

A case of water absorption and water/fertilizer retention performance of super absorbent polymer modified sulphoaluminate cementitious materials

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Abstract:

Porous concrete as plant bedding has been appropriately named planting concrete. Planting concrete is mainly used to prevent soil erosion and desertification along a motorway and to protect water and soil loss on the river bank. Plants could live in planting concrete and the roots of plants could through it to the ground. Compared to ordinary concrete, planting concrete could protect slopes and beautify the environment. This paper presented the investigation of water absorption and water/fertilizer retention performance of super absorbent polymer (SAP) modified sulphoaluminate cementitious materials for plants growing application. SAP was used to partially replace sulphoaluminate cement (SAC) for the preparation of a material with advanced water absorption performance and water/fertilizer retention properties which are necessary for plants growing in planting concrete. Mercury intrusion porosimetry was adopted to characterize the effects of SAP on the pore structure of hardened SAC-based pastes for plant growing. Hydration heat-evolution was employed for the hydration process of SAC-based materials. Experimental results showed that SAC-based materials delivered the best performance at a 0.5 wt.% SAP content. At this cement replacement level, the water absorption rate of hardened paste increased by 38.3% while the water retention performance of the SAC-based hardened paste increased 23.4% at 180 hours. Additionally, other property advancements were measured including reduction of the fertilizer pervasion rate by up to 11.2 wt.% at 35 days and the compressive strength of up to 55.2 MPa at 28 days.

Keywords: Water absorption; Water/fertilizer retention; Super absorbent polymer; Sulphoaluminate cementitious materials; Planting concrete.

1. Introduction

Porous concrete (no-fines concrete) used an appropriate amount of cement paste to coat and bond the coarse aggregate particles to create a system of high porosity and interconnected voids to quickly drain off water and meet needs of plants' roots growth [1] etc. Porous concrete was a unique and effective environmentally friendly material that was used for last four decades in North America, Europe, and Asia in various applications such as to reduce the amount of drain off water and improve the water quality near pavement sand parking lots [2-7]. Due to water-permeating, water-draining, water-retaining and plant growth performances of porous concrete, it has been applied in road pavement, sidewalks, parks and building extension, as well as for permeable gutters and plant bedding [1, 2, 8-11]. Porous concrete as plant bedding has been appropriately named 'planting concrete' (Fig.1). Planting concrete is mainly used to prevent soil erosion and desertification along a motorway and to protect water and soil loss on the river bank [2]. Though ordinary concrete had been used for slope protection for a long time, owing to its non-porosity, the

34 environment below it could not breathe so freely that the interconnections among water, soil and plants were cut off. Fortunately,
35 plants could live in planting concrete and the roots of plants could through it to the ground (Fig.1 (c)). So compared to ordinary
36 concrete, planting concrete could protect slopes and beautify the environment (Fig.1 (b)). Therefore, planting concrete has been
37 evaluated as an economical and environmentally friendly alternative to traditional impervious hard concrete for the purpose of
38 growing plants, conserving water and soil [12]. Generally, planting concrete consists of cementitious materials, coarse aggregate,
39 mixing water and admixtures (Fig.1 (a)). Because of planting concrete is created by surface coating technology (Fig.2), so among
40 the components, cementitious material directly determines the water absorption performance, the water and fertilizer retention
41 properties, the alkalinity and other relative properties of concrete, making it undoubtedly one of the most important components of
42 planting concrete.

43 Generally, Portland cement (PC) was adopted as cementitious material to prepare porous concrete as permeable facilities. The
44 major hydration products of PC are C-S-H and calcium hydroxide (CH; $C = CaO$, $H = H_2O$) [13, 14]. Therefore, the alkalinity (pH)
45 of pore fluid of hardened PC paste reached up to 13.5. Obviously, it was not suitable to prepare planting concrete because of
46 plants could not grow in this environment with high alkalinity. Fortunately, AFt ($C_3A \cdot 3CS \cdot H_{32}$; $A = Al_2O_3$, $S = SO_3$) and AFm
47 ($C_3A \cdot CS \cdot H_{12}$) are the main principle crystal products during the hydration of sulphotoaluminate cement (SAC). So SAC was a
48 low-alkali cement, its pore fluid alkalinity of hardened pastes was only about 11.5, making it a more favourable condition for plant
49 growth. In addition, the production of the clinker of SAC has the advantage of a lower calcination temperature ($\sim 1250^\circ C$), lower
50 carbon dioxide (CO_2) emissions and easier grinding with less energy required [15-20]. Furthermore, using SAC can shorten the
51 construction period due to its rapid hardening and high strength gain [21-23]. Therefore, the use of SAC is more suitable as a
52 cementitious material to prepare planting concrete.

53 However, the water absorption capacity, water/fertilizer retention properties of planting concrete prepared by traditional
54 sulphotoaluminate cementitious materials still cannot meet plant growing demand. So plants living in planting concrete could often
55 wither and die, defeating the primary purpose of the planting concrete. On the other side, SAPs are a group of polymeric materials,
56 which had the ability to absorb a significant amount of liquid from the surroundings and to retain the liquid within their structure
57 chain [24]. In addition, experimental researches on the properties of concrete with SAPs showed that SAPs could effectively
58 reduce shrinkage [24-29], cracking potential [30-32], and change the rheology of the fresh material [33, 34]. Therefore, at present,
59 SAP was often used as water/fertilizer retention agent in the agricultural industry [35, 36] or as water retention agent to improve
60 desiccation of concrete [37, 38]. According to the basic theory of 'fertilizer moves with water' [39], SAP also has a desirable
61 fertilizer retention capacity. So it was evident that SAP is suitable to improve the water absorption capacity, water/fertilizer
62 retention properties of cementitious materials.

63 Therefore, a SAP was added into SAC as a part of the cementitious material and aimed to prepare a cementitious material with an
64 enhanced water absorption performance, water/fertilizer retention properties. At the same time, urea was adopted as the fertilizer
65 to study the fertilizer retention property of SAC with SAP. Furthermore, basic physicochemical properties and mechanisms of
66 cementitious materials, such as alkalinity of pore fluid, mechanical properties, heat of hydration and pore structure, has been

determined. The intention of this paper is to offer useful data to improve further knowledge in planting concrete industry, especially for cementitious material.

2. Materials and methods

2.1 Materials

SAC (42.5 R, manufactured in China) was used as the main cementitious material, whose initial setting time and final setting time were 15 and 21 minutes, respectively. SAP from a local supplier with the water absorption capacity of 85g water per gram of it, and the absorption capacity was tested according to the teabag method. The teabag method was conducted as follows: 1) Some 0.2 to 0.3 g of SAP particles (exact mass m_1) were put in a teabag (mass m_2) which was pre-wetted in the corresponding liquid; 2) The teabag containing SAP was soaked in a beaker filled with the liquid under consideration; 3) After 3 hours, the teabag with the SAP was released to be weighed (mass m_3). The amount of absorbed liquid (m_w) in relation to the initial mass of SAP was calculated according to the following equation:

$$m_w = \frac{m_3 - m_2 - m_1}{m_1}$$

The chemical compositions of SAC were determined by X-ray fluorescence spectrometer (Tiger S8, Germany), and the results were shown in Table 1. FT-IR spectrometer (Nicolet 380, USA) was adopted to characterize the functional groups of SAP, the results were shown in Fig.3. Particle size distributions of SAC and SAP were determined by using a laser particle size analyzer (LS13320, USA) and the experimental data were shown in Fig.4.

Urea (with a purity of 99.0 wt.%, manufactured in China) was adopted as fertilizer. The urea was composed of no more than 0.005 wt.% water-insoluble substances, had an ignition loss of no higher than 0.01 wt.%, and a burette content of no more than 0.2wt. %

2.2 Experimental design

0.5wt.%, 1.0wt.% and 1.5wt.% SAC has been replaced by SAP and marked as SA 0.5, SA 1.0 and SA 1.5, respectively. A control sample of SAC without SAP was named SA ref. The mix proportions of the investigated SAC-based cementitious materials are shown in Table 2.

2.3 Simple preparation

The pastes without fertilizer were prepared with a water-to-binder weight ratio of 0.35, then cast in $20 \times 20 \times 20$ mm³ moulds and vibrated to remove air bubbles. The moulded pastes were put in a curing environment of $20 \pm 2^\circ\text{C}$ and 95+% RH. After 1 day, the specimens were demoulded and then placed in water at $20 \pm 2^\circ\text{C}$ for 2 days. After that, the hydration reactions of SAC pastes were stopped by leaving samples immersed in absolute ethyl alcohol for 24 hours.

The pastes containing fertilizer had been prepared and cured in the exact same conditions as described above, differentiating only in that fertilizer was predissolved in the mixing water. The fertilizer contents used were 4% (by weight) of binder.

Mortars were adopted to study the mechanical property of SAC with SAP, which were prepared and cured according to the Chinese National Standard GB 20472-2006 (equivalent to ISO 679:2009) [41].

2.4 Test methods

2.4.1 Planting properties

The water absorption capacities of hardened pastes were tested at $30\pm 2^\circ\text{C}$. Samples without fertilizer were cured for 3 days followed by drying at $30\pm 2^\circ\text{C}$ for 24 hours. Subsequently, they were accurately weighed and the results recorded as m_0 . Specimens were kept in deionized water until the weight did not increase more than 0.1 wt.%. Samples were taken out from water and the surface water of them was gently dried to remove. After which samples were accurately weighted and the data were recorded as m_1 [40]. The water absorption rate (WAR) of sample was calculated using the following equation:

$$\text{WAR} = \left(\frac{m_1 - m_0}{m_0} \right) \times 100\%$$

The samples after water absorption test were kept in an environment of $30\pm 2^\circ\text{C}$ and $20\pm 2\% \text{RH}$. At predetermined times (0.1 hour, 0.2 hour, ..., 0.5 hour, 0.75 hour, 1 hour, 1.5 hours, 2.5 hours, ..., 5.5 hours, 6 hours, 7 hours, 22 hours, 26 hours, 29 hours, 30 hours, 47 hours, 53 hours, 71 hours, 74 hours, 95 hours, 107 hours, 119 hours, 131 hours, 145 hours, 152 hours, 167 hours, 180 hours), the samples were accurately weighed again and the mass recorded as m_2 . The equation used to obtain water release rate (WRR) of a sample was as follows:

$$\text{WRR} = \frac{m_1 - m_2}{m_1 - m_0} \times 100\%$$

The hardened pastes' fertilizer retention property is shown by fertilizer release rate in deionised water. Every sample was kept in 100ml deionized water (Fig.5). At predetermined times (1 day, 3 days, 7 days, 14 days, 21 days, 28 days, 35 days), the fertilizer concentration of the soaking solution was determined by ultraviolet-visible spectrophotometry (UV-VIS) [42]. In addition, the soaking water should be replaced by another 100 ml pure deionised water after each test.

For the test of alkalinity (pH) of pore fluid of hardened pastes, ex-situ leaching [43] was adopted to prepare the pore liquid. Then the pH was measured by using a laboratory grade pH meter (pHs-3E, China).

2.4.2 Basic physicochemical properties

Mercury intrusion porosimetry (MIP) was employed to examine the pore structure of hardened pastes. An automatic mercury porosimetry (Pore Master-60, USA) was used, whose intrusion accuracy was $\pm 0.11\%$.

The bulk density of hardened paste samples was tested by the water vacuum saturation [44]. In order to remove the majority of the physically bound water, the specimens were dried at $65\pm 2^\circ\text{C}$ for 24 hours. After that, the hardened pastes were placed into a desiccator with de-aired water. For the duration of three hours, air was evacuated with a vacuum pump from the desiccators. The hardened pastes were then kept in water for more than 24 hours.

A conduction calorimeter (TAM Air C80, Sweden) operating at 25°C was used to determine the hydration heat flow. For such purpose, a water-to-binder of 0.35 was adopted, and the heat flow was recorded every 44 seconds until 72 hours.

The mechanical properties of samples were tested according to the Chinese National Standard GB 20472-2006 (equivalent to ISO 679:2009) [41].

3. Results and discussion

3.1 Planting properties

131 Water and fertilizer are necessary for plants growth. However, planting concrete is a concrete with high water permeability
132 coefficient. Loss of water and fertilizer take place most easily on planting concrete, which usually causes plants withering and
133 even dying away in large areas [48]. Therefore, it is important to enhance the water absorption capacity and water/fertilizer
134 retention property of planting concrete. This aim was achieved by improving the water absorption capacity and water/fertilizer
135 retention property of cementitious materials [46, 48].

136 Table 3 shows the WARs of hardened sulphoaluminate cementitious materials pastes. The WAR of SA ref was only 8.15 wt.%.
137 When the addition of SAP was 0.5 wt.%, the WAR increased by 38.3% to a value of 11.27 wt.%. With a dosage of 1.5 wt.% SAP,
138 the WAR reached up to 14.18 wt.%, an increase of 74.0% compared with SA ref. So it is evidently that the WARs increased with
139 the increasing of SAP addition. Therefore SAP proved to be suitable to improve the water absorption property of sulphoaluminate
140 cementitious materials pastes.

141 The results of water release rate of hardened pastes are shown in Fig.6, representing their water retention property. The water
142 release rate increased with the increase of exposure time. The water release rate of SA ref at 180 hours reached up to 84.6 wt.%,
143 suggesting that the water absorbed by hardened pastes could be released slowly when the RH decreased. On the other hand, the
144 water release rate of hardened pastes were decrease by 0.5 wt.% and 1.0 wt.% SAP, and the water release rate of SA 0.5 and SA
145 1.0 decreased 23.4% and 25.9% compared with SA ref at 180 hours. However, compared to SA ref the water release rate increased
146 when the SAP dosage was 1.5 wt.%. A possible reason was that the open porosity at sample surface or the volume of larger pore (>
147 100 μm) of hardened pastes increased by 1.5 wt.% SAP. Therefore, 0.5 wt.% and 1.0 wt.% SAP could improve the water retention
148 property of sulphoaluminate cementitious materials. Probably, this enhancement could be attributed to the increased internal
149 porosity imparted by SAP and the excellent properties of SAP in retaining water within their structure chain.

150 The results of fertilizer release rates from hardened pastes are presented in Fig.7, which represented the fertilizer-retention
151 property. It was obviously that the fertilizer release rates increased with the increase of the soaking time, such as SA ref, the
152 fertilizer release rate reached to 66.4 wt.% at 35 days, suggesting that the fertilizer added during mixing could be released slowly
153 from the hardened pastes. In addition, the fertilizer release rate grew with a straight-line at early ages (i.e. up to 7 days) and with
154 the further extending of soaking time the curves of fertilizer release rate became flatten, indicating that the velocity of fertilizer
155 release decreased with the increase of soaking time.

156 The fertilizer release rates (besides 1 day) of hardened pastes were decreased by 0.5 wt.%, 1.0 wt.% and 1.5 wt.% SAP. The 7 days
157 fertilizer release rate of SA 0.5, SA 1.0 and SA 1.5 were 24.7 wt.%, 25.3 wt.% and 29.5 wt.% lower than that of SA ref.
158 Furthermore, the 35 days fertilizer release rate of SA ref, SA 0.5, SA 1.0 and SA 1.5 were 66.4 wt.%, 55.2 wt.%, 62.3 wt.% and
159 65.2 wt.%. Compare with SA ref, the fertilizer release rate at 35 days were decreased 16.9%, 6.2% and 1.2% by 0.5 wt.%, 1.0 wt.%
160 and 1.5 wt.% SAP, respectively. Therefore, the optimum dosage of SAP for fertilizer retention was 0.5 wt.%.

161 The measured pore fluid pHs of hardened pastes are shown in Fig.8, which represented the alkalinity of pore fluid of hardened
162 cementitious materials pastes. A previous study [45] demonstrated that the pH of pore fluid of hardened PC paste was about 13 as
163 determined by ex-situ leaching (as following). The alkalinity (pH) of pore fluid of SA ref was 11.40, which was significantly less

164 than that of PC, suggesting once more that SAC was suitable to prepare planting concrete compared with PC. In addition, the pH
165 decreased slowly with the increase of SAP addition. The pH of SA 1.5 decreased by 0.14 to a value of 11.26 compared with SA ref.
166 A possible reason was that the total pore volume and pore liquid content of hardened pastes increased with the increase of SAP
167 addition, which reduced the concentrations of Ca^{2+} and OH^- of pore fluid and limited the formation and growth of CH crystals. So
168 the pH of pore fluid decreased with the increase of SAP addition. Hence, SAP played a positive role during the hydrating of SAC
169 to reduce CH can be concluded. The environment with low alkalinity was helpful for plant growing in planting concrete.
170 Therefore, this result further proves that sulphotoaluminate cementitious materials with SAP are suitable to prepare planting
171 concrete.

172 **3.2 Basic physicochemical characteristics**

173 The bulk densities of hardened cementitious materials pastes are presented in Fig.9. The bulk density of hardened pastes decreased
174 with the increasing of SAP addition. The bulk density of SA ref reached up to 1.88 g/cm^3 , while the bulk density of SA 0.5
175 decreased by 6.4% to a value of 1.76 g/cm^3 . When the dosage of SAP reached to 1.5 wt.%, the bulk density of hardened
176 cementitious materials pastes was only 1.64 g/cm^3 and 12.8% lower than that of SA ref. Therefore, SAP was beneficial to decrease
177 the bulk density of hardened cementitious materials pastes, which could help save the transportation costs of planting concrete. In
178 addition, these results also probably suggested that the compactness of hardened cementitious materials pastes decreased with the
179 increasing of SAP dosage, scilicet, the porosity of hardened pastes increased with the increasing of SAP dosage.

180 Fig.10 presents the pore structure of hardened pastes. The total pore volume of SA ref was only $85.0 \times 10^{-3} \text{ cm}^3 \text{g}^{-1}$ (Fig.10 (a)),
181 which can explain its poor water absorption capacity very well. Furthermore, the total pore volume increased with the increasing
182 of super absorbent polymer addition, which was probably due to the difference in the particle size between SAC and SAP (Fig.4)
183 and the water absorption performance of SAP, suggesting commendably that the water absorption capacity increased with the
184 increasing of super absorbent polymer addition (Table 1). When the addition of SAP was 0.5 wt.%, the total pore volume
185 increased by 35.2% to a value of $114.9 \times 10^{-3} \text{ cm}^3 \text{g}^{-1}$; When the addition of SAP was 1.5 wt.%, the total pore volume increased by
186 65.1% to a value of $140.3 \times 10^{-3} \text{ cm}^3 \text{g}^{-1}$. Hence SAP was suitable to enhance the total pore volume of hardened SAC-based
187 materials pastes.

188 The increase of pore volume of hardened pastes was mainly due to fine pores below $0.1 \mu\text{m}$ in diameter while the SAP content
189 was no more than 1.0 wt.% (Fig.10 (b)), in this particular case the most probable reason was incorporation of SAP powder into the
190 cementitious materials system often causes refinement of the pore structure. In addition, the water retention property can generally
191 be enhanced by various pore sizes [46, 47]. Therefore, the water retention property was enhanced by SAP as long as the SAP
192 dosage is no more than 1.0 wt.%. However with a SAP addition of 1.5 wt.%, the volume of pores between $0.1\text{-}200 \mu\text{m}$ in diameter
193 significantly increased, especially for pores between $100\text{-}200 \mu\text{m}$, which were harmful to the water/fertilizer retention property
194 and mechanical performance. Hence SAP addition could cause changes of pore structure of hardened pastes. At the same time, the
195 latter results also explain the change of water absorption performance, water and fertilizer retention property of hardened
196 SAC-based materials pastes prepared with varying dosages of SAP.

197 Fig.11 shows the relationship between total pore volume, WAR and bulk density of hardened cementitious materials pastes. The
198 correlation coefficient of total pore volume and WAR was 0.9993, which suggested that there was an extremely significant linear
199 correlation between them. In addition, the WAR of SA ref, SA 0.5, SA 1.0 and SA 1.5 were 8.15 wt.%, 11.27 wt.%, 12.76 wt.%,
200 and 14.18 wt.%, respectively. Because of water with a density of about 1.0 g/cm³ was adopted in all samples, so the WAR could
201 be expressed for SA ref, SA 0.5, SA 1.0 and SA 1.5 as $81.5 \times 10^{-3} \text{ cm}^3 \text{ g}^{-1}$, $112.7 \times 10^{-3} \text{ cm}^3 \text{ g}^{-1}$, $127.6 \times 10^{-3} \text{ cm}^3 \text{ g}^{-1}$ and 141.8×10^{-3}
202 $\text{cm}^3 \text{ g}^{-1}$. Furthermore, the total pore volume of SA ref, SA 0.5, SA 1.0 and SA 1.5 were $85.0 \times 10^{-3} \text{ cm}^3 \text{ g}^{-1}$, $114.9 \times 10^{-3} \text{ cm}^3 \text{ g}^{-1}$,
203 $128.2 \times 10^{-3} \text{ cm}^3 \text{ g}^{-1}$ and $140.3 \times 10^{-3} \text{ cm}^3 \text{ g}^{-1}$, respectively. Therefore, the difference between WAR and total pore volume decreased
204 with the increase of SAP addition and the WAR of SA 1.0 and SA 1.5 is over the total pore volume of them. The results proved
205 that the reason for WAR increased with the increase of SAP dosage was not only attribute to the increase of total pore volume, but
206 SAP also has excellent water absorption performance. Additionally, the correlation coefficient between total pore volume and bulk
207 density of hardened cementitious materials pastes reached up to 0.9994, suggesting that the bulk density decreasing with the
208 increase of SAP addition was due to the total pore volume increased with the increase of SAP content once again.

209 The hydration heat evolutions of sulphotoaluminate cementitious materials are presented in Fig.12. There was neglected effect of
210 SAP addition on the first exothermic heat peak (the dissolution heat, about 0.1 hour) of cementitious materials. The second
211 exothermic peak (at the age of 1-2 hours) was caused by the hydration of ye'elimite ($\text{C}_4\text{A}_3\text{S}$) and the main hydration product was
212 Aft ($\text{C}_4\text{A}_3\text{S} + 2\text{C}\text{S} + 38\text{H} \rightarrow \text{C}_3\text{A} \cdot 3\text{C}\text{S} \cdot 32\text{H} + 2\text{AH}_3$). The third exothermic peak (at the age of 2-4 hours) was caused by
213 $\text{C}_4\text{A}_3\text{S}$ hydrate which mainly produces Aft ($\text{C}_4\text{A}_3\text{S} + 2\text{C}\text{S} + 38\text{H} \rightarrow \text{C}_3\text{A} \cdot 3\text{C}\text{S} \cdot 32\text{H} + 2\text{AH}_3$). Additionally, the fourth exothermic
214 peak (at the age of 5-6 hours), which is the hydration of $\text{C}_4\text{A}_3\text{S}$ to produce AFm ($\text{C}_4\text{A}_3\text{S} + 18\text{H} \rightarrow \text{C}_3\text{A} \cdot \text{C}\text{S} \cdot 12\text{H} + 2\text{AH}_3$). There
215 was not effect of SAP on the kinds of exothermic peaks of sulphotoaluminate cementitious materials hydrate, but all of the main
216 exothermic peaks were delayed by SAP. It was probably that application of SAP could decrease the water of the environment of
217 $\text{C}_4\text{A}_3\text{S}$ hydration (because of the high WAR of SAP) and delayed the hydration of $\text{C}_4\text{A}_3\text{S}$. On the other hand, the cumulative heats
218 of SA 0.5, SA 1.0 and SA 1.5 were similar to those of SA ref at 1 and 3 days (Fig.12 (b)). Hence there was negligible effect of
219 SAP content (no more than 1.5 wt.%) on the 1 and 3 days cumulate heat of sulphotoaluminate cementitious materials' hydration.

220 Fig.13 shows the mechanical property of SAC with SAP. The 1 and 3 days compressive strength and flexural strength of
221 sulphotoaluminate cementitious materials could be decreased by SAP, but the 28 days compressive strength and flexural strength
222 could be increased by 0.5 wt.% SAP. Compared to SA ref, the 28d compressive strength of SA 0.5 increased 3.7MPa. Furthermore,
223 the flexural strength of SA 0.5 and SA 1.0 was similar to SA ref. And the 28d flexural strength could be increased a bit (~0.2 MPa)
224 by 0.5 wt.% SAP. Because of there was negligible effect of SAP content (no more than 1.5 wt.%) on kinds of exothermic peaks
225 and the 1 and 3 days cumulate heat of sulphotoaluminate cementitious materials' hydration, so the changes of mechanical property
226 could mainly due to the changes of pore structure of cementitious materials.

227 **Conclusions**

228 From the basis of multiple perspectives, the effects of SAP on water absorption, water/fertilizer retention and basic
229 physicochemical properties of sulphotoaluminate cementitious materials were investigated. The main conclusions that can be

summarized as following:

- (1) The water absorption rate of hardened sulphotoaluminate cementitious materials pastes increased with the amount of added SAP. After using 0.5 wt.% and 1.5 wt.% SAP, the water absorption rate was enhanced 38.3% and 74.0 % than that of SA ref.
- (2) The adoption of SAP proved to be suitable for the advancement of the water retention property of sulphotoaluminate cementitious materials when its addition is no more than 1.0 wt.%. At 180 hours, the water release rate decreased by 23.4% and 25.9% at 0.5 wt.% and 1.0 wt % SAP replacement level.
- (3) 0.5 wt.% SAP in the sulphotoaluminate cementitious materials was the best therapy for enhancing fertilizer retention. For this cement replacement level, the fertilizer release rate at 35 days reduced 16.9%.
- (4) The 1 and 3 days compressive strength and flexural strength of sulphotoaluminate cementitious materials could be decreased by SAP, but the 28 days compressive strength and flexural strength could be increased by 0.5 wt.% SAP. Compared to SA ref, the 28d compressive strength of SA 0.5 increased 3.7MPa.
- (5) There was not effect of SAP on the kinds of exothermic peaks of sulphotoaluminate cementitious materials hydrate, but all of the main exothermic peaks were delayed by SAP.
- (6) The total pore volume of hardened sulphotoaluminate cementitious materials pastes increased with the amount of added SAP. The total pore volume increased by 35.2% to a value of $114.9 \times 10^{-3} \text{ cm}^3 \text{ g}^{-1}$ when 0.5 wt.% SAP was incorporated, and the increase of pore volume was mainly due to fine pores of diameter below 0.1 μm .

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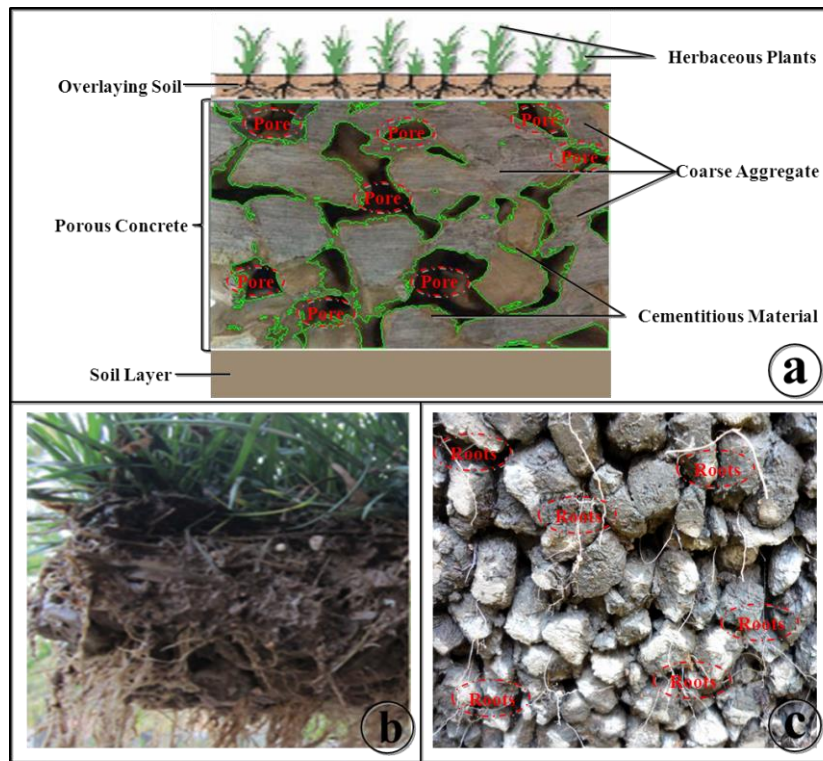
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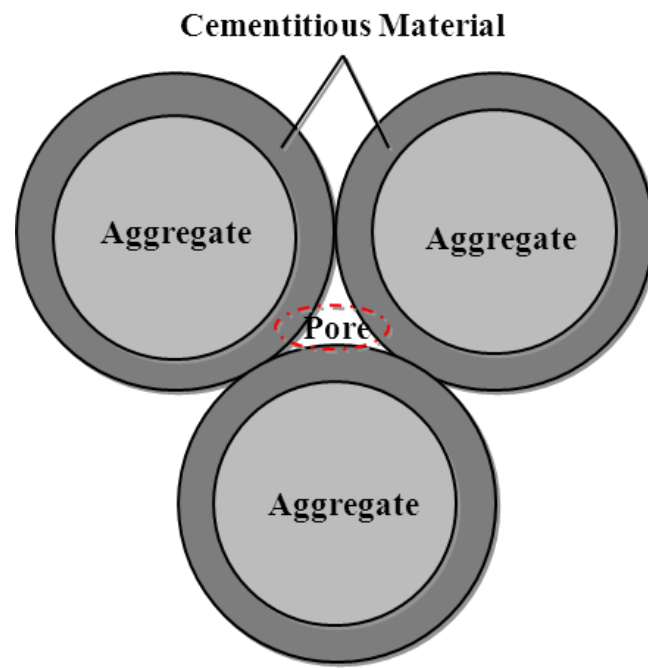


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354 Fig.1 (a) Sketch map of planting concrete; (b) Actual-effect pictures of planting concrete; (c) Actual- effect pictures of plants'

355 roots through the concrete.

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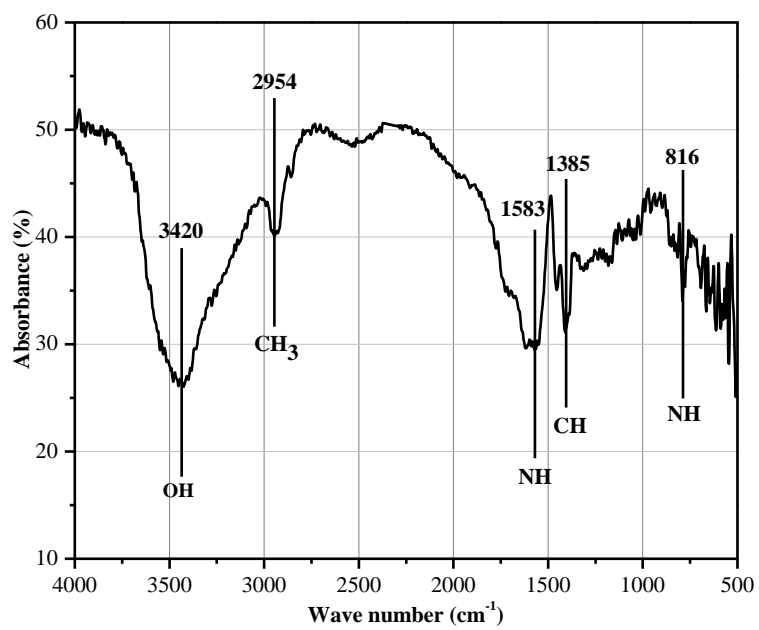


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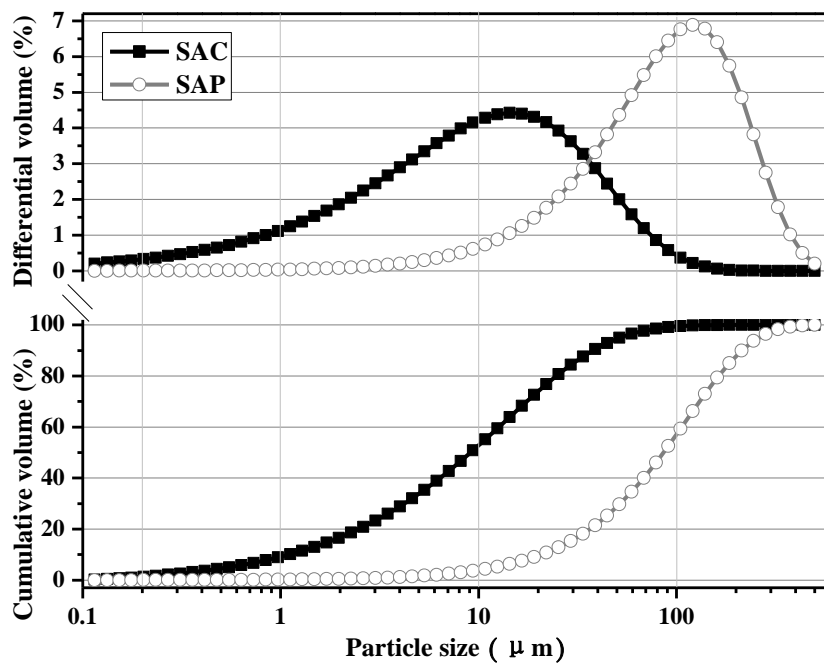
Fig.2 Schematic diagram of surface coating technology



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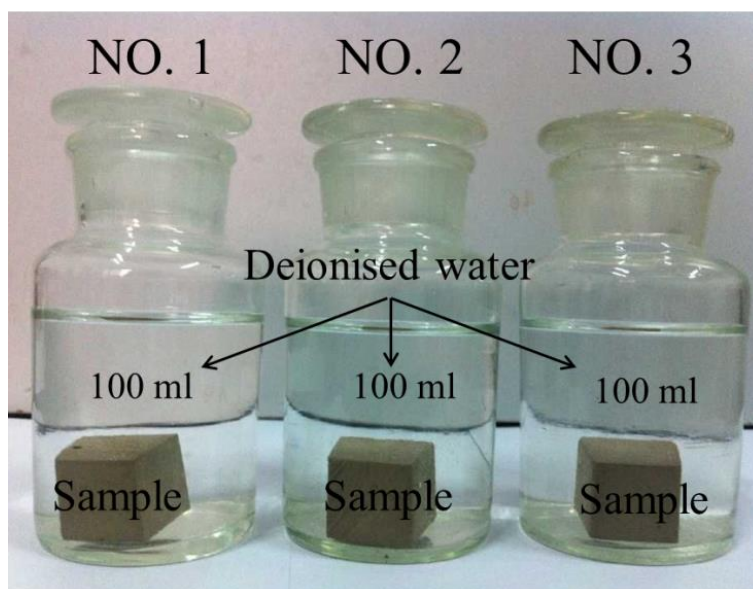
Fig.3 FT-IR analysis of SAP



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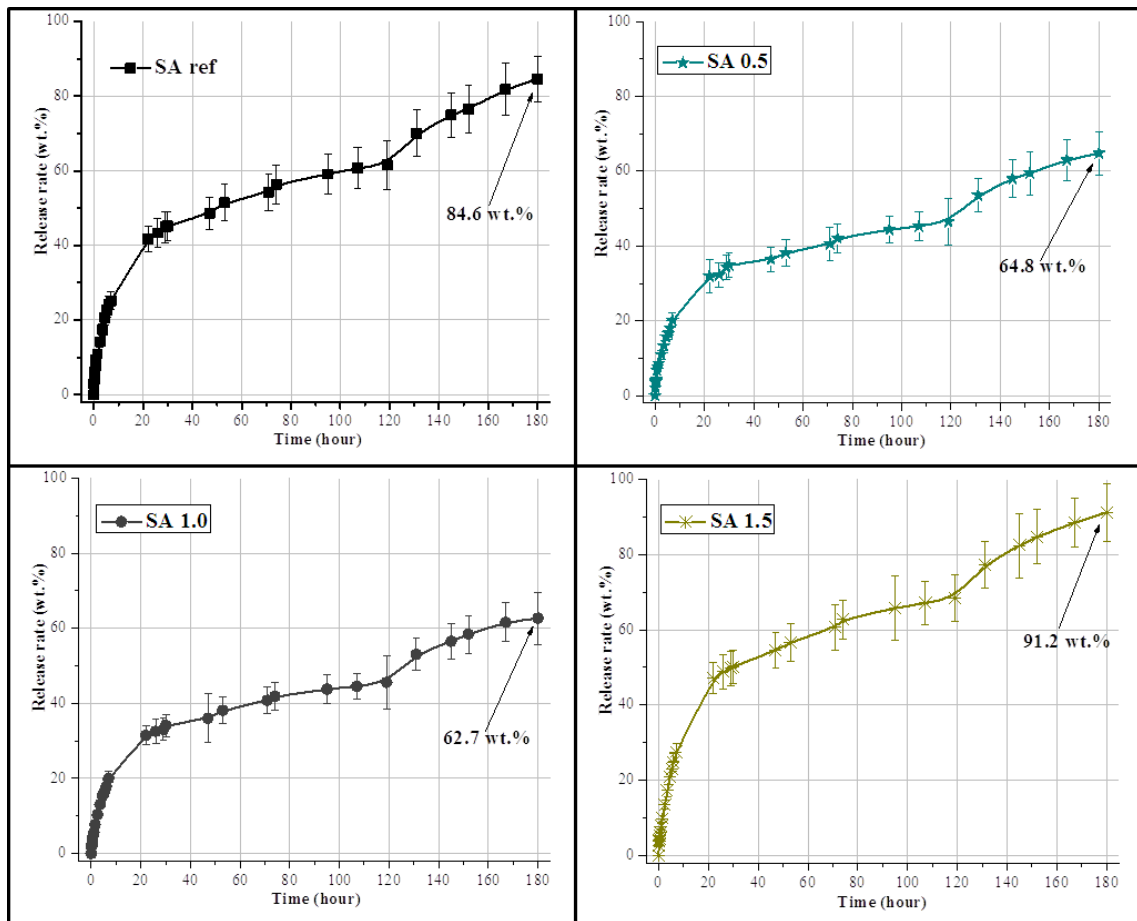
Fig.4 Particle size distributions of SAC and SAP



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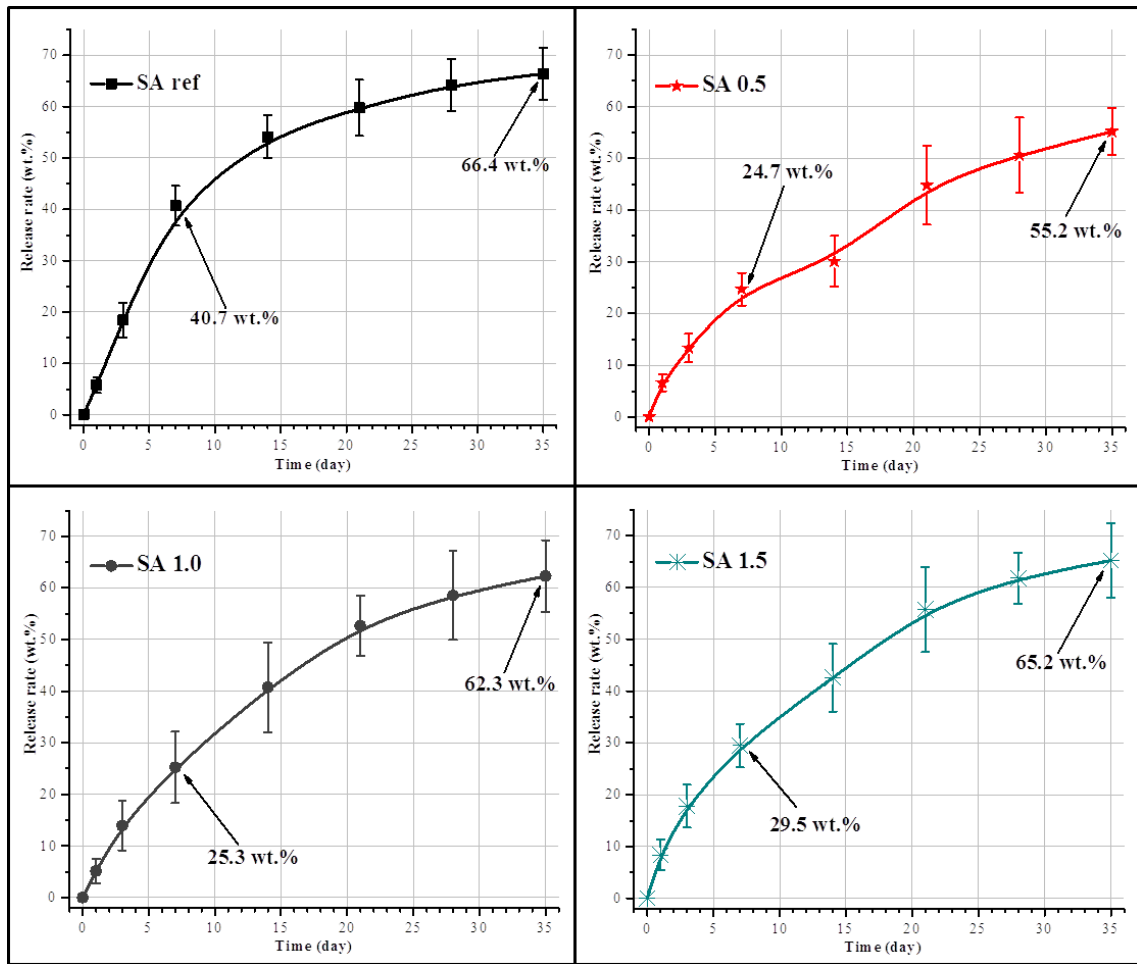
Fig.5 Pictures of the test of fertilizer release rate



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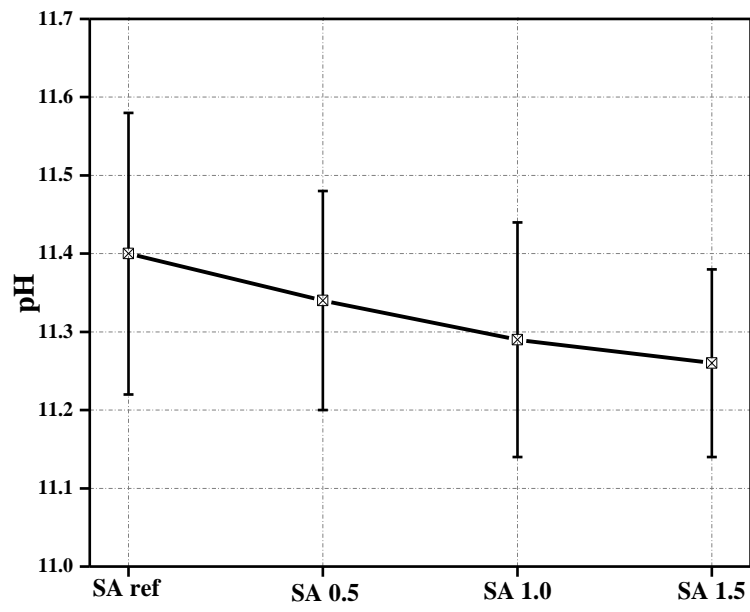
Fig.6 Water release rate of hardened pastes



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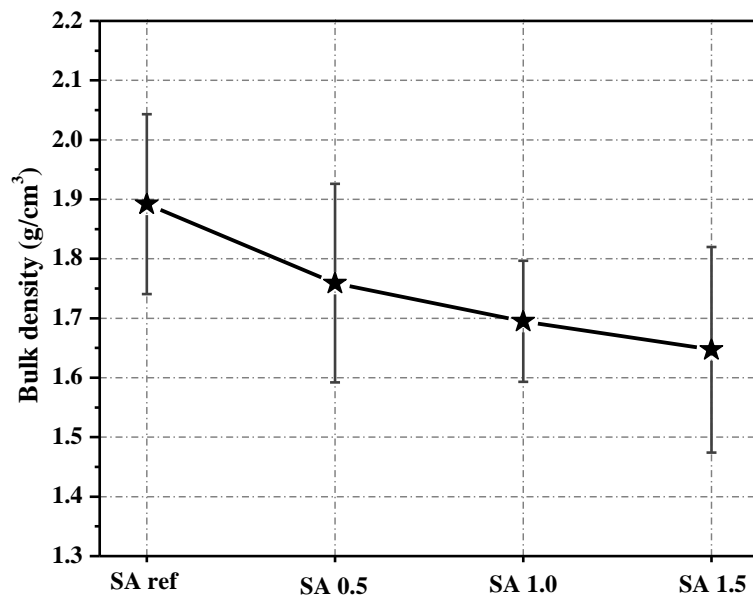
Fig.7 Fertilizer release rate of hardened pastes



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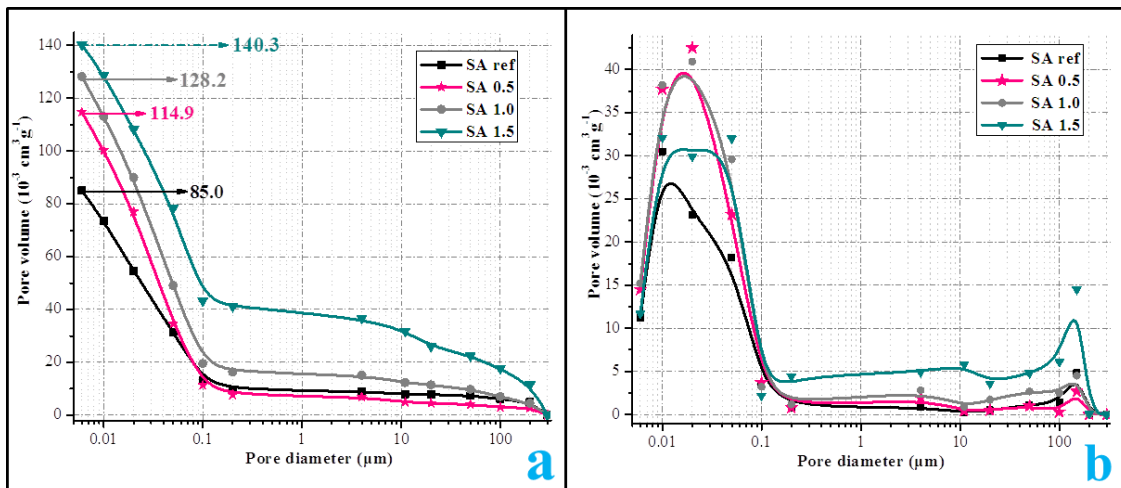
Fig.8 pH of pore fluid of hardened pastes



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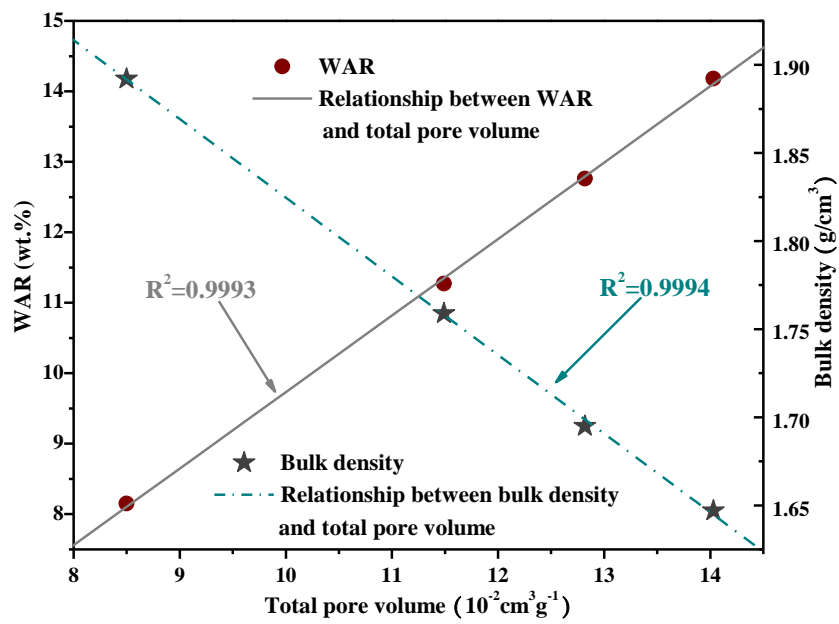
Fig.9 Bulk density of hardened pastes



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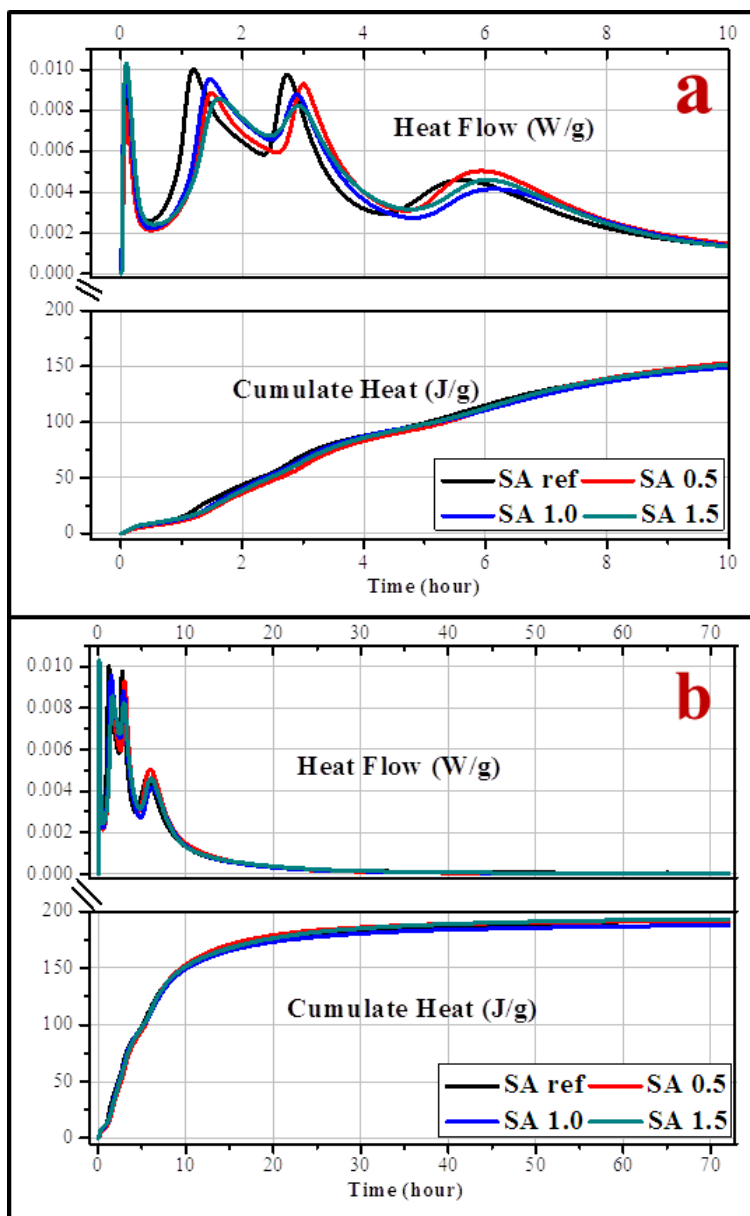
Fig.10 Pore structure; (a) Cumulative pore volume; (b) Pore size distribution



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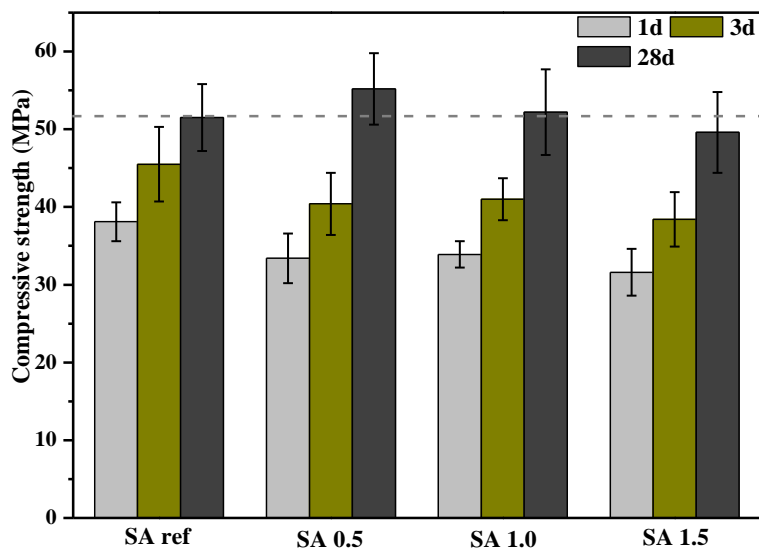
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Fig.11 Relationship between total pore volume and WAR, bulk density



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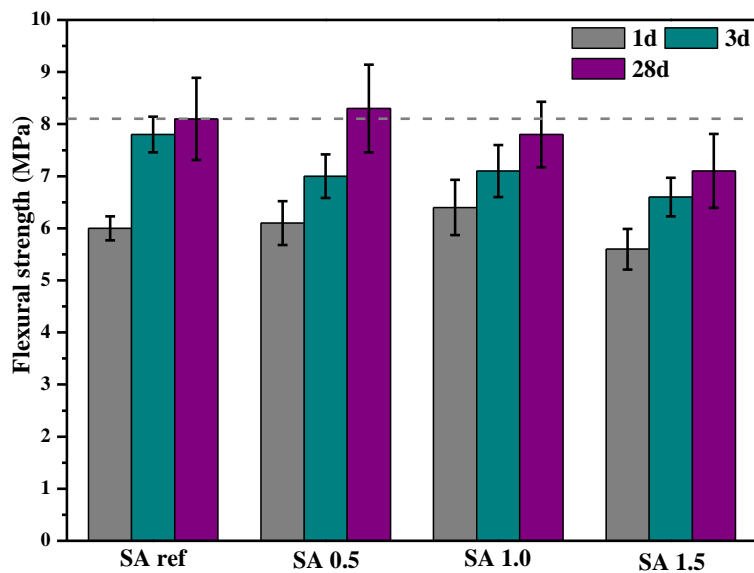
390 Fig.12 Hydration heat evolution of SAC with SAP; (a) Hydration heat evolution for 10 hours; (b) Hydration heat evolution for 72
 391 hours.



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(a) Compressive strength



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396

(b) Flexural strength

397

Fig.13 Mechanical property

398 Table 1

399

Table 1 Chemical compositions of SAC (wt.%)

Compositions	SiO ₂	CaO	Al ₂ O ₃	Fe ₂ O ₃	MgO	K ₂ O	Na ₂ O	TiO ₂	SO ₃	Los
SAC	9.60	45.16	21.64	2.45	1.28	1.38	0.17	1.03	10.73	6.35

400

401 Table 2

402

Table 2 Composition designs

No.	Composition (wt.%)	
	SAC	SAP
SA ref	100	0
SA 0.5	99.5	0.5
SA 1.0	99.0	1.0
SA 1.5	98.5	1.5

403 Table 3

404

Table 3 WARs of hardened pastes (wt.%)

NO.	SA ref	SA 0.5	SA 1.0	SA 1.5
WAR	8.15	11.27	12.76	14.18

405

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