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Study on Alkali Reduction Effect of SAP on Cementitious Composites

Wenxing Xu, Shuai He and Yangyi Zhu

School of Central South Forestry University of Science and Technology, Changsha 410004, China

Abstract: In order to improve the high alkalinity environment inside the cementitious composites, the effect of SAP doping on the pH value and compressive strength of cement slurry was investigated by doping Super Absorbent Polymer (SAP). The test results show that SAP can reduce the pH value of cementitious composites at 28d to a certain extent; the pH value of cementitious composites at 28d is significantly reduced when SAP doping is 0.3%, and the compressive strength is improved compared with that of the control group; SAP particles will form cracks with the middle of the cement matrix after the release of water to reduce the alkaline material outflow from the cement matrix, which will make the pH value of SAP specimens reduced.

Keywords: SAP; pH; Mechanical Properties; Cement.

1. Introduction

With the development and progress of society, people's demand for environmental ecology is increasing, in order to comply with the concept of building sponge cities, the concept of Ecological Concrete (EC) is proposed, that is, a new type of porous concrete structural material composed of a single particle size coarse aggregate, no sand or a small amount of sand, low-plasticity cementitious cementitious materials, and to meet the symbiosis of vegetation. The concrete is a new type of porous concrete structural material. However, during the hydration process of concrete, the pH value of pore water environment is as high as 12, which does not meet the conditions for plant growth. Therefore, the research on alkali-reducing technology for concrete is a key technology for the development of eco-concrete.

In order to reduce the pH value of concrete pores, the alkali reduction methods commonly used at home and abroad are: single or compound chemical methods, physical methods, agronomic methods and so on. Gao Ting[1] controlled the alkalinity within the pores of eco-concrete in a suitable range by mixing appropriate amounts of mineral admixtures, preferring low alkalinity cement varieties, spraying acidic modifying materials, and carbonation; Hu[2] prevented alkali efflux by mixing silane emulsions into eco-concrete, which formed a stable protective film on the surface; Huang[3] prepared eco-concrete by using a low alkalinity supersulfate cement to concrete, which lowered the pH of eco-concrete pore solution; Chen[4] effectively lowered the pH of concrete internal void solution by adding appropriate amount of phenylpropylene emulsion instead of sulphoaluminate cement; Tang[5] lowered the alkali by adding fly ash, and the optimum eco-concrete pH could be maintained at 8.7.

Super Absorbent Polymer(SAP) is a polymer with a three-dimensional spatial network structure, the complex spatial lattice structure so that it has a better water absorption, water release properties, often used in high-performance concrete internal maintenance materials, the formation of a certain number of “reservoir” within the concrete It forms a certain number of “reservoirs” inside the concrete, releasing water when the humidity inside the concrete decreases, providing conditions for the continuation of the hydration reaction of cement[6,7]. However, due to the complexity of SAP and cementitious composites, a unified understanding of the relationship between SAP dosage, optimum water-cement ratio, etc. and the performance of cementitious composites has not yet been reached. Based on this, this paper investigates the effect of different SAP dosage on pH and compressive strength of cementitious composites.

2. Raw Materials and Test Methods

2.1. Raw Materials

Cement grout test raw materials: cement for P·O 42.5 ordinary silica cement, produced by Hunan Pingtang South Cement Co., Ltd., its basic characteristics are shown in Table1; mixing water for tap water; water reducing agent for high performance polycarboxylic acid water reducing agent, the water reduction rate of 30%; SAP by the Yixing.

Table 1. Basic characteristics

Specific surface area($m^2 \cdot kg^{-1}$)	Setting time(min)		Flexural strength (MPa)		Compressive strength (MPa)	
	Initial setting	Final setting	3d	28d	3d	28d
336	178	228	5.1	8.1	25.0	46.2

2.2. Preparation of Specimens

In the test, the baseline water-cementitious ratio of 0.30 was used, and nine different SAP dosages were set, which were 0.10%, 0.15%, 0.20%, 0.25%, 0.30%, 0.35%, 0.40%, 0.45%, 0.50%, respectively, and the specific test programme is shown in Table 2. First of all, the cementitious material, SAP, water reducing agent fully mixed, according to the water-cementitious ratio of 0.30 to join the water solution, at a mixing speed of 200 r/min uniform, mixing 120s can be loaded into the mould to get prismatic specimens, specimen size of 40mm × 40mm × 160mm, to be maintained at room temperature for 24h after the removal of the mould, and put into a standard maintenance box, respectively, maintenance to 3d, 7d, 28d. The pH value and compressive strength of the specimens were determined.

Table 2. The specific test programme

Numble	SAP(%)	Cement(kg/m3)	Water reducing agent (%)	Total water consumption(kg/m^3)
1	0.00%	1953	0.02%	586
2	0.10%	1953	0.02%	586
3	0.15%	1953	0.02%	586
4	0.20%	1953	0.02%	586
5	0.25%	1953	0.02%	586
6	0.30%	1953	0.02%	586
7	0.35%	1953	0.02%	586
8	0.40%	1953	0.02%	586
9	0.45%	1953	0.02%	586
10	0.50%	1953	0.02%	586

2.3. Test Methods

The pH value test of the specimen adopts the method of soaking the net pulp, which reflects the acidity and alkalinity between the voids of the net pulp by determining the pH value of distilled water after soaking. Specimen maintenance to a certain age after placing the plastic box, injected into the mass ratio of 1:1 distilled water, distilled water should not be more than the height of the test block 1 ~ 2cm, sealed for 24h after the use of Sigma instrumentation PH818 type PH pH pH meter test pH value, the test will be immersed in cement mortar specimens stirred in the aqueous solution, to be read after reading the stability of the readings, the test 3 times to take the average value.

Cubic compressive strength test with reference to ‘GB/T 17671-2021 Cementitious Sand Strength Test Method (ISO Method)’, using DYE-300B microcomputer servo cement flexural and compressive testing machine.

3. Test Results and Analyses

The pH and compressive strength of the specimens with a water-cement ratio of 0.3 were determined for 3d, 7d and 28d, and the test data are shown in Table 3.

Table 3. The test data

Numble	SAP	pH				compressive strength(MPa)		
		3d	7d	28d		3d	7d	28d
1	0.00%	11.21	10.01	9.31		54.28	57.48	61.03
2	0.10%	11.65	10.71	9.16		38.93	55.88	66.08
3	0.15%	11.66	10.36	9.23		42.28	50.25	63.45
4	0.20%	11.60	10.99	8.91		39.50	51.95	67.23
5	0.25%	11.72	10.28	8.83		37.83	53.95	66.40
6	0.30%	10.80	9.62	8.78		46.93	59.17	70.10
7	0.35%	11.02	9.71	8.89		44.55	47.40	66.70
8	0.40%	11.20	10.21	8.77		40.93	50.53	65.63
9	0.45%	11.35	10.51	8.95		43.05	51.43	64.95
10	0.50%	11.57	11.12	9.45		42.60	52.08	64.38

3.1. Effect of SAP on the Alkalinity of Cementitious Slurries

P-O 42.5 cement and SAP particles were used to prepare cement net paste with SAP dosage of 0.10%, 0.15%, 0.20%, 0.25%, 0.30%, 0.35%, 0.40%, 0.45%, 0.50% and cement paste without SAP addition was the control group with a water-cement ratio of 0.30, and the results of the tests are shown in Fig. 1.

As can be seen from Fig. 1, the pH value of cement paste with the increase of SAP dosage shows a trend of first increase, then decrease and then increase. 3d age, when the SAP dosage is 0.25%, the highest pH value of the specimen, compared with the control group increased by 4.5%; when the SAP dosage is 0.30%, the specimen reduces the alkali effect is obvious, and the pH value of the specimen is reduced by 3.7% compared with the control group and the pH value is reduced by 7% compared with the specimen with 0.25% SAP dosage. The pH value of the specimen was reduced by 3.7% compared with the control group, and by 7.8% compared with the 0.25% SAP specimen. This is due to the fact that SAP absorbed part of the free water, which increased the concentration of alkaline ions (Ca^{2+}, K^{2+}, etc.) in the cement paste, resulting in an increase in the pH value of the SAP specimens.

With the increase of specimen age, the pH value of cement paste at 7d age was reduced compared with that of 3d, and the pH value of specimen 7d was the lowest when SAP doping was 0.30%, which was 3.9% lower compared with that of the control group. This is due to the fact that SAP promotes the hydration of cement to generate C-S-H gel, which fills the small capillary pores and small cracks inside the cement matrix, reduces the connected pores, prevents the alkaline material from flowing out, and reduces the pH value.

At the age of 28d, the hydration of cement paste was basically completed, and the pH value of the test group doped with SAP was generally lower than that of the control group, in which the pH value of the specimen was the lowest when the dosage of SAP was 0.30%, which was reduced by 5.7% compared with that of the control group. Due to the large specific surface area and pore structure of SAP particles after the release of water, it can adsorb alkaline cations in the cement, so that the alkaline cations are fixed on the surface of SAP and in the pores, and at the same time, after the release of water, SAP volume shrinkage occurs to form a shell-like morphology, which forms a crack in the middle of the cement matrix, slowing down the rate of alkaline ions flowing out of the cement matrix, and making the pH value of the SAP specimen significantly lower.

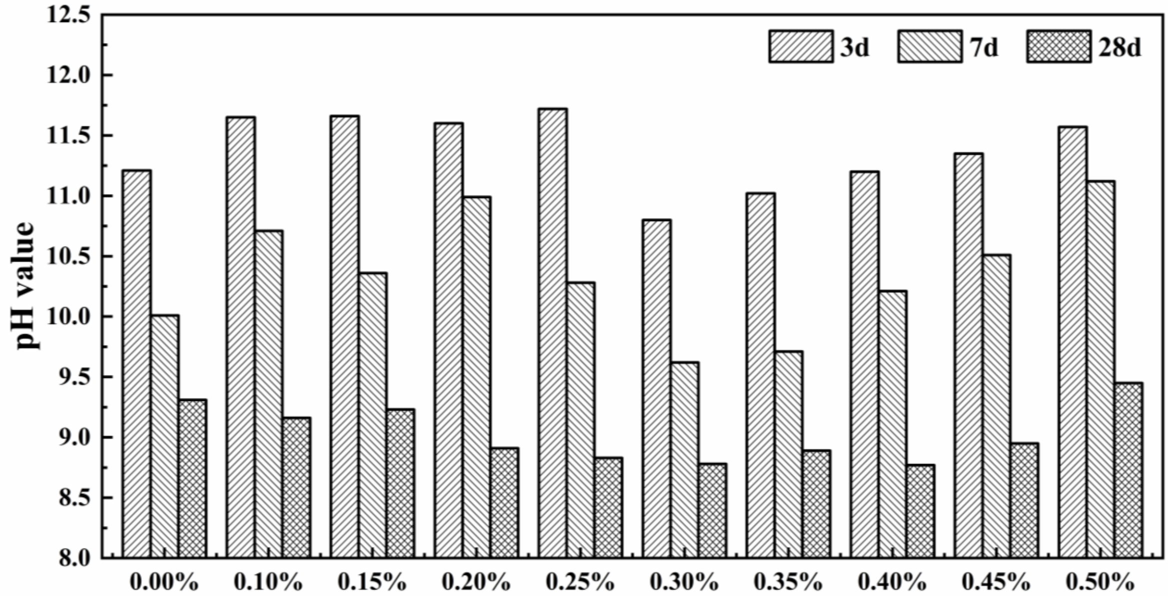

Fig 1. The results of the tests

3.2. Effect of SAP on the Compressive Strength of Cementitious Mortar

The effects of different dosages of SAP on the 3d, 7d and 28d cubic compressive strength of cementitious composites are shown in Fig. 2.

As can be seen in Figure 2, the compressive strength of the cement paste increased with the SAP dosage and showed a general trend of first increase and then decrease. 3d age, the compressive strength of SAP specimens compared with that of the control group have different degrees of reduction, of which, when the SAP dosage of 0.30%, the specimen's compressive strength was the highest, and its compressive strength compared with that of the control group decreased by 13.5%. This is due to the SAP water absorption makes the early hydration of cement incomplete, the compressive strength decreased, and SAP water absorption and expansion in the cement paste to produce large pores, is not conducive to the development of early strength of cement.

At the age of 7d, the compressive strength of the specimens increased, of which, when the SAP doping of 0.30%, the compressive strength of the specimens was the largest value, and compared with that of the control group increased by 2.9%, and when the SAP doping of 0.10% and 0.25%, the specimens had the largest increase in the compressive strength of the specimens compared with their 3d age, with an increase of 43.5% and 42.6%, respectively. This is due to the fact that as SAP exerts the 'internal conservation' effect, it continuously releases water to promote cement hydration and enhance the strength of the cement paste [8].

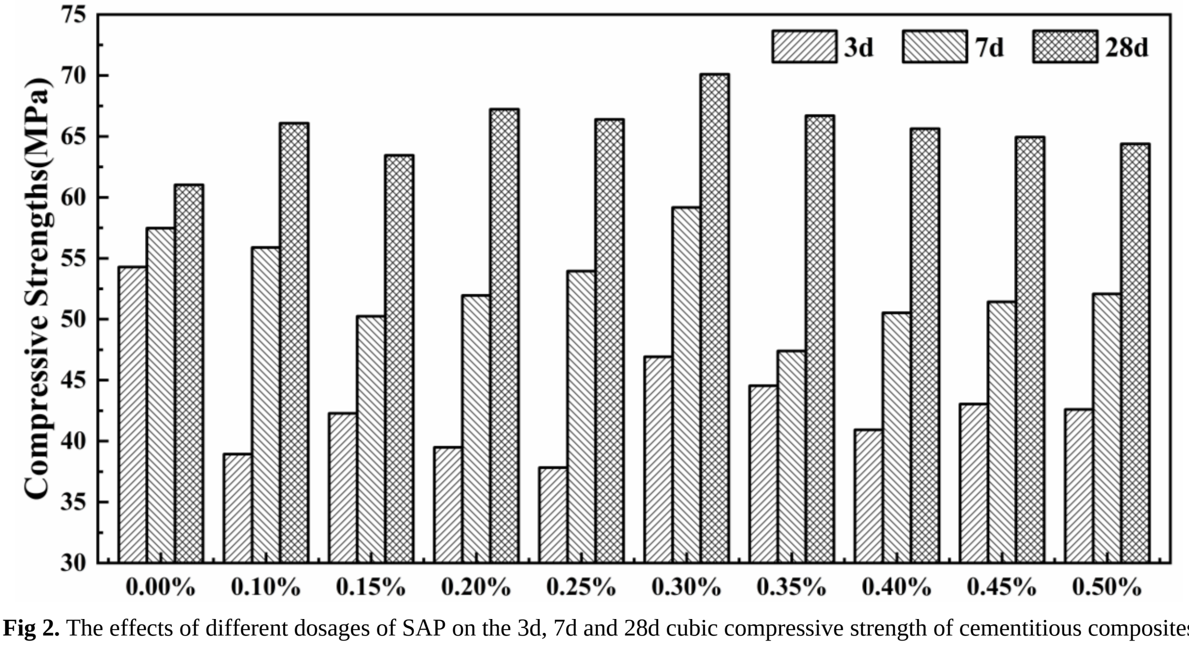

Fig 2. The effects of different dosages of SAP on the 3d, 7d and 28d cubic compressive strength of cementitious composites

With the increase of the age of the cement matrix, the compressive strength of the specimens doped with SAP was significantly improved at the age of 28d, and their compressive strength values were higher than those of the control group; when the SAP doping rate was 0.35%, the compressive strength value of the specimens was the largest, and it was increased by 14.8% compared with that of the control group. This is due to the continuous and slow release of water in the late stage of SAP, which promotes the hydration of cement to generate C-S-H and Aft, filling the pores in the cement paste, improving its densification and increasing its strength.

3.3. Relationship between Alkalinity and Compressive Strength of Cement Screeds

Figure 3 shows the relationship between alkalinity and compressive strength of specimens at 3d, 7d and 28d for SAP doping.

As can be seen from Fig. 3, with the increase of SAP dosage, the pH value of the cement paste shows a trend of first rise, then fall and rise again, and the compressive strength of the cement matrix shows a trend of first rise and then fall. At the age of 3d, the pH value of the specimen is reduced by 3.7% compared with that of the control group when the dosage of 0.30% of SAP is used, and the compressive strength of the specimen is reduced by 13.5% compared with that of the control group. This is due to the better water absorption of SAP particles can make it absorb part of the water, so that the concentration of alkaline ions in the cement paste increased, which led to an increase in the pH value of SAP specimens, and SAP absorbed water and swelled to produce large pores in the cement matrix [9], resulting in a significant reduction in its compressive strength.

At the age of 7d, the pH value of the specimen was reduced compared to 3d, and the compressive strength was increased to different degrees compared to 3d. When the dosage of SAP was 0.30%, the pH value of the specimen at 7d was the lowest, which was 3.9% lower than that of the control group; and the compressive strength of the specimen at 7d was the largest, which was 2.9% higher than that of the control group. This is due to the fact that the internal maintenance effect of SAP can promote the generation of hydration products to fill the small capillary pores, reduce the small cracks inside the cement matrix, reduce the connecting pores, reduce the alkaline material outflow inside the cement matrix, reduce the pH value, and make the structure denser, so the 7d compressive strength of SAP specimens was increased significantly.

With the growth of age, at the age of 28 d, the pH value of the test group specimens doped with SAP was generally lower than that of the control group specimens, and the compressive strength was higher than that of the control group, in which the pH value of the specimens was the smallest when the dosage of SAP was 0.30%, which was reduced by 5.7% compared to that of the control group, and the compressive strength was as high as 70.10 MPa. This was due to the fact that SAP particles form a layer of organic film after the release of water [10] and forms cracks with the middle of the cement matrix, reducing the outflow of alkaline ions from the cement matrix, resulting in a significant decrease in the pH of the specimens. The gradual release of internal conservation water in the SAP gel at a later stage improves the hydration of the cement, induces the transformation of low-strength C-S-H to high-strength C-S-H in the matrix [11], and improves the compressive strength of the cement matrix.

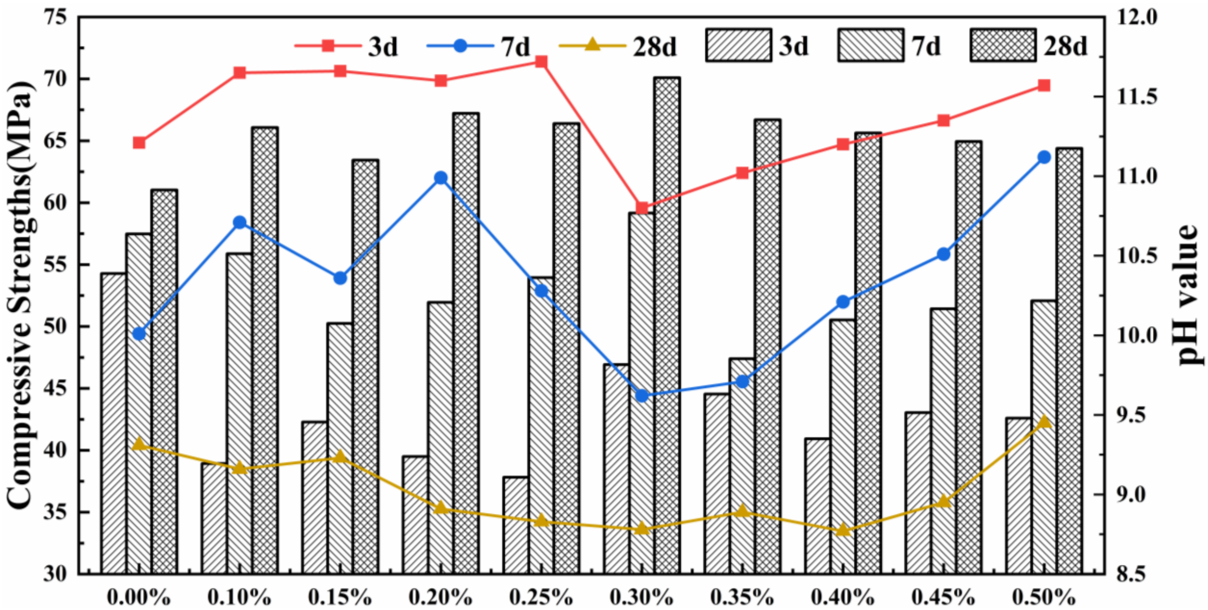

Fig 3. The relationship between alkalinity and compressive strength of specimens at 3d, 7d and 28d for SAP doping

4. Micro-morphological Analysis

Scanning electron microscope tests were carried out on the SAP specimens with 0.30% dosing at the age of 28d, and Fig. 4 shows the microscopic morphology of the SAP specimens. As shown in Fig. 4, at the age of 28d, irregular slumping cracks were formed between SAP and cement matrix after water release, and there were more flocculent and fibrous C-S-H gel in the cracks between SAP particles and cement matrix, which indicated that SAP was slowly releasing water and slumping phenomenon, and the slumping cracks were able to slow down the rate of alkaline ions out of the cement matrix and reduce the rate of alkaline ions in the cement matrix, and the slumping cracks were able to slow down the rate of alkaline ions in the cement matrix. The slumping cracks can slow down the flow rate of alkaline ions out of the cement matrix and reduce the activity of alkaline ions in the cement matrix. At the same time, the porous structure and large specific surface area of SAP can adsorb alkaline cations in the cement, reduce the alkaline ions in the cement, and lower the pH value of the cementitious materials. Due to the 'internal conservation' effect of SAP, it slowly releases water and promotes the unhydrated cement clinker in the vicinity to continue hydration, generating a large number of C-S-H gels in the cracks, and the cluster-like C-S-H gels grow in a staggered manner, and at the same time, continuously refining the pore structure, enhancing the densification of the cement structure, and increasing the strength of the cement matrix.

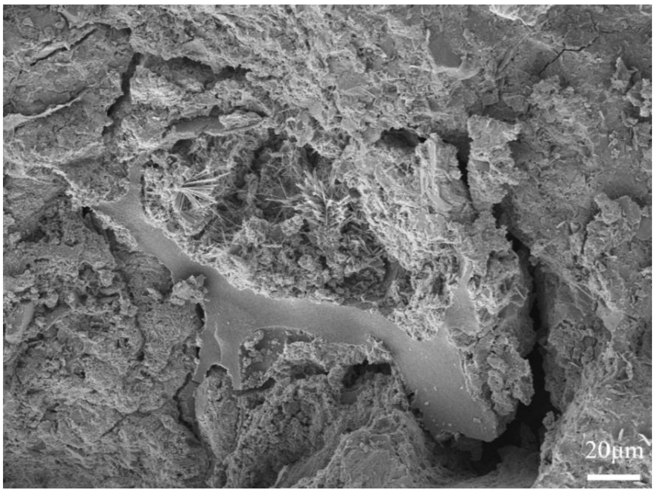

Fig 4. The microscopic morphology of the SAP specimens

5. Summary

(1) The incorporation of appropriate amount of SAP reduced the alkalinity of the cement matrix to a certain extent, in which the SAP specimens dosed with 0.30% had the best overall effect, the pH at 28d was reduced by 5.7% compared to that of the control group, and the pH at 28d was reduced to 8.78.

(2) SAP doping significantly enhanced the compressive strength of the cement matrix, with the increase of SAP doping, the compressive strength of the specimens showed a trend of increasing and then decreasing, when the SAP doping of 0.30%, the compressive strength of the specimens at 28d was increased by 14.8% compared with that of the control group, and the value of the compressive strength of the specimens at 28d reached 70.10 MPa.

(3) After the release of water from SAP particles, cracks will be formed in the middle of the cement matrix, reducing the alkaline ions from the cement matrix, making the pH value of SAP specimens significantly reduced, and the pH value of 28d decreased to 8.78; the gradual release of water from the internal conservation in the SAP gel improves the hydration of the cement, and promotes the transformation of low-strength C-S-H to high-strength C-S-H in the matrix, improving the 28d compressive strength of SAP specimens at 28d.

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