Dy^{3+}, and the results show that Dy^{3+} exists in the phosphors under continuing excitation at 175 nm [9,10].

The incorporation of several kinds of functional material as an alternative component in cement-based materials is one of the most important methods for improving its actual performance [11–13]. As a type of emerging special materials, the long-lasting luminescent materials and super-hydrophobic materials have become the international research focuses and frontiers in the field of high technology and new materials [14,15]. The development of luminescent materials extensively utilized in daily life has made considerable progress in the field of building materials, especially the construction materials with luminescent applications, such as luminescent paint, luminescent glass, luminescent ceramics, luminescent gypsum and emergency signs [16–20]. Meanwhile, super-hydrophobic materials have been increasingly applied in many industries as surface functional treatment materials relying on the characteristics of excellent hydrophobicity, anti-icing and self-cleaning performance [21–29]. Numerous researches indicated that the surface hierarchical micro-and nano-structure of lotus leaves can not only drain away water, but also remove dust from the surface, thereby keeping the surface of the lotus leaves clean at any time, which is called "lotus effect" [30–34]. An early study found that the self-cleaning feature is caused by the presence of micro papillary structure on rough surfaces, waxy materials with a hydrophobic surface and nano-structures, and the water has a larger contact angle and a smaller rolling angle on this super-hydrophobic surface [35–42].

Several researches have offered a new thought of material anti-icing research by coating with low surface energy materials on the rough surface to prepare super-hydrophobic coatings [43–45]. Some scholars have applied super-hydrophobic materials to the pavement, and it was found that using super-hydrophobic materials could prolong the icing time and reduce the bonding strength between ice and road [46,47]. Ding et al. [48] prepared a type of super hydrophobic polysiloxane/TiO_2 nanocomposite coating with excellent durability in various environments, which can be used for large-scale fabrication of self-cleaning coatings for practical applications. Nishimoto et al. [49] built super-hydrophobic surfaces using dip-coating technology on a wide variety of substrates such as glass and the obtained surfaces had the advantages of good abrasion resistance and high transparency, which was suitable for the surface of various materials required high transmittance. Moreover, Hejazi et al. [50], Menini et al. [51] and Arabzadeh et al. [52,53] evaluated the performance of super-hydrophobic and anti-icing of cement concrete pavement and asphalt concrete pavement, respectively; and the results indicated that the spray time and content of super-hydrophobic had an obvious effect on icephobic, superhydrophobic and skid resistance of pavement, and the given results proved that the performance of pavement deicing and anti-freezing could be achieved.

Currently, although the long afterglow luminescent materials and super-hydrophobic materials have been increasingly employed in the industrial applications owing to their excellent properties, and several researches have been undertaken to establish influence toward their luminescent properties and hydrophobicity, few have been utilized in road cement-based materials. The SLCPM specimens were produced by the cooperation of binary structures of luminescent materials and hydrophobic materials at the micro and nanometer scales in this study, which can not only keep more stable long persistence performance, but also keep good self-cleaning performance to prevent water and dust from polluting. After that, the luminescent properties and hydrophobicity of SLCPM co-doped LP and RP and coated different types of hydrophobic materials were studied. Finally the mechanisms were analyzed with a scanning electron microscope (SEM) analysis and spectral analysis. Obtaining super-hydrophobic and luminescent cement-based pavement materials would be a promising technology to solve traffic safety problems caused by the sudden power cut in the tunnel, airfield runway or other important places, and provide a good direction to improve the performance of emerging road building materials.

2. Materials and methods

2.1. Raw materials

- Cement (C): white Portland cement, P·W42. 5, produced in Albo Portland Co. Ltd. Its basic physical properties are shown in Table 1.
- Luminescent powder (LP): rare earth kelly luminescent powder produced by Guangzhou Zhongming Chemical Technology Co. Ltd. Its main components are $SrAl_2O_4$: Eu^{2+}, Dy^{3+}. The afterglow time visible to the human eye is more than the minimum brightness of 0.32 cd/m^2 up to 8 h, specification for 600 meshes.
- Reflective powder (RP): also called phosphors, gray reflective powder produced by Guangzhou Zhongming Chemical Technology Co. Ltd. The main chemical composition is SiO_2. Specification for 200 meshes.
- Water reducing agent: high efficient naphthalene water reducing agent, which is brown yellow powder. The main performance indicators are shown in Table 2.
- Hydrophobic materials: hydrophobic fluoro silanes, colorless transparent Liquid, produced by Shenzhen Bao Shunmei biotechnology Co. Ltd.
- Ethanol: commercially available industrial analytical pure. The main parameters are shown in Table 3.

Table 1
The basic properties of white cement.

Indexes	Standard value [54]		Measured value	
	3 d	28 d	3 d	28 d
Flexural strength/MPa	3.5	6.5	5.9	8.7
Compressive strength/MPa	17.0	42.5	25.2	47.8
Fineness/%	≦10		0.3	
Specific surface area/$m^2·kg^{-1}$	/		460	
Initial setting time/min	≧45		140	
Final setting time/min	≦600		190	
Whiteness	≧87		89	