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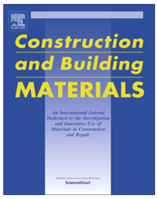

Influence of polymer latex on the setting time, mechanical properties and durability of calcium sulfoaluminate cement mortar

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HIGHLIGHTS

- Polymer latexes perform water-reduction effect and delay the setting of CSA cement.
- SBR latex modified CSA cement mortar performs the best properties.
- Polymer latex modified CSA cement mortars perform good durability.
- Shrinkage rate of CSA cement mortar is decreased by addition of polymer latex.
- Polymer latex contributes to the flexural strength increasing of CSA cement mortar.

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ABSTRACT

In this study, three different types of polymer latexes (styrene butadiene rubber (SBR), styrene acrylic ester (SAE) and polyacrylic ester (PAE)) with three different dosages (0%, 10% and 20%) were employed to prepare polymer latex modified calcium sulfoaluminate (CSA) cement mortar based on the same workability. The setting time, mechanical properties including strength, shrinkage, weight loss, water capillary adsorption, anti-penetration property and durability properties such as resistance to freeze-thaw cycle, carbonization and sulfate attack were measured. The experimental results show that polymer latexes perform good water-reduction effect and delayed setting behavior on CSA cement mortar. Meanwhile, polymer latexes are helpful to enhance the mechanical properties of CSA cement mortar. Generally, SBR latex modified mortar performs the best properties in terms of strength, weight loss, water capillary adsorption and anti-penetration property. Addition of polymer latex decreases strength when subjected to extreme conditions, however, polymer latex modified mortars perform good resistance to carbonization and sulfate attack, although only SBR latex improves the freeze-thaw cycle resistance.

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1. Introduction

Polymer latexes are widely utilized for modification of cement mortar and concrete [1]. The key properties of polymer latexes are their ability to form flexible and homogeneous polymer films after dehydration [2], which provide good adhesion and cohesion in cement mortar and concrete [3]. Meanwhile, polymer latexes bring many superior properties to overcome some of the shortcomings of conventional cement and concrete [4]. Among these polymer latexes, SBR (styrene butadiene rubber), SAE (styrene acrylic ester), EVA (ethylene–vinyl acetate) and PAE (polyacrylic ester) latex are the most frequently used latex types [3,5].These polymer latexes contribute to improve workability [6], increase mechanical strength [6–8], decrease porosity [5,9], reduce the water absorption and permeability [8,10,11] and improve the durability [8,11]. Because of these superior properties, polymer latexes make possible for a variety of niche applications in terms of repair mortars, tile adhesives, waterproofing membranes and self-leveling floors [12].

Calcium sulfoaluminate (CSA) cement was developed in the 1970 s by China Building Materials Academy [13], it mainly consists of ye'elimite ($C_4A_3\bar{S}$), belite (C_2S), and anhydrite ($C\bar{S}$) in various ratios [14], these phases could be formed at 1250 °C, which is 200 °C lower than that of Portland cement (OPC) clinker [15]. Besides, less CO_2 is released from the production of CSA clinker due to the lower limestone amount [16]. Meanwhile, CSA cement demonstrates several advantageous properties, e.g. fast drying and setting, high strength at early stage [17], low shrinkage, good resistance to sulfate-rich environments [18] and high frost and

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corrosion resistance [19], etc. Thus, CSA cement has been promoted as one alternative to OPC because of above environmental and technical benefits.

Contrary to OPC in which alite (C_3S) is the dominant phase which accounts for main mechanical properties, CSA cement performs different hydration reactions. Ye'elimite reacts with calcium sulfate immediately to form ettringite (AFt) and aluminum hydroxide (AH_3) gel according to Eq. (1) [20]. This reaction is mainly responsible for the early mechanical proprieties of CSA cement matrix, which are generally superior to OPC [21]. When calcium sulfate is completely consumed, ye'elimite will react with only water to generate monosulfate (AFm) according to Eq. (2). The presence of lime which could be from the hydration products of OPC benefits to accelerate hydration kinetics and generate more ettringite according to Eq. (3). When ye'elimite is completely consumed, belite (C_2S) begins to react with aluminum hydroxide and water to give rise to strätlingite (C_2AH_8) formation according to Eq. (4) [21]. Some other hydrates such as calcium silicate hydrate (C-S-H) gel, monocarboaluminate or hydrogarnet could be formed when minor phases present in the clinker formulations [15,22].

$$C_4A_3\bar{S} + 2C\bar{S} + 38H \rightarrow C_3A \cdot 3C\bar{S} \cdot 32H + 2AH_3 \tag{1}$$

$$C_4A_3\bar{S} + 18H \rightarrow C_3A \cdot C\bar{S} \cdot 12H + 2AH_3 \tag{2}$$

$$C_4A_3\bar{S} + 8C\bar{S} + 6CH + 74H \rightarrow 3C_3A \cdot 3C\bar{S} \cdot 32H \tag{3}$$

$$C_2S + AH_3 + 5H \rightarrow C_2ASH_8 \tag{4}$$

While there are an extremely large number of studies on the performance of polymer-modified cement mortar and concrete based on OPC, there is a few of literatures reporting the effect of polymers on the properties of CSA cement. Chang et al. [23] synthesized two kinds of SBR latexes with and without emulsifier respectively and investigated these two latexes on the performance of their modified rapid hardening calcium sulphoaluminate cement mortars. The results show that water to cement ratio of polymer modified CSA cement mortar is lower than that of control mortar, the more polymer is added, the less water is required when the same level of flow table value is achieved. The compressive and flexural strengths of latex modified CSA mortar are also lower than that of control mortar. Ye et al. [24] and Meng et al. [25] investigated the mechanical properties of CSA cement mortar modified with VAE polymer powders. The addition of VAE polymer in CSA cement mortar benefits to improve flexural and adhesion strengths while decreases compressive strength. Zhang et al. [26] investigated SBR and VAE latexes modified CSA cement mortar and revealed both of these two latexes would decrease flexural strength which conflicts with literatures [24,25]. Brien et al. [27] assessed adhesion characteristics for polymer modified CSA cement mortar by the use of four different kinds of redispersible polymer powders at a consistent polymer/cement ratio of 0.15, and the results show that SBR polymer demonstrates the poorest adhesion performance. Brien et al. [28] also found that the split tensile strength of CSA cement mortar gradually decreases when with more VAE polymer powders, which is not well consistent with literature [24]. The durability of polymer modified CSA cement mortar was also evaluated to some extent. Li et al. [29,30] and Lu et al. [31] analyzed the sulfate resistance of SAE latex modified CSA cement mortar, the results indicate that SAE latex contributes to increase impermeability as well as sulfate resistance to CSA cement mortar.

It can be seen from above analysis that the study on the influence of polymer latex on CSA cement mortar has not been well reported. Considering the increasing interest on the application of polymer modified cement mortar in infrastructures such as bridge and pavement, residential construction and renovation mainly for waterproofing, tile adhesion, and the fast construction for time as well as cost saving, there will be booming for the development of polymer modified calcium sulfoaluminate cement-based materials. In this study, the influence of polymer latex on the setting behavior, mechanical properties and durability of CSA cement mortar is investigated. Three widely used polymer latexes including SBR, SAE and PAE latex and one CSA cement are taken to analyze. Mortars with three different ratios (0%, 10%, and 20%) by solid of polymer latex to CSA cement at a constant workability were investigated.

2. Experimental

2.1. Materials

The cement used in this investigation was one rapid-hardening CSA cement, its chemical composition was shown in Table 1 and the mineral composition was displayed in Table 2. It has a Blaine fineness of 5350 cm^2/g. The median diameter of the particle size distribution (D_{50}) of the CSA cement is 9.0 μm. Three kinds of polymer latexes including SBR, SAE, and PAE latex were separately added to modify the properties of CSA cement mortar. The parameters of these three polymers were shown in Table 3. Tap water and standard sand according to ISO 679:2009 [32] were used in all experiments.

2.2. Mix proportions, specimen preparation and test methods

Three different types of polymer latexes (SBR, SAE and PAE) have been employed to prepare polymer modified mortars. The sand to cement ratio was kept constant at 3 for all mixtures. Polymer latex was mixed with water firstly and then a certain amount of CSA cement was weighted into the liquid for the fresh mortar preparation in accordance to ISO 679:2009 [32]. The water to cement ratio (m_w/m_c) was adjusted by keeping the same flow table value. The constant flow table value was achieved referring to EN 459-2:2010 [33], aiming at a similar state of workability for the CSA cement mortar matrix. The flow table values of fresh mortars were determined by the cone-shaped metal ring, which was filled with fresh mortar on a shaking table and vibrated 25 times within 25 s, and then the final diameter of the mortar mix in two vertical directions was measured. The average value of the measured diameters is the so-called flow table value. The water to cement ratio of the polymer latex modified CSA cement mortars was determined by fixing the flow table value at a constant value of (170 ± 5) mm, as listed in Table 4. Meanwhile, the water-reduction rate of polymer latex was calculated according to Eq. (5).

$$WRA = \frac{W_c - W_p}{W_c} \tag{5}$$

where:

WRA: water-reduction rate;
W_c: water requirement of control mortar;
W_p: water requirement of polymer latex modified mortar.

The setting time of polymer latex modified CSA cement mortar was determined according to ISO 9597:2008 [34] by the use of Vicat apparatus. The hardened specimens for the measurement of mechanical strength, dry shrinkage and water capillary adsorption were prepared by casting fresh mortar mixtures into 40 mm × 40 mm × 160 mm prismatic molds and compacted with an external vibrator, the mortar specimens with molds were cured initially under 20 °C ± 1 °C and 95% ± 1%RH, then all specimens were demolded one day after casting and then kept in 20 °C ± 2 °C and 50% ± 5%RH for subsequent curing. The compressive and flexural strength values were determined according to standard ISO 679:2009 [32]. The shrinkage rate of the hardened mortars was determined referring to EN 13454-2:2003 [35], which was calculated according to the length of the mortar at different curing ages and the initial length which was measured after demolding at 1 day.

The water capillary adsorption of polymer latex modified CSA cement mortar was measured according to standard ISO 15148-2002 [36]. The mortar specimens were cured for 6 days at 20 °C ± 1 °C and 50% ± 5%RH after demolding and then taken out to dry at 40 °C for 2 days. The four around surfaces were sealed with paraffin before the upside of the specimens was dipped into water. The water capillary adsorption was calculated based on the adsorbed water at different times. The anti-penetration capacity was determined by using Chinese standard DL/T 5126-2001 [37]. Conical mortar specimens with upside and underside surface diameters of 70 mm and 80 mm, height of 30 mm were prepared with the same curing process as above mentioned. When the total curing age reached 7 days, the around surface of the specimens were sealed with paraffin wax and the underside surface was contacted with water. The water pressure was increased step by step to 2.0 MPa to

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