Construction and Building Materials 96 (2015) 666–672

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

The study of an energy efficient cool white roof coating based on styrene acrylate copolymer and cement for waterproofing purpose—Part II: Mechanical and water impermeability properties

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HIGHLIGHTS

- The low Tg of the binder endows the cool waterproof coating with good flexibility.
- The coating's high tensile strength is due to the cross-linked nature of the binder.
- Thermal, alkali, water and UV treatments increase the tensile strength of the coating.
- Thermal, alkali, water and UV treatments reduce the coating's breaking elongation.
- The cool white waterproof coating has excellent waterproofing efficacy.

ARTICLE INFO

Article history:
Received 10 April 2015
Received in revised form 26 July 2015
Accepted 9 August 2015

Keywords:
Water based
Styrene acrylate emulsion
Mechanical properties
Water impermeability
Adhesion strength
Interpenetrating network structures

ABSTRACT

The mechanical properties and water impermeability of the developed cool white roof coating based on styrene acrylic copolymer and cement are systematically investigated in the current paper. The coating has good tensile properties, adhesion strength and compliance at low temperature. In particular, the coating possesses excellent water impermeability. The good flexibility and compliance at low temperature result from the low glass transition temperature of the high elastic styrene acrylate copolymer emulsion. Compared with the untreated specimens, after thermal, alkali, water immersion and ultraviolet treatments, the tensile strength of the coating is increased, while its breaking elongation is decreased. In addition, the coating has good artificial accelerated weather resistance in terms of mechanical properties. The excellent water impermeability of the coating stem from the cross-linked nature of the high elastic styrene acrylate copolymer emulsion, the formation of interpenetrating network structures and the Ca^{2+} bridging effect.

1. Introduction

Polymer-modified cement-based waterproof coatings, characterized by the combination of the advantages of the hard, brittle hydrated cement with those of the flexible and elastic polymer [1], are two-component coatings [2]. Compared to the conventional cementitious materials and polymer waterproof coatings, these generic type of coatings have the following advantages: ease of use; possession of not only extensibility and impermeability of polymers but also high strength, good durability and ease of bonding to wet substrates of cementitious materials; and water soluble nature, thus they are environmentally friendly [2–9]. Therefore, this generic type of waterproof coating is widely used in the waterproof engineering of external walls and roofs of buildings, among others.

Although polymer-modified cement-based waterproof coatings have been extensively investigated in China [2–9], to the best of our knowledge, only a few scientific papers and books to date are related to this topic [10–14]. These studies simply focus on the application performances of the polymer-modified cement-based waterproof coatings. More specifically, these studies do not involve the mechanical and waterproofing properties of the coatings themselves. With respect to the mechanical and waterproofing

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http://dx.doi.org/10.1016/j.conbuildmat.2015.08.033
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properties of cool white roof coatings based on styrene acrylate copolymer and cement, to the best of our knowledge, there appears to be no papers, to date, that provide relevant information.

In the companion paper [15], we described the optical properties of the developed cool white roof coating based on styrene acrylate copolymer and cement before and after dirt accumulation and artificial accelerated weathering. We also estimated the cooling effect of the developed cool white roof coating based on styrene acrylate copolymer and cement. In the current paper, we present the mechanical and water impermeability of the coating and scientifically explain the causes of the good mechanical properties and water impermeability of the coating via an elaborate analysis of the molecular structure of the binder, the film formation mechanism and the chemical reactions that occurred.

2. Materials and methods

2.1. The composition of the cool white roof coating for waterproofing purpose

The developed cool white roof coating based on styrene acrylate copolymer and cement is a two-component coating. The liquid component was composed of high elastic styrene acrylate copolymer emulsion, wetting agent, dispersant, antifoaming agent, stain-resistant agent, silane coupling agent and titanate coupling agent. The solid component was composed of white cement, titanium dioxide rutile, Altiris 800, talcum and ground calcium carbonate. The weight content of each ingredient for the solid and liquid components of the coating was described in detail in the companion paper [15].

As shown below, the glass transition temperature Tg of the selected styrene acrylate copolymer emulsion is lower than −10 °C. Because dirt pickup problems are very critical in coatings formulated with binders with Tg lower than −10 °C in big cities located in hot climates, it should be noted that the developed cool white roof coating based on styrene acrylate copolymer and cement is recommended not to be applied in hot climates.

2.2. Glass transition temperature measurement

Following the British standard BS, EN 12614 [16], the glass transition temperatures Tg of the styrene acrylate copolymer emulsion were measured using a Differential Scanning Calorimeter (Mettler-Toledo International Inc., Switzerland) with a temperature and sensitivity accuracy of ±0.1 °C and ±0.2 μW, respectively. The device was calibrated with indium and tin. The measurements were performed in an inert atmosphere using nitrogen at a flow rate of 50 ml min^{-1}. An empty pan was used as a reference. Scanning rates of 10 °C min^{-1} were kept during the heating and cooling processes. The scanning temperature range was between −70 °C and 200 °C. Upon completion of the DSC run, the DSC pans were re-weighed to determine if any weight loss occurred. When weight loss was detected, the corresponding DSC data were omitted and another replicate measurement was performed.

2.3. Tensile measurements and exposure conditions

According to the Chinese national standard GB/T 23445-2009 (polymer-modified cement compounds for waterproofing membrane), the tensile properties of the developed cool white roof coating based on styrene acrylate copolymer and cement in the initial state and after thermal, alkali, water immersion and UV treatments, together with the tensile properties of the coating after 720 h of artificial accelerated weathering, were measured with an electrical tensile tester (CMT 4104, Sans Ltd., China) using a 1 kN load cell and a crosshead speed of 200 mm min^{-1}. The elongation at the break is the breaking elongation. The thickness of all of the specimens was (1.5 ± 0.2) mm. The preparation process of the coating films was described in the companion paper [15]. In accordance with the Chinese national standard GB/T 23445-2009, the geometries of the samples used in the tensile tests under different exposure conditions and the corresponding exposure conditions are described below.

For the tensile properties of the specimens after thermal treatment, the dumb-bell-shaped samples were used and the neck length of the dumb bell samples was 25 ± 0.5 mm. The specimens were placed into a drying oven at (80 ± 2) °C for (168 ± 1) h and then cooled to room temperature in a dryer.

For the tensile properties of the specimens after alkali treatment, at (80 ± 2) °C, the long-strip-shaped specimens (120 mm × 25 mm) were immersed into a mixture of a 0.2% NaOH solution and supersaturated $Ca(OH)_2$ for (168 ± 1) h and were then dried in a drying oven at (60 ± 2) °C for 6 h ± 15 min. Subsequently, the specimens were kept for (18 ± 2) h under standard laboratory conditions [23 ± 2 °C, relative humidity 50 ± 5%, unless otherwise indicated] prior to testing.

For the tensile properties of the specimens after water immersion treatment, the long-strip-shaped specimens (120 mm × 25 mm) were immersed in water for (168 ± 1) h. The temperature of the water was kept at (23 ± 2) °C. Next, the specimens were placed into a drying oven at (60 ± 2) °C for 18 h and then cooled to room temperature in a dryer.

For the tensile properties of the specimens after UV treatment, the dumb-bell-shaped samples were used and the neck length of the dumb bell specimens was 25 ± 0.5 mm. The specimens were placed into a UV chamber (Beijing Beifang Lihui Instrument Equipment Co., Ltd.) for 240 h. The UV lamp a UVA-340 lamp (Q-Lab Corporation, USA) with a peak emission at 340 nm [17]. The distance between the specimens and the UV lamp was (470–500) mm, and the air temperature was (45 ± 2) °C. After treatment, the specimens were cooled to room temperature in a dryer.

For the tensile properties of the specimens after artificial accelerated weathering, the dumb-bell-shaped samples were used and the neck length of the dumb bell specimens was 25 ± 0.5 mm. The specimens were placed into a Xenon lamp weather resistance test chamber (SN-66, Beijing Beifang Lihui Test Instrument Equipment Co., Ltd.) for 720 h. The exposure conditions were described in detail in the companion paper [15].

Upon completion of tensile tests, the retention percentage of the tensile strength of the specimens may be determined using Eq. (1):

$$R_t = \frac{T_1}{T} \times 100 \quad (1)$$

where T and T_1 are the average tensile strength values before and after the above mentioned treatments, respectively.

The results were reported based on the mean of at least five independent measurements for each treatment.

2.4. Adhesion strength measurements

The adhesion strength values of the cool white roof coating based on styrene acrylate copolymer and cement in the initial state and after the water immersion and alkali treatments on cement mortar substrates were tested using the pull-out test method in accordance with the procedure specified by the Chinese national standard GB/T 16777-2008 (test methods for building waterproofing coatings). To this end, the predetermined dosages of the liquid component and solid component of the coating were mixed for 5 min and then applied to the molding surfaces of 8-shaped cement mortar specimens (78 mm × 22.5 mm × 22.2 mm). The cement mortar was composed of cement (1/42.5 R), the medium sand and water. The ratio of the cement and the medium sand was 1:1 and the denseness of the mortar was 70–90 mm. The cement mortar specimens were cured in water for 10 days and then moved to a dryer at (50 ± 2) °C for (24 ± 0.5) h. The fracture surfaces of two cement mortar specimens were tightly attached. The thickness of the coating between two specimens was no more than 0.5 mm. Therefore, the displacement is smaller than 0.6 mm, which is accordance with the requirement specified by the European standard Cen, EN 1062 [18]. The prepared specimens were cured for 96 h under standard laboratory conditions prior to performing the test. Because the cool white roof coatings based on styrene acrylate copolymer and cement are probably directly applied to some wet substrates, it is of particular pertinence to test the adhesion strength of the coatings to the wet substrates. To this end, the 8-shaped cement mortar specimens were placed into water at (23 ± 2) °C for 24 h and then the water at the molding surface was removed by dry cloth, followed by the application of the coatings. After curing, the above 8-shaped specimens were located in the clamping jaw of an electrical tensile tester, as shown in Fig. 1. Next, the samples were stretched on both sides at a constant crosshead speed of (5 ± 1) mm min^{-1} until failure occurred.

The results were reported based on the mean of at least three independent measurements for each treatment.

2.5. Measurements of compliance at low temperature

According to the Chinese national standard GB/T 16777-2008, to measure the compliance at low temperature for the developed cool white roof coating based on styrene acrylate copolymer and cement, three specimens (120 mm × 25 mm) and a round rod with a diameter of 10 mm were placed into the refrigerating fluid of a low temperature freezer and kept at −10 °C for 1 h. Subsequently, inside the refrigerating fluid, the specimens were bent 180° around the round rod and then immediately picked up. The specimens were examined for any crack and/or fracture.

2.6. Water impermeability measurements

According to the Chinese national standard GB/T 23445-2009, the water impermeability of the developed cool white roof coating based on styrene acrylate copolymer and cement was tested using a water impermeability tester (DTS-III, Shanghai Lei Yun Test Instrument Manufacturing Co., Ltd., China), as shown in Fig. 2. Three coating specimens (150 mm × 150 mm) with a thickness of