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The study of an energy efficient cool white roof coating based on styrene acrylate copolymer and cement for waterproofing purpose—Part I: Optical properties, estimated cooling effect and relevant properties after dirt and accelerated exposures

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HIGHLIGHTS

- The addition of Altiris 800 greatly increases the NIR reflectance of the coating.
- The cool white roof coating can reduce the roof surface temperature by 30.8 °C.
- The low Tg of the binder endows the cool coating with moderate dirt resistance.
- Artificial accelerated weathering reduces the solar reflectance of the coating.
- The inferior weather resistance is due to the presence of C=C in the polymer chains.

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ABSTRACT

The composition and the preparation process of a bi-functional cool white roof coating based on styrene acrylate copolymer and cement that integrates both a good cooling effect and good mechanical properties and water impermeability are introduced. Its optical properties, cooling effect and relevant properties after dirt and accelerated exposures are systematically explored. Compared with the conventional polymer-modified cement-based waterproof coating, the cool white roof coating based on styrene acrylate copolymer and cement has a much higher solar reflectance due to the presence of the titanium dioxide rutile and Altiris 800, and it can significantly reduce the coating surface temperature. The sticky nature of the high elastic styrene acrylate copolymer emulsion makes it easy for the cool white roof coating based on styrene acrylate copolymer and cement to collect pollutants and thus endows the coating with moderate dirt resistance. Four hundred hours of artificial accelerated weathering decreases the solar reflectance of the cool white roof coating based on styrene acrylate copolymer and cement and the cooling effect of the coating. The artificial accelerated weather resistance of the cool white roof coating based on styrene acrylate copolymer and cement is qualitatively good.

1. Introduction

Concrete is one of the most widely used construction materials in modern construction [1,2] because of its good reliability and durability [3]. It is inherently a porous material [3–6], and its surface inevitably contains micro-pores, micro-voids and micro-cracks [3,4,7]. These structural defects provide easy paths for water penetration into the interior of the concrete [4,7].

Under alkaline conditions, carbon steel reinforcements embedded in concrete structures are in a passive condition. They are not corroded by the penetrating water because the inherently high alkalinity of concrete promotes the formation of a thin protective oxide layer (the so-called passive film) on the rebar surface [3,8–10]. However, once the passive layer is destroyed, corrosion occurs in the presence of water and oxygen on the metal surface [9].

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Depassivation is mainly caused by concrete carbonation and chloride ions [3,8], and water is the main vehicle for the penetration of water-dissolved carbon dioxide and chloride [5,11]. Moreover, water is also a carrier for other aggressive agents such as sulfate and sulfur dioxide [11]. In addition, water is the major factor responsible for the development of alkali aggregate reactions and phenomena such as the deterioration caused by freeze/thaw cycles [5]. Basically, most reinforcement corrosion and the consequent deterioration of reinforced concretes structures are caused by water. The deterioration of reinforced concrete structures has become a worldwide problem in the last few decades. Substantial resources are used to repair and rehabilitate the decayed structures. In some cases, the cost of repair even exceeds the initial investment [1,12–15]. Therefore, there is a clear need to prevent the deterioration of reinforced concrete structure using waterproofing materials.

Many waterproof materials can provide an effective and efficient protection for concrete from the penetration of water and thus enhance its long-term durability; among these, polymer-modified cement-based waterproof coatings are widely used in indoor and outdoor concrete due to the combined advantages of the hard, durable inorganic hydrated cement and the flexible and elastic polymer [8,9,14,16].

One of the main components of the polymer-modified cement-based waterproof coatings is cement. As shown below, even white cement absorbs strongly throughout the solar spectrum. When used as filler, it is effective in decreasing the solar reflectance of the resultant waterproof coating. Consequently, painting the exterior of buildings with polymer-modified cement-based waterproof coating necessarily results in higher building surface temperatures, which increase the building heat gain and the energy consumption for cooling in summer. Therefore, from the stand point of building energy efficiency, it is of utmost importance to increase the solar reflectance of the waterproof coatings.

The question that then arises is how can we protect and preserve the new and existing construction structures from the penetration of water so that they are durable for many years to come and possess high solar reflectance for energy efficiency? An easy solution is simply to apply a conventional cool coating (e.g., the cool white roof coating developed in our previous work [17]) as the topcoat and a conventional polymer-modified cement-based waterproof coating as the undercoat. However, this solution may increase the coating thickness and the difficulty in workability. A better alternative is to develop a single-layer polymer-modified cement-based energy-efficient cool waterproof coating that can do this efficiently, effectively and economically. However, to the best of our knowledge, in all of the published literature available thus far, there appears to be no paper that described a technique to create a single-layer polymer-modified cement-based energy efficient cool waterproof coating.

To address the lack of information regarding the preparation of polymer-modified cement-based energy efficient cool waterproof coatings, we explored a method to manufacture cool white roof coatings based on styrene acrylate copolymer and cement by mixing white cement with titanium dioxide rutile, Altiris pigments (large-sized titanium dioxide rutile) and other fillers. The paper consists of Part I and Part II. In this part, the development procedures for this coating are presented. Test data are presented on the optical properties of the conventional polymer-modified cement-based waterproof coating and the energy efficient one. Furthermore, the cooling effect of the cool white roof coating based on styrene acrylate copolymer and cement relative to the conventional waterproofing one is estimated. In addition, the effects of dirt accumulation and artificial accelerated weathering on the optical properties of the cool white roof coating based on styrene acrylate copolymer and cement are presented and discussed.

2. Materials and methods

2.1. Selection of materials

To prepare the cool white roof coatings based on styrene acrylate copolymer and cement, the following commercially available materials were selected: a high elastic styrene acrylate copolymer emulsion, purchased from Beijing Hengtai Chemicals Co., Ltd.; a conventional titanium dioxide rutile, grade Ti-Pure R-902, purchased from DuPont Chemicals Co., Ltd.; a titanium dioxide rutile, grade Altiris 800, generously supplied by Huntsman Corporation; a white cement, grade 325; talcum; and ground calcium carbonate.

To improve the quality and the waterproofing properties of the coatings, a dispersant, a wetting agent, an antifoaming agent, a stain-resistant agent, a silane coupling agent and a titanate coupling agent were also selected.

2.2. Preparation of cool white roof coatings

Both the conventional polymer-modified cement-based waterproof coating and the cool white roof coating based on styrene acrylate copolymer and cement are two-component coatings. The compositions of the liquid component A for both the conventional polymer-modified cement-based waterproofing coating and the cool white roof coating based on styrene acrylate copolymer and cement were identical and they are summarized in Table 1. The compositions of the solid component B for the conventional polymer-modified cement-based waterproof coating and the cool white roof coating are listed in Tables 2 and 3, respectively. For both coatings, the polymer/cement ratio and water/cement ratio were 1:1 and 1:4.4, respectively. The mixing temperature was 25 °C.

The preparation of the cool white roof coating based on styrene acrylate copolymer and cement proceeded as follows: the high elastic styrene acrylate copolymer emulsion was first added into the mixing setup, followed by the addition of the wetting agent, dispersant, half amount of antifoaming agent, stain-resistant agent, silane coupling agent and titanate coupling agent. The mixture was stirred at high speed of 1000 rounds min^{-1} for 20 min, and the liquid component was obtained. The white cement, titanium dioxide rutile, Altiris 800, talcum and ground calcium carbonate were added into a solid mixer according to the above weight contents and mixed at the speed of 60 rounds min^{-1} for 60 min and the solid component was produced. A predetermined amount of water (water:cement = 1:4.4) was added into the prepared liquid component and mixed for 5 min, followed by the slow addition of the prepared solid component and the remaining half amount of antifoaming agent. The mixture was mixed for 25 min, and the final product was manufactured.

2.3. Specimen preparation

Proper preparation of the specimen is a critical process for accurate coating performance tests. The above resultant cool white roof coating based on styrene acrylate copolymer and cement was poured into prefabricated glass mold (35 mm × 35 mm × 2.5 mm) three times to prepare the film. The dry coating thickness, measured by a PosiTector 200-Ultrasonic coating thickness gauge, was approximately 1.5 ± 0.2 mm. All of the cured specimens were maintained for four days under standard laboratory conditions [23 ± 2 °C, relative humidity 50 ± 5%, unless otherwise indicated] and then demolded. The demolded films were then put into a drying oven and kept at 40 °C for two days prior to testing.

2.4. Spectral reflectance measurements

The spectral reflectance of the conventional polymer-modified cement-based waterproof coating and the cool white roof coating based on styrene acrylate copolymer and cement was measured using a UV/VIS/NIR spectrophotometer (Perkin Elmer Lambda 750) equipped with an integrating sphere (150-mm diameter, Labsphere RSA-PE-19). Following ASTM Standard E903-12 (Standard test method for solar absorbance, reflectance and transmittance of materials using integrating spheres), the broadband reflectance [ultraviolet (UV), visible (VIS), near

Table 1
The compositions of the liquid component A for the conventional polymer-modified cement-based waterproofing coating and the cool white roof coating based on styrene acrylate copolymer and cement.

Materials	Weight content (%)
Styrene acrylate copolymer emulsion	95
Wetting agent	0.5
Dispersant	0.5
Antifoaming agent	1.5
Stain-resistant agent	1.5
Silane coupling agent	0.5
Titanate coupling agent	0.5